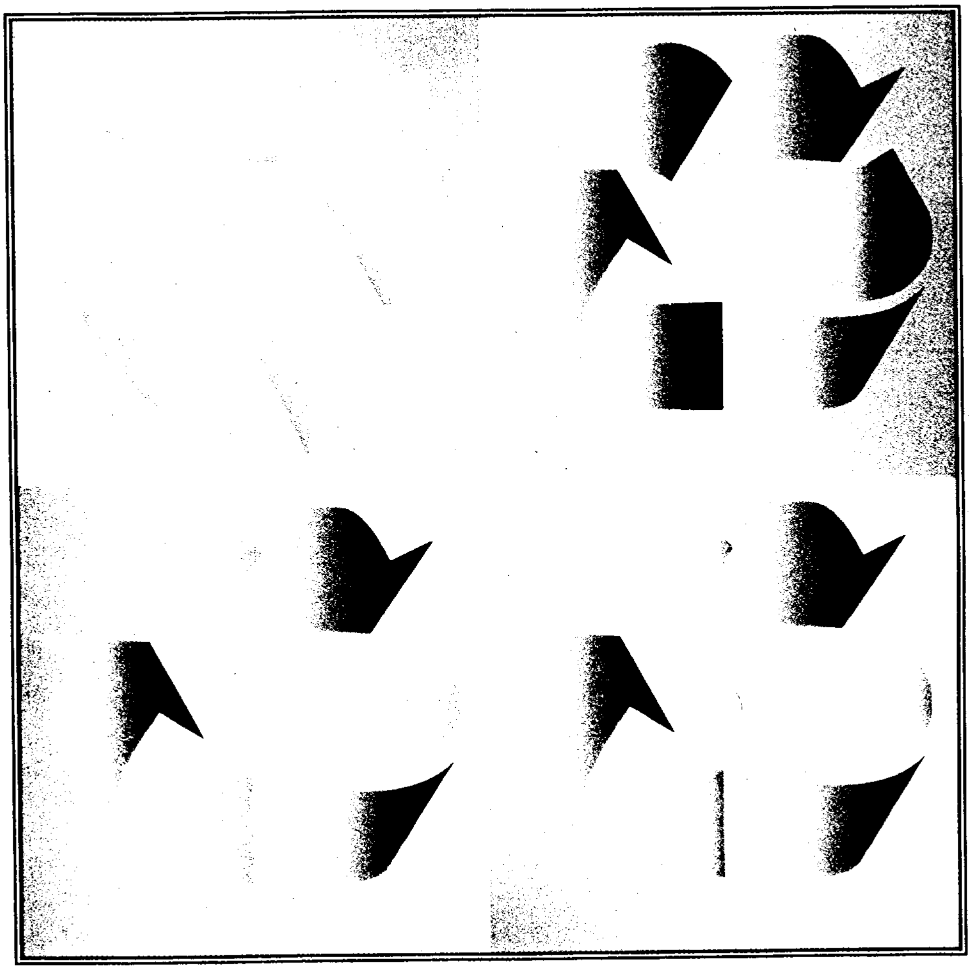
AEN
NEA
Nuclear Energy Agency

NUCLEAR DECOMMISSIONING

RECYCLING AND REUSE OF SCRAP METALS



OCDE
OECD
PARIS

NUCLEAR DECOMMISSIONING

RECYCLING AND REUSE OF SCRAP METALS

A Report by a Task Group of
the Co-operative Programme on Decommissioning

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium,Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995) and Hungary (7th May 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of all European Member countries of OECD as well as Australia, Canada, Japan, Republic of Korea, Mexico and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

- *encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
- *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
- *developing exchanges of scientific and technical information particularly through participation in common services;*
- *setting up international research and development programmes and joint undertakings.*

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

The OECD NEA Co-operative Programme on Decommissioning of Nuclear Installations set up, in 1992, a Task Group entrusted with the task to study the problems and possible criteria associated with the recycle and reuse of metallic materials resulting from decommissioning.

The Task Group carried out a thorough analysis of this issue and proposed an approach to the release of those materials from regulatory control which is briefly discussed in this report. Two companion documents, not for publication, describe in detail the assumptions and calculations which are at the basis of the proposed clearance levels.

The approach proposed by the Task Group is broader than and differs in some respects from guidance which was recently prepared by Expert Groups of the International Atomic Energy Agency and the European Commission. This report expresses the point of view of the members of the Task Group and is offered as a contribution to the international debate in this area. It is published on the responsibility of the OECD Secretary General and does not commit the Organisation nor its Member countries.

Acknowledgements

The NEA Secretariat wishes to express its sincere appreciation to Magnox Electric plc, United Kingdom, for its financial contribution towards the publication of this report.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	**Definition**
Bq/g	becquerel per gram
BSS	*Basic Safety Standards*
BWR	boiling-water reactor
CEA	Commissariat à l'énergie atomique (France)
EC	European Commission
CFR	*United States Code of Federal Regulations*
FAO	Food and Agriculture Organization
IAEA	International Atomic Energy Agency
ICRP	International Commission for Radiological Protection
ILO	International Labour Organization
LLW	low-level waste
NEA	Nuclear Energy Agency
NUREG	[Report prepared or sponsored by the] United States Nuclear Regulatory Commission
OECD	Organization for Economic Co-operation and Development
PAHO	Pan American Health Organization
PHWR	pressurised heavy water reactor
PWR	pressurised-water reactor
Sv/a	sievert per year
t/a	tonne per year (metric system)
WHO	World Health Organization

EXECUTIVE SUMMARY

Introduction

Significant volumes of waste will be generated from decommissioning nuclear facilities throughout the world. Existing regulations throughout the world currently require most of this waste to be classified as "low-level" nuclear waste and be directed to regulated disposal facilities. However, currently operating waste facilities have limited capacities and are insufficient to accommodate the large volumes of waste that will be generated from decommissioning the world's nuclear facilities. Public opposition to the siting and licensing of new radioactive waste facilities makes the expansion of available waste capacity difficult and serves to increase already high disposal costs.

Concrete, steel and other valuable materials comprise a large portion of the waste generated by decommissioning activities. The inherent value of these materials and the need to reduce waste directed to radioactive disposal facilities makes recovery through some form of decontamination a prudent, if not necessary, undertaking. Furthermore, recyclable materials sent to waste facilities must ultimately be replaced with new materials. Adverse health and environmental impacts from mining and milling processes associated with the replacement of these materials are significant considerations which should not be ignored by those who intend to adequately assess the merits of recycling metal, concrete and other recoverable materials.

The OECD/NEA Co-operative Programme on Decommissioning is a forum established in 1985 for sharing valuable scientific and technical information, and for enhancing international co-operation among experts directly involved in decommissioning projects throughout the world. In 1992, the Co-operative Programme on Decommissioning chartered a Task Group on Recycling and Reuse to conduct an examination of the current state of the nuclear industry so that it might identify obstacles to recovering scrap metals and concrete generated from decommissioning nuclear facilities. The Task Group, focusing on metals, also was to identify and determine the effectiveness of methods for overcoming these obstacles. Its findings and conclusions, which are contained in the following report, are intended to provide information and insights into the practicality and usefulness of release criteria form the perspective of organisations currently engaged in actual decommissioning activities.

In accordance with this mission, the Task Group examined existing and proposed standards and regulations to determine whether the current regulatory environment is conducive to recovering these materials. The Task Group also examined the health, environmental, and socio-economic impacts associated with disposal and replacement of scrap metals, and compared these impacts with those associated with a proposed "tiered" regulatory regime that would allow large portions of these materials to be recycled and reused. Finally, the Task Group examined the technical adequacy and cost-effectiveness of available decontamination techniques.

Current Practices

One component of the Task Group's examination was a survey of 25 completed and on-going decommissioning projects. This survey suggested that, in some cases, efforts to recycle and reuse materials generated by the projects had been limited by regulatory requirements.

Specifically, most recycling initiatives continue to be governed by case-specific release criteria, or licenses, which vary from country to country or project to project. Consequently, shipment of material between countries, and even to other facilities within the same country, have been made extremely difficult by the absence of uniform criteria which would allow facilities to release or accept the material. Recycling and reuse initiatives were found to have been further complicated by variations in the quality assurance requirements, sampling protocols, required instrumentation, and documenting practices used by the surveyed projects.

The information compiled by the Task Group indicated that approximately 362 000 tonnes (t) of materials had been released from the projects since 1979 under varying criteria. Significantly, conditional or restricted release criteria had been applied to large quantities of scrap metals and other waste products, providing valuable insight as to the effectiveness of these alternative waste management practices. These case studies indicate that recycle can be effectively performed and regulated as an attractive alternative to storage and disposal as low-level waste.

International Standards and Release Criteria

The absence of consistent, internationally accepted release criteria remains a significant impediment to the recovery of large portions of radioactive scrap metals. A number of international "clearance" levels have been proposed by various international organisations to address this deficiency. "Clearance" is here distinguished from "exemption" based on the extent to which subject material has entered practices or facilities governed by radiological regulatory regimes. Clearance levels apply to materials that previously were subject to regulation (*e.g.*, components of a nuclear reactor or fuel facility). Exemption levels establish thresholds below which radiological restriction is deemed unnecessary. Accordingly, a clearance standard defines an activity level below which previously regulated materials no longer warrant regulation. Exemption criteria are used to determine which materials or practices initially require or do not require regulation. Although exemption levels are not directly related to the Task Group's examination, the great disparity between existing exemption levels and proposed clearance levels is a subject that warrants considerable attention.

Currently proposed clearance levels focus almost entirely on "unconditional" clearance, or unrestricted release of the material in question. The proposals are intended to form the bases for release criteria so trivial and comprehensive in scope that they will be readily accepted. However, a variety of alternatives, in addition to unconditional clearance, are available that are not addressed by these proposals. As previously mentioned, material has been released from facilities for transport to melting facilities. Following melting, remaining radionuclides are allowed to decay to the point that the material can be released. This approach would not be available under an "unconditional" release standard.

The absence of international "conditional" release criteria would unnecessarily hinder the transport and melting of scrap metal; particularly if implementing such an option requires transhipment of the material across national boundaries.

Moreover, existing international guidance, particularly ICRP 60, suggests that analyses of standards to govern radiological practices should include assessments of non-radiological impacts associated with the practices. Current proposals are based almost entirely on radiological considerations.

The Task Group's examination found that non-radiological health, environmental, and socio-economic considerations associated with directing large volumes of radioactive scrap metals to disposal facilities and replacing them with new material significantly exceed any radiological assessment of adverse impacts.

Finally, despite the availability of data from operating melting facilities, proposed international clearance levels have tended to use models that make use of largely conservative assumptions as a safeguard against uncertainty. These models incorporate data and assumptions that multiply the conservatism of the basic assumptions. Resulting criteria, already subject to pressures for general acceptability, are so conservative that non-radiological risks associated with related processes exceed by orders of magnitude the reductions to radiological risks. Consequently, the perceived radiological benefit gained by overly-conservative assumptions are negated by demonstratable increases in non-radiological risks where metals are subsequently replaced.

Health, Environmental and Socio-economic Impacts

Two fundamental options are available for managing the disposition of radioactive scrap metal; disposal and replacement, and recycling and reuse. In order to more effectively evaluate the health, environmental, and socio-economic impacts of these two management alternatives, the Task Group compared disposal and replacement, with a "tiered" system of release criteria. This "tiered" system would establish residual radioactive contamination levels applicable to end-use or final destination options for material generated by decommissioning operations. This is intended to optimise the materials to be recycled with the available options for reuse.

Physical risks to workers from workplace accidents and to the public from transportation accidents exceed the risks attributable to either alternative from radioactive materials or chemicals. Radiological risks to the public from both alternatives would be kept to very low levels (approximately 10^{-5} fatalities per year of practice). In contrast, non-radiological health risks associated with disposal and replacement are much higher than those associated with recycling and reuse. This disparity results primarily from accident risks to workers associated with steel mill and blast furnace operations, and increased transportation risks consequential to new materials production. For example, the risk of a worker fatality associated with the replacement of 50 000 t of radioactive scrap metal is approximately 15 fatal or serious injuries to workers in steel mill and blast furnace operations, nearly twice the risk for steel smelting and milling operations for recycling.

Moreover, environmental and socio-economic impacts attributable to disposal and replacement exceed those for recycling and reuse. Land use, disruption and environmental damages from mining operations and environmental impacts associated with the additional energy requirements of replacement processes are but two of the many contributing factors documented in greater detail in the Task Group's Report that lead one to this conclusion. Environmental impacts associated solely with the disposal and replacement alternative also include increased leaching of heavy metals from soils and mining wastes into surface and ground water, and sedimentation of streams and rivers.

With regard to adverse socio-economic impacts, both alternatives likely will confront some form of public opposition. Recycling and reuse must overcome the negative stigma associated with the nuclear industries of most countries.

However, the disposal option must overcome public opposition to the siting and licensing of new disposal facilities necessary to accommodate the needs of the decommissioning community. Other economic factors, including effects of recycling on scrap metal markets, also tend to favour recycling and reuse management alternatives. Even if recycling radioactive scrap metal is deemed unacceptable today, consideration of benefits from recycling the material still should be examined over an extended period of time.

Technological Capabilities

A variety of decontamination techniques exist that provide means to recycle and reuse radioactive scrap metals. A particularly important methodology is melting. During the melting process, caesium 137 volatilises from the metal. In most reactor scrap metal, the remaining radioactive elements have short half-lives (*e.g.*, cobalt 60), permitting material to be reused at some predetermined time in the future. Melting also results in considerable volume reduction and permits far more accurate measurements of radioactivity.

Although melting represents a major component of recycling practices, other decontamination techniques are available that are less intensive and would still permit items to be reused. These include wet and dry blasting techniques, as well as chemical processes. The decommissioning industry currently is in a state of transition, evolving from techniques for use in maintenance applications, to those for use in decommissioning nuclear facilities. Moreover, a single technology may not be capable of decontaminating to below required clearance levels. Consequently, decontamination frequently is implemented in stages, ultimately decontaminating the material to the required activity levels.

The current state of characterisation methodologies constitutes what should be a significant consideration in the process of developing release. In order to effectively apply release standards based on specific activity or surface contamination, means must be available to demonstrate or verify compliance. A number of practical constraints significantly influence instrument capability, including the geometrical complexity of materials and the sensitivity of available instruments relative to the prescribed criteria. Some of the proposed clearance levels will challenge state-of-the-art and practicality of measurement technologies and instrumentation.

Case Studies

The Task Group also reviewed a number of case studies to determine the cost-effectiveness of pursuing recycling and reuse options. In many of these cases, implementation of available technologies resulted in significant cost-savings compared to direct disposal alternatives. The techniques available to the decommissioning community routinely yield savings in excess of 50 per cent. Savings generally result from either volume reduction, reuse of the material, or sale of decontaminated materials. One noteworthy example was a pilot project conducted by Belgoprocess which used a dry abrasive blasting system to decontaminate and unconditionally release steel scrap metal from a Eurochemic reprocessing facility. Cost savings approached 70 per cent over supercompaction and disposal. This conclusion is heavily influenced by the cost of local or national waste disposal.

Conclusions

The Task Group's examination indicates that recycling and reusing materials generated from decommissioning nuclear facilities is both practicable and cost-effective. The most significant impediment to pursuing this waste management alternative is the absence of consistent, internationally accepted release criteria.

Current proposals to remedy this deficiency remain extremely conservative, do not address a variety of conditional release alternatives, and consequently may not promote efforts to most effectively use available technologies. The OECD/NEA Task Group report documents evidence of the need to establish clearance criteria for different kinds of accepted practices. In this context, the Task Group has proposed a "tiered" system of release criteria to facilitate discussion of appropriate conditional international release criteria.

The establishment of unconditional release criteria is a critical step to filling the need for a consistent, internationally accepted standard. However, such criteria should be established in a manner that will encourage, rather than preclude, the future establishment of conditional release criteria. The group hopes that the debate on recycle will be benefited by the analysis conducted and that the discussion of the various proposals for release standards be considerate of the points identified in this work. Most importantly, this work provides some unique insight into the state of the recycle world from nuclear decommissioning perspective.

INTRODUCTION

Approximately 30 million tonnes* (t) of scrap metals likely will be generated during the next 50 years from dismantling and decommissioning nuclear facilities [1]. A large portion of this material will be only slightly contaminated and, if completely recovered, will have an estimated value of $10-15 billion as scrap, based on US scrap metal price ranges for 1990 through 1993. Moreover, available low-level waste repository capacity currently is insufficient to accommodate the scrap metal that will be generated from decommissioning the world's nuclear facilities. As the siting and licensing of new high and low-level waste disposal facilities has been the subject of intense political opposition, costs associated with disposal likely will continue to increase as access becomes more restricted. Therefore, alternative management strategies for this material, other than disposal in repositories and eventual replacement via mining and commercial production, warrant further consideration.

The Nuclear Energy Agency (NEA) Co-operative Programme on Decommissioning established the Task Group on Recycling and Reuse in 1992. The Task Group was charged with examining means for maximising the recovery of valuable materials that partially comprise waste resulting from decommissioning activities. The Task Group also was to examine means for minimising the quantity of waste from such operations. Much of the Task Group's work has been concentrated on metal recycling and reuse. In the future, when currently operating commercial nuclear power stations will have to be dismantled, there will also be large quantities of concrete to be processed. This is an area that will require separate analysis, similar to the work on metals.

The Task Group's examination and report are the product of experts from seven countries and constitute a synthesis of surveys, analyses, and case studies. The report is intended to provide information and insights, as of the end of 1994, into the practicality and usefulness of release criteria from the perspective of organisations currently engaged in actual decommissioning activities. Two companion volumes to this report provide a more detailed discussion of the findings and bases of the Task Group's examination [1, 2].

Six chapters comprise the report.

- Chapter 1 describes the results of the Task Group's survey of various historic decommissioning projects, including the quantity and content of the materials released from the facilities, and a description of the criteria under which the materials were released.
- Chapter 2 provides an overview of international recommendations and guidelines applicable to radiological exemption and clearance practices. Particular emphasis has been placed on analyses and proposals associated with conditional and unconditional clearance levels that may be applicable to recycling or reusing radioactive scrap metal.

---

* The unit of weight used throughout this document is the "tonne" , also known as "metric ton", which is equivalent to 1 000 kg.

- Chapter 3 presents the Task Group's assessment of the health, environmental, and socio-economic impacts of the two principal radioactive scrap metal management alternatives: disposal and replacement, and recycling and reuse. As part of this assessment, the Task Group evaluated the impacts of a "tiered" system of release criteria for radioactive scrap metal and compared these impacts to those associated with conventional disposal and replacement.

Such a system provides the flexibility to establish release levels that can accommodate the possible final destinations and end-uses of radioactive scrap metal. This "tiered" system is illustrated conceptually in Figure 1.

- Chapter 4 provides a description of the technical capabilities and limitations of some practices that are available for use in decommissioning operations. Included in this discussion are melting, as well as various chemical and physical decontamination practices. Additionally, a discussion of issues related to measurement capabilities is included as such capabilities and/or limitations pertain to the establishment and implementation of release criteria.
- Chapter 5 of the report describes the Task Group's findings associated with the cost-effectiveness of various recycling and decontamination techniques. Its assessment is based on cost comparisons of decontamination techniques and conventional disposal.
- Finally, Chapter 6 presents the Task Group's findings and conclusions.

The Task Group has proposed the "tiered" system as depicted in Figure 1, to appropriately clear or release metals based upon their intended usage and residual contamination levels:

- *Tier A* corresponds to the currently proposed unconditional release levels. Tier-A metals could be unconditionally released from regulatory control for reuse or recycle. Tier A would have a surface limit in becquerels per square centimetre (Bq/cm^2) for surface contamination and a volumetric limit in becquerels per gram (Bq/g) for volumetric contamination.
- *Tier B* corresponds to currently proposed conditional clearance levels. Tier-B materials would be decontaminated and melted in a regulated environment and then conditionally released for subsequent melting and fabrication in non-nuclear commercial facilities. The Tier-B limit would be expressed in becquerels per gram.
- *Tier C* is an extension of the current conditional release philosophy. Tier-C metals would be melted and fabricated in a controlled environment and released for a specified initial industrial use. Tier-C metals would generally be limited to contamination by radionuclides with relatively short half-lives. This Tier C provides for initial industrial usage and subsequent radioactive decay that would allow for subsequent unrestricted use following the useful life of the initial product.
- *Tier D* does not involve release from the regulated environment. This Tier D accommodates recycle of contaminated materials for continued usage in the regulated nuclear environment, the most common example would be for metal waste containers.

In general, the Task Group concludes that a substantial quantity of waste generated from decommissioning activities can be recycled and reused. The Task Group's survey of just 25 decommissioning projects identified more than 300 000 t of material that had been released under varying criteria Its review of the health, environmental, and socio-economic impacts of recycling and reuse alternatives. indicates that such practices involve very low levels of radiological exposure and will substantially reduce risks relative to available alternatives. Based on its examination of the capabilities and limitations of currently available technologies, recycle and reuse alternatives can provide cost-effective

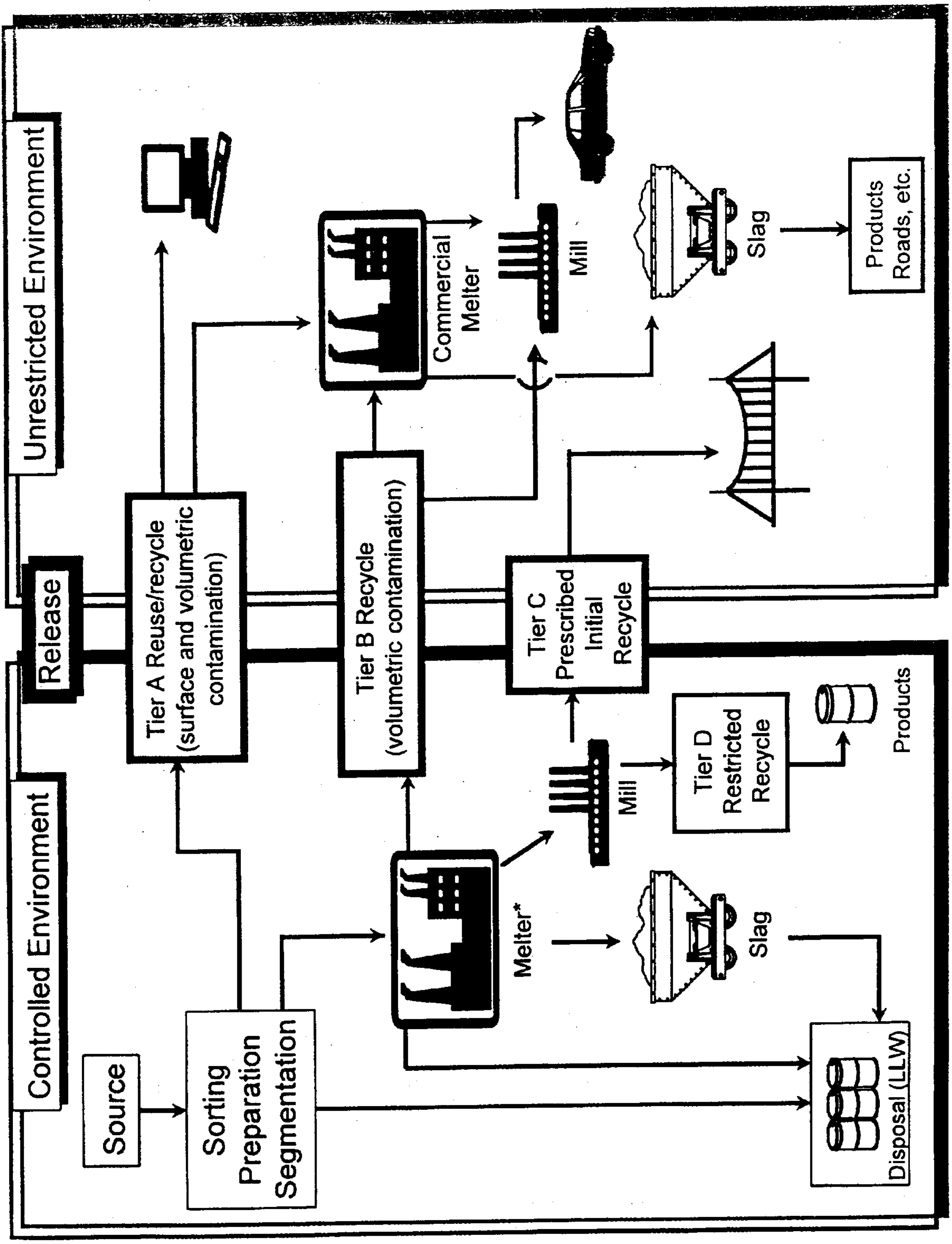


Figure 1. Conceptual Illustration of Tier Release System

methods for dispositioning the large volume of scrap metal generated from decommissioning nuclear facilities. The Task Group's review of 18 individual case studies indicates that recycling/reuse alternatives routinely yield savings in excess of 50 per cent of comparable disposal alternatives.

Finally, recycling techniques, such as melting, provide means to substantially reduce the volume of scrap metal that otherwise would permanently consume valuable low-level waste repository capacity.

The Task Group's examination also indicates that the absence of consistent and generally acceptable release criteria serves to restrict the utilisation of recycle and reuse waste management practices. Currently, material is released under varying criteria or on a case-by-case basis, frequently prohibiting countries from best utilising the available recycling technologies and facilities. Transhipment of scrap metals for melting and processing across international boundaries to regional trade partners is particularly limited, if not prohibited, by the absence of internationally recognised criteria. Several international organisations have proposed criteria to address the release of some of the material in question. Unfortunately, these proposals fall short of addressing the specific needs of the decommissioning community and may unintentionally hinder efforts to recover valuable scrap metal through recycling and reuse practices.

The large quantity of material that now, or soon will require dispositioning as a result of decommissioning activities, the inherent value of this material, and the continually diminishing availability of repository capacity, provide sufficient evidence of the need to establish consistent clearance criteria for different kinds of accepted practices. This report documents a number of cost-effective methods for minimising materials directed to disposal facilities and provides evidence that, if non-radiological health, environmental, and socio-economic impacts are considered in the justification of these methods, such methods result in significant risk reduction when compared to disposal and subsequent replacement of the material. Current proposals will address only a limited number of these methods for dispositioning the material. Accordingly, while steps to establish internationally accepted unconditional release criteria are to be commended, such criteria should not preclude the establishment of conditional clearance criteria in the future, particularly for scrap metal and other valuable materials that can be reused.

REFERENCES

[1] Nieves, L.A., et al., 1995, *Evaluation of Radioactive Scrap Metal Recycling*, ANL/EAD/TM-50, Argonne National Laboratory, Argonne, Illinois

[2] OECD/NEA, Co-operative Programme on Decommissioning, *Comprehensive Report of the Task Group on the Recycling, Reuse and Release of Materials from Nuclear Facilities*, March 1996.

Chapter 1

CURRENT POLICIES AND EXPERIENCES

To understand better current international policies that govern the release of materials, and experiences acquired from decommissioning activities, the Task Group conducted a survey that solicited data from completed and ongoing decommissioning projects. These included projects to decommission reactors, fuel facilities, uranium milling plants, and isotope production facilities. Information was received from 25 projects located in nine different countries.

Despite the absence of consistent international release criteria, national clearance standards or clearance approved on a case-by-case basis had been used to release approximately 362 000 t of material from the various decommissioning projects since 1979. The material included carbon and stainless steels, lead, concrete, soil, and gravel.

Although the general concept of clearance implies complete removal of regulatory control, a variety of clearance alternatives had been implemented. For example, metal had been transported to melting facilities where it was melted into ingots. In those cases where the metal met the appropriate criteria, it then was released for unconditional use. Other material subsequently was stored to permit the radioactive elements to decay to the permissible release levels or was released for reuse in other nuclear related applications. Table 1 provides a more detailed description of the total quantities and types of materials released in accordance with each of the various types of release practices.

Release criteria varied. For example, a project in Sweden used a beta-gamma (unrestricted release) surface contamination limit of 4.0 Bq/cm^2, a factor of 10 higher than the equivalent release limit used by a Belgian project. Similarly, total specific activity limits, again for beta-gamma emitters, varied by equally significant margins. Nuclide specific limits also had been applied in France, Germany, Great Britain and the United States. Tables 2 and 3 provide release criteria for unrestricted reuse or disposal without radiological restrictions.

Similarly, applicable policies and regulations imposed a variety of measurement requirements to demonstrate that material met the appropriate release criteria. More often than not, variations in the release criteria were accompanied by differences in measurement regimes. These differences also impacted the selection of appropriate instrumentation, frequency of measurement, sampling protocols, documenting practices, and quality assurance requirements.

Based on the results of this survey, a common base from which to establish clearance standards continues to elude the international community, although protection of human health and safety remains the common goal of the various regulatory regimes.

Nevertheless, differences are notable and potentially may become a source of confusion. The survey indicates that existing or proposed regulations associated with clearance standards differ among the different countries not only in existing or proposed clearance levels, but also required procedures and quality assurance requirements. Moreover, the authority to permit release generally is delegated to various types of control organisations. Because regulations for most projects/plants continue to be applied on a case-by-case basis, and may differ even within a single country, equally divergent approaches to clearance are applied from one project/plant to another. Consequently, exchanges of materials from one country to another, or even from one project/plant to another, are confronted with difficult, if not insurmountable obstacles.

Table 1. Material Released from the Surveyed Projects

Release practice	Quantity (estimate)	Type of material
Unrestricted reuse	6 750 t	Carbon steel
	900 t	Stainless steel
	420 t	Various metals (no decontamination)
	2 130 t	Various metals (after decontamination)
	2 800 t	Gravel
	156 000 t	Other
Disposal without radiological restrictions	34 700 t	Concrete
	36 600 t	Soil and gravel
	308 t	Other
Restricted reuse within the nuclear industry	33 t	Various metals (no decontamination)
	1 100 t	Various metals (after decontamination)
	349 t	Concrete
	814 t	Other
Disposal with radiological restrictions	4 090 t	Carbon steel
	3 490 t	Stainless steel
	44 100 t	Concrete
	57 900 t	Soil and gravel
	7 220 t	Other
Restricted release to a specific melter	220 t	Various metals (no decontamination)
	2 025 t	Various metals (after decontamination)

Table 2. Surface Contamination Limits for Beta/Gamma Emitters

Contamination limit	Country	Additional information
0.37 Bq/cm^2	Germany	Over 100 cm^2 for fixed and removable contamination and for each single item
0.40 Bq/cm^2	Finland	Removable surface contamination over 0.1 m^2 for accessible surfaces
0.40 Bq/cm^2	Belgium	Mean value for removable surface contamination over 300 cm^2, for beta-gamma emitters and alpha emitters with low radiotoxicity
0.83 Bq/cm^2	USA	Surface contamination above background over no more than 1 m^2, with a maximum of 2.5 Bq/cm^2 above background if the contaminated area does not exceed 100 cm^2
4.00 Bq/cm^2	Sweden	Mean value for removable surface contamination over 100 cm^2, with a maximum of 40 Bq/cm^2 if the contaminated area does not exceed 10 cm^2

Table 3. Specific Activity Limits Regardless of Type of Emission

Contamination limit	Country	Additional information
0.10 Bq/g	Germany	– – –
0.10 Bq/g	Sweden	Over and above the content of natural activity that occurs in corresponding goods outside the nuclear installation (primarily for limiting the activity in materials that, having been melted down, can be reused in new products)
0.40 Bq/g	Great Britain	Total activity for solids, other than closed sources, that are substantially insoluble in water
0.40 Bq/ml	Great Britain	Total activity for organic liquids that are radioactive solely because of the presence, either separately or simultaneously, of carbon 14 and tritium
1.00 Bq/g	Germany	Reuse of metal in a general melting facility
N/A	USA	The United States has not developed a volumetric release standard

Chapter 2

INTERNATIONAL RECOMMENDATIONS AND GUIDELINES

Various international organisations have issued, or are in the process of issuing recommendations or guidelines that may affect recycling and reuse applications. The International Commission on Radiological Protection's (ICRP) Publication 60 (1991) [1], which essentially provides principles for radiological protection standards, forms the basis for most of these recommendations. Particularly relevant is its recommended process for justifying practices. In this context, the ICRP suggests a two-stage process for justification in which options are first selected that "can be expected to do more good than harm". In the second stage, the net benefit of the change is examined with the recommendation that "the detriment to be considered is not confined to that associated with the radiation – it includes other detriments and the costs of the practice. Often, the radiation detriment will be a small part of the total. The justification of a practice thus goes far beyond the scope of radiological protection".

Of the recommendations and guidelines relevant to this discussion, the International Atomic Energy Agency's (IAEA) Principles for the Exemption of Radiation Sources and Practices from Regulatory Control, IAEA Safety Guides, Safety Series No. 89 (1988) [2], and the IAEA Draft Safety Guide SS.111.G-1-5, Recommended Clearance Levels for Radionuclides in Solid Materials, (1994) [3], are particularly noteworthy. Subsequently, in January 1996, this IAEA guidance was further formalised in IAEA-TECDOC-855 "Clearance Levels for Radionuclides in Solid Materials. Application of Exemption Principles." However, the present report is based on material available to the Task Group at the time of writing. Additionally, the European Commission (EC) Group of Experts referred to in Article 31 of the *Euratom Treaty* have drafted a document entitled, "Recommended Radiological Protection Criteria for the Recycling of Metals from the Nuclear Power Industry", (1995) [4]. The guidance in all these documents is essentially focused on the aspects concerning the protection against radiological risks; other detriments were not considered.

IAEA Guidelines and Recommendations

In 1988, the IAEA and the Nuclear Energy Agency (NEA), in co-operation, issued Safety Series No. 89 [2] to recommend a policy for exemptions from the basic safety system of notification, registration and licensing that form the basis of regulatory control. The IAEA subsequently presented Safety Series No. 111-P-1.1 [5], which provides a methodology for exemption by recycling or reuse of materials from nuclear facilities. This document is intended to provide examples of procedures that national authorities may use in setting appropriate exemption levels. The IAEA also used the results of Safety Series No. 111-P-1.1 as one of several sources of input to its process for establishing unconditional release criteria for solid materials.

Safety Series No. 89

Safety Series No. 89 sets forth two basic criteria for determining whether a practice can be exempted from regulatory control: (1) the individual risk must be sufficiently low as to warrant no regulatory concern, and (2) radiation protection, including the costs of regulatory control, must be optimised.

Because an individual may be exposed to radiation doses from several practices, and because each of these practices potentially may be judged exempt, the IAEA Safety Series No. 89 stresses the importance of ensuring that total dose does not exceed the individual exemption dose criterion of 100 µSv/a. Consequently, it recommends that each exempt practice utilise only part of the 100 µSv/a criterion for exemption. National authorities reasonably may apportion a fraction of the total to each practice to be exempted.

The recommendation implies that individual doses to a critical group(s) from a given exempt practice should be in the order of "tens" of millisieverts per year. Safety Series No. 89 also recommends that optimisation be based on cost/benefit analyses that consider the collective dose commitment and the cost of regulatory protection. If a cost/benefit analysis, in its early stage, indicates that the collective dose commitment resulting from one year of the unregulated practice will be less than approximately 1 man-Sv, the practice can be exempted without more detailed examination of other options provided that an individual dose criterion of about 10 µSv/a is also satisfied.

Draft Safety Guide 111.G-1-5

More recently, in December 1994, the IAEA prepared draft Safety Guide SS.111.G-1-5. This document is intended to recommend a set of unconditional clearance levels to be applicable to solid materials irrespective of use or destination subsequent to release from control. In this document, the IAEA distinguishes the term "exemption" from the term "clearance" based on the relationship between a source or practice and applicable regulatory control. The activity levels at which a source or practice may be exempt from regulatory control are much higher than those for clearance of sources or practices.

A radiation source or practice that has never entered the regulatory regime is evaluated to determine whether its activity level or activity concentration exceeds a threshold below which regulatory control is deemed unnecessary. Such thresholds for the level of activity or activity concentration are defined as exemption levels. According to the IAEA document, exemptions encompass those situations that are not normally regulated and typically include small sources of radiation such as tracers used in research, calibration sources, and some consumer products containing small sources or low levels of activity per unit mass. Although the use of a source may be exempt, the resulting disposal may not be exempt (*e.g.*, sealed radioactive sources).

Clearance applies to radiation sources or practices that previously have been subject to regulatory control and subsequently are removed from control based on a finding that they do not exceed a defined activity level or activity concentration. The corresponding levels of activity or activity concentrations are called clearance levels. Clearance applies to materials and scrap for recycle and reuse, and wastes containing low levels of radioactivity from within the nuclear fuel cycle or from other regulated facilities (*e.g.*, hospitals, research laboratories and industry). When regulatory control may be removed, materials are said to be cleared from regulatory control. *Unconditional clearance* would permit materials to be moved from the originating facility and recycled, reused, or placed in an appropriate disposal facility within the Member State or in any other state or country without restriction. *Conditional clearance* applies to specified materials that are subject to restrictions relating to a specific destination or use within the same state or country.

International Basic Safety Standards

A revision of the *International Basic Safety Standards* for protection against ionising radiation was recently published (1994). This fifth revision, called *International Basic Safety Standards for Protection against Ionising Radiation and the Safety of Radiation Sources*, is jointly sponsored by the

Food and Agriculture Organization (FAO), the IAEA, the International Labour Organization (ILO), the OECD/NEA, the World Health Organization (WHO), and the Pan American Health Organization (PAHO). It is based on the recommendations contained in ICRP Publication 60.

Of particular interest is the guidance associated with exemption and clearance. According to the *Basic Safety Standards*, sources may be exempted from the requirements of the Standards if: (1) the sources comply with the requirements for exemption given in its annex; or (2) the sources comply with any other exemption level defined by the regulatory authority and based on the criteria provided in Safety Series No 89 [2].

The *International Basic Safety Standards* also suggest that sources, materials, and objects utilised in authorised practices may be released from the requirements of the Standards subject to satisfying clearance requirements approved by the regulatory authority. This revision also suggests that, where appropriate, such requirements should take into account the previous exemption criteria and should not lead to higher clearance levels than the exemption levels.

IAEA Exemption and Clearance Levels

Table 4 presents a comparison of the exemption levels proposed in the revision to the *International Basic Safety Standards*, with the IAEA's Safety Series No. 111-G-1-5 recommended clearance levels. The difference between the exemption levels and the unconditional clearance levels can vary by orders of magnitude for individual nuclides. The IAEA activity concentration values are the levels below which unconditional clearance of material from facilities under regulatory control would be permitted. The numerical values of the IAEA clearance levels for surface contamination (Bq/cm^2) are the same as those for mass concentration (Bq/g). Where appropriate, both mass and surface criteria should be applied simultaneously (*e.g.*, for metal objects and buildings). For many materials, it will be possible to apply only mass concentration values (*e.g.*, for materials with uneven or rough surfaces, such as insulation material).

The IAEA's derivation of unconditional clearance levels is based on selected radiological assessments conducted in recent years related to landfill disposal and incineration of wastes, and to the recycle and reuse of ferrous and non-ferrous metals and concrete. The values presented, resulting from these studies and normalised to a basis of 10 μSv/a, have been used to establish overall ranges of values for each radionuclide. From these ranges, the recommended clearance levels are based on analysis of the two lowest values, representing the most constraining scenarios and their adjustment to order-of-magnitude categories.

EC Recommendations or Guidelines

The European Commission (EC) *Basic Safety Standards* (BSS) [6], available at the time of writing, which are intended to ensure the health protection of the general public and workers against the dangers of ionising radiation, primarily are based on ICRP Publications No. 26 [7] and No. 30 [8]*. Pursuant to Article 31 of the *Euratom Treaty*, a group of experts published a recommendation in 1988 on radiological protection criteria for the recycling of materials from the dismantling of nuclear installations. This report, Radiation Protection No. 43, contains recommended clearance levels for steel scrap and equipment resulting from the dismantling of nuclear power plants [9].

---

* The EC has issued in 1996 new *Basic Safety Standards* based on ICRP Publication 60.

Table 4. IAEA Proposed Exemption and Clearance Levels (in Bq/g)

Nuclide	IAEA *Basic Safety Standards* exemption levels	IAEA recommended unconditional clearance levels	Nuclide	IAEA *Basic Safety Standards* exemption levels	IAEA recommended unconditional clearance levels
^{3}H	1 000 000	3 000	^{106}Ru	–	3
^{14}C	10 000	300	^{129}I	–	30
^{32}P	1 000	300	^{131}I	–	3
^{35}S	100 000	3 000	^{111}In	100	3
^{36}Cl	10 000	300	^{123}I	100	30
^{45}Ca	–	3 000	^{125}I	1 000	30
^{51}Cr	–	30	^{137}Cs	10	0.3
^{55}Fe	10 000	300	^{147}Pm	10 000	3 000
^{59}Fe	10	3	^{198}Au	100	3
^{57}Co	100	30	^{201}Tl	100	30
^{58}Co	10	3	^{226}Ra+	10	0.3
^{60}Co	10	0.3	^{239}Pu	1	0.3
^{63}Ni	100 000	3 000	^{241}Am	1	0.3
^{85}Kr	100 000	–	^{144}Ce	–	30
^{89}Sr	1 000	300	^{241}Pu	–	30
^{90}Sr+	100	3	^{192}Ir	–	3
^{90}Y	–	300	^{210}Po	–	3
^{99}Tc	10 000	300	^{237}Np	–	0.3
^{109}Cd	–	300	^{238}U	–	0.3

However, based on recent experiences and new analyses, the Article 31 Group of Experts decided to convene a working party to update its original recommendation and to extend it to other materials, including steel-alloys, aluminium, aluminium-alloys, copper, and copper-alloys. The recommendations contained in that document are based on ICRP Publication 60, the EC *Basic Safety Standards*, and several recent studies that currently remain unpublished. The document concludes that slightly radioactive metal scrap, components, and equipment from nuclear installations can be authorised for clearance to the public domain.

The EC Working Party's approach to clearance provides two distinct options for releasing material: direct reuse, and melting followed by recycle and reuse. For direct reuse, the EC Working Party's proposed clearance levels apply only to surface contamination (Table 5), while mass specific and surface specific levels (Table 6) are provided for materials that will be recycled by melting. The tables provided below present the lowest value among those for steel, copper or aluminium.

We understand that all values for mass activity concentrations in Table 6 have later been rounded up to 1 Bq/g. The following provisions apply to the use of these clearance levels:

- The mass specific clearance levels are the total activity per unit mass of the metal being released and are intended as an average over moderate amounts of metal (*i.e.*, masses of a few hundred kilograms or less).

- The surface specific clearance levels are the total surface activity concentration, fixed plus non-fixed, and are intended as an average over moderate areas; in this context, over several hundred square centimetres. For non-accessible surfaces, it must be assumed that the clearance levels for surface activity are exceeded if some degree of surface contamination reasonably can be expected.

The EC draft proposal also recommended that, whenever economically sound, recycling within the nuclear industry should have priority over clearance to the public domain. Moreover, the recommended clearance levels do not apply to metal items or scrap that were melted under regulatory control before clearance.

Table 5. EC Proposed Nuclide Specific Clearance Levels for Direct Reuse of Metal

Nuclide	Surface specific (Bq/cm^2)	Nuclide	Surface specific (Bq/cm^2)
^{3}H	10 000	^{137}Cs	10
^{14}C	1 000	^{147}Pm	1 000
^{54}Mn	10	^{151}Sm	1 000
^{55}Fe	1 000	^{152}Eu	1
^{60}Co	1	^{154}Eu	1
^{59}Ni	10 000	^{234}U	0.1
^{63}Ni	1 000	^{235}U	0.1
^{65}Zn	10	^{238}U	0.1
^{90}Sr	1	^{237}Np	0.1
^{94}Nb	1	^{238}Pu	0.1
^{99}Tc	1 000	^{239}Pu	0.1
^{106}Ru	10	^{240}Pu	0.1
^{108m}Ag	1	^{241}Pu	1
^{110m}Ag	1	^{241}Am	0.1
^{125}Sb	10	^{244}Cm	0.1
^{134}Cs	1		

Table 6. EC Proposed Nuclide Specific Clearance Levels for Metal Scrap Recycling

Nuclide	Mass specific (Bq/g)	Surface specific (Bq/cm^2)	Nuclide	Mass specific (Bq/g)	Surface specific (Bq/cm^2)
^{3}H	1 000	100 000	^{134}Cs	0.1	10
^{14}C	100	1 000	^{137}Cs	1	100
^{54}Mn	1	10	^{147}Pm	1 000	1 000
^{55}Fe	10 000	10 000	^{151}Sm	10 000	1 000
^{60}Co	1	10	^{152}Eu	1	10
^{59}Ni	10 000	10 000	^{154}Eu	1	10
^{63}Ni	10 000	1 000	^{234}U	1	0.1
^{65}Zn	1	100	^{235}U	1	0.1
^{90}Sr	10	1	^{238}U	1	0.1
^{94}Nb	1	10	^{237}Np	1	0.1
^{99}Tc	100	1 000	^{238}Pu	1	0.1
^{106}Ru	1	10	^{239}Pu	1	0.1
^{108m}Ag	1	10	^{240}Pu	1	0.1
^{110m}Ag	1	10	^{241}Am	1	0.1
^{125}Sb	10	100	^{244}Cm	1	0.1

Conclusions

The IAEA and EC proposals constitute a meaningful first step in the evolution of consistent international clearance standards for dispositioning waste generated from decommissioning nuclear installations. However, the proposals do not fully address conditional clearance, or only apply to a limited number of countries. Equally significant, each proposal seeks to develop standards that are intended to represent a common level of release so trivial and comprehensive in scope that they would be readily accepted. Comments that are applicable to the more general topic of current international efforts to develop release criteria are:

- The IAEA proposal is intended to provide de minimis release criteria. Although such criteria will be useful in certain contexts, if issued alone, it may be misinterpreted to preclude or at least hinder useful and effective recycle technologies.
- Efforts to develop release criteria continue to be based on models that incorporate conservative assumptions as a safeguard against uncertainty and unacceptability. In addition, models are often used as bases for other models, multiplying the conservatism of the basic assumptions of the analyses. As a result, reductions in radiological risk may be exceeded by the non-radiological risks associated with alternative practices or risks from related processes.

- In the context of radioactive scrap metal, non-radiological health, environmental, and socio-economic risks associated with replacement of the materials, not only negate, but surpass recycling.
- A mass of available data from measurements and recent modelling efforts provides an adequate basis from which to develop unconditional and conditional release standards. Reliance solely on models and calculated assumptions may yield questionable, frequently overly-conservative results.

REFERENCES

[1] International Commission on Radiological Protection, 1990, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, United Kingdom.

[2] International Atomic Energy Agency, 1988, *Principles for the Exemption of Radiation Sources and Practices from Regulatory Control*, IAEA Safety Series No. 89, Vienna, Austria.

[3] International Atomic Energy Agency, October 1994, *Recommended Clearance Levels for Radionuclides in Solid Materials: Application of Exemption Principles*, IAEA Draft Safety Guide, Safety Series No. 111-G-1-5, Vienna, Austria.

[4] Commission of European Communities, February 1995, *Recommended Radiological Protection Criteria for the Recycling of Metals from the Dismantling of Nuclear Installations*, EURO295 (DE/BS), CEC draft proposal, Luxembourg.

[5] International Atomic Energy Agency, 1992, *Application of Exemption Principles to the Recycle and Reuse of Materials from Nuclear Facilities*, IAEA Safety Series No. 111-P-1.1, Vienna, Austria.

[6] Commission of European Communities, 1984, *CEC Basic Safety Standards for the Health Protection of the General Public and Workers against the Dangers of Ionising Radiation.* Council Directive 80/836 EURATOM, last amended September, 1984, OJ L 265 (1984); to be revised COM(93) 349 final, Brussels, July 20, 1993.

[7] International Commission on Radiological Protection, 1977, *Recommendations of the International Commission on Radiological Protection*, Publication 26, Pergamon Press, Oxford, United Kingdom.

[8] Clark, R.H., *1990 Recommendations of the ICRP*, Supplement to the Radiological Protection Bulletin No. 119 (1991).

[9] Commission of European Communities, 1988, *CEC Radiological Protection Criteria for Recycling of Materials from the Dismantling of Nuclear Installations*, Radiation Protection No. 43, Luxembourg.

Chapter 3

HEALTH, ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS

For the purposes of this report, the Task Group has defined the recycle or reuse of materials resulting from decommissioning as a practice. In the opinion of the Task Group, the justification of a practice should encompass far more than simply the detriment attributable to risks from radiation. The Task Group examined the justification for release of radioactive materials from regulatory control for purposes of recycling or reuse by considering, not only the risks from radiation, but also major non-radiological socio-economic, environmental, and health effects. In this context, a "tiered" system for release criteria has been used as the basis for comparing the human health, environmental, and socio-economic impacts of recycle/reuse management practices with those attributable to disposal and subsequent replacement of radioactive scrap metal.

The alternative to releasing radioactive scrap metal for recycling is disposal as low-level waste in unrestricted landfills and low-level waste disposal facilities. This requires cutting and packaging radioactive scrap metal for transportation and disposal, and also may involve decontamination to reduce worker exposures and melting to reduce volume. As disposal would withdraw radioactive scrap metal from the world's stocks of metal, the materials would be replaced by metal newly produced from ore. The processes required for such replacement include mining, ore enrichment or refining, metal smelting, casting and fabrication, and the production of the energy required to accomplish these activities. Inherent to these activities are significant health, environmental, and socio-economic impacts that must be considered as part of any comprehensive justification of recycling, given that disposal and replacement currently is the principal alternative for disposition of metal scrap.

Four tiers (A through D) would comprise the system, each incorporating options in accordance with specified release criteria and type of end use. Tiers A, B, and C pertain to public/industrial releases from the regulatory environment, whereas Tier D involves recycling within the nuclear industry. Tier A-1 has surface activity levels and A-2 volumetric activity levels that apply to objects that are released in their original form (*e.g.*, office furniture, tools, or structural steel). Tiers B and C pertain to scrap with fixed-surface or volumetric activity that would be decontaminated and then melted in a controlled (licensed) facility. Ingots then would be released for recycling under Tier B-1 (remelted at a commercial smelter) or Tier B-2 (milled without dilution). Melting serves as a decontamination measure for some radionuclides and also would facilitate measurement of the activity in the metal. Tier B has volumetric activity levels that are appropriate for a wide range of metal products in unrestricted uses. Slag from the commercial melting is assumed to be used in paving highways or parking lots.

Tier-C release requires restricted distribution of finished metal products from a controlled melting and milling facility to prescribed initial uses that involve minimal public exposure. In the future, when the metal is again recycled (30 years assumed), it would be treated as common scrap. The main advantage of Tier-C recycling is the ability to use metals that are contaminated with relatively short-lived radionuclides, while controlling health risks. Usable metal with activity exceeding Tier-C levels would be recycled for use in environments with radiation controls (Tier D).

As envisioned, the "tiered" system shown in Figure 1 would address a broad range of restricted and unrestricted end uses. Such a system possesses the advantages of matching radioactive scrap metal supply with demand, while ensuring that health risks and environmental impacts meet international guidelines.

Moreover, a "tiered" system would facilitate the control of health risks by tailoring release limits to the radiological characteristics of radioactive scrap metal and its potential end uses.

Where recycling is considered cost prohibitive or impractical, scrap would be disposed of as low-level waste.

Human Health Risks

The present chapter summarises the findings of the Task Group concerning the assessment of health risks. Companion documents to this report [6, 16] provide a detailed discussion of the basis for the assessments made by the Group.

There are potential health risks to workers and the general public associated with both the recycle/reuse and the disposal/replacement alternatives for radioactive scrap metal management. These alternatives involve health risks from exposures to radiation and toxic elements, as well as from industrial and transportation accidents (health risk estimates are summarised in Table 7). According to the Task Group assessment, for both alternatives, the physical 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.

Table 7. Summary of Health Risks from the Radioactive Scrap Metal Management Alternatives

Impact categories	Recycle/reuse	Dispose and replace
*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
Non-radiological 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

---

* Risk estimates represent maximum individual lifetime risk associated with a 50 000-t throughput, operated so that individual dose does not exceed 10 µSv/a.

** Maximum individual lifetime risk of cancer fatality resulting from one year of exposure at the maximum permissible concentration in the United States.

Recycling scrap metal that meets the derived activity levels proposed in this report for Tier A, B, or C would result in a lifetime cancer fatality risk level for an individual of the general public of less than 10^{-7} to 10^{-6} from annual exposure (based on [1]).

Risks to commercial metal workers would be of a similar magnitude and could be reduced to even lower levels by employing protective measures. The total population risk level would be less than 10^{-2} to 10^{-1} cancer fatalities from an annual recycling practice of 50 000 t. For the disposal/replacement alternative, some miners would be exposed to naturally occurring radioactivity that could exceed the regulatory *dose* limit for nuclear workers, at least in the United States. However, such dose levels are more likely for non-ferrous metals than for iron mining.

The non-radiological 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 melting, and to commercial smelting. Overall, these 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 on the order of 10^{-3} for each 100 km that 50 000 t of radioactive scrap metal or replacement materials are shipped by truck. Transportation requirements, and therefore accident risks, are likely to be several times higher for disposal/replacement.

With regard to chemical exposures, risks to commercial metal workers and the public from melting radioactive scrap metal would be less than those generated by smelting metal from ore. For the portion of scrap metal that comprises the relatively large quantity of suspect, but probably non-radioactive 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 radioactive scrap metal.

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 radioactive scrap metal recycling.

Radiological Health Risks

In keeping with ICRP recommendations, radiological risks to the public from either recycle/reuse or disposal/replacement would be kept at very low levels (approximately 10^{-5} fatalities per year of practice). For the radioactive scrap metal recycle alternative, radiological health risks were estimated for Tier A, B, and C product 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 to radiation workers from activities prior to radioactive scrap metal release – such as metal sorting, decontamination, and packaging – were not evaluated as these activities would be conducted in an environment where exposures would be maintained below regulatory limits and likely would be required for either recycling or disposal of radioactive scrap metal. Disposal of radioactive scrap metal at low-level waste sites also would be conducted by radiation workers. Consequently, it is assumed that both worker and public exposures would be maintained below regulatory limits.

The risk estimates for disposal of radioactive scrap metal as low-level waste are based on regulatory limits and public exposure scenarios from previous studies. Tables 8 through 10 provide information associated with derived dose estimates for Tiers A through C.

Potential radiological impacts from the radioactive scrap metal alternatives were assessed in terms of total effective dose equivalent. 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) [2].

Radiological risks from metal recycle/reuse have been analysed previously by various international organisations. This independent analysis was conducted by the Task Group to:

- develop and evaluate an expanded set of scenarios – including smelting emissions, landfill disposal, and transportation – that is appropriate for the "tiered" release concept proposed in this study,
- expand the nuclide categories considered, to include volatile elements and radon parents,
- incorporate recently developed methodology and available information,
- emphasise a realistic approach to development of release standards.

To meet these objectives the analysis was to: (1) calculate baseline doses for the recycling alternatives and options using parameters based on previous studies, (2) perform a sensitivity analysis for key parameters to determine uncertainty levels and the degree to which they have been handled conservatively, and (3) advance the concepts of previous studies by identifying potentially appropriate release level ranges based on additional information regarding important parameters and using dose criteria that, in themselves, are protective of human health.

Radiological impacts have been analysed with the RESRAD-BUILD methodology [3]. Inclusion of features such as room size and ventilation rate allow RESRAD-BUILD to investigate the effects of parameters that are unavailable in NUREG/CR-5512 [4] and to assess potential risks from radon gases, which have not been previously considered. The framework of exposure scenarios and assumptions was taken from the IAEA Safety Series No. 111-P-1.1 [5]. A more detailed description of the analysis, including the technical assumptions and methodology, is provided in a companion document to this report [6].

Release levels for each tier were derived assuming a public individual dose of 10 µSv/a [1], thereby restricting cancer fatality risks to individual members of the public, including industrial workers, from unrestricted recycling/reuse to less than 10^{-6}. The Task Group used this 10 µSv/a value as a reference point, but it does not endorse the assumed 10 µSv/a, and feels that additional justification of this choice should be developed for the practice of recycling metals. (See discussion of regulations and policy in Chapter 2). For this analysis, a "practice" is interpreted as a single commercial smelter/mill that accepts 50 000 t/a of radioactive scrap metal and produces consumer products.

Two parameters that play a key role in individual dose estimates for recycle scenarios (Tiers B and C) for both worker and public doses are the radioactive scrap metal dilution and radionuclide partitioning factors. Incorporating realistic values for these parameters substantially reduces conservatism in dose estimates. In the Task Group's modified-conservative case presented in the following tables, the radioactive scrap metal dilution factor is assumed to be 1:10, and nuclide partitioning factors from the literature are applied.

The population collective dose sums all doses estimated for exposed population groups. As the population dose accounts for the total exposure resulting from recycling radioactive scrap metal, it is highly dependent on the annual throughput. The relation of throughput to Tier-A applications is highly uncertain, so population dose was not calculated for Tier A.

Doses to Workers from Recycling

In each of the recycling activities for Tier B, commercial metal workers would receive exposures from the radioactive scrap metal. Worker scenarios for each step in the recycling process were adapted from Safety Series No. 111-P-1.1 [3]. Annual baseline doses for workers were estimated on the basis of 2 000 hours of exposure and were scaled for throughput of 50 000 t. Worker doses under the Tier-C prescribed-first-use scenarios and the Tier-D scenarios that involve shielding blocks and radwaste containers are limited to nuclear facility workers.

Table 8 lists constraining individual worker doses for Tier B-1, release to a commercial melter, and Tier B-2, release to a commercial mill for processing. For Tier B-1, the constraining doses are for the slag worker and small object caster scenarios. The sheet and coil worker scenarios are constrained for Tier B-2 which only involves rolling and fabrication of the metal.

Table 8. Constraining Individual Worker Doses for Tier B-1 and B-2 Worker Scenarios with 50 000-t Throughput

		Tier B-1 Commercial melter*	**Tier B-2 Commercial milling****
Nuclide category	**Representative nuclide**	**Constraining scenario Individual dose*** (μSv/a)**	**Constraining scenario Individual dose*** (μSv/a)**
Alpha	^{227}Ac	4.9×10^{1}	8.1×10^{0}
	^{241}Am	2.1×10^{0}	5.3×10^{-1}
	^{239}Pu	1.5×10^{0}	1.3×10^{-3}
	^{238}U	2.2×10^{0}	5.5×10^{-1}
Beta	^{90}Sr	4.4×10^{-1}	9.4×10^{-2}
	^{99}Tc	1.1×10^{-2}	7.0×10^{-4}
Gamma	^{60}Co	1.5×10^{1}	6.0×10^{1}
	^{137}Cs	4.5×10^{1}	1.3×10^{1}
	^{65}Zn	3.4×10^{-1}	9.0×10^{0}

Worker collective doses are based on a radioactive scrap metal activity concentration of 1 Bq/g, a dilution factor of 1:10, and realistic nuclide partitioning factors. The highest worker collective dose is for cobalt 60, 7×10^{-4} man-Sv. The dilution assumption reflects metallurgical alloying practices. It is not proposed as a technique to achieve clearance.

Doses to the Public from Reuse/Recycling – Tier A

A standard, conservative building occupancy scenario [4] was analysed for reuse of a building or as a bounding case for large equipment. Uniform contamination of the four walls of a 5 × 5 × 3 m room

---

* All values include a dilution rate of 1:10 and partitioning, and are based on the slag worker scenario, except those for cobalt 60 which are for the small object caster scenario.

** Values are based on the coil and sheet worker scenarios and do not involve any dilution of the radioactive scrap metal or partitioning of the activity.

*** Doses are based on an radioactive scrap metal activity concentration of 1 Bq/g at the point of release.

was assumed. A less conservative scenario was also developed for surface contamination of an area of 1 m^2, which was assumed to generically characterise small tools or equipment.

Results presented in Table 9 assumed that the surface had been decontaminated to the extent that only 1 per cent of the activity present could become airborne. Parent nuclides with decay chains that emit radon and its decay progeny are evaluated. Nuclides associated with significant radon doses include radium 224, radium 226, thorium 230 and thorium 232.

For volume-contaminated tool reuse, Tier A-2, only external exposure is included in the dose calculation because all contamination is assumed to be non-transferable. To represent a large tool, a 1-m^3 object and geometries for the ingot caster scenario [5] were used, assuming no dilution or partitioning of nuclides. Table 9 presents individual doses for all three scenarios.

Table 9. Constraining Individual Public Doses for Reusing Radioactive Scrap Metal Under Tier A-1 and A-2 Scenarios

		Tier A-1 – Surface contamination		Tier A-2 – Volumetric contamination
		Tools and equipment*	Building occupancy	Tools and equipment**
Nuclide category	Representative nuclide	Individual dose*** (in µSv/a)	Individual dose*** in µSv/a)	Individual dose**** (in µSv/a)
Alpha	^{227}Ac ^{241}Am ^{239}Pu ^{238}U	8.5×10^{0} 9.1×10^{-1} 6.9×10^{-1} 2.7×10^{-1}	4.0×10^{2} 4.2×10^{1} 4.0×10^{1} 7.7×10^{0}	9.1×10^{0} 2.2×10^{-1} 1.5×10^{-3} 6.2×10^{-1}
Beta	^{90}Sr ^{99}Tc	3.7×10^{-2} 5.9×10^{-4}	9.1×10^{-1} 9.9×10^{-3}	1.1×10^{-1} 6.2×10^{-4}
Gamma	^{60}Co ^{137}Cs ^{65}Zn	9.3×10^{0} 2.3×10^{0} 1.5×10^{0}	3.4×10^{1} 8.6×10^{0} 5.3×10^{0}	6.7×10^{1} 1.5×10^{1} 1.0×10^{1}
Volatile nuclides	^{3}H ^{129}I	6.3×10^{-4} 1.7×10^{0}	3.8×10^{-2} 1.0×10^{2}	_***** _*****
Radon******	^{224}Ra ^{226}Ra ^{232}Th	6.8×10^{0} 2.7×10^{1} 6.2×10^{2}	4.1×10^{2} 1.6×10^{3} 3.7×10^{4}	_***** _***** _*****

---

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

** For volumetric contamination, a 1 m^3 object is used for generic assessment of tools and equipment.

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

**** Doses are based on a radionuclide activity concentration of 1 Bq/g.

***** Not analysed.

****** Radium 224 and radium 226 are parent nuclides of radon 220 and radon 222, respectively; thorium 232 decays to radium 224.

Recycle to Consumer Products and Prescribed Initial Use – Tiers B and C

Doses from the use of consumer products primarily result from external exposures to gamma radiation, although for some nuclides ingestion is the primary pathway under the frying pan scenario. For unrestricted metal recycling, basic scenarios and assumptions follow Safety Series No. 111-P-1.1 [5]. Commercial remelting with resulting nuclide partitioning and dilution is assumed for Tier B-1, while Tier B-2 assumes fabrication without remelting of ingots. Tier B-1 also includes the use of slag in highway pavement.

External exposure is the only identifiable pathway to the public for the Tier C prescribed-initial-use scenarios. These scenarios were developed to represent the use of structural steel and reinforcing bars in bridges and public buildings. Estimated doses for Tiers B and C are shown in Table 10. For Tier B, the maximum individual doses are associated with the taxi driver scenario (external) and the frying pan scenario (ingestion). The constraining scenario for Tier C is the public building scenario.

Table 10. Constraining Public Doses for Recycling Radioactive Scrap Metal Under Tier B-1, B-2, and C Scenarios

Nuclide category	Representative nuclide	Tier B-1 Commercial melting*	Tier B-1 Pavement scenario (slag from commercial melt)**	Tier B-2 Consumer products scenarios (commercial milling)*	Tier C Prescribed initial use scenarios (controlled melt and milling)***
		Individual dose (in µSv/a)****	Individual dose (in µSv/a)****	Individual dose (in µSv/a)****	Individual dose (in µSv/a)****
Alpha	^{227}Ac	2.4×10^{-1}	3.3×10^{-3}	2.4×10^{1}	–
	^{241}Am	5.8×10^{-2}	7.9×10^{-5}	5.8×10^{0}	–
	^{239}Pu	7.1×10^{-3}	5.2×10^{-7}	7.1×10^{-1}	–
	^{238}U	2.3×10^{-2}	2.3×10^{-4}	2.3×10^{0}	–
Beta	^{90}Sr	1.2×10^{-3}	3.5×10^{-5}	1.2×10^{-1}	3.4×10^{-2}
	^{99}Tc	6.2×10^{-5}	2.3×10^{-8}	6.2×10^{-3}	–
Gamma	^{60}Co	8.3×10^{0}	2.3×10^{-4}	8.3×10^{1}	1.9×10^{1}
	^{137}Cs	2.2×10^{-3}	5.5×10^{-3}	2.2×10^{1}	3.2×10^{0}
	^{65}Zn	1.4×10^{-2}	3.7×10^{-5}	1.4×10^{1}	2.9×10^{0}

From the metal mass of each end-use product and the radioactive scrap metal throughput, the number of products potentially distributed annually is estimated as a basis for calculating total public exposure. Population doses for Tier B are dominated by the building occupancy (20 to 40 per cent) and

---

* With one exception, the constraining scenario is the taxi driver; the frying pan scenario is constraining for plutonium 239.

** The exposures shown are for slag, but the derived levels are for radioactive scrap metal release.

*** Because of its long half-life (2 × 10^5 years), technetium 99 is not considered for Tier C release. The public building scenario is constraining.

**** Tier B-1 doses are based on a radioactive scrap metal activity concentration of 1 Bq/g at the point of release to a commercial smelter, a dilution rate of 1:10, and nuclide partitioning factors. Tier-B-2 and Tier-C doses are based on 1 Bq/g without dilution or partitioning after release.

frying pan (10 to 30 per cent) scenarios. For Tier C, the constraining dose is from use of reinforcing steel in concrete in a public building. In both tiers, cobalt 60 population doses substantially exceed 1 man-Sv. This suggests a need to control high-energy gamma emitters such as cobalt 60 in the stock of recycled metals. Either restricting concentrations to very low levels or storing materials contaminated with cobalt 60 until it decays to appropriate levels would provide public protection.

Doses to the Public from Smelter Emissions

Dose estimates for radioactive emissions during commercial smelting are estimated for the maximally exposed individual based on a 50 000 t/a radioactive scrap metal throughput containing 1 Bq/g of each nuclide. Doses are predominantly from the inhalation pathway, and exposures to residual activity after the first year and from other pathways are negligible. Doses from emissions from processing radioactive scrap metal in a commercial smelter are lower than doses from other scenarios and, therefore, do not constrain release levels.

Population *collective* doses from radioactive emissions are estimated for a 50 000-t throughput with a 1 Bq/g concentration of each nuclide. The doses were estimated with the CAP88-PC code [7] and the same parameters used for the individual dose calculation. Doses from air emissions are generally orders of magnitude lower than those from worker exposures or public end-use scenarios.

Doses to Workers and the Public from Radioactive Scrap Metal Transportation

Radiological risks from transporting radioactive scrap metal would occur regardless of whether the metal were shipped for disposal or for decontamination and recycling. Current US regulations [8] specify dose limits equivalent to 100 μSv/h at 1 m from the package surface and 20 μSv/h at the crew compartment. Radioactive scrap metal shipments with activity levels consistent with public (including smelter and mill workers) dose constraints would usually result in an external radiation field much lower than the regulatory limits for transportation. Detailed evaluation indicated that external dose for a typical radioactive scrap metal shipment is about two orders of magnitude less than US regulatory limits [9].

Shipping 50 000 t of radioactive scrap metal for a distance of 100 km in 20-t shipments would result in a maximum individual dose of 2×10^2 μSv/a (lifetime cancer fatality risks of 1×10^{-5}) for the crew. For the crew and general public, the collective dose from transporting 50 000 t is 2×10^{-2} man-Sv, with estimated cancer fatality risks of 8×10^{-4}.

Doses from Disposal Alternatives

Two radioactive scrap metal disposal alternatives were evaluated, disposal at an unrestricted landfill and disposal at a dedicated low-level waste site. Only individual doses were estimated for disposal alternatives. Collective doses were not calculated, because the uncertainties associated with site-specific parameters preclude meaningful estimates.

The unrestricted disposal scenario assumed a pile of scrap metal (corresponding to a 50 000-t mass) buried in a public landfill. For surface contamination, individual doses for most nuclides are less than 10 μSv/a. For volumetric contamination, doses are generally on the order of 10 μSv/a. Doses were calculated using the RESRAD environmental pathway analysis code [3]. Relatively high doses from some nuclides, such as radium 226 or iron 129, indicate that they require more constraining activity levels (*i.e.*, less than 1 Bq/g) to reduce doses to 10 μSv/a.

Doses from disposal of radioactive scrap metal at a low-level waste site were not specifically calculated. However, low-level waste must meet existing disposal regulations (such as 10 CFR 61 [10]), so health risks from radioactive scrap metal disposal are likely to be similar to those estimated for low-level waste in general. Doses from a low-level waste disposal facility to the maximally exposed individual, an intruder, range from 35 to 200 µSv/a [11]. Individual public doses must not exceed the regulatory limit of 1 mSv/a [2] [12].

Ranges of Derived Release Levels

In all cases the release level for each nuclide under each tier was obtained by dividing the assumed 10-µSv/a reference level by the most constraining worker or public dose from the previous tables.

For Tier A (surface contamination), the derived release levels shown in Table 11 for the conservative building occupancy scenario are generally consistent with existing standards (*e.g.*, Regulatory Guide 1.86 [13]) and with the derived levels in Safety Series No. 111-P-1.1 [5],

Table 11. Derived Release Levels for Reusing Radioactive Scrap Metal Under Tier A-1 and A-2 Scenarios

Nuclide category	Representative nuclide	Tier A-1 Surface contamination		Tier A-2 Volumetric contamination
		Tools and equipment*	Building occupancy	Tools and equipment**
		Derived levels*** (in Bq/cm²)	Derived levels*** (in Bq/cm²)	Derived levels**** (in Bq/g)
Alpha	^{227}Ac	1.2×10^{0}	2.5×10^{-2}	1.1×10^{0}
	^{241}Am	1.1×10^{1}	2.4×10^{-1}	4.6×10^{1}
	^{239}Pu	1.5×10^{1}	2.5×10^{-1}	6.9×10^{3}
	^{238}U	3.7×10^{1}	1.3×10^{0}	1.6×10^{1}
Beta	^{90}Sr	2.7×10^{2}	1.1×10^{1}	9.4×10^{1}
	^{99}Tc	1.7×10^{4}	1.0×10^{3}	1.6×10^{4}
Gamma	^{60}Co	1.1×10^{0}	3.0×10^{-1}	1.5×10^{-1}
	^{137}Cs	4.4×10^{0}	1.2×10^{0}	6.7×10^{-1}
	^{65}Zn	6.8×10^{0}	1.9×10^{0}	9.8×10^{-1}
Volatile nuclides	^{3}H	1.6×10^{4}	2.6×10^{2}	_*****
	^{129}I	5.9×10^{0}	1.0×10^{-1}	_*****
Radon ******	^{224}Ra	1.5×10^{0}	2.4×10^{-2}	_*****
	^{226}Ra	3.7×10^{-1}	6.3×10^{-3}	_*****
	^{232}Th	1.6×10^{-2}	2.7×10^{-4}	_*****

---

* Area of surface contamination is 1 m² for generic assessment of tools and equipment.

** For volumetric contamination, a 1-m³ object is used for generic assessment of tools and equipment.

*** Doses are based on a radionuclide activity concentration of 1 Bq/cm² and a surface transfer factor of 0.01 assumes loose contamination has been removed by decontamination.

**** Activity concentration that results in an individual dose of 10 µSv/a.

***** Not analysed.

****** Radium 224 and radium 226 are parent nuclides of radon 220 and radon 222, respectively; thorium 232 decays to radium 224.

except that radon emissions were not previously accounted for. Consideration of radon emission results in relatively large dose estimates for nuclides with radon in their decay chains. However, these estimates have large uncertainty ranges because of the uncertainty regarding the radon emanation rate from surface contamination. Dose build-up from decay product ingrowth is a concern for these nuclides and has been considered in deriving Tier-A release levels.

If radon gas and its progeny were included in deriving levels based on 10 µSv/a, radionuclides such as radium 226 would have such low release levels that it would be difficult, if not impossible, to measure compliance. For alpha emitters, the controlling parameter appears to be the contaminant emission rate (*i.e.*, surface resuspension factor). For beta emitters, the ingestion rate is dominant. Empirical data for these key factors are limited, particularly pertaining to surfaces treated by current decontamination techniques. Continued research efforts, especially in experimental areas, are needed to improve upon the existing information.

For recycling, in contrast to Tier-A reuse scenarios, derived release levels are strongly influenced by the scrap throughput level defined as a "practice" for the purposes of the analysis. For instance, a throughput of 10 000 t, as assumed in most previous studies, would increase release levels by five times compared to a 50 000-t throughput (the assumption of 50 000 t was based on estimates of metal availability in the near future from decontamination and decommissioning operations). The lack of international consensus on definition of a "practice" in this particular area contributes to the ambiguity in determining appropriate release levels.

Derived release levels for constraining individual dose scenarios for Tiers B-1 and B-2 (volumetric contamination) and Tier C (prescribed-initial-use) are summarised in Table 12. Tier-B-1 release levels

Table 12. Derived Release Levels for Reusing Radioactive Scrap Metal Under Tier B-1, B-2, and Tier C, Showing the Constraining Scenarios*

		Tier B-1 Commercial melt		**Tier B-2 Commercial milling**		**Tier C Prescribed initial use**	
Nuclide category	**Representative nuclide**	**Derived levels (in Bq/g radioactive scrap metal)**	**Constraining scenario**	**Derived levels (in Bq/g radioactive scrap metal)**	**Constraining scenario**	**Derived levels (in Bq/g radioactive scrap metal)**	**Constraining scenario**
Alpha	^{227}Ac	2×10^{-1}	Slag worker	4×10^{-1}	Taxi driver	–**	–
	^{241}Am	5×10^{0}	Slag worker	2×10^{0}	Taxi driver	–**	–
	^{239}Pu	7×10^{0}	Slag worker	1×10^{1}	Frying pan	–**	–
	^{238}U	5×10^{0}	Slag worker	4×10^{0}	Taxi driver	–**	–
Beta	^{90}Sr	2×10^{1}	Slag worker	9×10^{1}	Taxi driver	3×10^{2}	Public - building
	^{99}Tc	1×10^{3}	Slag worker	2×10^{3}	Taxi driver	–**	–
Gamma	^{60}Co	7×10^{-1}	Caster	1×10^{-1}	Taxi driver	5×10^{-1}	Public - building
	^{137}Cs	2×10^{-1}	Slag worker	5×10^{-1}	Taxi driver	3×10^{0}	Public - building
	^{65}Zn	3×10^{1}	Slag worker	7×10^{-1}	Taxi driver	3×10^{0}	Public - building

---

* Levels are constrained by 10 µSv/a and are based on 50 000-t throughput. Tier B-1 is constrained by worker dose while Tiers B-2 and C are constrained by public dose.

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

for all nuclides are constrained by commercial smelter worker exposures. This is also true if the radioactive scrap metal throughput of a commercial smelter is 10 000 t rather than 50 000 t. The only case in which public dose is nearly as constraining as worker dose is the cobalt 60 taxi-driver scenario. Slag product exposure scenarios were analysed for Tier B-1 but were not constraining. Release levels for Tiers B-2 and C were derived from a radioactive scrap metal activity concentration without dilution after release and are constrained by public exposure to products. Except for zirconium 65, which is much lower than for Tier B-1, the release levels for Tier B-2 are of the same order of magnitude as Tier B-1. This indicates that Tier-B-1 levels would be sufficiently protective, even if ingots that were released for remelt were directly milled.

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

Non-radiological Health Risks

Although the radiological health risks from either recycling or disposal and replacement are relatively low, this is not the case for nonradiological risks. Both alternatives involve substantial health risks from workplace and transportation accidents as well as from worker and public exposures to chemicals that are carcinogenic or toxic. Of these two types of risks, the accidental fatality and injury risks to the public and workers are higher and much more immediate. Health risks for individuals from chemical exposures and accidents are summarised in Table 13.

Many aspects of replacement processes are conducted within environments that are less stringently regulated than the environment in which recycle/reuse alternatives would operate. The highest human health risks are those associated with accidents in the workplace. Replacement necessarily involves coal mining, iron mining, and coke production, occupations that have relatively high accident rates. In addition, the risk of a worker fatality associated with the replacement of 50 000 t of radioactive scrap metal, is approximately 15 fatal or serious injuries to workers in steel mill and blast furnace operations compared to approximately eight for steel smelting and milling operations for recycling. Consequently, risk to workers from replacement/disposal alternatives exceed those for recycling alternatives.

Moreover, because of the multiple stages involved in replacement/disposal practices, transportation requirements exceed those associated with recycle/reuse practices. Replacement must consider, not only shipment of wastes, but also transportation of the coal and ores necessary for steel production.

Risks of transportation accident fatalities are approximately 10^{-3} for each 100 km that 50 000 t of material is shipped by truck. Accordingly, risk attributable to potential transportation accidents is an order of magnitude higher for disposal/replacement.

Table 13. Health Risk Estimates for Radioactive Scrap Metal (Steel) Management Alternatives

Activity	Group affected	Risk type	Health risk estimate from one year of activity*
Activities common to both alternatives			
Radioactive scrap metal transportation**	• Public • Truck drivers	• Accident/fatalities • Radiation/cancer • Radiation/cancer	• 5×10^{-3} (collective) • Negligible • 1×10^{-5}
Radioactive scrap metal disposal (low-level waste)	• Nuclear workers • Public	• Radiation/cancer • Radiation/cancer	• 10^{-3} (regulatory limit)*** • 5×10^{-5} (regulatory limit)***
Recycling activities			
Radioactive scrap metal decontamination and preparation	• Nuclear workers	• Radiation/cancer • Chemical/cancer	• 10^{-3} (regulatory limit)*** • 10^{-3} (regulatory limit)***
Controlled melting	• Nuclear workers • Public	• Radiation/cancer • Chemical/cancer • Radiation/cancer • Chemical/cancer	• 10^{-3} (regulatory limit)*** • 10^{-3} (regulatory limit)*** • Unquantified • Unquantified
Ingot transportation**	• Truck drivers • Public	• Radiation/cancer • Accident/fatalities • Radiation/cancer	• 1×10^{-5} • 5×10^{-3} (collective) • Negligible
Commercial smelting	• Smelter workers • Public	• Radiation/cancer • Chemical/cancer • Accident/fatalities and injuries • Radiation/cancer • Chemical/cancer	• $10^{-7} - 10^{-6}$ *** • 10^{-3} (regulatory limit)*** • 8×10^{0} • 3×10^{-8} *** • 2×10^{-4}
Metal end use	• Public	• Radiation/cancer	• $10^{-7} - 10^{-6}$ ***
Disposal and replacement activities			
Iron ore mining and enrichment	• Miners • Public	• Radiation/cancer • Chemical/cancer • Accident/fatalities • Chemical/cancer	• $5 \times 10^{-5} - 1 \times 10^{-2}$ • 10^{-3} (regulatory limit)*** • 1×10^{-2} • Unquantified
Ore transportation	• Public	• Accident/fatalities	• 1×10^{-3} - 4×10^{-2} (collective)****
Coking coal production Coke transportation Pig iron production (blast furnace)	• Miners • Oven workers • Public • Public • Workers • Public	• Accident/fatalities • Chemical/cancer • Chemical/cancer • Accident/fatalities • Radiation/cancer • Chemical/cancer • Accident/fatalities and injuries • Radiation/cancer • Chemical/cancer	• 2×10^{-3} - 3×10^{-2} • 1×10^{-2} - 6×10^{0} • 1×10^{-3} - 7×10^{-2} • 1×10^{-3} - 4×10^{-2} (collective)**** • Unquantified • 10^{-3} (regulatory limit)*** • 7×10^{0} • Unquantified • 2×10^{0}
Steel smelting (basic oxygen process)	• Smelter workers • Public	• Radiation/cancer • Chemical/cancer • Accident/fatalities and injuries • Radiation/cancer • Chemical/cancer	• Unquantified • 10^{-3} (regulatory limit)*** • 8×10^{0} • Unquantified • 2×10^{0}

---

* Assumes 50 000 t of radioactive scrap metal or replacement steel. All risks are for the most exposed individuals unless designated as collective.

** Assumes 100 km per round trip and 20 t per shipment.

*** Maximum individual lifetime risk of cancer fatality resulting from one year of exposure at hte maximum permissible concentration in the United States

**** Rail transport has the lowest rate and truck transport the highest.

Environmental Risks

Similarly, the potential for adverse environmental impacts is much higher for replacement/disposal alternatives. Although recycling and reuse alternatives will impact the environment by utilising relatively small amounts of low-level waste disposal capacity, replacement/disposal presents more severe adverse impacts to the environment from land use, disruption, and damage that results from mining and related processes. The production of 1.0 t of steel from raw materials requires more than 2.0 t of iron ore and 0.5 t of coke. Furthermore, extracted ore constitutes only a fraction of the material produced during mining operations. A general summary of the environmental impacts of both radioactive scrap metal management alternatives is presented in Table 14.

Other environmental impacts attributable to replacement/disposal practices (over and above those associated with smelting, which are shared by both recycling/reuse and replacement/disposal) also include increased leaching of heavy metals from soils and mining wastes into surface and ground water, increased sedimentation of streams and rivers, emissions of toxic chemicals from mining operations, waste piles, and coke production, and increased energy requirements. Energy requirements for radioactive scrap metal replacement likely would be twice that for recycling.

Finally, recycling radioactive scrap metal would conserve valuable natural resources. For example, the use of recycled radioactive scrap metal would reduce raw material consumption by 90 per cent and mining wastes by 97 per cent [14].

Socio-economic Impacts

Public Acceptability

Recycling/reuse and disposal/replacement each present different socio-economic impacts. Those issues determined to be potentially of most concern are public acceptability of recycling/reuse practices and availability of adequate low-level waste disposal capacity. Public acceptance of the practice of recycling metals with traces of radioactivity may be problematic because of the stigma associated with the nuclear industry in most industrialised countries. However, products containing low levels of added or naturally occurring radioactivity are widely used, and small quantities of radioactive scrap metal have been successfully recycled in a number of countries. Public perceptions of risk related to products containing radioactive materials (like smoke alarms) are influenced by product familiarity, benefit, and the extent to which the radioactive aspects of the product are publicised. Notwithstanding the large quantities of naturally occurring radionuclides released in the course of metal, petroleum, phosphate, and coal production, the public generally does not attach a nuclear stigma to these industries.

Perceptions of low-level waste disposal repositories are subject to similar public scrutiny and heightened sensitivity. Replacement/disposal alternatives will present requirements for increased disposal capacity in excess of the capacity of currently operating facilities. Disposal of the current international radioactive scrap metal inventory as low-level waste will require a disposal capacity of 5 million m^3 [6]. This translates into total disposal costs of $5 billion [6] at current US rates for surface disposal. Moreover, siting and licensing of both high and low-level waste facilities have been the subject of intense political opposition. As a result, disposal costs are likely to continue to increase while access is likely to become more restricted.

Ultimately, public perceptions of the acceptability of both radioactive scrap metal management alternatives will influence significantly the implementation of either alternative. Consequently, additional information on the relative risks of both management alternatives could be a determining factor in the formation of public opinion and in the decision making process.

Table 14. Environmental Impacts of Activities Associated with Radioactive Scrap Metal (Steel) Management Alternatives

Resource affected	Recycle/reuse	Dispose and replace
Land use	Some low-level waste involved, but no new sites required.	Substantial expansion of low-level waste 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 and smelting effluents.	Acidification of surface water flowing from mining sites. Increased leaching of heavy metals from soils and mining wastes into surface water and groundwater. Leaching of radioactive elements from mining wastes into surface water and groundwater. Increased sedimentation of streams and rivers. Release of heavy metals from smelting into surface water.
Air quality	Emissions of SO_2 from smelting. 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	Low-level waste 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.

Other Socio-economic Factors

Other factors examined as part of the Task Group's evaluation included potential market impacts of increased radioactive scrap metal recycling and inequitable social or geographic shifts in the impacts of dispositioning radioactive scrap metal.

During the period 2010 through 2043, total radioactive scrap metal inventory could contribute as much as 500 000 t/a of iron and steel, 100 000 t/a of copper, and 40 000 t/a of stainless steel to international markets [6]. Of these materials, only copper may be recycled in sufficient quantities to depress prices measurably, and even then, only in certain regional markets.

Comparisons of potential annual radioactive scrap metal flow with demand for scrap metal in regional markets indicate that radioactive scrap metal is unlikely to constitute significant portions of scrap imports or impact annual variations in scrap consumption within the affected markets. Consequently, price impacts associated with recycle/reuse practices likely would be minor.

The distribution of impacts among world regions differs between recycling/reuse and disposal/replacement. Radioactive scrap metal would probably be recycled or disposed of in facilities located in its region of origin. Radioactive scrap metal inventory is greatest in relatively industrialised countries, so the impacts of recycling and of disposal would most likely occur in these regions. In contrast, the increased mining and processing of raw materials required for metal replacement is likely to take place in less developed countries where much of the world's ore production and refining occurs. Consequently, the disposal/replacement option is likely to result in substantial risk and impact shifting from more to less developed regions.

The issue of possible impacts from radioactivity in the metal supply on sensitive technologies (such as high-sensitivity films or computer chips) has been found to have controllable impacts. This issue has to be, and has been, dealt with by the industry regardless whether radioactive scrap metal is recycled or not, because many types of finished metal contain low levels of radioactivity from both natural and man-made sources.

Conclusions

On balance, the radioactive scrap metal recycling/reuse alternative appears to have considerable advantages over disposal/replacement. Both health risks and environmental impacts are likely to be substantially lower for recycling.

For each alternative, the health risks from workplace and transportation accidents are greater in magnitude than the risks from exposure to radioactivity or chemicals. The nonradiological risks are at least twice as high for disposal/replacement as they are for recycling, with the result that recycling/reuse has lower health risks overall. A tiered system of release criteria for a wide range of end uses has been found advantageous for matching radioactive scrap metal supply with demand while controlling public health risks at a very low level.

Environmental impacts from disposal/replacement of radioactive scrap metal are likely to be an order of magnitude greater than those for recycling. This is true of effects on land, water, and air quality, as well as for mineral and energy resources.

Recycling is not expected to have any significant effect on scrap metal markets nor on radioactivity-sensitive industrial technology. There are concerns, however, about the public acceptability of radioactive scrap metal recycling/reuse, as there are about acceptability of expanding low-level waste disposal capacity. Radioactive scrap metal disposal would unnecessarily use relatively scarce and valuable capacity. In addition, metal replacement activity probably would result in risk and impact shifting from regions of radioactive scrap metal origin to less-developed regions of the world.

REFERENCES

[1] IAEA, 1988, *Principles for the Exemption of Radiation Sources and Practices from Regulatory Control*, IAEA Safety Series No. 89, Vienna, Austria.

[2] International Commission on Radiological Protection, 1991, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, United Kingdom.

[3] Yu, C. et al., 1994, *RESRAD-BUILD: A Computer Model for Analyzing the Radiological Doses Resulting from the Remediation and Occupancy of Buildings Contaminated with Radioactive Material*, ANL/EAD/LD-3, Argonne National Laboratory, Environmental Assessment Division, Argonne, Illinois.

[4] US Nuclear Regulatory Commission, 1992, *Residual Radioactive Contamination from Decommissioning: Volume 1, Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*, NUREG/CR-5512, Washington, D.C.

[5] International Atomic Energy Agency, 1992, *Application of Exemption Principles to the Recycle and Reuse of Materials from Nuclear Facilities*, IAEA Safety Series No. 111-P-1.1, Vienna, Austria.

[6] Nieves, L.A. et al., 1995, *Evaluation of Radioactive Scrap Metal Recycling*, ANL/EAD/TM-50, Argonne National Laboratory, Argonne, Illinois.

[7] US Environmental Protection Agency, 1992, *User's Guide for CAP88-PC, Version 1.0*, 402-B-92-001, Office of Radiation Programs, Washington, D.C.

[8] US Nuclear Regulatory Commission, 1993, *Packaging of Radioactive Material for Transport and Transportation of Radioactive Material under Certain Conditions*, 10 CFR Part 71, Revised, Washington, D.C.

[9] Chen, S.Y. et al., 1995, *Assessment of Risks and Costs Associated with Transportation of DOE Radioactively Contaminated Carbon Steel*, Argonne National Laboratory, Argonne, Illinois.

[10] US Nuclear Regulatory Commission, 1993, *License Requirements for Land Disposal of Radioactive Waste*, 10 CFR Part 61, Revised, Washington, D.C.

[11] EG&G Idaho, Inc., 1987, *Conceptual Design Report Alternative Concepts for Low-Level Radioactive Waste Disposal*, DOE/LLW-60T, National Low-Level Radioactive Waste Management Program, Idaho Falls, Idaho.

[12] US Nuclear Regulatory Commission, 1993, *Radiation Protection, Code of Federal Regulations*, Title 10, Part 20, Washington, D.C.

[13] US Nuclear Regulatory Commission, 1974, *Termination of Operating License for Nuclear Reactors*, Regulatory Guide 1.86, Washington, D.C.

[14] Lund, H., 1993, *The McGraw-Hill Recycling Handbook*, Mc Graw-Hill Inc. New York, New York.

[15] Yamamoto, H. and Kato, S., 1995, *Effects on Radiation Sensitive Instruments from Recycling of Contaminated Metal*, p. 229 in Proc. Second Workshop on Residual Radioactivity and Recycling Criteria jointly sponsored by the USEPA and the JAERI, JAERI-Conf 95-015, Tokai, Japan.

[16] Organisation for Economic Co-operation and Development, Nuclear Energy Agency, *Comprehensive Report of the Task Group on the Recycling, Reuse and Release of Materials from Nuclear facilities*, March 1996, Paris.

TECHNOLOGY

Technological capability will be an integral component in the development and implementation of future release standards and criteria. The current state of three significant technologies was reviewed to determine characteristics and/or limitations that are applicable to recycling/reuse processes.

Melting

Melting is an effective technique for decontaminating, characterising, and recovering radioactive scrap metal and likely would be an instrumental component of many recycle/reuse alternatives. Unfortunately, only limited quantities of radioactive scrap metal thus far have been released for melting. However, within the last five years, four plants have begun melting contaminated metals on an industrial scale. Figure 2 illustrates the relative accomplishments of each of these facilities based on material processed per years operational.

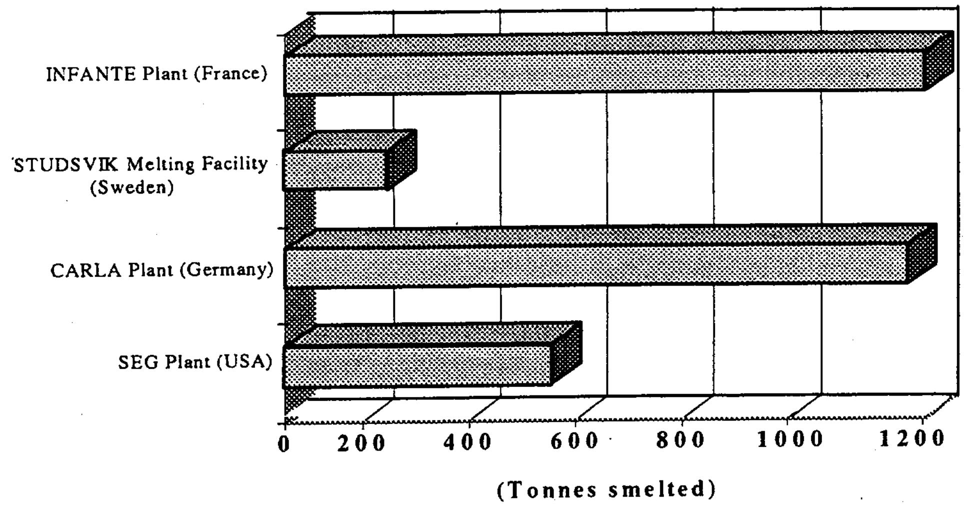


Figure 2. Radioactive Scrap Melting Facility Accomplishments

Melting inherently produces a "decontamination" effect on a gamma emitter of particular concern, caesium 137. Because it volatilises from the metal and accumulates in the dust collected by ventilation filters, caesium 137 is almost entirely removed during the melting process. Additionally, uranium and other oxides can be removed from the metal in the slag, thereby reducing the quantity of alpha emitters. cobalt 60 and other fission by-products are the dominate remaining nuclides. The relatively short half-life of these nuclides (5.3 years for cobalt 60) permit consideration of alternatives that otherwise would be precluded by the presence of caesium 137.

Melting also simplifies procedures for radioactive metal characterisation and eliminates difficulties associated with inaccessible surfaces, since any remaining radioactivity content is homogenised over the total mass of the ingot. As a result, melting can serve as the last step in the decontamination and release of components with complex geometries. Chemical methods that remove radionuclides that otherwise would remain in ingots after melting also may be used to decontaminate material prior to melting.

Decontamination Techniques for Decommissioning

Objectives and Selection Criteria

Decommissioning requires consideration of decontamination techniques to reduce both the cost and health risks associated with decommissioning nuclear facilities. Removal of contamination from components or systems reduces the dose levels in installations. As a result, access to the installations is made easier, permitting the use of hands-on techniques for dismantling as opposed to the more expensive use of robotics or manipulators. Similarly, decontamination can reduce the contamination levels of components or structures such that derived wastes can be disposed of in lower, and therefore more economical, waste treatment and disposal classifications. In fact, decontamination may reduce the contamination level to levels that would permit disposal as waste exempt from regulatory control.

Many decontamination techniques have been developed to support maintenance work in nuclear installations. These same techniques, with relative success, also have been adopted for use in operations to decommission nuclear installations and components. However, the objectives differ among the techniques based on the type of application. For example, decontamination in support of maintenance applications has, as its objective, the eventual reuse of the component. As a result, non-destructive methods must be employed to decontaminate the components.

The objective of decontamination for decommissioning is to maximise the removal of activity to achieve clearance levels, thus permitting the release of the material and possible reutilization without radiological restrictions. In many cases, removal of a thin layer of the structural material is necessary to achieve this objective. Consequently, decontamination methods required for decommissioning activities are considerably more aggressive than those used during the service life of a plant. In fact, such decontamination frequently requires somewhat destructive techniques to meet clearance levels.

Other contributing factors in the selection process include secondary waste production and reuse, quantity of material to be decontaminated, and accessibility for measurement and verification. In some cases, secondary wastes from decontamination can be reused or recycled. Although such activities, used on a limited scale in maintenance applications, likely would not contribute significantly to the selection process, the quantities of such waste and the corresponding potential for cost savings increase the significance of such factors in the selection process for large scale decommissioning projects.

Similarly, the quantities of contaminated materials generated as a result of decommissioning processes, and therefore made available for decontamination, generally do not favour techniques that are labour intensive, difficult to handle, or present difficulties should automation be practicable.

Industry currently is in a state of transition, evolving from techniques for use in maintenance applications, to those for use in decommissioning nuclear facilities. A very limited quantity of information is available on the efficiency of usable techniques to meet low release criteria. Moreover, not all available methods and techniques are capable of decontaminating to below the required clearance levels. Consequently, decontamination frequently is implemented in stages, the objective being to eventually decontaminate the material to the required activity levels.

Characteristics of Some Selected Decontamination Techniques

Abrasive Blasting Systems

Both wet and dry abrasive blasting systems have been used with some success. Such systems provide mechanical methods, derived from conventional industry, that give very high decontamination factors. The longer the operations are continued, the more destructive they are. However, wet abrasive systems produce a mixture of dust and water droplets that may be difficult to treat. Care must be taken not to introduce the contamination into the material surface (hammering effect), potentially compromising the ability to meet clearance levels. Finally, abrasive blasting techniques are inappropriate for complicated surfaces where uniform access can not be guaranteed.

Aggressive Chemical Decontamination

Aggressive chemical decontamination techniques also have been used successfully. Such techniques involve dissolution and removal of metal and oxide layers from surfaces using acid solutions at temperatures of 50 to 70 °C and over. Required decontamination levels can be obtained by continuing the process as long as necessary, taking care to ensure that tank or piping walls are not penetrated by corrosion. These techniques are also suitable for use on complex geometries and for uniform treatment of inner and outer pipe surfaces. However, aggressive chemical decontamination requires efficient recycling of reactive chemicals. Insufficient recycling of by-products will require dispositioning of large quantities of secondary wastes that may be difficult to treat.

Electrochemical Decontamination Processes

Electrochemical decontamination processes involve soaking material or components in an electrolyte bath, or moving a pad over the surface of the material being decontaminated, resulting in the dissolution and removal of metal and oxide layers from the component. The electrolyte is continuously regenerated by recirculation. These processes can be applied only to conducting surfaces but they are highly effective and give a high decontamination factor.

However, use is limited by (1) the size of the bath (soaking), and (2) the geometry of the surfaces and access to the area being treated (pad). Consequently, electrochemical decontamination processes are inapplicable for industrial decontamination of complex geometries (*e.g.*, pipes, etc.).

Other Decontamination Techniques

Other decontamination techniques, including ultrasonics, high pressure water jetting or steam spraying, thermal erosion, pastes, gels, foams, etc. also have been used in decommissioning. However, some require relatively complex application procedures or require further development to permit general industrial or large scale application.

Overview of Decontamination Processes for Decommissioning

The OECD/NEA Co-operative Programme on Decommissioning has established a Task Group to examine and report on the status of decontamination technology within the context of decommissioning. The Task Group's examination has focused on decontamination for both dose reduction and waste recategorization or clearance, and has included in its examination, the decontamination of both metallic and concrete surfaces. As part of this examination, the Task Group is conducting a survey among decommissioning project managers to determine the technical and economic merits of different decontamination techniques.

Table 15. Overview of Decontamination Processes for Decommissioning

Metal Decontamination	Closed Systems	Open Systems
CHEMICAL PROCESSES		
Oxidation processes		
• ODP/SODP	•*	
• Cerium/Sulfuric acid		•
• Cerium/Nitric acid		•
Oxidation-reduction processes		
• APCE/NPOX	•	•
• TURCO	•	•
• CORD	•	•
• CABDEREM, CANDECOM		•
• CONAP		•
• AP/NP + LOMI for PWR	•	
• EMMA	•	
LOMI for BWR	•	
Phosphoric-acid based processes		•
Foams	•	
Various reagents		
• HNO_3		•
• HNO_3 + HF	•	•
• HNO_3/NaF	•	•
• HCl	•	•
• DECOHA		•
ELECTROCHEMICAL PROCESSES		
• Phosphoric acid		•
• Nitric acid		•
• Nitric acid – Electrodeplating		•
• Sodium sulfate – ELDECON process		•
• Oxalic acid		•
• Citric acid		•
• Sulfuric acid		•
• Other electrolytes		•
PHYSICAL PROCESSES		
• Ultrasonic cleaning		•
• High-pressure water		•
• CO_2 ice blasting		•
• Ice water		•
• Freon substitutes		•
• Abrasives wet	•	•
• Abrasives dry		•
• Grinding/Planing		•
COMBINED MECHAN./CHEM. PROCESSES		
• Pastes + HP cleaning		•
• Foams/Gels/HP cleaning		•
• Vacuum cleaning (Dry/Wet)		•

---

* Decontamination technique applied for open or closed systems.

Table 15 provides a list of processes identified as being of interest for decontamination. Processes used in closed systems (*e.g.*, full system decontamination of the primary circuit of a reactor or the partial decontamination of closed loops), are distinguished from those applicable to open tanks (*e.g.*, decontamination of dismantled pieces). Additionally, surface decontamination and demolition processes for concrete are presented in the Table 16.

Table 16. Overview of Concrete Decontamination Processes for Decommissioning

Concrete Decontamination	Surface Decontamination	Concrete Demolition
• Kelly process	•	
• Scabbling	•	
• Sand blasting	•	
• Wet abrasives	•	
• Milling	•	
• Explosives		•
• Microwaves	•	
• Drill/Spalling.		•
• Drill/Lime expansion		•
• Jack hammer		•

Measurement and Instrumentation

In order to effectively apply release standards based on specific activity or surface contamination, adequate measurement methods must be available to enable concerned parties to demonstrate or verify that material is below the established clearance levels. The Task Group examined the primary radioactivity evaluation methods and selection criteria to determine whether state-of-the-art instrumentation is capable of meeting the requirements of the applicable standards, in the context of recycling/reuse applications.

Despite the various methods and instruments available to quantify radioactivity in equipment and materials, a number of practical constraints significantly influence capability. These include the geometrical complexity of the materials to be measured, the influence of natural radioactivity, the accessibility of the material, and the sensitivity of available instruments relative to the criteria to be met. As a result of these constraints, sufficient consideration of measurement capability is a necessary component of appropriately developed standards and criteria. For example, the Task Group found that multiple measurements of the same material may vary based on changes resulting from subsequent processing.

One or more of these constraints were identified in several of the case studies. During implementation of its plan to melt slightly contaminated fuel racks, Belgoprocess found that its initial measurements to determine the activity levels in 32 t of stainless steel were inaccurate. The discrepancy was identified as a result of post-melt measurements of the ingots and resulting slag and dust. Similarly, the Swedish Radiation Protection Authority proposed to reduce the level for external contamination from beta-gamma emitters from 40 kBq/m^2 to 10 kBq/m^2. The Ringhals nuclear power plant conducted two separate tests of its portal monitors to determine the lowest levels at which reliable measurements could be obtained under normal working conditions. Its tests, which used state-of-the-art technology, indicated that reliable measurements to the 10 kBq/m^2 criteria could not be accomplished under normal conditions.

Conclusion

In summary, the technologies needed to support recycling exist. Several countries have developed smelting facilities. A wide range of decontamination techniques exist. Finally, characterisation and measurement technologies exist to verify decontamination. Of these three areas, the characterisation and measurement technologies are the critical elements. Some of the proposed clearance levels present great challenges to state-of-the-art equipment and techniques.

Chapter 5

CASE STUDIES

Chapter 4 of this report describes various types of technology for characterising and decontaminating radioactive scrap metal. A variety of projects have been, or soon will be conducted that demonstrate, not only the feasibility, but also the cost-effectiveness of some of these techniques. The Task Group reviewed information associated with 18 projects that used alternative methods for dispositioning waste from decommissioning. The projects were categorised by the intended type of release and final destination of the material. Table 17 provides basic information associated with each of the projects. Finally, Figure 3 illustrates the estimated cost savings associated with some of these projects as a percentage of the original estimated cost for dispositioning the material utilising conventional disposal methods. Based on the magnitude of potential savings, application of two decontamination techniques are particularly noteworthy: abrasive blasting and melting.

Abrasive Blasting

Belgoprocess's initial demonstration project to determine the feasibility of using abrasive blasting techniques followed by recycling, indicated that this technique could yield substantial cost savings over conventional supercompaction and disposal. Based on the technique's proven cost-effectiveness, Belgoprocess conducted further evaluations to determine the relative merits of installing an industrial scale automated dry abrasive blasting system to decontaminate 309 t of scrap metal. Its evaluation was confined specifically to the materials and related costs associated with the decommissioning of the Eurochemic Reprocessing plant. Nevertheless, the Belgoprocess evaluation indicated that abrasive blasting may yield cost savings of 67 per cent over conventional low-level waste supercompaction and disposal.

Melting

Similarly, a CEA examination indicated that a 52 per cent cost savings over conventional low-level waste disposal may be realised from melting the loops of the PEGASE reactor and reusing the material to produce waste containers. This 52-per-cent saving translates into approximately 1 067 000 FF (1993).

Conclusion

In general, the case studies demonstrate that recycling alternatives can yield significant cost savings over conventional low-level waste disposal alternatives. The average estimated cost savings among the reviewed projects was 47 per cent of applicable disposal costs.

Table 17. Case Histories of Recycling/Reuse/Disposal

No.	Project	Category	Technology	Status
1	BWR preheater	Free release/recycling	Melting	Completed
2	PHWR steam generator	Free release/recycling	Decon/melting	Completed (ingots stored for decay)
3	PWR steam generator	Free release/recycling	Decon/melting	Study
4	Fuel racks SGHWR	Free release/recycling	Decon/measurement	Study
5	Fuel racks Belgoprocess	Free release/recycling	Melting	Completed (ingots stored for decay)
6	Aluminium heat exchangers	Free release/recycling	Melting	In progress
7	Driptray-reprocessing plant	Free release/recycling	Decon/measurement	Completed
8	Reprocessing plant components	Free release/recycling	Decon/measurement	Planned
9	Eurochemic pilot project	Free release/ unrestricted disposal	Measurement	Completed
10	Concrete from G3	Free release/ unrestricted disposal	Measurement/ crushing	Completed
11	Heads of prestressing cables-G3	Free release/ unrestricted disposal	Measurement	Completed
12	G1 scrap air circuit	Restricted release/ authorised disposal	Decon/measurement	In progress
13	Contaminated soil	Restricted release/ authorised disposal	Measurement	Completed
14	G2/G3 glasswool	Restricted release/ authorised disposal	Measurement	Completed
15	Siloe reactor heat exchangers	Restricted release/ controlled recycling	Decon/melting	Completed (cast into shield blocks)
16	Nuclear centre scrap	Restricted release/ controlled recycling	Decon/melting	Completed
17	G2/G3 scrap	Restricted release/ controlled recycling	Decon/melting	Completed (ingots stored for reuse)
18	Rapsodie stainless steel primary circuit	Restricted release/ controlled recycling	Decon/melting	Completed (ingots stored for reuse)

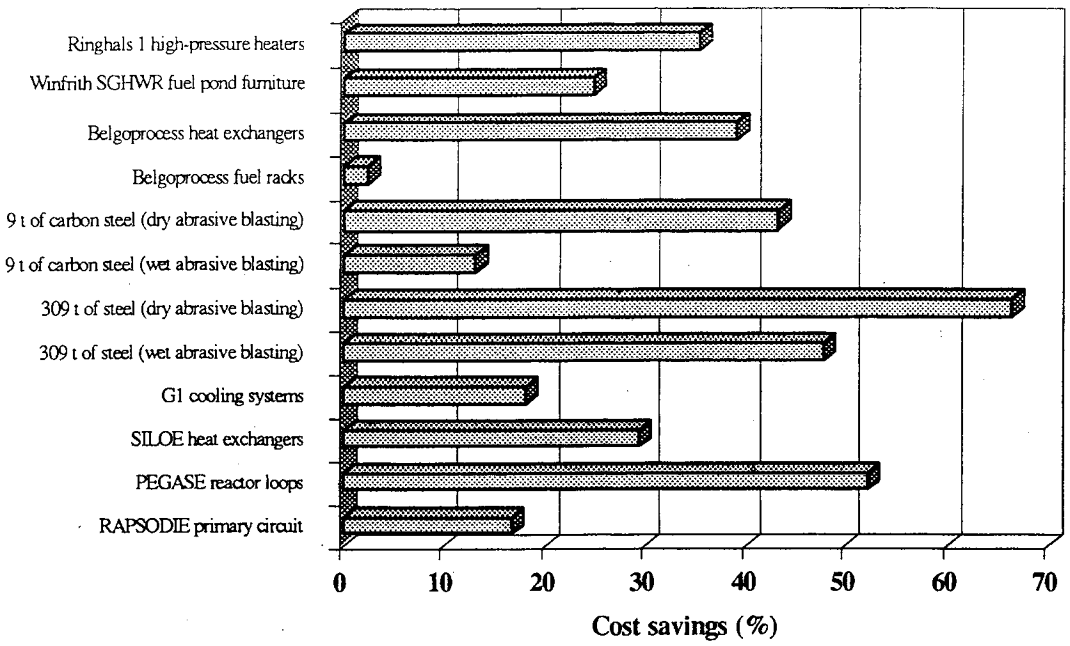


Figure 3. Selected Recycling Projects: Savings as a Percentage of Conventional Low-level Waste Disposal Alternatives

Chapter 6

CONCLUSIONS

1. Substantial quantities (3×10^7 t) of scrap metals (predominantly steel) are likely to be generated in the near future from decommissioning and dismantling nuclear facilities. Without release standards, these potentially valuable metals cannot be systematically recovered through reuse or recycle practices. A significant portion of this material is only slightly, or not at all, contaminated with radioactivity. Disposition of the radioactive scrap metals currently relies on disposal at licensed low-level waste burial facilities or, less commonly, release on the basis of a detailed evaluation.

2. A comparison of the relative merits of disposal and replacement versus recycle and reuse practices shows that recycle and reuse produces lower human health risks and environmental impacts by more than a factor of two. Moreover, disposal and replacement alternatives for radioactive scrap metal management may involve imposition of greater health and environmental impacts in less-developed countries (from ore mining and processing) than those associated with recycling in industrialised countries.

3. The IAEA and the NEA have developed a policy (*i.e.*, IAEA Safety Series 89, 1988) on exemption of radioactive materials from regulatory control requirements. IAEA Safety Series No. 89 proposed that doses to the critical group from an exempted practice be limited to some "tens" of millisieverts per year and that, if the collective dose commitment resulting from annual operation of a practice would be less than 1 man-Sv, further optimisation is unnecessary. The former level is intended to limit individual risks and the latter for optimisation of radiation protection efforts. Based on these levels, the IAEA has proposed criteria (1994) for the unconditional clearance of radioactive materials from regulatory control. Similarly, the Working Party of the Article 31 Group of Experts of the European Commission has proposed clearance levels for reuse and recycle of radioactive metals (EC 1994). Both proposals consider optimisation of radiation protection and limitation of individual risk, but neither has provided justification for the practice of recycle or reuse that is addressed in that guidance.

4. The International Commission on Radiological Protection (ICRP 60, 1991) suggested a two stage process for justification of a practice in which options are first selected that "can be expected to do more good than harm". In the second stage, the net benefit of the change is examined with the recommendation that: "The detriment to be considered is not confined to that associated with the radiation – it includes other detriments and the costs of the practice. Often, the radiation detriment will be a small part of the total. The justification of a practice thus goes far beyond the scope of radiological protection".

The IAEA proposal provides a single "unconditional" clearance level which is intended for all materials, ranging from trash and building debris to valuable metals. The extent to which the practice of releasing materials can be said to do "more good than harm" varies based on a number of factors, including the value of the material in question. Consequently, the resulting justification is different for metals as compared to trash. Accordingly, the justification of the "practice" should be very different for the release of metals. The IAEA proposal does not incorporate this distinction in its proposed clearance criteria. Justifications that consider major environmental impacts and non-radiological health effects, in addition to radiological health risks, strongly support radioactive scrap metal recycling and reuse.

5. To address the release of all types of materials to unknown destinations, the IAEA has proposed a single set of "unconditional" clearance levels that represent a conservative, common denominator across wide ranging release situations. The proposed unconditional clearance levels may therefore be inappropriately low for the release of scrap metal for recycling. The risks associated with scrap metal decontamination and processing are relatively well characterised, and release levels that are suitably protective of public health can be much less restrictive than those proposed by the IAEA. This is evidenced by the recent EC proposal on the release of metals. The EC proposal is well executed, but is based only on European experience. From a broader perspective, the Task Group strongly advocates expanding the EC effort into an international standard for "conditional" release of metals.

6. To evaluate the alternatives for radioactive scrap metal management, the Task Group has analysed a "tiered" system of release criteria appropriate for a range of end uses. The tiers provide four basic options:

(1) Tier A for reuse or melting of surface contaminated metal objects following decontamination or certification;

(2) Tier B for a controlled initial melt for decontamination and certification, followed by metal recycle in commercial smelters or mills and processing into consumer products;

(3) Tier C for controlled initial melt and fabrication, followed by designated initial use (*e.g.*, bridges) of metal (only appropriate for short half-life radionuclides) and

(4) Tier D for restricted recycle within the nuclear industry. This approach has the advantage of matching radioactive scrap metal supply with demand while risk to the public is kept to an appropriately low level. The analysis incorporates realistic operating data from current processes while still maintaining a considerable degree of conservatism to account for uncertainties. The tier approach is similar to that of the EC, which has proposed different release levels for reuse of surface contaminated materials and for material destined for melting at a commercial smelter.

7. The Task Group has presented a number of examples of the release of radioactive scrap metal for recycling or disposal that has been permitted on a case-by-case basis. These case histories illustrate that it is not only feasible to safely release the metals, but also cost beneficial. Decontamination and melting techniques have proven to be effective in meeting release levels. Moreover, recycling is economically advantageous relative to the alternative of radioactive scrap metal disposal in licensed low-level waste facilities.

8. Material recycling standards need to be developed within the broad context of health risks from radioactivity in the environment. Regulatory agencies are becoming more concerned with the potential hazards posed by the relatively large amounts of unregulated, naturally-occurring radioactive materials released by several industries, including the fertiliser and petroleum industries.

Naturally-occurring radioactive materials frequently have been encountered in the feed stock of scrap metal, and media coverage of some metal and mill contamination events has led to public concern. The activity levels in naturally occurring radioactive materials (mostly from alpha emitters such as radium 226 and radium 228) commonly are much higher than those proposed for radioactive scrap metal release for recycling. In comparison, the scrap metal recycle release levels derived in this report present insignificant health or environmental hazards. This conclusion assumes that radioactive scrap metal recycling would be effectively regulated and that the ALARA principle would be implemented.

9. Development of generally accepted clearance standards is crucial for radioactive scrap metal release alternatives. A technological basis for implementing criteria also is an integral component of the process. Measurement capability for removable surface activity depends on the contamination mechanism (*e.g.*, wet or dry), on surface characteristics (roughness, chemistry, and material), on decontamination methods, and on the type of wipe test applied. Moreover, the removable fraction can change (*e.g.*, via rusting) so that scrap that met the clearance standard at the time of release may not meet it at a later time. In some instances, state-of-the-art instrumentation may not be capable of meeting the requirements of risk-based standards. As an example, if radon gas and its progeny are considered, radionuclides such as radium 226 would have such low release levels that it would be very difficult, if not impossible, to measure and, therefore, to enforce compliance. On the other hand, allowing higher clearance levels to accommodate detection capabilities would be inconsistent with risk-based standards. Thus, an ALARA approach may provide an appropriate compromise between risk-based and technology-based standards.

10. Although a risk-based approach for setting radioactive scrap metal release levels is generally accepted, varying degrees of conservatism have been incorporated in different analyses. As a result, derived release levels have ranged over several orders of magnitude. Comparing this Task Group analysis with the proposed IAEA and EC clearance levels reveals the generally conservative nature of the latter two proposals. The differences partially reflect the differing objectives of each set of clearance levels, with the IAEA proposal intended for all materials, the EC for metals, and the Task Group for steel. Some inconsistencies are due to analytical methods that could be resolved through improved co-ordination. The differences accentuate the need for a consistent set of international standards intended for various release circumstances and for materials possessing varying commodity values and transborder trade ramifications. For metals, assumptions regarding major factors, such as industry practices (*e.g.*, mixing of scrap metal batches to adjust metal chemistry) and radionuclide partitioning (separation of unwanted elements from the ingot during metal melting), can greatly impact the derived levels. Ultra-conservative assumptions should be avoided in developing release standards. It would be preferable to employ realistic data for parameter values, incorporate estimates of the range of parameter uncertainty, and then add an appropriate margin of public protection.

11. Much of the Task Group's work has been concentrated on metal recycling and reuse. In the future, when currently operating commercial nuclear power stations will have to be dismantled, large quantities of concrete also will need to be processed. This is an area that will require separate, additional analysis.

12. In conclusion:

- A set of separate international standards applicable specifically to metal release is needed. These standards should be based on realistic scenarios that make use of available data from existing practices.
- Research is needed to validate/calibrate the models and calculations used to derive risk-based release levels. This should be based on data from existing practices, so that excessive and unduly costly conservatism can be avoided.
- In addition to radiological health risks, as indicated in the ICRP 60 recommendations, other types of health and environmental risks should be considered in developing release levels.

LIST OF TASK GROUP MEMBERS

Mr. Lucien TEUNCKENS
Belgoprocess N.V.
Belgium

Mr. Stefan THIERFELDT
Brenk Systemplanung
Germany

Mr. Alejandro RODRIGUEZ
ENRESA
Spain

Mr. Magnus WESTERLIND
Swedish Radiation Protection Institute
Sweden

Mr. Judson LILLY
US Department of Energy
United States

Mr. Michel JEANJACQUES
CEA-DCC/DRDD-UDIN
France

Mr. Kazuo FUJIKI
Japan Atomic Energy Research Institute
Japan

Mrs. Ann-Christin SANDIN
Swedish Nuclear Power Inspectorate
Sweden

Mr. Anthony HOWDEN
Winfrith Technology Centre
United Kingdom

Mrs. Leslie NIEVES
Argonne National Laboratory
United States

Chairman
Mr. William E. MURPHIE
US Department of Energy
United States

Secretary
Mr. Shankar MENON
Programme Co-ordinator
Sweden

MAIN SALES OUTLETS OF OECD PUBLICATIONS
PRINCIPAUX POINTS DE VENTE DES PUBLICATIONS DE L'OCDE

AUSTRALIA – AUSTRALIE
D.A. Information Services
648 Whitehorse Road, P.O.B 163
Mitcham, Victoria 3132 Tel. (03) 9210.7777
Fax: (03) 9210.7788

AUSTRIA – AUTRICHE
Gerold & Co.
Graben 31
Wien I Tel. (0222) 533.50.14
Fax: (0222) 512.47.31.29

BELGIUM – BELGIQUE
Jean De Lannoy
Avenue du Roi, Koningslaan 202
B-1060 Bruxelles Tel. (02) 538.51.69/538.08.41
Fax: (02) 538.08.41

CANADA
Renouf Publishing Company Ltd.
1294 Algoma Road
Ottawa, ON K1B 3W8 Tel. (613) 741.4333
Fax: (613) 741.5439

Stores:
61 Sparks Street
Ottawa, ON K1P 5R1 Tel. (613) 238.8985

12 Adelaide Street West
Toronto, ON M5H 1L6 Tel. (416) 363.3171
Fax: (416)363.59.63

Les Éditions La Liberté Inc.
3020 Chemin Sainte-Foy
Sainte-Foy, PQ G1X 3V6 Tel. (418) 658.3763
Fax: (418) 658.3763

Federal Publications Inc.
165 University Avenue, Suite 701
Toronto, ON M5H 3B8 Tel. (416) 860.1611
Fax: (416) 860.1608

Les Publications Fédérales
1185 Université
Montréal, QC H3B 3A7 Tel. (514) 954.1633
Fax: (514) 954.1635

CHINA – CHINE
China National Publications Import
Export Corporation (CNPIEC)
16 Gongti E. Road, Chaoyang District
P.O. Box 88 or 50
Beijing 100704 PR Tel. (01) 506.6688
Fax: (01) 506.3101

CHINESE TAIPEI – TAIPEI CHINOIS
Good Faith Worldwide Int'l. Co. Ltd.
9th Floor, No. 118, Sec. 2
Chung Hsiao E. Road
Taipei Tel. (02) 391.7396/391.7397
Fax: (02) 394.9176

CZECH REPUBLIC – RÉPUBLIQUE TCHÈQUE
National Information Centre
NIS – prodejna
Konviktská 5
Praha 1 – 113 57 Tel. (02) 24.23.09.07
Fax: (02) 24.22.94.33
(*Contact* Ms Jana Pospisilova, nkposp@dec.niz.cz)

DENMARK – DANEMARK
Munksgaard Book and Subscription Service
35, Nørre Søgade, P.O. Box 2148
DK-1016 København K Tel. (33) 12.85.70
Fax: (33) 12.93.87

J. H. Schultz Information A/S,
Herstedvang 12,
DK – 2620 Albertslung Tel. 43 63 23 00
Fax: 43 63 19 69

Internet: s-info@inet.uni-c.dk

EGYPT – ÉGYPTE
The Middle East Observer
41 Sherif Street
Cairo Tel. 392.6919
Fax: 360-6804

FINLAND – FINLANDE
Akateeminen Kirjakauppa
Keskuskatu 1, P.O. Box 128
00100 Helsinki

Subscription Services/Agence d'abonnements :
P.O. Box 23
00371 Helsinki Tel. (358 0) 121 4416
Fax: (358 0) 121.4450

FRANCE
OECD/OCDE
Mail Orders/Commandes par correspondance :
2, rue André-Pascal
75775 Paris Cedex 16 Tel. (33-1) 45.24.82.00
Fax: (33-1) 49.10.42.76
Telex: 640048 OCDE

Internet: Compte.PUBSINQ@oecd.org

Orders via Minitel, France only/
Commandes par Minitel, France exclusivement :
36 15 OCDE

OECD Bookshop/Librairie de l'OCDE :
33, rue Octave-Feuillet
75016 Paris Tél. (33-1) 45.24.81.81
(33-1) 45.24.81.67

Dawson
B.P. 40
91121 Palaiseau Cedex Tel. 69.10.47.00
Fax: 64.54.83.26

Documentation Française
29, quai Voltaire
75007 Paris Tel. 40.15.70.00

Economica
49, rue Héricart
75015 Paris Tel. 45.75.05.67
Fax: 40.58.15.70

Gibert Jeune (Droit-Économie)
6, place Saint-Michel
75006 Paris Tel. 43.25.91.19

Librairie du Commerce International
10, avenue d'Iéna
75016 Paris Tel. 40.73.34.60

Librairie Dunod
Université Paris-Dauphine
Place du Maréchal-de-Lattre-de-Tassigny
75016 Paris Tel. 44.05.40.13

Librairie Lavoisier
11, rue Lavoisier
75008 Paris Tel. 42.65.39.95

Librairie des Sciences Politiques
30, rue Saint-Guillaume
75007 Paris Tel. 45.48.36.02

P.U.F.
49, boulevard Saint-Michel
75005 Paris Tel. 43.25.83.40

Librairie de l'Université
12*a*, rue Nazareth
13100 Aix-en-Provence Tel. (16) 42.26.18.08

Documentation Française
165, rue Garibaldi
69003 Lyon Tel. (16) 78.63.32.23

Librairie Decitre
29, place Bellecour
69002 Lyon Tel. (16) 72.40.54.54

Librairie Sauramps
Le Triangle
34967 Montpellier Cedex 2 Tel. (16) 67.58.85.15
Fax: (16) 67.58.27.36

A la Sorbonne Actual
23, rue de l'Hôtel-des-Postes
06000 Nice Tel. (16) 93.13.77.75
Fax: (16) 93.80.75.69

GERMANY – ALLEMAGNE
OECD Bonn Centre
August-Bebel-Allee 6
D-53175 Bonn Tel. (0228) 959.120
Fax: (0228) 959.12.17

GREECE – GRÈCE
Librairie Kauffmann
Stadiou 28
10564 Athens Tel. (01) 32.55.321
Fax: (01) 32.30.320

HONG-KONG
Swindon Book Co. Ltd.
Astoria Bldg. 3F
34 Ashley Road, Tsimshatsui
Kowloon, Hong Kong Tel. 2376.2062
Fax: 2376.0685

HUNGARY – HONGRIE
Euro Info Service
Margitsziget, Európa Ház
1138 Budapest Tel. (1) 111.62.16
Fax: (1) 111.60.61

ICELAND – ISLANDE
Mál Mog Menning
Laugavegi 18, Pósthólf 392
121 Reykjavik Tel. (1) 552.4240
Fax: (1) 562.3523

INDIA – INDE
Oxford Book and Stationery Co.
Scindia House
New Delhi 110001 Tel. (11) 331.5896/5308
Fax: (11) 371.8275

17 Park Street
Calcutta 700016 Tel. 240832

INDONESIA – INDONÉSIE
Pdii-Lipi
P.O. Box 4298
Jakarta 12042 Tel. (21) 573.34.67
Fax: (21) 573.34.67

IRELAND – IRLANDE
Government Supplies Agency
Publications Section
4/5 Harcourt Road
Dublin 2 Tel. 661.31.11
Fax: 475.27.60

ISRAEL – ISRAËL
Praedicta
5 Shatner Street
P.O. Box 34030
Jerusalem 91430 Tel. (2) 52.84.90/1/2
Fax: (2) 52.84.93

R.O.Y. International
P.O. Box 13056
Tel Aviv 61130 Tel. (3) 546 1423
Fax: (3) 546 1442

Palestinian Authority/Middle East:
INDEX Information Services
P.O.B. 19502
Jerusalem Tel. (2) 27.12.19
Fax: (2) 27.16.34

ITALY – ITALIE
Libreria Commissionaria Sansoni
Via Duca di Calabria 1/1
50125 Firenze Tel. (055) 64.54.15
Fax: (055) 64.12.57

Via Bartolini 29
20155 Milano Tel. (02) 36.50.83

Editrice e Libreria Herder
Piazza Montecitorio 120
00186 Roma Tel. 679.46.28
Fax: 678.47.51

Libreria Hoepli
Via Hoepli 5
20121 Milano Tel. (02) 86.54.46
Fax: (02) 805.28.86

Libreria Scientifica
Dott. Lucio de Biasio 'Aeiou'
Via Coronelli, 6
20146 Milano Tel. (02) 48.95.45.52
Fax: (02) 48.95.45.48

JAPAN – JAPON
OECD Tokyo Centre
Landic Akasaka Building
2-3-4 Akasaka, Minato-ku
Tokyo 107 Tel. (81.3) 3586.2016
Fax: (81.3) 3584.7929

KOREA – CORÉE
Kyobo Book Centre Co. Ltd.
P.O. Box 1658, Kwang Hwa Moon
Seoul Tel. 730.78.91
Fax: 735.00.30

MALAYSIA – MALAISIE
University of Malaya Bookshop
University of Malaya
P.O. Box 1127, Jalan Pantai Baru
59700 Kuala Lumpur
Malaysia Tel. 756.5000/756.5425
Fax: 756.3246

MEXICO – MEXIQUE
OECD Mexico Centre
Edificio INFOTEC
Av. San Fernando no. 37
Col. Toriello Guerra
Tlalpan C.P. 14050
Mexico D.F. Tel. (525) 665 47 99
Fax: (525) 606 13 07

NETHERLANDS – PAYS-BAS
SDU Uitgeverij Plantijnstraat
Externe Fondsen
Postbus 20014
2500 EA's-Gravenhage Tel. (070) 37.89.880
Voor bestellingen: Fax: (070) 34.75.778

Subscription Agency/
Agence d'abonnements :
SWETS & ZEITLINGER BV
Heereweg 347B
P.O. Box 830
2160 SZ Lisse Tel. 252.435.111
Fax: 252.415.888

NEW ZEALAND – NOUVELLE-ZÉLANDE
GPLegislation Services
P.O. Box 12418
Thorndon, Wellington Tel. (04) 496.5655
Fax: (04) 496.5698

NORWAY – NORVÈGE
NIC INFO A/S
Ostensjoveien 18
P.O. Box 6512 Etterstad
0606 Oslo Tel. (22) 97.45.00
Fax: (22) 97.45.45

PAKISTAN
Mirza Book Agency
65 Shahrah Quaid-E-Azam
Lahore 54000 Tel. (42) 735.36.01
Fax: (42) 576.37.14

PHILIPPINE – PHILIPPINES
International Booksource Center Inc.
Rm 179/920 Cityland 10 Condo Tower 2
HV dela Costa Ext cor Valero St.
Makati Metro Manila Tel. (632) 817 9676
Fax: (632) 817 1741

POLAND – POLOGNE
Ars Polona
00-950 Warszawa
Krakowskie Prezdmiescie 7 Tel. (22) 264760
Fax: (22) 265334

PORTUGAL
Livraria Portugal
Rua do Carmo 70-74
Apart. 2681
1200 Lisboa Tel. (01) 347.49.82/5
Fax: (01) 347.02.64

SINGAPORE – SINGAPOUR
Ashgate Publishing
Asia Pacific Pte. Ltd
Golden Wheel Building, 04-03
41, Kallang Pudding Road
Singapore 349316 Tel. 741.5166
Fax: 742.9356

SPAIN – ESPAGNE
Mundi-Prensa Libros S.A.
Castelló 37, Apartado 1223
Madrid 28001 Tel. (91) 431.33.99
Fax: (91) 575.39.98

Mundi-Prensa Barcelona
Consell de Cent No. 391
08009 – Barcelona Tel. (93) 488.34.92
Fax: (93) 487.76.59

Llibreria de la Generalitat
Palau Moja
Rambla dels Estudis, 118
08002 – Barcelona
(Subscripcions) Tel. (93) 318.80.12
(Publicacions) Tel. (93) 302.67.23
Fax: (93) 412.18.54

SRI LANKA
Centre for Policy Research
c/o Colombo Agencies Ltd.
No. 300-304, Galle Road
Colombo 3 Tel. (1) 574240, 573551-2
Fax: (1) 575394, 510711

SWEDEN – SUÈDE
CE Fritzes AB
S–106 47 Stockholm Tel. (08) 690.90.90
Fax: (08) 20.50.21

For electronic publications only/
Publications électroniques seulement
STATISTICS SWEDEN
Informationsservice
S-115 81 Stockholm Tel. 8 783 5066
Fax: 8 783 4045

Subscription Agency/Agence d'abonnements :
Wennergren-Williams Info AB
P.O. Box 1305
171 25 Solna Tel. (08) 705.97.50
Fax: (08) 27.00.71

SWITZERLAND – SUISSE
Maditec S.A. (Books and Periodicals/Livres
et périodiques)
Chemin des Palettes 4
Case postale 266
1020 Renens VD 1 Tel. (021) 635.08.65
Fax: (021) 635.07.80

Librairie Payot S.A.
4, place Pépinet
CP 3212
1002 Lausanne Tel. (021) 320.25.11
Fax: (021) 320.25.14

Librairie Unilivres
6, rue de Candolle
1205 Genève Tel. (022) 320.26.23
Fax: (022) 329.73.18

Subscription Agency/Agence d'abonnements :
Dynapresse Marketing S.A.
38, avenue Vibert
1227 Carouge Tel. (022) 308.08.70
Fax: (022) 308.07.99

See also – Voir aussi :
OECD Bonn Centre
August-Bebel-Allee 6
D-53175 Bonn (Germany) Tel. (0228) 959.120
Fax: (0228) 959.12.17

THAILAND – THAÏLANDE
Suksit Siam Co. Ltd.
113, 115 Fuang Nakhon Rd.
Opp. Wat Rajbopith
Bangkok 10200 Tel. (662) 225.9531/2
Fax: (662) 222.5188

TRINIDAD & TOBAGO, CARIBBEAN TRINITÉ-ET-TOBAGO, CARAÏBES
SSL Systematics Studies Limited
9 Watts Street
Curepe
Trinadad & Tobago, W.I. Tel. (1809) 645.3475
Fax: (1809) 662.5654

TUNISIA – TUNISIE
Grande Librairie Spécialisée
Fendri Ali
Avenue Haffouz Imm El-Intilaka
Bloc B 1 Sfax 3000 Tel. (216-4) 296 855
Fax: (216-4) 298.270

TURKEY – TURQUIE
Kültür Yayinlari Is-Türk Ltd. Sti.
Atatürk Bulvari No. 191/Kat 13
06684 Kavaklidere/Ankara
Tél. (312) 428.11.40 Ext. 2458
Fax : (312) 417.24.90
et 425.07.50-51-52-53

Dolmabahce Cad. No. 29
Besiktas/Istanbul Tel. (212) 260 7188

UNITED KINGDOM – ROYAUME-UNI
HMSO
Gen. enquiries Tel. (0171) 873 0011

Postal orders only:
P.O. Box 276, London SW8 5DT
Personal Callers HMSO Bookshop
49 High Holborn, London WC1V 6HB
Fax: (0171) 873 8463

Branches at: Belfast, Birmingham, Bristol,
Edinburgh, Manchester

UNITED STATES – ÉTATS-UNIS
OECD Washington Center
2001 L Street N.W., Suite 650
Washington, D.C. 20036-4922 Tel. (202) 785.6323
Fax: (202) 785.0350
Internet: washcont@oecd.org

Subscriptions to OECD periodicals may also be placed through main subscription agencies.

Les abonnements aux publications périodiques de l'OCDE peuvent être souscrits auprès des principales agences d'abonnement.

Orders and inquiries from countries where Distributors have not yet been appointed should be sent to: OECD Publications, 2, rue André-Pascal, 75775 Paris Cedex 16, France.

Les commandes provenant de pays où l'OCDE n'a pas encore désigné de distributeur peuvent être adressées aux Éditions de l'OCDE, 2, rue André-Pascal, 75775 Paris Cedex 16, France.

8-1996

OECD PUBLICATIONS, 2 rue André-Pascal, 75775 PARIS CEDEX 16 - No. 79525 1996
PRINTED IN FRANCE

This report was published thanks to the generous contribution of

MAGNOX

Magnox Electric plc
United Kingdom