

Recycling and Reuse of Materials Arising from the Decommissioning of Nuclear Facilities



Radioactive waste Management

Recycling and Reuse of Materials Arising from the Decommissioning of Nuclear Facilities

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Cover photos: Shield blocks manufactured at EnergySolutions' Bear Creek Facility (EnergySolutions); Shielding containers for 400-litre drums (SCK•CEN); Flower beds at the Ningyo-Toge Centre constructed from cleared aluminium pipes from the gas centrifuges at the uranium enrichment pilot plant (IAEA).

Foreword

The Nuclear Energy Agency (NEA) Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking of organisations mainly from NEA member countries. The objective of the CPD is to acquire and share information from operational experience in decommissioning nuclear installations that is useful for future projects. The programme reports to the NEA Steering Committee through the Radioactive Waste Management Committee (RWMC) and has strong ties to the RWMC Working Party on Decommissioning and Dismantling (WPDD).

In 1992, the CPD convened a task group to review CPD members' experience of recycling and reuse of scrap metals arising from the decommissioning of nuclear facilities, and a report was published based on the findings of this group. Since this time, a further 20 years of decommissioning experience has been gained. Considering the rapid increase in the number of decommissioning projects worldwide the CPD once again convened a new task group to review this experience against the conclusions and recommendations of the 1996 publication and to report on the changes and improvements to the practice of recycling and reuse. The group was also tasked with extending their review to include other materials arising from decommissioning operations such as concrete and soils. This report summarises work carried out between September 2014 and September 2016, providing observations, recommendations and conclusions based on current experience.

This report represents the opinions of the Co-operative Programme of Decommissioning (CPD), drawn from practices and experiences in handling slightly contaminated material arising in nuclear decommissioning. It represents the views of individual organisations and does not necessarily represent the overall opinion of the responder countries. The report findings are based on a collation and evaluation of the questionnaire responses and case studies. Therefore, the report should not be taken as representing the opinions of the Nuclear Energy Agency or the governments of its member countries.

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Glossary

Definition of terms¹

The following terms were defined in constructing the survey questionnaire used to gather data about recycling and reuse of materials from decommissioning projects.

Clearance

Removal of radioactive materials or radioactive objects within authorised practices from any further regulatory control by the regulatory body.

Unconditional release

This term applies to material that has met clearance criteria is no longer subject to further radiologically based restrictions for its further usage or disposal.

Conditional release (also referred to as specific clearance in the Basic Safety Standards)

Applies to material that has met clearance criteria that are specific to an identified first usage, and for which a specific set of relevant exposure scenarios have been used to calculate doses to potentially affected persons.

Restricted use

The use of an area or of materials, subject to restrictions imposed for reasons of radiological protection and safety.

Unrestricted use

The use of an area or of materials without any radiologically based restrictions.

Other terms used in the report comply with IAEA definitions.¹

1. These definitions are drawn from the glossary in the 2008 IAEA report *Managing Low Radioactivity Material from the Decommissioning of Nuclear Facilities*. For reasons of simplification, the term “clearance” is used in this questionnaire to refer to both clearance and release, although there may be differences in practice. The term “unconditional” is used consistently to mean “unrestricted”, and “conditional” is used for “restricted”. More recent terminology is available in the IAEA *Safety Glossary: Terminology used in Nuclear Safety and Radiation Protection – 2016 Revision*.

Abbreviations and acronyms

ALARA	As low as reasonably achievable
BAT	Best available technique
BSS	Basic Safety Standards
BWR	Boiling water reactor
CPD	Co-operative Programme on Decommissioning
EC	European Commission
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IRPA	International Radiation Protection Association
LLW	Low-level waste
NEA	Nuclear Energy Agency
NPP	Nuclear power plant
OECD	Organisation for Economic Co-operation and Development
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo-Paris Convention)
PWR	Pressurised water reactor
RWMC	Radioactive Waste Management Committee (NEA)
TAG	Technical Advisory Group
TGRRM	Task Group on Recycling and Reuse of Materials (NEA)
VLLW	Very low-level waste
WPDD	Working Party on Dismantling and Decommissioning (NEA)

Executive summary

Introduction

Throughout the world, significant volumes of scrap and waste materials consisting of mainly concrete and steel arise from decommissioning nuclear facilities. Already in 1996, approximately 30 million tonnes (t) of scrap metals were estimated to be generated by the dismantling and decommissioning of nuclear facilities. The inherent value of these materials and the need to reduce the volume of material destined for radioactive waste disposal facilities make their recovery through recycling and reuse not only prudent, but necessary.

In 1992, the NEA Co-operative Programme on Decommissioning (CPD) (Annex A) commissioned a Task Group on Recycling and Reuse to review the practice of recycling and reuse within the nuclear industry and to identify obstacles to recovering scrap materials resulting from decommissioning activities. The task group, focusing mainly on metals, was also to identify the effectiveness of methods for overcoming these obstacles. Its findings and conclusions are outlined in the report, *Recycling and Reuse of Scrap Metals* (NEA, 1996).

Considering the expected and rapid increase of decommissioning projects over the coming years, the CPD commissioned a new Task Group on Recycling and Reuse of Materials (TGRRM) in 2014 to update the 1996 report based on decommissioning experience gained since 1996. The task group reviewed practices both for metals and for other materials (notably concrete) arising in significant volumes from decommissioning activities. In accordance with this mission, the task group examined existing and proposed standards and regulations, and compared these with those existing in 1996 so as to determine whether the current regulatory environment is more or less conducive to recovering these materials. The task group also examined to what extent the “tiered” regulatory regime proposed in the 1996 report had been adopted. To support this review, the task group gathered information from member organisations of the CPD programme using a survey questionnaire, case studies and the experiences of task group members. Overall, 32 questionnaire responses were received from 27 organisations in 12 countries, 1 non-OECD member economy and the European Commission, representing the experience and practice of 97 nuclear sites.

The quality of information and the conclusions and recommendations from the original 1996 report are not in question. The objective of this report is to update the conclusions from the 1996 report so as to reflect recent experience. The current validity of the 1996 conclusions and recommendations is thus under review in order to understand whether the recycling and reuse of materials from nuclear decommissioning projects has developed into a mature activity, or if obstacles remain.

Current practices

Respondents to the questionnaire reported that, driven largely by cost – the cost of conditioning and disposal is often significantly greater than the cost of decontamination and clearance – clearance and subsequent recycling and reuse of different types of materials has been applied on a large scale where the practice is allowed by national

regulation. Improvements to decontamination and measurement techniques have enabled lower clearance criteria to be met.

It was also noted that the practice is still limited by regulatory requirements and TGRRM thus concludes that the international harmonisation of regulation recommended in 1996 has not been fully implemented. In addition, more examples exist today of cleared materials being rejected by recycling companies and local stakeholders.

International standards and release criteria

The 1996 report found the absence of consistent, internationally accepted release criteria to be a significant impediment to the recovery of materials arising from the decommissioning of nuclear facilities. Since 1996, a number of leading reference and guidance documents have been published, in particular on the European level:

- Radiation Protection 89 (RP 89) – *Recommended Radiological Protection Criteria for the Recycling of Metals from the Dismantling of Nuclear Installations.*
- Radiation Protection 113 (RP 113) – *Recommended Radiological Protection Criteria for the Clearance of Buildings and Building Rubble from the Dismantling of Nuclear Installations.*
- Radiation Protection 122 (RP 122) – *Practical Use of the Concepts of Clearance and Exemption – Part 1: Guidance on General Clearance Levels for Practices.*

It is not mandatory for EU member states to adhere to these EU guidance documents since they have an advisory function only aiming to ensure a harmonised approach within the European Community. The application of clearance levels by competent authorities is not prescribed by the Directive (2013/59/Euratom), nor does it prescribe harmonisation of clearance levels since factors other than radiological protection may also be taken into consideration.

This report concludes that despite the adoption of these recommendations to a certain extent by some countries, harmonisation is far from complete. This is reflected in the difficulties that operators experience in transferring materials for processing between countries and in gaining stakeholder understanding regarding the safety aspects of having different clearance criteria in adjacent countries.

Such recommendations go some way to address the tiered system proposed in the 1996 report; clearance levels no longer focus on “unconditional” clearance, or unrestricted release of the material in question. The conditional clearance of metals is addressed in RP 89, published in 1998, providing international “conditional” release criteria.

The 1996 report argued that the release criteria at that date were too conservative, since they were based on conservative assumptions as a safeguard against uncertainty and unacceptability and were often modelled in a way that further intensified the conservatism. Since 1996, they have become even more conservative. In 1996, the International Atomic Energy Agency (IAEA) recommended unconditional clearance levels for Cobalt 60, (Co-60) and Caesium 137, (Cs-137) (two very important isotopes in NPPs), of 0.3 Bq/g (see IAEA-TECDOC-855, *Clearance levels for radionuclides in solid materials*, 1996). In RP 122, the unconditional clearance levels are 0.1 Bq/g for Co-60 and 1 Bq/g for Cs-137.

The Basic Safety Standards (BSS) Directive (2013/59/Euratom), proposes an unconditional clearance level of 0.1 Bq/g for Cs-137. However, this clearance level will present a significant challenge in demonstrating that unconditional clearance criteria can be achieved and will likely result in increased volumes of materials being classified as radioactive waste for disposal.

Health, environmental and socio-economic impacts

The 1996 report reviewed the impact of two fundamental options available for managing the disposition of radioactive scrap metal, namely “disposal and replacement” and “recycling and reuse”. The report concluded that on balance, the recycling and reuse of radioactive scrap metal appeared to have advantages over disposal and replacement, with both health risks and environmental impacts expected to be lower for recycling. For socio-economic issues, the report concluded that the key concerns were likely to be with public acceptability because of a generally negative perception of the nuclear industry as a whole.

The present report has found no evidence to challenge the 1996 report and notes that considerable volumes of material have been and will continue to be cleared, recycled and reused as nuclear decommissioning progresses. The main driver is perceived to be the high cost of conditioning and disposal compared with the costs of decontamination and clearance. Countries where disposal is relatively cheap (e.g. France, United States) tend to choose the disposal option, whereas countries where disposal is expensive (e.g. Belgium) prefer clearance to the maximum possible extent.

This report discusses the national standards for radiological protection that must be established at the national level to comply with the BSS Directive and notes the efforts over several decades towards international harmonisation of safety standards. The new BSS incorporates the latest recommendations from the International Commission on Radiological Protection (ICRP) published in 2007 and harmonises the EU regime with the IAEA Basic Safety Standards. The protection and safety system aims to assess, manage and control exposure to radiation so that radiation risks, including risks related to health and the environment, are reduced to a reasonably achievable extent.

Conditions for success

The 1996 report considered the impact of stakeholder perceptions on both options (“disposal and replacement” and “recycling and reuse”) and concluded that public perceptions of the acceptability of both alternatives would have a significant influence on their implementation. Respondents to the 2016 questionnaire clearly stated that stakeholder issues such as social/industry acceptance, perception of risk, politics/government intervention and lack of confidence/understanding are still significant obstacles (in total >50%) to adopting such a policy for recycling and reuse. TGRRM recommends a number of “keys to succeed” designed to assist in the removal of these obstacles such as: a programme of stakeholder involvement; incentives to promote policies for recycling and reuse; communication with the industry and the public; and dialogue with the industry to develop reliable outlets for recyclable materials.

Conclusions

Recycling of materials arising from the decommissioning of nuclear facilities is seen to be increasing for both metals and concrete despite the ongoing lack of harmonisation of regulation between countries. Several international guidelines now exist for how clearance and release of these materials should be regulated, and many countries have developed specific criteria for clearance, recycling and reuse. Improvements in decontamination and clearance measurement techniques have enabled operators to gain clearance for their materials even though the pessimistic clearance criteria have been further reduced to even lower and more conservative levels. The concept of a tiered system has been successfully incorporated in many countries and conditional clearance criteria are being developed on a national basis.

The key drivers for the development of recycling routes are generally the unavailability of disposal facilities and a comparison of the costs between recycling options and disposal options.

Stakeholder acceptance of recycling and reuse of materials remains a barrier to the successful recycle and reuse of materials from the decommissioning of nuclear facilities. As witnessed in some countries, greater involvement of operators and regulators in communicating directly with recyclers and the public to validate the safety of the clearance process can lead to enhanced trust and alignment of objectives.

Reference

NEA (1996), *Recycling and Reuse of Metal Scrap*, OECD, Paris.

Chapter 1. Introduction

The NEA Co-operative Programme on Decommissioning (CPD) 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 (for more information, see Annex A). In 1992, the CPD convened a Task Group on Recycling and Reuse to conduct an examination of the experience of member organisations from 13 countries and 25 decommissioning projects in recovering scrap metals generated from decommissioning of nuclear facilities. The task group, focusing on metals, was also to identify and determine the effectiveness of methods to improve scrap metal recovery.

The task group stated that approximately 30 million tonnes (t) of scrap metals are likely to be generated by the dismantling and decommissioning of nuclear facilities (Nieves et al., 1995). A large proportion of this material would be only slightly contaminated and, if decontaminated and released, would have a high value on the scrap metal market. If release for recycling and reuse is not an available option, the material would have to be placed in low-level waste repositories for disposal. As of today, worldwide repository capacity is insufficient to accommodate all the scrap metal that would 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 in many countries, costs associated with disposal will likely 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 task group concluded that, after treatment, significant quantities of materials and waste generated from decommissioning could be recycled and reused. Furthermore such recycle and reuse options could provide a cost-effective solution to the management of waste arisings. The group went on to conclude that the most significant impediment to recycling and reuse was the absence of consistent national release standards as applied to the nuclear industry. The International Atomic Energy Agency (IAEA) and the European Commission (EC) had proposed standards with the purpose of agreeing to an internationally accepted set of release levels. However, proposals to address this need were seen by the nuclear industry as extremely conservative. The task group considered that a graded approach should be taken, and proposed a "tiered" system of release criteria to facilitate discussion of appropriate conditional international release criteria.

The group's findings and conclusions, published in the 1996 report entitled *Recycling and Reuse of Scrap Metals* (NEA, 1996), were intended to provide information and insights into the practicality and usefulness of release criteria from the perspective of industry organisations currently engaged in decommissioning activities.

Twenty years of progress and development in the nuclear decommissioning industry have been gained since undertaking this comprehensive investigation. In that time, membership of the CPD has increased in proportion to the increase in the number of facilities under decommissioning, and there are now 70 projects from 14 NEA member countries, 1 non-OECD member economy and the European Commission participating in its information exchange programme (as of 31 December 2016). Since there will be a rapid increase in decommissioning projects as nuclear power plants throughout the world are shut down either at the end of design life, for economic reasons or because national

governments have changed their attitudes towards nuclear energy, the CPD decided that another review of the recycling and reuse of materials should be undertaken to consider whether recycling and reuse has been more universally implemented, and if not, why.

The CPD Management Board approved the Task Group on Recycling and Reuse of Materials (TGRRM) at the 32nd meeting of the CPD Management Board in 2013 and the task group was convened in September 2014. TGRRM members are volunteers from CPD member organisations, together with individual CPD sponsored specialists approved by the CPD Management Board. The TGRRM was comprised of ten expert representatives from CPD member organisations and three sponsored specialists, and a CPD Programme Co-ordinator in all eight countries were involved. The task group was mandated for two years from 10 September 2014 to 9 September 2016.

The Technical Advisory Group (TAG – the information exchange forum for the CPD) decided that the scope of the report should be expanded to include all materials (concrete, etc.) and not be limited to metals.

The task group proceeded to review the experience of the nuclear industry (mainly but not limited to CPD members) over the past 20 years of decommissioning activities and to prepare this report on recycling and reuse of materials arising from decommissioning. The quality of information and the conclusions and recommendations from the original 1996 report are not in question; this report has been prepared to update those conclusions to reflect recent experience. The report discusses the current validity of the 1996 conclusions and recommendations in order to understand whether the recycling and reuse of materials from nuclear decommissioning projects has developed into a mature activity or not. To enable the report to be read as a “stand-alone” document and be understood without needing to refer to the 1996 report itself, a summary of the 1996 report is provided in Chapter 2.

The report considers the following:

- review of the 1996 report and its conclusions;
- the reasons to adopt a recycle and reuse strategy, and the regulatory and social aspects that such a strategy should address;
- policies, regulations and regulatory controls;
- stakeholder issues: health, environmental and socio-economic impacts;
- conditions to develop and implement a viable strategy;
- conclusions drawn from this review and, as appropriate, comparisons with the conclusions of the 1996 report.

The report does not contain details of decontamination techniques for metal or concrete as these have been comprehensively studied by CPD task groups and reported on in 1999 (NEA, 1999) and 2011 (NEA, 2011). Similarly, techniques for undertaking release measurements were studied and reported in 2006 (NEA, 2006).

The task group chose to gather data by preparing a detailed questionnaire. The questionnaire recipients were targeted by the task group members as being individuals who were known to be specialists and experienced in this aspect of the industry. The result was a higher than expected return of completed questionnaires.

Case studies have been used to illustrate important aspects of the report. Because these have been provided in many different formats, they have not been published as an appendix to the report but have been quoted in the text as appropriate to the subject.

A review of international guidance and legislation (IAEA, EU, government websites, etc.) relating to recycling and reuse was undertaken and has been summarised in the report.

Task group members, who are all specialists working in the nuclear and decommissioning industry, drew upon their own personal experience to further illustrate industry experience and to add to the base of information from which conclusions and recommendations have been drawn.

The CPD Agreement ensures that information exchange is confidential and this report, prepared on behalf of the CPD for publication, has been carefully written to avoid attribution, while preserving important information. Raw data from the questionnaire is not made available to readers for reasons of confidentiality.

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Chapter 2. Review of the 1996 report

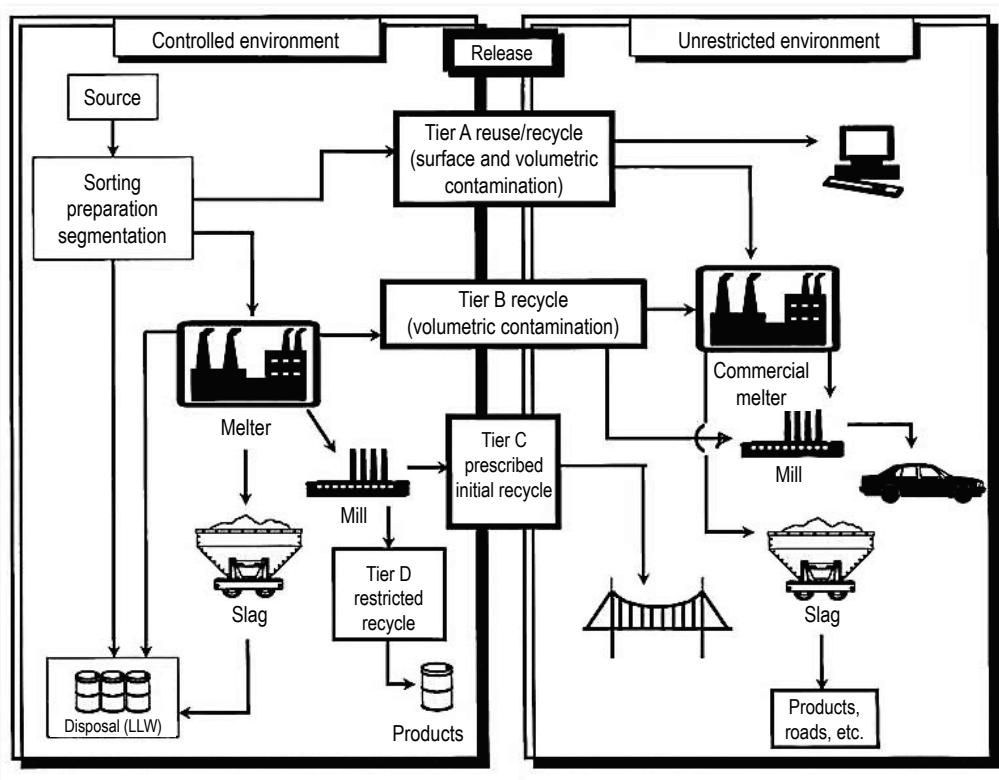
As this report is a review of the 20 years of decommissioning experience since the initial 1996 report on *Recycling and Reuse of Metals* (NEA, 1996) was prepared, it has been written as a commentary on the conclusions and recommendations of the 1996 report. As such, it requires reference to the 1996 report for complete understanding. In order for this report to be read “stand-alone”, this chapter presents the significant findings from the 1996 report to inform the reader of the conclusions and recommendations drawn from that work. For those readers who may wish to read the full 1996 report it can be obtained from the NEA. Members of the CPD programme may download the paper from the CPD password-protected area of the NEA website.

Summary and conclusions

The initial aim of the TGRRM was to conduct an examination of the current state of recycling and reuse in the nuclear industry, identifying issues in recovering concrete, steel and other valuable materials comprising a large portion of the waste generated during the decommissioning of nuclear facilities. The inherent value of these materials, and the cost of waste directed to radioactive disposal facilities makes recovery, through some form of decontamination, a prudent, if not necessary, undertaking. Furthermore, recyclable materials disposed of as waste 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.

Focusing on metals, the 1992 task group report, published in 1996, provides information and insights into the practicality and usefulness of release criteria from the perspective of organisations engaged in decommissioning activities. Furthermore, the task group examined the health, environmental, and socio-economic impacts, as well as the technical adequacy and cost-effectiveness of available decontamination techniques, 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. The tiered system provides four basic options (Figure 2.1):

- Tier A: Material that is surface contaminated or only slightly activated metal would be decontaminated as possible and unconditionally released for reuse or melting.
- Tier B: Material that is volume contaminated would be melted in a regulated environment to achieve decontamination, followed by metal recycle in commercial smelters or mills, and processing for use in consumer products (conditional clearance).
- Tier C: Material containing short half-life products would be melted and fabricated in a controlled environment, and released for a specific initial industrial use (e.g. steel bridge). Only possible for contamination or activation by radionuclides with “short” half-lives (depending on the useful life of the product).
- Tier D: Material that cannot be released from regulatory control will be recycled or reused in the nuclear industry (e.g. waste containers for final storage). Tier D does not involve release from regulatory control.

Figure 2.1. Conceptual illustration of the tier release system

Source: NEA (1996).

The task group pointed out that the establishment of internationally agreed, unconditional release criteria is a critical step to filling the need for a consistent, internationally accepted standard. It was suggested that such criteria should be established in a manner that will encourage, rather than preclude, the future establishment of conditional release criteria.

In preparation of the 1996 report, the task group surveyed 25 ongoing and completed decommissioning projects and suggested that efforts to recycle and reuse materials generated by the projects be governed by regulatory requirements. However, most recycling initiatives are governed by case-specific release criteria, or licences, which varied from country to country or project to project. Consequently, shipment of material between countries, and even to other facilities within the same country, was found to be extremely difficult due to the absence of uniform criteria. Further complications were identified such as variations in the quality assurance requirements, sampling protocols, required instrumentation, and documenting practices.

Yet even in such a regulatory environment, there has been conditional or restricted release criteria applied to a significant amount of scrap metals, providing experience as to the use of such waste management practices as an alternative to storage and disposal as low-level waste.

To address this issue, a number of international "clearance" levels have been proposed by various international organisations. These proposed clearance levels focus almost entirely on "unconditional" clearance, or unrestricted release of the material in question. In addition to unconditional clearance, a variety of alternatives, were available that are not addressed by these proposals. Transport and melting of scrap metal is such an example. The absence of international "conditional" release criteria makes shipment of such material across national boundaries a regulated process.

Moreover, existing international guidance evaluated by the task group, particularly ICRP 60, suggested that analyses of standards to govern radiological practices should include assessments of non-radiological impacts associated with the practices. However, the proposed international clearance levels were based almost entirely on radiological considerations.

The task group's examination concluded 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. The resulting conservatism becomes so significant that non-radiological risks, associated with related processes, exceed by orders of magnitude the reductions to radiological risks. Consequently, the radiological benefits gained by overly conservative assumptions are negated by increases in non-radiological risks where metals are subsequently replaced.

Health, environmental and socio-economic impacts

Two fundamental options were available for managing the disposition of radioactive scrap metal; disposal and replacement or 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 the "tiered" system of release criteria discussed previously. This "tiered" system would establish residual radioactive contamination levels applicable to end-use or final destination options for material generated by decommissioning operations. This was 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 exceeded 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.

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 the 1996 report.

With regard to adverse socio-economic impacts, both alternatives likely will confront some form of public opposition. The task group pointed out that recycling and reuse must overcome the negative stigma associated with the nuclear industries of most countries. In order to reach this aim, it has to be highlighted that recycling and reuse allows not only the preservation of non-renewable and rare natural resources, but also a reasonable use of limited storage capacities.

Technological capabilities

A variety of decontamination techniques that provide means to recycle and reuse radioactive scrap metals existed already. A particularly important methodology evaluated by the task group was melting. Although melting represents a major component of

recycling practices, other decontamination techniques were available, which were less intensive and would still permit items to be reused. These include wet and dry blasting techniques and chemical processes. 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. Since publishing of the report in 1996, two CPD task groups have reported on decontamination of metals and concrete from decommissioning (NEA, 1999 and 2011).

In order to effectively apply release standards based on specific activity or surface contamination, characterisation methodologies must be available to demonstrate or verify compliance. The task group pointed out that some of the proposed clearance levels have challenged state-of-the-art and practicality of measurement technologies and instrumentation available at the time of writing. Measurement technologies have been focus in another CPD report published 2006 (NEA, 2006).

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. 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. This conclusion is heavily influenced by the cost of local or national waste disposal.

1996 conclusions

The task group's examination indicated that, in their opinion recycling and reusing materials generated from decommissioning nuclear facilities is both practicable and cost effective. An element that could facilitate more effective implementation of this waste management alternative is the absence of consistent, internationally accepted release criteria.

Proposals evaluated by the task group to address this issue remained extremely conservative, did not address a variety of conditional release alternatives, and were estimated to not promote efforts to most effectively use available technologies. The task group report suggested the need to establish clearance criteria for different kinds of accepted practices. To this end, the task group proposed the "tiered" system of release criteria to facilitate discussion of appropriate conditional international release criteria.

The CPD still feels that the establishment of unconditional release criteria is a critical step to developing a consistent, internationally accepted standard. However, the CPD feels that such criteria should be established in a manner that encourages, rather than precludes, the future establishment of conditional release criteria. The 1996 task group shared their hope that the debate on recycling would benefit from the analysis conducted and that the discussion of the various proposals for release standards would consider the points identified in their work. Most importantly, their work provided some unique insight into the state of the recycle world from nuclear decommissioning perspective.

References

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NEA (2011), “Decontamination and Demolition of Concrete Structures”, NEA/RWM/R(2011)1.

NEA (2006), “Comprehensive Report of the Task Group on Activity Measurements at Release Levels”, NEA/RWM/CPD(2006)2.

Chapter 3. Current policies and regulations

The 1996 report on the *Recycling and Reuse of Scrap Metals* concluded that while there had been significant quantities of materials released by the decommissioning projects under study, the lack of consistent international release standards had restricted such releases. Either national clearance standards, or case-by-case clearance standards had been applied by decommissioning projects to clear materials.

This variation of release criteria, along with differing policies and measuring requirements, were felt to have restricted movement of material from one country to another. The transfer of waste arising from the nuclear industry is not allowed from one country to another, however, material may be transferred between countries for the purpose of decontamination and/or recycle and reuse. Such transfers are restricted by the absence of consistent international release standards.

Since the publication of the 1996 report, most countries have developed policies and regulation that are generally derived from IAEA guidance. Feedback since 1996 indicates that clearance regulations have become more restrictive than they were in 1996, mostly due to the lowering of release limits. This section outlines the key policies and regulations that govern the recycling, reuse and clearance of materials from the nuclear industry today.

Policies and regulations

There are four international documents that provide high-level guidance for relevant competent authorities when establishing clearance levels.

The underpinning document for clearance is:

- The IAEA RS-G 1.7, *Application of the Concepts of Exclusion, Exemption and Clearance* (included in the International BSS).
- Three other leading reference documents are published by the European Commission:
 - Radiation Protection 89 (RP 89) – *Recommended Radiological Protection Criteria for the Recycling of Metals from the Dismantling of Nuclear Installations*.
 - Radiation Protection 113 (RP 113) – *Recommended Radiological Protection Criteria for the Clearance of Buildings and Rubble from the Dismantling of Nuclear Installations*.
 - Radiation Protection 122 (RP 122) – *Practical Use of the Concepts of Clearance and Exemption – Part 1, Guidance on General Clearance Levels for Practices*.

Clearance levels as recommended by these guidance documents are the same whether applied to operating facilities or to those under decommissioning.

It should be noted that within the EU there are efforts to create standard criteria across all the member countries of which several are heavily involved in nuclear decommissioning. In 2013, the EU published a Council Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation (2013/59/EURATOM). Adoption of this directive by member countries is in progress.

As indicated previously, a significant number of countries have developed national regulations that are based on these international regulations and guidance. In just a few cases, international guidelines have been directly adopted by countries as their national regulation (e.g. Japan and Spain) or used by countries to regulate on a case-by-case basis (e.g. Italy). France is an exception. Having no national regulation for clearance, France has introduced the concept of zoning, whereby wastes from a radioactive zone are considered as radioactive waste regardless of their actual radioactivity and waste from the non-radioactive zone is classed as conventional waste.

Clearance of materials for unrestricted use/unconditional clearance

Today, a legal framework for clearance of materials for unrestricted use exists in most countries. Compared with the tiered system from the 1996 report (Chapter 2), unconditional clearance could be referred as tier A. The mass-specific limits for the same radionuclide may vary from country to country, but always within the RP 89 limits. One example is Caesium-137 where the mass-specific limit varies from 0.1 Bq/g to 1 Bq/g. For mixtures of artificial radionuclides, the weighted sum of the nuclide specific activities or concentrations (for various radionuclides contained in the same matrix) divided by the corresponding release limit must be applied. This is typically referred to as a “sum of fractions”, “sum of quotients” or “summation formula”. In some countries, additional surface specific limits are applied. For example, Belgium uses the surface specific limits from their transportation legislation and Germany uses nuclide specific limits which have to be applied whenever an object has a measurable surface (BfS, 2014).

The unconditional clearance of building rubble and concrete blocks from nuclear areas is a challenge for national regulations and experience shows that special arrangements have had to be made at a local level between the operator and regulator to achieve a practical clearance methodology.¹ The approved release limits are either mass specific, surface area specific or in some cases, a combination of both. For example in Germany the methodology to release concrete blocks and building rubble uses mass-specific limits. For whole buildings, surface specific release limits are applied with clearance measurement performed on the standing structure before release for conventional reuse of the building or for demolition. In Belgium, at the Eurochemic site, the methodologies for taking clearance measurements on this complex reprocessing facility were varied according to the location (for instance whether the room had been an active cell or a clean corridor) and operational history (accidents/spillages) of the facility. In Sweden and Germany, clearance levels for buildings depend on the endpoint. For demolition, the levels are an order of magnitude higher than if the building is to be reused.

Building rubble and concrete unconditionally cleared in this way is generally released to industrial recycling facilities or conventional disposal sites. Once material is unconditionally cleared, it is free from any regulatory control and may be used without regard to its nuclear origin often as fill material in the construction of roads.²

In addition to metals, building rubble and concrete blocks, a number of countries also allow the release of other materials for unrestricted reuse, treatment or disposal such as liquids (e.g. oils), soil, wood, insulation (e.g. rock wool), plastics, electrical cables, electronic scrap and many more.¹ In the United States, Belgium, Germany and the United Kingdom the applied release limits for these materials are typically the same as for metal. In Italy these release limits are only applied for dry solid materials whereas the release of other materials (e.g. oils) is regulated on a case-by-case basis.

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1. Personal experience from task group members.
 2. Answers from questionnaire.

It should be noted that while unconditional clearance is generally a well-regulated practice in many countries followed by unrestricted recycling and reuse of the materials through conventional industries, there are some countries (e.g. Japan, Denmark) where although regulations exist to allow unconditional clearance, the cleared material has experienced difficulties in being used in conventional industry because of a lack of acceptance by the recycling industry, stakeholders and the local authorities.

Clearance of materials for restricted use/conditional clearance

A legal framework for conditional clearance exists in many countries. Since 1996 there has been some development but not as much as for unconditional clearance. Compared with the tiered system from the 1996 report (Chapter 2), conditional clearance could be referred to as tier B. Germany and Belgium have specific regulations and release limits for conditional clearance within their national legislation. In Sweden and the United States, conditional clearance is subject to site-specific approvals and permissions. In Sweden, pre-approved clearance levels also exist for hazardous waste, but approval must be requested. The United Kingdom has an additional waste classification (very low-level waste) which allows certain wastes to be disposed at landfill sites with appropriate permits. In Italy, Germany and Sweden, there are restrictions for recycling of metals destined to be cleared through the melting process. The cleared metal has to be melted and mixed with metallic material of different origins in the ratio of 1 to 10.

In the German Radiation Protection Ordinance, both mass-specific limits and surface specific limits may be applied:

- Mass-specific limits are used for concrete and rubble with the restriction that this material is deposited within a conventional disposal site. Additional characterisation may be required to ensure that the material complies with the conventional waste acceptance criteria of the disposal site.
- Surface specific limits are used to clear whole buildings prior to demolition, and the resulting building rubble can then be recycled in a conventional recycling facility. However, the building must be demolished and may not be reused for a different purpose.

Other countries (e.g. Italy and Spain) refer to international documents and their scope of regulations (RP 89, RP 113, RP 122, and RS-G 1.7). According to the EC BSS, specific/conditional clearance limits can be approved by national authorities for justified practices. Justification has been interpreted as, for example, demonstrating environmental benefits.

Waste area zoning (French regulated nuclear facilities)

In France they have adopted a clearance process that is significantly different to the processes adopted by other countries. The French process involves zoning the areas in a nuclear facility to separate those containing conventional non-nuclear material from those with a nuclear content to meet the requirements of the Basic Nuclear Installation (BNI) (JORF, 2012). Zoning is established using an analytical approach in which the facility's (BNI's) design, operating rules and history are considered to determine the presence or absence of added radioactivity. Zoning is supported by radiological maps that confirm the appropriateness of classification and validate the operational nature of the lines of defence adopted to ensure materials containment.

Waste area zoning evolves over time following an incident, or as a function of modifications or work performed (including decommissioning) on the facility. It is separate, but consistent, with radiation protection zoning which also controls plant operations, and must maintain traceability over time.

The facilities are thus divided into two types of areas (zones):

- Nuclear waste areas in which the waste produced is likely to be contaminated or activated. Waste from these areas is termed “nuclear waste” and is disposed of through appropriate disposal methods.
- Conventional waste areas in which the waste produced is not likely to be contaminated or activated. Waste from these areas is termed “conventional waste” and is disposed of through “ordinary” disposal methods, subject to characterisation and measurement.

Although the zoning regulation precludes clearance for recycling and reuse, it is technically possible to seek an exemption to recover and recycle the raw materials used in the structures and equipment of French nuclear facilities. Any exemption application must demonstrate compliance with certain conditions and show a positive balance of the advantages given by recycling. It is notable that to date none of the three main French nuclear operators, Areva, CEA or EDF has attempted an application through this process.

Under these zoning regulations large volumes of waste are sent to the Very low-level waste (VLLW) repository for disposal. As more French reactors are shut down for decommissioning, the VLLW repository will become increasingly filled. To maintain decommissioning progress it will be necessary to have sufficient VLLW disposal facility capacity, or to change the regulations to allow other pathways for potentially reusable material.

Changes/improvements since 1996

Since 1996, there have been significant efforts among a number of countries, (Germany, United Kingdom, Sweden, Belgium and Italy) to utilise radionuclide-specific clearance limits for unconditional and conditional clearance. In these situations, the summation formula is typically applied for situations where a mixture of radionuclides exists. Formula 1 shows how summation is calculated for surface contamination or specific activity. To approve clearance, the result of summation must be less than 1.

$$\sum_i \frac{C_i}{Cl_i} \leq 1$$

Formula 1

C_i : specific activity of radionuclide i (in Bq/g or Bq/cm²)

Cl_i : Clearance level of radionuclide i (in Bq/g or Bq/cm²)

Tables 3.1 and 3.2 compare release criteria as published in the 1996 report (column 2 and 3) with changes since 1996 (column 4 and 5) and adds data from countries that did not contribute to the 1996 report. The tables have been populated with data compiled from the questionnaire and the literature review by task group members.

The responses to the 2015 CPD questionnaire and the experience of the task group deployed to review the 20 years of progress since the 1996 report published its recommendations lead to the conclusion that despite the recommendations of the 1996 report, the CPD feels that clearance levels remain insufficiently developed, and the harmonisation of release criteria between countries has not developed sufficiently to be used for a general adoption of recycling and reuse of materials from decommissioning projects. Furthermore, regulations introduced since 1996 have tended to reduce the clearance levels for significant radionuclides, like Caesium-137 and Cobalt-60, thus requiring more decontamination and characterisation before materials can be eligible for unconditional release.

Table 3.1. Surface contamination limits of alpha and beta/gamma emitters

	1996 report		Status 2016	
	Surface contamination limit for beta/gamma emitters	Additional information as written in the 1996 report	2016 contamination limits	Changes since 1996
Germany	0.37 Bq/cm ²	Applied over 100 cm ² for fixed and removable contamination for each single item	Radionuclide specific (summation formula)	The total activity limit has been replaced by radionuclide-specific limits. For single items with fixed and removable contamination they are applied as a mean value over 1 000 cm ² , and for buildings the area is increased to 1 m ² . This was established in 2001 in the German Radiation Protection Ordinance.
Finland	0.40 Bq/cm ²	Applied to removable surface contamination over 0.1 m ² for accessible surfaces	Alpha: 0.4 Bq/cm ² Strong beta/gamma emitters: 4 Bq/cm ² Weak beta/gamma emitters: 40 Bq/cm ²	When these limits are applied to recyclable metals cleared for melting and are averaged over 0.1 m ² of accessible areas. Loose contamination up to 10% of the total contamination.
Belgium	0.40 Bq/cm ²	Applied to the mean value for removable surface contamination over 300 cm ² , for beta-gamma emitters and alpha emitters with low toxicity	Alpha: 0.04 Bq/cm ² Beta/gamma emitters: 0.4 Bq/cm ²	No change in legislation since 1996.
United States	0.83 Bq/cm ²	Limits apply to the average Surface contamination above background over no more than 1 m ² , with a maximum of 2.5 Bq/cm ² above background for contaminated areas not exceeding 100 cm ²	Alpha: Radionuclide specific Beta/gamma emitters: 0.83 Bq/cm ²	No changes in legislation. However, in 2013, the ANSI/HPS published N13.12, <i>Surface and Volume Radioactivity Standard for Clearance</i> , which to date (2016) has not been formally adopted by United States regulatory agencies as the universal standard for clearance of materials.
Sweden	4.00 Bq/cm ²	Limits are applied to the 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	Alpha: 0.4 Bq/cm ² Beta/gamma emitters: 4 Bq/cm ²	Mean value is now to be measured over 300 cm ² and is only valid for material with well-defined surfaces. For buildings and rooms, nuclide specific levels apply (different levels for reuse and demolition). For further details see Table 3.2.
Italy		Not included in the 1996 report	Radionuclide specific (summation formula)	No changes in legislation. Clearance is regulated on a case-by-case basis (usually during the licensing of decommissioning).
Spain		Not included in the 1996 report	Radionuclide specific (summation formula, note that surface clearance levels apply only to concrete)	Clearance is regulated on a case-by-case basis (usually during the licensing of decommissioning). The levels are derived from EU-levels (RP 122 for the Unconditional Clearance and RP 113 for the Conditional clearance-Building reuse or demolition-), but are in each case confirmed by the Regulatory Authorities; Consejo de Seguridad Nuclear (CSN) and Ministry of Industry, Energy and Tourism.

Table 3.2. Specific activity limits regardless of type of emission

	1996 report		Status 2016	
	Contamination limit for beta/gamma emitters	Additional information as written in the 1996 report	2016 contamination limits	Changes since 1996
Germany	0.10 Bq/g		Radionuclide specific (summation formula)	The total activity limit has been replaced by radionuclide-specific limits as applied to the mean value for less than 300 kg. For unrestricted released concrete the mean value is 1 000 kg. This change was introduced in 2001 in the German Radiation Protection Ordinance.
Germany	1.00 Bq/g	As applied to the reuse of metal in a general melting facility.	Radionuclide specific (summation formula)	The total activity limit has been replaced by radionuclide-specific limits and is applied to mean value less than 300 kg with the condition that the cleared material must be reused in melting facilities with a turnover of 40 000 Mg per year. This change was introduced in 2001 in the German Radiation Protection Ordinance.
Sweden	0.10 Bq/g	Limits are applied to activity levels that are 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).	Radionuclide specific (summation formula)	Nuclide specific levels are used for unconditional clearance and conditional clearance for oil and hazardous waste. There are no specified clearance levels for soil (clearance levels will be decided by the regulator on a case-by-case basis). The clearance levels are based on RP 122 part 1 and RP 113. In 2011 a new regulatory code was issued (SSMFS 2011:2) together with an Industry code of practice (R-11-15 in Swedish) prepared by the Swedish Nuclear Fuel and Waste Management Co. (SKB).
United Kingdom	0.40 Bq/g	The limits apply to the total activity for solids, other than closed sources, that are substantially insoluble in water.	Radionuclide specific (summation formula)	The total activity limit has been replaced by radionuclide-specific limits which are derived from the Basic Safety Standards Directive. Guidance on legislation applicable to the clearance of radioactive waste has been provided by the government (Guidance on the scope of and exemptions from the radioactive substances legislation in the United Kingdom, September 2011). The UK nuclear industry has also published a nuclear industry code of practice, Clearance and Radiological Sentencing: Principles, Processes and Practices for Use by the Nuclear Industry, issue 2 December 2012.
United States		The United States has not developed release standard.	Radionuclide specific (summation formula)	Primarily, radionuclide-specific limits are derived from dose or risk standards based on future use scenarios that utilise pathway specific analysis models. Models utilise site-specific or generally accepted default parameter values to derive clearance limits. ANSI/HPS published N13.12, <i>Surface and Volumes Radioactivity Standard for Clearance</i> (2013), but this has not been formally adopted by US Regulatory Agencies as a universal standard for clearance of materials.
Belgium			Radionuclide specific (summation formula)	Belgian legislation is also derived from the BSS Directive. As such, there are radionuclide-specific limits.

Table 3.2. Specific activity limits regardless of type of emission (cont'd)

	1996 report		Status 2016	
	Contamination limit for beta/gamma emitters	Additional Information as written in the 1996 report	2016 contamination limits	Changes since 1996
Italy		Not included in the 1996 report.	Radionuclide specific (summation formula)	Each site has specific clearance levels. Each activity mass concentration measurement has to consider a general mass not greater than 1 000 kg or a general volume not greater than 1 m ³ ; for metallic materials the specific activity mass concentration has to consider a metallic mass not greater in any case, than 400 kilograms. It must be noted that mass-specific clearance levels cannot be greater than the "exclusion level", which is set at 1 Bq/g, regardless of the nuclide, in the Decree n. 230/1995.
France		Not included in the 1996 report.	No clearance limits for wastes from nuclear waste zones	Waste zoning is required under the regulations that apply to nuclear facilities. Waste zoning defines areas where wastes can have become activated or contaminated (nuclear waste zone) and zones where there is no possibility of contamination or activation (conventional waste zone). By law clearance of materials from the nuclear waste zone is not permitted.
Finland		Not included in the 1996 report.	Limits are Radionuclide specific (summation formula) The legislation includes limits for conditional clearance for landfill disposal: alpha emitters: 0.1 Bq/g; strong beta/gamma emitters: 1 Bq/g; weak beta/gamma emitters: 10 Bq/g; and limits for unconditional clearance.	Conditional clearance for landfill disposal: Limits are applied to measurements averaged over a maximum of 500 kg of waste and annual amounts are restricted to less than 100 tonnes per facility. Unconditional clearance levels are radionuclide specific derived from IAEA Safety Guide RS-G-1.7. This procedure is not applicable to waste that is flammable or volatile or can otherwise cause particularly easy radiation exposure.
Spain		Not included in the 1996 report.	Radionuclide specific (summation formula) Alpha: 0.04 Bq/cm ² Beta/gamma emitters: 0.4 Bq/cm ²	Clearance is regulated on a case-by-case basis (usually during the licensing of decommissioning). The levels are derived from EU-levels (RP 122 for the Unconditional Clearance and RP 89 for Conditional clearance-Reuse and Recycling-) but are in each case confirmed by the Regulatory Authorities; Consejo de Seguridad Nuclear (CSN) and Ministry of Industry, Energy and Tourism. Surface and mass measurements have to comply with clearance levels. In case of unconditional clearance, the mass concentration is averaged in a metallic mass not greater than one metric ton.
Japan		The relevant regulation was established in 2005.	Radionuclide specific (summation formula)	Mass concentration is averaged in an object (metallic, concrete, glass wool or rock wool only) "Objects" have a mass not greater than one ton in principle. Japanese Clearance levels were set by considering IAEA RS-G-1.7. Basically, those levels were studied based on the annual exposure, 10 µSv/y.

An opportunity for greater harmonisation has arisen within the countries of the European Union. In December 2013, the EU issued 2013/59/Euratom, *Basic safety standards for protection against the dangers arising from exposure to ionising radiation* (EU, 2013).

Implementation of the directive by member countries should help to harmonise the EU community and align them to the IAEA International BSS. Under EU law member countries must adopt the directive into their legislation by 2018, however within these arrangements member countries may apply a level of interpretation to the requirements which may result in some differences between countries.

The directive does not deal with the release limits and criteria for conditional clearance, and member countries have the opportunity to implement conditional release limits at a national level.

This directive (EU, 2013) issued incorporates the latest recommendations from the ICRP (ICRP 103) and outlines general exemption and (unrestricted) clearance criteria:

- the radiological risks to individuals caused by the practice are sufficiently low, as to be of no regulatory concern;
- the type of practice has been determined to be justified;
- the practice is inherently safe.

Application of these criteria would be through the use of release limits that, in particular for significant radionuclides, such as Caesium-137 and Cobalt-60, could become more restrictive.

In an effort to harmonise guidance documents in the United States, ANSI/HPS³ has recently published *Surface and Volume Radioactivity Standard for Clearance* (ANSI/HPS, 2013). This standard is intended to provide guidance in a manner consistent with the recommendations of the IAEA. However, unlike the IAEA recommendations which includes clearance, exemption and exclusion, this ANSI/HPS Standard only focuses on clearance. Since publication, this guidance has been situationally applied by some agencies but has yet to be formally adopted in national regulations or policies.

Conclusions

1. Substantial quantities of material from decommissioning and dismantling nuclear facilities have been generated in the past, and will be generated in the near future. Since the publication of the 1996 report, there have been changes in legislation in many countries, generally implementing release standards on a national or case-by-case level. Several international guidelines now exist to address how clearance and release of materials should be regulated. The TGRRM analysis of the last 20 years shows that there is still a lack of harmonisation between countries. The TGRRM feels that this harmonisation is necessary not only to share techniques, waste treatment facilities, minimising/reducing volume of waste, but also to increase general acceptance and particularly public acceptance. Regulatory coherence, through international commitment, remains a critical gap that the TGRRM feels must be filled. This is particularly the case for material treatment being operated in different countries, and becomes increasingly apparent as products using recycled materials cross borders of countries with different requirements. The EU BSS 2013/59/Euratom is a good start, but without further development and harmonisation of these release standards across the international community, the TGRRM feels that there will always be materials which cannot be systematically recovered through reuse or recycle practices.

3. Health Physics Society Development of American National Standards.

2. In the 1996 report, it was concluded that the clearance levels presented by the IAEA (IAEA Safety Series 89, 1988) and the EC group of experts (Working Party of the Article 31 Group of Experts of the European Commission, 1994) were both based on the concept of optimising radiation protection rather than justification based on the ICRP definition “do more good than harm”. Since 1996, this concept remains prevalent and clearance levels have changed slightly, but in practice, the *de minimis* approach generally prevails as the basis for both conditional and unconditional clearance.
3. To address the release of all types of materials to unknown destinations, the 1996 task group concluded that the IAEA proposed set of “unconditional” clearance levels represented a conservative, common denominator across wide ranging release situations. However, the TGRRM felt that release levels for materials where decommissioning and processing are relatively well characterised could be much less restrictive than those proposed by the IAEA and remain protective of public health. The TGRRM thus concluded that, in its opinion, the IAEA unconditional clearance levels may be inappropriately low for many nuclear installation decommissioning projects. In 1996, conditional clearance was regulated in the European BSS, but through a set of general clearance requirements, and required approval by a national authority. The publication of a new EU BSS (EU BSS 2013/59 Euratom), continues to require national authority approval for conditional clearance, and the TGRRM feels that release limits have become even more restrictive than in 1996.
4. The 1996 task group concluded that although a risk-based approach for setting material release limits is generally accepted, varying degrees of conservatism have been incorporated in different analyses. As a result, derived release levels can range over several orders of magnitude. These variations accentuate the need for a consistent set of international standards for common release circumstances. The TGRRM suggests that overly conservative assumptions should be avoided in developing release standards. As mentioned in the 1996 report, it would be preferable to employ more realistic data for parameter values, and incorporate estimates of the range of parameter uncertainties, prior to adding an appropriate margin of public protection. Additionally, *de minimis* levels tied to dose are conservative without having to determine risk. The TGRRM feels that conditional clearance should be adopted in regulations, and that criteria for conditional clearance could be less conservative than for unconditional clearance by assuring specific conditions as to how the material will be handled. This would assure the appropriate limitation of potential exposures.

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Chapter 4. Experience since 1996

This chapter reviews the current practice of recycling and reuse in comparison with the conclusions drawn in the report from 1996. This analysis is based on a set of case studies and the questionnaire responses.

Furthermore, recycling and reuse is described for a variety of materials in order to exemplify how different clearance approaches, recycling options, decontamination and characterisation methods have been applied for different materials.

Current practice of recycling and reuse

General results from questionnaire analysis

From the questionnaire survey, it appears that recycling is most commonly achieved through unconditional clearance and conventional materials recycling (corresponding to Tier A in the 1996 report, see Chapter 4). This can be expected since, for nuclear installations, most of the building structures and process systems are clean or only slightly contaminated. Furthermore, it can be expected that recycling after conditional clearance or recycling within the nuclear industry are seen as exceptions, only attempted when unconditional clearance is not achievable. This is to some extent supported by the questionnaire results concerning the recycling routes used (Table 4.1).

Table 4.1. Recycling routes reported in the questionnaires

Routes	Number of responses
Conditional clearance and conventional recycling	2
Conditional clearance and recycling within the nuclear industry	4
Recycling within the nuclear industry without clearance	3
Unconditional clearance and conventional recycling	15
Was any other route to recycling used?	2
Total	26

The result may also reflect a lack of established procedures for conditional clearance (clearance levels, material processing routes, regulatory framework, etc.).

Metals and especially steel appears to be most commonly recycled followed by concrete and other materials (e.g. wood and plastics). This is in line with the view of the 1996 report where metals were singled out as the most important material for recycling. However, it may also reflect that few decommissioning projects have reached the stage where large concrete structures are demolished. Process systems (consisting mainly of steel) are typically removed first, which means that steel will dominate the cleared and recycled materials in the early stages of decommissioning.

A comparison of three Belgian projects (from the authors' experience) in different stages of decommissioning clearly shows that the ratio cleared steel/cleared concrete changes

(substantially) as a function of time. In the Belgian Reactor 3 (BR3), decommissioning project where building clean-up has begun, but no buildings have been cleared yet, the ratio cleared steel/cleared concrete is 1/2. In the Belgonucléaire decommissioning project, where one of the main buildings has been cleared and demolished, the ratio cleared steel/cleared concrete is 1/20. Finally, in the Eurochemic decommissioning project, which has come to an end and the whole building has been demolished, the ratio is 1/200. (All values quoted as at December 2015.)

Metals

The 1996 report focuses entirely on recycling and reuse of metals. Metals are expensive compared to other construction materials and are often relatively easy to decontaminate. Melting also simplifies reprocessing and recycling of metals and this process is well-established within conventional waste management. It is therefore not surprising that the questionnaire results indicate that metals (steel in particular), are the most commonly recycled and reused materials.

Although steel is the most abundant metal in decommissioning waste and the most commonly recycled metal, other metals are recycled as well. Copper is recycled due to its relatively high value. Lead and aluminium are recycled since their inherent properties are undesirable in repositories for radioactive waste (chemotoxicity and hydrogen gas production, respectively). Consequently, acceptance criteria for radioactive waste enforce limitations on the amount of lead and aluminium. For example, acceptance criteria in Belgium limit the amount of aluminium in a drum with unconditioned waste to 10 kg in order to limit the hydrogen gas production. Other repositories such as the UK Low Level Waste Repository have similar restrictive waste acceptance criteria (LLWR, 2014; Vlaanderen, 2014; SKB, 2014).

Steel and other metals are typically sent for recycling after decontamination and unconditional clearance. Decontamination may involve chemical/water jet washing, dry/wet blasting or the application of gels or a combination of such methods and the metals are cleared based on surface activity measurements and/or mass activity measurements. Metals are also recycled after melting at a controlled facility followed by clearance of the ingots. Homogenisation during the melting process allows representative samples to be taken from the ingots, which simplifies characterisation. Clearance is then typically demonstrated against mass-specific clearance values. Furthermore, melting often reduces the activity level of the metal since some nuclides accumulate in the slag (depending on the metal [Björkwall et al., 2014]) or are volatilised (e.g. Cs-137).

The unconditionally cleared metals are recycled as conventional scrap metal without any specific end point. Tools and equipment can also be unconditionally cleared for direct reuse (e.g. clearance of an emergency power diesel generator at Wiederaufarbeitungsanlage Karlsruhe [WAK], Germany).

In some cases, conditional clearance as proposed in RP 89 (EC, 1998) is applied. Conditional clearance is approved when the material is processed and recycled through a route that reduces exposure compared to unrestricted recycling and reuse. The metal could for example be sent to a conventional melting facility where mixing of the material with conventional (non-active) metal is ensured. This approach is applied by Studsvik Nuclear (Sweden). Conditional clearance has in this case been approved (SSM, 2011) under a set of conditions that ensures that remelting and mixing with non-active metal (as described in RP 89) is carried out at the conventional melting facility. These conditions require Studsvik Nuclear to carry out regular audits of the melting facility and to document and review all steps in handling the material from its original owner to the final recipient.

The total amount of cleared metal from the melting facility at Studsvik Nuclear between 1987 and 2015 is given in Table 4.2 below including both conditionally and unconditionally cleared metals.

Table 4.2. Metals processed by melting at the Studsvik nuclear site between 1987 and 2015

Metal	Amount/tonnes
Carbon steel	32 000
Stainless steel	5 200
Aluminium	2 033
Lead	1 153
Brass	307
Copper (not cables)	99
Cables (stripping coating from the copper)	3 896

At NPP Stade in Germany, 13 000 tonnes of scrap metal have been dismantled (as per 2014) and 30% has been sent for melting. Scrap that can be decontaminated (with a reasonable effort to meet levels for unconditional clearance) is typically treated and cleared on site. Conditional clearance after off-site melting in a controlled facility is the preferred route for material with contamination levels below RP 89 levels but exceeding unconditional clearance levels. For scrap with complex geometry and hard-to-reach surfaces, melting is also preferred in order to simplify characterisation and radiological sentencing (Bacmeister, 2014).

In Spain, the decommissioning of NPP Vandellos-1 has released 8 000 tonnes of materials (metals mainly) from the active area and an additional 8 000 tonnes from conventional areas/components. Most of this material has been sent for recycling.

There are also examples of recycling and reuse of metals within the nuclear industry without clearance. In these cases the material has been reused as radiation shielding material or for construction of radioactive waste containers. Socodei in France uses scrap metal from nuclear installations to produce integrated radiation protection in waste packages. Recycling and reuse of lead as shielding material within the nuclear sector has been applied at for example SCK•CEN, Belgium (see case studies below) and the dismantling of accelerators in Saclay, France. At the NPP Vandellos-1 in Spain, 72 tonnes of contaminated ferrous material was sent for recycling by DURATEK (now EnergySolutions) in the United States to manufacture shielding for the Fermi Laboratory in Chicago.

EnergySolutions uses melting for recycling of metals within the nuclear industry. The molten metal is poured into moulds forming (10-ton) shield blocks (Figure 4.1) which are then used in the nuclear industry (e.g. High Energy Physics Labs).

Figure 4.1. Shield blocks manufactured at EnergySolutions' Bear Creek Facility



Source: EnergySolutions.

Most of the metals recycled by EnergySolutions are ferrous, but small amounts of lead and aluminium have been recycled on a case-by-case approval. Table 4.3 summarises the cumulative mass of recycled metal from different countries.

Table 4.3. Cumulative metals received by EnergySolutions from different countries

Country of origin	Approximate time for first shipment	As of July 2015/tonnes
United States	1991	62 380
Belgium	1996	304
Canada	2006	2 033
Germany	2000	1 153
Spain	2001	99
United Kingdom	2006	307
Non-US subtotal		3 896
Total with United States		66 276

In order to meet the needs for recycling materials from the nuclear industry and to mitigate the limited availability of interim and final disposal facilities for radioactive waste, Siempelkamp has developed options to recycle contaminated metals from operation and decommissioning of nuclear facilities. Their melting plant CARLA has been in operation since 1989. The metal is recycled for new applications both within and outside the nuclear industry.

While Studsvik Nuclear, EnergySolutions and Siempelkamp have installations at their premises to which materials for treatment must be delivered, Hinneburg is a company that can offer melting services at the customer's premises (see case studies on lead melting below).

Concrete

Large amounts of concrete debris will arise from decommissioning of nuclear installations. The total volume will be dominated by concrete from cleared buildings. The buildings are typically cleared after surface and/or mass activity measurements prior to being demolished. The concrete is then treated as conventional building rubble and recycled accordingly. Alternatively concrete structures are cut into smaller pieces and cleared individually (e.g. Ringhals NPP, Sweden [see case studies below]). At SCK-BR3 in Belgium, both methods have been applied. Additionally some concrete is crushed on-site prior to clearance. Clearance is then carried out on the crushed material (using mass-specific activity measurements). This approach has been applied by BelgoProcess.

Crushing of concrete could also allow separation of fine aggregate from coarse aggregate fractions. It has been demonstrated that contamination typically penetrates the fine (porous) aggregates, but not the denser coarse aggregates (NEA, 2011). Hence, such separation would allow the coarse aggregates to be cleared and recycled even if contamination has penetrated the concrete structure.

The use of concrete as backfilling material appears to be an attractive solution for recycling concrete from decommissioning of nuclear installations. For example, at the NPP Vandellós-1 in Spain, 77 000 tonnes of concrete from building structures together with 1 900 tonnes of cleared concrete from active areas have been reused on site for land restoration purposes. Additional cases can be found in the list of case studies below.

Recycling of conditionally cleared concrete has been applied for site remediation purposes. Backfilling with concrete crushed on site can reduce exposure to the general public and therefore allow higher clearance levels compared to unconditional clearance. This procedure has been applied for decommissioning of the sorting plant at the uranium processing facility in Ranstad, Sweden.

Since reusing concrete as backfilling material typically requires clearance in order to meet the desired end point of a decommissioning project, examples of concrete recycling without clearance are scarce. However, at the SCK•CEN in Belgium, slightly activated heavy concrete has been proposed to be recycled as an active mortar for immobilisation of low-level radioactive waste (NEA, 2011).

Case studies of recycling and reuse

The materials listed in the table below (Table 4.4) represent a range of materials chosen to highlight a particular recycling case. Cases have been selected to illustrate recycling of different materials as well as different approaches to clearance and recycling.

Table 4.4. Case studies of recycling and reuse of materials

Project	Site	Country	Material	Amount/tonnes	Physical form/processing	Tier	Endpoint
BWR turbine rotors Ringhals NPP	Ringhals NPP	Sweden	Steel	360	Large/whole component	A	Conventional recycler
Berkeley boilers	Berkeley NPP	United Kingdom	Steel	3 200 ¹	Segmented component/melting	A, B ²	Conventional recycler
Lead from removable shielding	BR3 NPP	Belgium	Lead	34	Encapsulated lead/melting	A, D	New hot cells
Fuel reprocessing plant	Eurochemic	Belgium	Concrete/steel	25 166/2 439	Building structures and rubble	A	Conventional recycler
Concrete from PWR Containment	Ringhals NPP	Sweden	Concrete	200	1 tonne concrete blocks	A	On-site construction
Sorting plant decommissioning	Ranstad uranium processing facility	Sweden	Concrete	15 000	Building structures and rubble	B	Site remediation
Release of cable	Wiederaufarbeitungsanlage Karlsruhe (WAK)	Germany	Copper	4.15	Off-site cable shredder	A	Conventional recycler
Concrete debris recycling	JRR-3 research reactor	Japan	Concrete	1 800	Concrete rubble	A	Site remediation
Gas centrifuges	Ningyo-Toge centre	Japan	Aluminium	11	Pipes	D	On-site construction
Off-gas building decommissioning	Caorso NPP	Italy	Concrete/steel	7 200/908	Crushed concrete/scrap metal	A	On-site construction
Turbine building	Caorso NPP	Italy	Concrete/steel	-/8 272	Whole building/scrap metal	A	Reuse
Calder Hall cooling towers	Calder Hall NPP, Sellafield	United Kingdom	Concrete	5 200	Crushed concrete	A	Conventional recycler/site remediation
Windscale pile chimney	Windscale, Sellafield	United Kingdom	Concrete	3 000	Crushed concrete	A	On-site construction
Waste management building	MZFR, WAK, Karlsruhe	Germany	Concrete	3 530	Whole building	A	Conventional recycler
Plant decommissioning	NPP Vandellós-1	Spain	Concrete	78 962	Concrete structures	D	Reuse on-site

Note: The tier column refers to the tiered concept proposed in the 1996 report, but with the extension of the concept to materials other than metals.

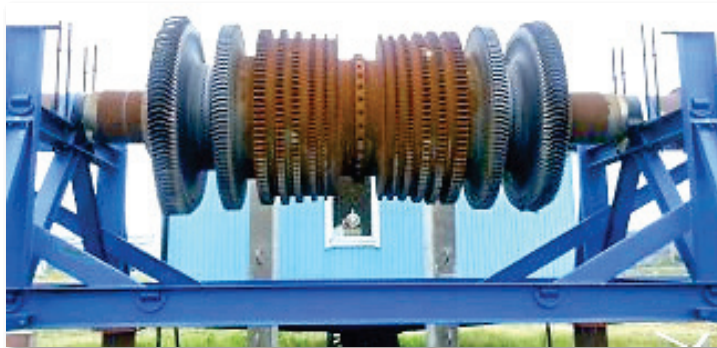
1. As per 2013, 11 out of 15 boilers had been processed.
2. The material was cleared and released under Studsvik's licence allowing both conditional and unconditional clearance.

Metals

Clearance and recycling of large metal components

For large metal components clearance and recycling of the whole component or large (<1 tonne) pieces may be a cost-effective approach compared to segmentation and melting. The clearance procedure then follows an approach similar to clearance of buildings, where the component surface is monitored in sections. This methodology has recently been used at the Ringhals NPP in Sweden where six decommissioned BWR turbine rotors (Figure 4.2) were cleared and sent for recycling. The turbine blades were removed and the rotors were decontaminated using wiping and chemical treatment followed by blasting. The blasting proved to be the most efficient step in the decontamination process.

Figure 4.2. Turbine rotor during nuclide specific measurements



Note: Measurements were done outdoors in a low-background area at the site.

Source: Anders Höglund, Vattenfall.

The rotors were measured with nuclide specific gamma spectroscopy in ten locations. To verify the decontamination results, scrape samples were taken on several locations where contamination had been identified initially.

All six rotors, 360 tonnes in total, were cleared and sent to a conventional recycler. This approach is estimated to have been three to four times less costly compared to off-site segmentation and melting. Secondary waste from the blasting generated 20 x 200-litre drums of spent shot, which will be disposed of as VLLW.

In other cases, it can be beneficial to avoid extensive on-site processing and clearance measurements. At the Berkeley NPP in the United Kingdom, 15 boilers (heat exchangers for the Magnox plants) were dismantled and transported whole to the Studsvik site in Sweden (Saul et al., 2014). At Studsvik, the boilers were segmented and steel shot blasted to achieve low enough contamination levels to meet clearance criteria. The segments were melted and clearance measurements were carried out for representative samples of the molten metal. Approximately, 95% of the incoming weight of each boiler could be cleared (as per 2013, 3 200 tonnes from 11 boilers have been cleared). The remaining 5% consisted of cutting and blasting residues, dust from ventilation systems and slag from the melting process. This waste was returned to the United Kingdom for disposal at the LLWR.

On-site melting and clearance of lead for recycling

The Belgian nuclear installation BR3 has contracted Hinneburg three times to manage contaminated lead. The first time was in 2003 in order to process the lead in the elements of the removable shielding wall in the refuelling channel. The project was carried out by on-site melting using heating blankets (Figure 4.3).

Figure 4.3. On-site melting of lead using heating blankets at the BR3 NPP



Source: SCK•CEN.

All ingots of this melting campaign (34 tonnes) (Figure 4.4) were unconditionally cleared and recycled to produce new hot cells. The following radiological characterisation was carried out to determine suitability for unconditional clearance. Before the melting, samples of the lead were taken and analysed to find out if the lead was activated above the clearance levels. After the melting, a sample was taken from each ingot. These samples (cylindrical with a diameter of 60 mm and a height of 10 mm) were analysed by alpha and gamma spectroscopy to confirm that nuclide specific mass clearance levels were not exceeded. Furthermore, the upper part of each ingot was surface measured to confirm that surface clearance levels ($\beta, \gamma < 0.4 \text{ Bq/cm}^2$ and $\alpha < 0.04 \text{ Bq/cm}^2$) were not exceeded.

Figure 4.4. Unconditionally cleared lead ingots from on-site melting at the BR3 NPP



Source: SCK•CEN.

Recycling of metals without clearance

In the second (2008) and third (2011) lead melting campaigns by SCK•CEN at the BR3 in Belgium, 46 tonnes of contaminated lead were recycled without clearance. In the second campaign, 32 tonnes of lead delivered by the Belgian commercial nuclear power plants KCD (Doel) and CNT (Tihange) was melted. The delivered lead was more contaminated than in the previous campaign, making unconditional clearance impossible. As an alternative the lead was processed into different types of shielding material, e.g. shielding containers for 400-litre drums (Figure 4.5) and aluminium profiles, which once filled with lead, can be used to build movable shielding walls (Figures 4.6 and 4.8). Another type of shielding material produced were U-shaped lead blocks, which can be used to shield piping close to the floor by placing the U *upside down* over the piping. Hence, the lead was recycled within the nuclear industry without clearance (corresponding to Tier D in the 1996 report, see Chapter 2).

Figure 4.5. Shielding containers for 400-litre drums



Source: SCK•CEN.

Figure 4.6. Lead-filled shielding blocks for constructing movable shielding walls



Source: SCK•CEN.

In the third and last campaign, on-site melting using only furnaces was applied (Figure 4.7). Most of the lead (33 tonnes) came from SCK with additional, smaller quantities (14 tonnes) from Doel. The lead from the Belgian nuclear research centre, for which the provenance was well known and which was only very slightly contaminated, was unconditionally cleared after melting.

Figure 4.7. On-site melting of lead using furnaces



Source: SCK•CEN.

The radiological characterisation measurements carried out to prove unconditional clearance were the same as during the first campaign (see above) although measurements for activation were unnecessary because it was known that activation was not applicable in this case. However, the lead from Doel was more contaminated and, as in the previous project, was melted and poured into aluminium profiles for recycling in shielding walls (Figure 4.8).

Figure 4.8. Movable shielding wall



Source: SCK•CEN.

Recycling of copper

Copper for clearance and recycling is typically found in cables. Cables can be either be cleared intact and sent for conventional recycling or the cables can be processed (to separate copper from the plastic insulation) and the material fractions can be cleared separately. Both approaches have been used at WAK, Germany, where 4.15 tonnes of copper from decommissioned cables were cleared and sent for recycling. The latter approach has the advantage that, in some cases, the copper wire can be cleared even if the other material fractions do not meet clearance levels for unconditional clearance. However, this approach requires dedicated cable granulation equipment on-site.

Recycling of aluminium

Recycling of aluminium is attractive from an environmental and economical point of view given the high energy required to produce aluminium from bauxite ore. Furthermore, as mentioned above, aluminium can be problematic in disposal facilities because of rapid hydrogen gas production during oxidation. At the Ningyo-Toge uranium enrichment plants in Japan, aluminium from gas centrifuges was cleared to meet requirements for recycling. However, due to lack of public acceptance, no conventional recycler would accept the material. As a consequence 11 tonnes of the aluminium was reused for the construction of flower beds at the uranium gallery site for visits to the Ningyo-Toge centre (Figure 4.9).

Figure 4.9. Flower beds at the Ningyo-Toge Centre constructed from cleared aluminium pipes from the gas centrifuges at the uranium enrichment pilot plant



Source: JAEA.

Concrete

Recycling of unconditionally cleared concrete

As discussed earlier concrete is typically cleared as crushed concrete material, concrete block or as entire building structures. At the R2 reactor (PWR) at the Ringhals NPP, 525 tonnes of concrete was removed when the bottom of the containment structure had to be repaired to fulfil containment integrity criteria. The concrete was removed in blocks of 1 tonne each (Figure 4.10) and each block cleared individually based on wipes, scintillator measurements and gamma-measurements. At the time of this report, 200 tonnes have been unconditionally cleared.

The concrete contains a small amount of epoxy, and even though the epoxy is hardened (hence not classified as hazardous), the presence of epoxy has made it difficult to find a recipient for the material. Instead the concrete is planned to be used on-site as backfilling material for the foundation of a new storage area on-site.

Figure 4.10. One-tonne concrete blocks for clearance



Source: Vattenfall.

The Caorso NPP in Italy has formally been in decommissioning since 2014, but with some decommissioning activities approved since 2000. When decommissioning the off-gas and hold-up facility applied a slightly different approach to management of cleared concrete compared to the example from the Ringhals NPP described above. Clearance measurements were carried out for the building structure as a whole using manual gross-gamma monitors and in situ gamma spectrometry, but to limit problems with dust, the structure was demolished by cutting the concrete into blocks. The material was subsequently crushed and partially (approximately 40% of the 7 200 tonnes) used as back-fill material on-site after additional leaching tests. The remaining material was cleared and released off-site to authorised facilities mainly for recycling.

At Eurochemic, Belgium, clearance and recycling of concrete is achieved through several routes. Concrete debris from the pipe penetrations is sieved and immediately crushed to grain size 0-5 mm. The concrete is first checked on absence of artificial contamination using several NaI scintillators that are mounted on the conveyer belt in the concrete processing facility and subsequently sampled and checked by means of gamma detectors in the laboratory.

Whole building structures are decontaminated (mainly by means of scabbling and shaving) and cleared after in situ surface contamination measurements (portable monitors: $<0.04 \text{ Bq/cm}^2$ alpha and $<0.4 \text{ Bq/cm}^2$ beta-gamma) followed by in situ sampling, based on statistical formulae. For critical areas (higher risk of contamination) additional analyses are carried out for samples of the demolished (and crushed) concrete prior to clearance.

As per 2013, a total of 25 166 tonnes (94% of the total concrete amount) has been cleared and sent to conventional recycling. Metal and concrete parts are decontaminated by means of dry abrasive blasting prior to clearance mainly based on surface activity measurements using portable monitors.

Clearance of standing building structures are typically preferred over clearance of building rubble after demolition due to the relative efficiency of radiological sentencing based on surface activity measurements compared to batch wise clearance of concrete rubble. However, when contamination penetrates into the construction material extensive material sampling and ex-situ analysis will still be required. During decommissioning of a waste storage and hot workshop building at the multipurpose research reactor (MZFR) at KTE, Germany, approximately 1 000 material samples were taken for tritium analysis in addition to surface activity measurements. 3 530 tonnes of concrete was cleared and sent for recycling.

At the Japan Research Reactor No. 3 (JRR-3) concrete rubble from earlier modification work on the reactor was cleared and recycled in 2012 (Nanri et al., 2013) after being stored as radioactive waste since 1990 (at which time there were no regulations for release from regulatory control). The material consisted of contaminated (including tritium) and possibly activated concrete.

The material was handled in pallets with 100 kg of concrete in each. For each pallet Co-60 activity measurements were made with gamma spectrometry and a 50 g representative sample was taken for nuclide specific analysis. The contents of ten pallets were packed into 1-tonne units for clearance and their respective samples were pooled for tritium analysis and measurement of gamma-emitting nuclides (Co-60, Cs-134, Cs-137 and Eu-152).

After clearance, the concrete was submitted to sieve tests, abrasion tests and foreign matter tests to meet the requirements for concrete recycling. 1 800 tonnes of concrete were used as infill and site profiling material to address subsidence on-site caused by the Great East Japan Earthquake in 2011 and as base material for new construction.

On-site reuse of crushed concrete has been applied at Sellafield UK where concrete from the Calder Hall cooling towers and the Windscale pile 2 reactor chimney has been used for on-site infrastructure works. The pile chimney concrete has also been used as bulk fill around LLW containers at the UK LLW repository in West Cumbria.

Reuse of buildings

Direct reuse of materials is typically not an attractive option in decommissioning projects where removal of materials off-site is a priority. However, reuse of cleared buildings can often be a favourable alternative to building new installations for interim storage and waste management. As an example the turbine building of the Caorso NPP, mentioned in the previous section, will be reused as buffer storage and will host facilities for super-compaction and grouting of radioactive waste.

Conditional clearance of concrete

Conditional clearance of the sorting plant at the uranium processing facility in Ranstad, Sweden has been approved by the Swedish Radiation Protection Authority (SSM, 2013). The plant has been used for crushing and sorting of uranium rich ore. Uranium contaminated waste has also been stored within the facility. Hence, uranium contamination is the only source of radioactivity.

The whole site has been in decommissioning since 2010. An application for conditional clearance for the sorting plant was made in 2012. The application included dose calculations from the recycling of building rubble for site remediation purposes. The application was revised (based on questions made by the authority) and finalised in 2013 and the application was approved later the same year.

Ranstad's application includes 9 000 tonnes of building rubble (rebar and lining removed), which will be crushed and used as backfilling material on-site. Furthermore, a concrete slab from the foundation (6 000 tonnes) will be left intact as a basis for a new building foundation.

As justification, Ranstad concluded that it would not be feasible to remove uranium contamination to meet the clearance levels for unconditional clearance. Furthermore, the uranium concentration in the building material would be similar to the naturally occurring uranium concentrations in the area.

Review of relevant statements/conclusions from the 1996 report

In the 1996 report, it was suggested that the conservative clearance levels proposed by the IAEA would prohibit recycling. In the present questionnaire results, clearance levels are ranked by four projects as the most significant regulatory requirement to meet in order to recycle and reuse materials, and by one project as the second most significant. However, unconditional clearance is indeed utilised in most decommissioning projects, and as has been pointed out in the 1996 report and elsewhere, most of the material produced during decommissioning will be clean or only slightly contaminated. For example, the decommissioning projects in Spain managed by Enresa have a recycling ration of 95% for the total amount of materials. Hence, while regulatory clearance levels may be a measurement challenge, they do not seem to prevent clearance and recycling.

The tiered system for recycling was promoted in the 1996 report. It can be concluded that even though clearance levels for unconditional clearance have been adopted by many countries, there still exist possibilities for conditional clearance and recycling within the nuclear industry.

In the 1996 report it was concluded that metals were the most important material to recycle due to its relatively high cost and due to environmental and safety aspects of producing new material from ore. The TGRRM feels that this conclusion is still valid today, and that recycling of concrete has also become increasingly important from an environmental point of view. For decommissioning projects within the nuclear industry, the focus is typically on waste minimisation and efficient removal of material from the site. Hence, metals are the most important material when decommissioning process systems, whereas concrete becomes more important when buildings are decommissioned.

Reuse of concrete as infill material appears to be a cost efficient method for recycling concrete, which eliminates the need to find a recycler willing to accept material from the nuclear industry as well as eliminating transports. However, this will typically require some harmonisation of the clearance levels for back-fill materials, and for clearance levels for the soil/land.

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Chapter 5. Health, environmental and socio-economic impacts

The 1996 report reviewed the impact of two fundamental options available for managing the disposition of radioactive scrap metal, namely disposal and replacement and recycling and reuse. The health, environmental and socio-economic impacts of disposal and recycling arrangements were evaluated against the “tiered” system of release criteria. In addition, a detailed companion document (Nieves et al., 1995) provided a comprehensive evaluation of health environmental and socio-economic impacts.

The 1996 report concluded that on balance, the recycling and reuse of radioactive scrap metal appeared to have advantages over disposal and replacement with both health risks and environmental impacts expected to be lower for recycling. For socio-economic issues the report concluded that the key concerns were likely to be with public acceptability due to a generally negative perception of the nuclear industry as a whole.

For this review the focus is more on higher level generic impacts utilising relevant national and international expectations on impacts from nuclear facilities while also addressing experiences gained since the production of the 1996 report as waste management practices and technologies have developed. This report also expands on the 1996 report and includes recycle and reuse of materials other than metals.

Health and environment

The general principles of managing radioactive waste in a safe manner are set out in the *Fundamental Safety Principles* (IAEA, 2006). Measures to prevent or restrict the generation of radioactive waste have to be put in place in the design and planning of facilities and activities that have the potential to generate radioactive waste. The reuse and recycling of wastes and materials can be undertaken as a means of reducing or minimising the volumes of waste that need to be managed or disposed.

Requirements for radiation protection, both for workers and members of the public, have to be established at a national level, with due regard in Europe to Council Directive 2013/59/EURATOM, the Basic Safety Standards (BSS) Directive (EU, 2013). This revision of the Euratom BSS consolidated five existing Euratom Directives and reflects efforts over several decades towards the international harmonisation of safety standards. The new Euratom BSS incorporates the latest recommendations from the International Commission on Radiological Protection (ICRP), published in 2007, and harmonises the EU regime with the International Basic Safety Standards. The system of protection and safety aims to assess, manage and control exposure to radiation so that radiation risks, including risks of health effects and risks to the environment, are as low as reasonably achievable. “Radiation risks” is a general term which refers to:

- detrimental health effects of radiation exposure (including the likelihood of such effects occurring);
- any other safety related risks (including those to the environment) that might arise as a direct consequence of:
 - exposure to radiation;

- the presence of radioactive material (including waste) or its release to the environment;
- a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation.

The Euratom BSS document identifies three key principles for practices involving radioactive substances:

- **Justification:** Decisions introducing a practice shall be justified in the sense that such decisions shall be taken with the intent to ensure that the individual or societal benefit resulting from the practice outweighs the health detriment that it may cause.
- **Optimisation:** Optimisation is the process whereby an operator selects the technical or management option that best meets the full range of relevant health, safety, environmental and security objectives, taking into account factors such as social and economic considerations.
- **Limitation of dose:** This provides a mechanism of dose limits which ensure that no individual shall be exposed to ionising radiation leading to an unacceptable risk under normal circumstances.

The Euratom BSS identifies dose constraints and reference levels used for optimisation of protection. This aims to ensure that all exposures are controlled to levels that are as low as reasonably achievable (ALARA), taking into account economic, societal and environmental factors. Dose constraints are applied to occupational exposure and public exposure in planned exposure situations i.e. an exposure that arises from the planned activity that results in an exposure due to a source. In this situation provision for protection and safety can be made before embarking on the activity and any associated exposures and likelihood of occurrence can be restricted or managed by good design of facilities, equipment and operating procedures and by training. Dose constraints are set separately for each source under control and serve as boundary conditions in defining the range of options for the purposes of optimisation and protection. The ICRP recommends a range of doses within which the value of a dose constraint would usually be chosen. At the lower end of this range, the dose constraint represents an increase of up to approximately 1 mSv over the dose received in a year from exposure to naturally occurring radiation sources. Typically this would be used in establishing dose constraints for public exposure in planned exposure situations. Dose constraints of 1-20 mSv would be used when establishing dose constraints for occupational exposure in planned exposure scenarios.

The occupational and public exposure dose limits are summarised below:

Exposure scenario	Dose limits
Occupational exposure (workers over 18 years of age)	<p>An effective dose of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years) and of 50 mSv in any single year.</p> <p>An equivalent dose to the lens of the eye of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years) and of 50 mSv in any single year.</p> <p>An equivalent dose to the extremities (hands and feet) or to the skin of 500 mSv in a year.</p> <p>Additional restrictions apply to occupational exposure for a female worker who has notified pregnancy or is breastfeeding and also to apprentices or students between 16 and 18 years of age.</p>
Public exposure	<p>An effective dose of 1 mSv in a year.</p> <p>In special circumstances, a higher value of effective dose in a single year could apply, provided that the average effective dose over five consecutive years does not exceed 1 mSv per year.</p> <p>An equivalent dose to the lens of the eye of 15 mSv in a year.</p> <p>An equivalent dose to the skin of 50 mSv in a year.</p>

These ICRP recommendations form the basis of international arrangements for the protection of people and environment, and are implemented through the establishment of government legislation and enforced by an appropriate regulatory body. The management of waste or materials, including disposal, clearance and recycling activities, needs to demonstrate compliance with occupational and public exposure dose limits, as well as conventional health, safety and environmental impacts.

The IAEA has also published a number of safety standards including General Safety Requirements Part 5, *Predisposal Management of Radioactive Waste* (IAEA, 2009), which applies the fundamental safety principles (IAEA, 2006) to the management of radioactive waste prior to disposal. GSR-5 defines predisposal as all of the stages in the management of radioactive waste from its generation up to disposal, including processing (pre-treatment, treatment and conditioning), storage and transport.

GSR-5 also identifies the requirements that must be satisfied in the predisposal management of radioactive waste and the objectives, criteria and requirements for the protection of human health and environment that apply to the siting, design, construction, commissioning, operation and shutdown of facilities and the requirements that must be met to ensure the safety of such facilities and activities. These include a number of aspects required to control the radiological and non-radiological hazards associated with radioactive wastes. Requirements for radiation protection and dose limits for exposure to workers and members of the public have to be established at the national level with due regard to Euratom BSS. Facilities which manage radioactive materials would typically demonstrate compliance through the implementation of an appropriate dose/environmental monitoring programmes agreed with the relevant safety and/or environmental regulator. The results of these programmes are, in some cases, collated and made publically available, e.g. the UK Radioactivity in Food and Environment reports which are published annually and summarise all of the sites monitoring programmes in the United Kingdom (CEFAS, 2014). Similar examples are available in Germany on regulatory agency websites (UM, n.d.) and Italian Environmental Data Reports which are published annually (ISPRA, 2015).

In many countries the ALARA principle is also applied to management of wastes and materials, particularly with respect to minimisation of radioactive waste arisings and disposals. There is also a long standing commitment under the OSPAR Convention (OSPAR, 1992) to apply best available techniques (BAT) at nuclear facilities to minimise and, as appropriate, eliminate any pollution caused by radioactive discharges from nuclear industries.

BAT is defined as the latest stage of development of processes, facilities or methods of operation which indicate the practical suitability of a particular measure for limiting waste arisings and disposal. In determining what constitutes BAT consideration shall be given to:

- comparable processes, facilities or methods which have been tried out successfully;
- technological advances and changes in scientific knowledge and understanding;
- the economic feasibility of such techniques;
- time limits for installation in both new and existing plants;
- the nature and volume of the disposals concerned.

The requirements to use BAT have been part of the regulatory framework for non-radioactive Pollution Prevention and Control (PPC) for many years, and there are increasing regulatory drivers to apply BAT principles to the management of radioactive wastes and materials in a proportionate manner, taking into account a balanced view of environmental, societal and economic aspects.

The use of BAT or a similar approach is widely applied in the UK and is supported by a “Nuclear Industry Code of Practice on Best Available Techniques for the Management of the Generation and Disposal of Radioactive Wastes” (SDF, 2010). The NEA Committee on Radiation Protection and Public Health (CRPPH) issued, in 2012, a report on Good Practice in Effluent Management for Nuclear Power Plant New Build, which addressed ALARA and BAT aspects of effluent management, including waste aspects (NEA, 2012).

Transport

Radioactive wastes will typically require some transport from the point of generation to treatment facilities, and worker and public exposures must be managed. The recycle and reuse of materials may result in increased transport requirements, as the treatment facilities may be located at greater distances than waste conditioning and disposal facilities from the site where the materials are generated. IAEA have produced a specific safety guide document Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (IAEA, 2014). The requirements in the Transport Regulations are formulated on the International BSS dose limits for members of the public and conservative assumptions of exposure conditions of the critical group in order to provide reasonable assurance that actual doses from transport will not exceed selected dose constraints or public dose limits.

This has resulted in three categories for monitoring and assessing radiation doses from transport. The first category establishes a dose range where little action is needed to evaluate and control dose. The upper limit for this is 1 mSv per year, which coincides to the dose limit for a member of the public. The second category has an upper limit of 6 mSv per year which is 3/10 of the limit on effective dose for workers, (averaged over five years). The third category is for any situation in which the occupational exposure is likely to exceed 6 mSv per year.

Some countries have adopted the Transport Regulations by reference while others have incorporated them into their national regulations with possibly some minor variations. As transport of materials may involve national and international shipments, it is necessary to consult the regulations for the particular mode of transport to be used for the countries where the shipment will be made, and all countries through which the material may be shipped.

Socio-economic impacts

Since the publication of the 1996 report, there has been a significant increase in general public awareness of the importance of recycling and reuse of resources, driven primarily by the application of waste hierarchy in the conventional waste management industry. In some countries, limited and expensive disposal options for decommissioning waste provides economic incentives to reduce radioactive waste generation. Feedback from the questionnaire suggests that the majority (90%), of the companies that responded have either adopted, or plan to adopt, a policy of waste minimisation by decontamination to reach conditional or unconditional clearance limits.

Questionnaire responses show that the key drivers for the development of recycling routes are cost and regulatory drivers.

Cost factors are important and can vary significantly from country to country. Where there is limited disposal capacity for LLW there tends to be increased pressure to divert materials which can readily be decontaminated and recycled to preserve capacity for wastes which can only be disposed of at a suitably engineered disposal facility.

Other factors such as stakeholder and public acceptance also need to be taken into account, and questionnaire feedback shows that there are a range of stakeholders who have an influence on the clearance, recycling and reuse of waste and materials.

Figure 5.1. Key company policy drivers

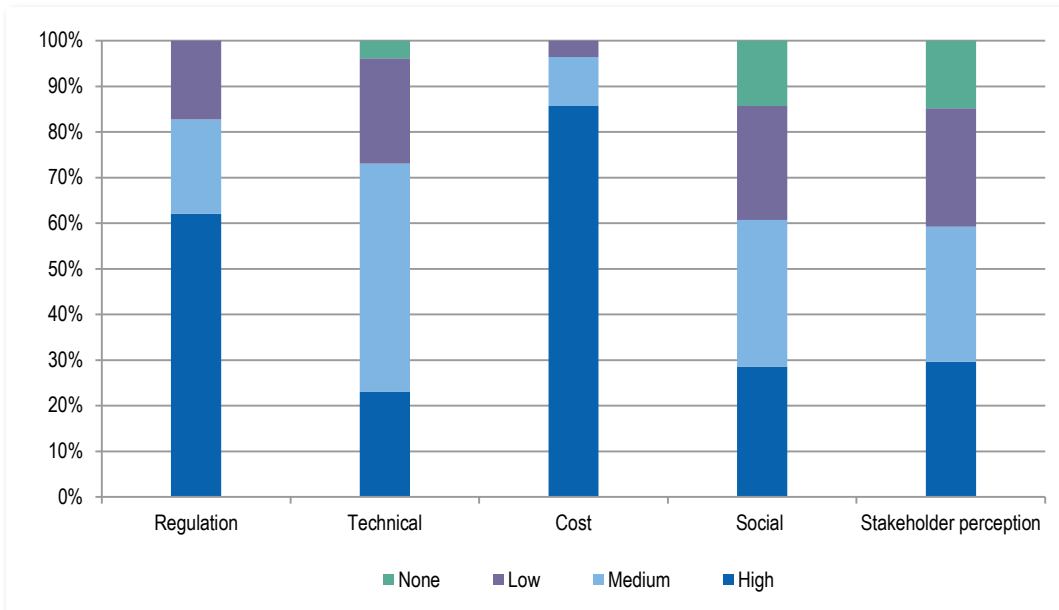
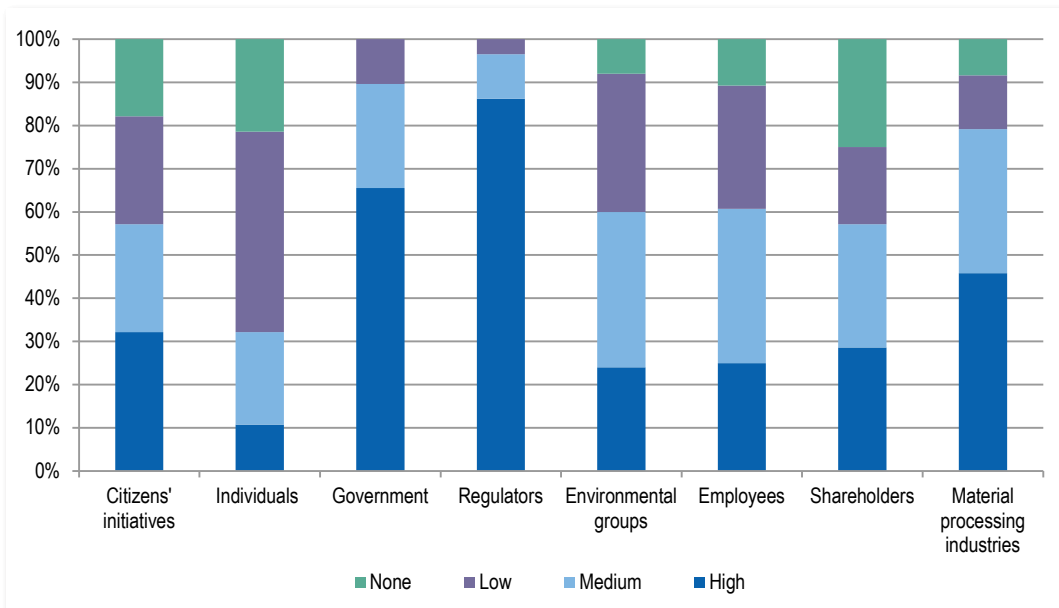


Figure 5.2. Stakeholders who influence clearance, recycling and reuse



Public acceptance of the practice of recycling/reusing materials with traces of radioactivity can sometimes be problematic because of the stigma associated with the nuclear industry in most industrialised countries. However, quantities of radioactive scrap metal have been successfully decontaminated, cleared and recycled in a number of countries.

The recycling of steel is a global market and it is possible that materials cleared in one country could feasibly end up in products used in a country which has no clearance practices. The absence of a harmonised and consistent approach to the recycling and reuse of materials cleared from a nuclear site will only continue to exacerbate this issue.

The recycling and reuse of materials may also require the development of new facilities which in turn may result in public concern due to the construction, licensing and operation of new facilities and increased transportation of radioactive materials. This may be offset to some extent by the positive economic impact that the construction and operation of new facilities may bring to areas where the new facilities are located.

Conclusions

The management of radioactive materials either by reuse, recycling or by disposal has the potential for health, environmental and socio-economic impact. Since the 1996 report, there has generally been greater consolidation and alignment of the requirements to control dose and exposure to workers, members of the public and the environment driven by international agreements and legislation. Materials and wastes which undergo unconditional clearance pose radiological impacts that meet regulatory requirements, and are managed as non-radioactive materials or waste. While recycling and reuse of materials from the nuclear industry has increased over recent years, there are still issues over public acceptability on all aspects associated with the management of materials from the nuclear industry. As more decommissioning programmes commence, the volumes of wastes generated that may be suitable for recycling and reuse will increase significantly. To facilitate the management of materials and wastes from decommissioning, stakeholder engagement will be essential. As one aspect of this, the TGRRM feels that consideration could be given to establishing a harmonised and consistent approach to the recycling and reuse of materials from nuclear sites throughout the industry.

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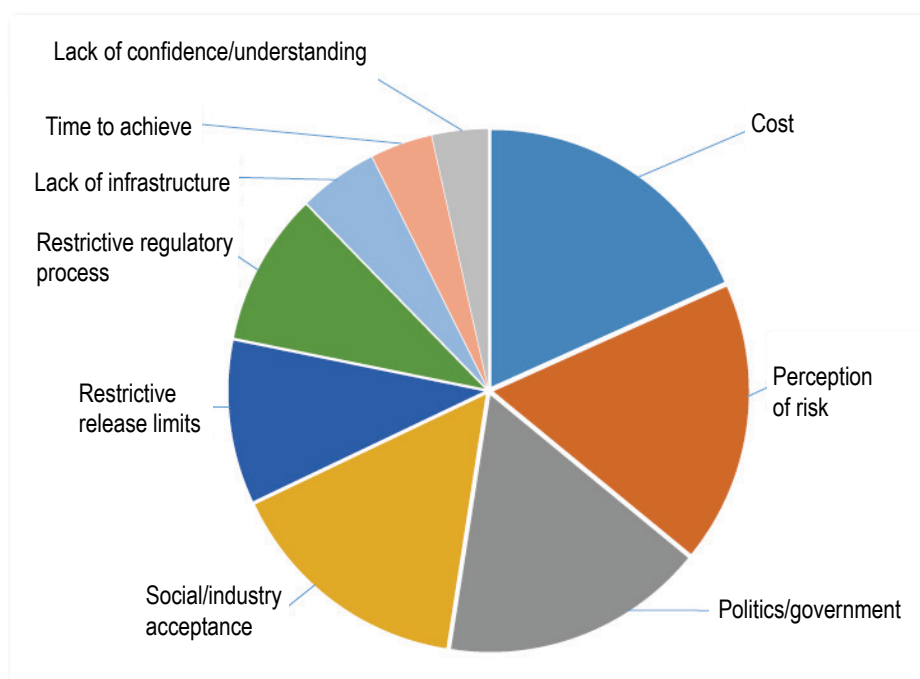
Chapter 6. Conditions to succeed

Recycling and reusing materials from nuclear facilities is a complex task. There are many regulatory and organisational factors that must work in harmony to achieve a successful programme for recycling and reuse of the many materials resulting from nuclear facility decommissioning. The need for policies and strategies that promote safe recycling and reuse of materials; the need for a net benefit, having taken all aspects of the activity into account; and the need for acceptance of conditional or unconditional release by relevant stakeholders, are just a few of the factors that must be managed. Many of these factors are common to all projects worldwide, but the magnitude of their individual importance is often most dependent on local and national considerations. To achieve success, programme co-ordinators must identify an overall strategy very early in the project and implement an optimisation process to identify management actions such that appropriate materials may be recycled and reused.

Challenges to recycling and reuse

The challenges to the recycling and reuse of materials arising from the decommissioning of nuclear facilities are similar throughout the nuclear industry worldwide. The members participating in the task group questionnaire felt that the most common challenges are those illustrated in Figure 6.1. The following section discusses the TGRRM member's views of each of these challenges.

Figure 6.1. Stakeholder-identified challenges to the recycle and reuse of materials



Cost

Cost is a question primarily for the dismantler, and generally only becomes a challenge when recycling and reuse is shown to be more expensive than the direct waste disposal option. In many cases the production costs (decontamination, conditioning and measurement over and above such activities required for waste disposal) associated with the unconditional release of materials for recycling or reuse may be viewed as an investment as these costs may be recouped in part, or total, through the recycling process. These production costs may also be a challenge if they are substantial as compared to waste management options, in particular direct disposal costs. Comparison tools for optimisation assessment (e.g. cost/benefit analysis, multi-attribute analysis.) could be used to evaluate the total costs associated with recycling, both invested and recouped, as compared to the various waste management options available to the dismantler. At the minimum, an international comparison of volumes, technologies and costs associated with recycling and reusing materials would be useful for planners.

Social/industry acceptance

As compared to conventional recycled materials, the quantity of materials to be recycled from the nuclear industry is generally low, and in many cases the recycling industry does not wish to take on the risk burden by accepting these materials when other recyclable materials are more readily available. Similarly, manufacturers and consumers may reject materials or commercial goods containing recycled materials from the nuclear industry.

Politics/government intervention

In many countries, the public views the nuclear industry with suspicion and through this influence may cause undue pressure to political and government leaders to not allow recycling and reuse of valuable materials from the nuclear industry. In some cases however, government intervention could provide a positive influence on the nuclear industry by eliminating many of the challenges discussed herein. In all cases, the level of scrutiny placed on these activities should be commensurate with the scale of risk arising from the activity.

Restrictive regulatory process and release limits

Both nationally and internationally, approaches to define the extent of regulatory systems and associated dose criteria or limits utilised within those systems have not been completely consistent and the TGRRM feels they would benefit from further international study. The ICRP suggests an individual dose criterion of 10 Sv in a year as a criterion below which material could be exempted from regulatory control (ICRP, 2007). The ICRP further recommends that the criteria for exemption should be broader when the effort to control is judged to be excessive compared to the associated risk, being situation specific and with multiple attributes that include societal factors involved in determining whether or not it is warranted to control certain exposure situations. In practice, regulators may require dose criteria more restrictive than 10 Sv in a year for unrestricted release of recyclable materials. The system of radiological protection recommended by the ICRP influences the formulation of regulations, and the system's crucial principles of justification, optimisation, and limitation provide the basis for deciding the scope of radiological protection regulations related to unrestricted release of materials.

Lack of infrastructure

The necessary infrastructure to accept materials unconditionally cleared for recycling, particularly scrap metals is extensive. However, due to a variety of reasons, many of which are discussed in this report, a substantial number of suitable facilities may be or may become closed to materials from the nuclear industry. Strategies and approaches to address these challenges warrant further study.

Time to achieve outcome

In the decommissioning of nuclear facilities, there are many contributing factors that affect the time to achieve final disposition of materials. Phased decommissioning efforts to separate materials suitable for recycling or reuse may increase the time necessary to achieve final disposition. Conventional disposal methods, with less material segregation during dismantling operations, are often quicker and easier to use, thus making the effort to recycle and reuse these materials less attractive. Additional time and resources to prepare regulatory analysis, environmental or public safety assessments, and various other administrative processes to further demonstrate that the materials can be safely reused or recycled may also contribute to this issue.

Lack of confidence/understanding

Ionising radiation has been studied very intensively for more than a century. Compared with other influences to human health, it is well understood scientifically. However, public understanding of ionising radiation is generally low and results in misinformation, lack of confidence in those that work in the industry and most importantly, fear. In fact, surveys indicate people perceive radiation risks in very different ways, nuclear power and nuclear waste as being high risk and medical or radon exposures posing much lower risk. As applied to recycle and reuse of materials from nuclear facilities, this perception gap demonstrates that acceptance of risk is conditioned by a number of factors, such as trust in the industry and evaluating radiation risk in perspective to other risks they understand and accept. Further complicating this factor is the heightened fear, anger and distrust experienced by the public following major world events. This level of fear had reduced in many countries during the first decade of the 21st century following the Chernobyl accident in 1986 but has since grown even stronger following the Fukushima Daiichi accident in 2011.

Keys to succeed

In order to successfully optimise recycling and reuse of materials, many initiatives can be implemented and should be considered in the planning phase of decommissioning projects.

Stakeholder involvement

During the 11th Congress of the International Radiation Protection Association (IRPA) in 2004, considerable discussions were held on the benefits of involving stakeholders to play an important and integral part of radiological protection activities. Subsequent workshops resulted in the development of ten guiding principles intended to aid in promoting stakeholder involvement in the process of reaching decisions pertaining to radiological protection (IRPA, 2015). Principles include:

- identifying opportunities for engagement and ensuring that the level of engagement is proportionate to the nature of the radiation protection issues and their context;
- initiating the process as early as possible, and developing a sustainable implementation plan;
- enabling an open, inclusive and transparent stakeholder engagement process;
- seeking out and involving relevant stakeholders and experts;
- ensuring that the roles and responsibilities of all participants and the rules for co-operation are clearly defined;

- collectively developing objectives for the stakeholder engagement process, based on a shared understanding of issues and boundaries;
- developing a culture which values a shared language and understanding, and favours collective learning;
- respecting and valuing the expression of different perspectives;
- ensuring a regular feedback mechanism is in place to inform and improve current and future stakeholder engagement processes;
- applying the IRPA Code of Ethics in their actions within these processes to the best of their knowledge.

Promoting these principles throughout the decommissioning process will aim to develop trust and credibility with the decision-making process in order to improve the sustainability of any final decision regarding the recycling and reuse of materials from nuclear facilities.

Incentives to promote policy for recycling and reuse

Subsidies and incentives are typically offered by many governments to promote certain actions. As discussed above, the costs associated with recycling and reusing materials from the nuclear industry can be cost prohibitive at times. Subsidies and incentives may be utilised as a policy tool at national and local levels for promoting the benefits of reutilisation of these resources in a manner that promotes occupational safety, public health and environmental protection.

Tiered release criteria

As discussed in Chapter 4, a “tiered” system provides a methodology to appropriately clear or release materials based on intended usage and residual contamination levels. This allows for a graded approach to recycling and reuse that addresses many of the challenges discussed earlier in this chapter.

- Tier A: Material that is surface contaminated or only slightly activated metal would be decontaminated as possible and unconditionally released for reuse or melting.
- Tier B: Material that is volume contaminated would be melted in a regulated environment to achieve decontamination, followed by metal recycle in commercial smelters or mills, and processing for use in consumer products (conditional clearance).
- Tier C: Material containing short half-life products would be melted and fabricated in a controlled environment, and released for a specific initial industrial use (e.g. steel bridge). Only possible for contamination or activation by radionuclides with ‘short’ half-lives (depending on the useful life of the product).
- Tier D: Material that cannot be released from regulatory control will be recycled or reused in the nuclear industry (e.g. waste containers for final storage). Tier D does not involve release from regulatory control.

Public/industry/regulator dialogue

Information sharing and addressing concerns through direct and public dialogue campaigns are commonly used throughout the nuclear industry, and may be utilised to address concerns surrounding recycling and reuse of materials. Stakeholder and public meetings provide a forum to focus on single issues and information sharing on safety measures and practical actions. More recent communications campaigns are becoming sophisticated with use of social media outlets. A well-coordinated effort to create a constructive two-way communication campaign between the industry, the regulator and

the public can help to establish confidence in the decision process. This is critical to successfully implement recycling and reuse programmes.

Reliable outlets for recyclable materials

There is a need to have reliable outlets, both nationally and internationally, for recyclable materials. Many of these materials have considerable commercial value and may relieve the economic and environmental burdens of treating it solely as waste. A well-established relationship between the nuclear industry and the recycle industry can have a considerably positive effect to help build stakeholder and public acceptance of materials.

Conclusions

Numerous challenges to recycling and reuse of materials from nuclear facilities persist at a local level throughout most member countries. The Task Group on Recycling and Reuse of Materials feels that success stories, such as those included in this report, need to be shared internationally to help build consensus for the safe recycling and reuse of these valuable materials.

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Chapter 7. Conclusions

Based on the study of the evolution of regulation and practice of recycling and reuse since the 1996 CPD report, the Task Group on Recycling and Reuse of Materials has drawn the following conclusions:

- While the transfer of waste remains prohibited between countries, substantial quantities of materials, particularly scrap metals and concrete, are routinely available to member countries for recycling or reuse as a result of the decommissioning and dismantling of nuclear facilities. Several international guidelines exist for how clearance and release of these materials should be regulated, and many countries that have developed specific criteria for recycling or reuse have achieved high levels of success. Nevertheless, harmonisation of regulations among countries has not evolved significantly in the past 20 years, which may continue to be a challenge to future recycling and reuse efforts as well as general acceptance.
- In the 1996 report, the task group analysis concluded that recycle and reuse produces lower human health risk and environmental impact than disposal and replacement. For the application of conditional clearance, international guidance continues to stress that human health and environmental impacts must be justified and protection optimised. Experience since 1996 suggests that more countries are incorporating *de minimis* clearance standards into their regulations and almost any socio-economic benefit will provide sufficient justification for clearance. Public acceptance of recycling and reuse, however, remains low.
- The IAEA and European Commission have developed high-level guidance and criteria that provide a framework for national-level policies and procedures. For unconditional clearance, most countries use the general limits introduced in these documents with minimal to no further restrictions. For conditional clearance, no international consensus guidance exists, and national legislation and site-specific regulations are routinely imposed by authorities for release of any material.
- While the process of justification from ICRP 60 apply universally, as noted in conclusion 4 of the 1996 report and discussed in Chapter 5 of this report, many countries are moving towards incorporating ICRP 103 which maintains the expectation that the planned activity is expected to do more good than harm while evolving, “from the previous process-based approach of practices and interventions to an approach based on the characteristics of radiation exposure situations.” Since 1996, the TGRRM feels that while experience of ICRP 103 implementation still considers optimisation and limitation of individual radiological risk, it has not sufficiently incorporated the broad concept of justification into protection decision processes.
- To evaluate the alternatives for radioactive scrap metal management, the previous task group proposed a “tiered” system of release criteria appropriate for a range of end uses (see Chapter 2). The concepts of a tiered system have been successfully incorporated in many countries. Although expressed specifically for metals in the previous report, the concepts can be readily expanded and provide guidance in evaluating other materials for recycle and reuse, beyond metals.
- TGRRM has presented a number of case studies illustrating examples of the release of materials for recycling and reuse. Many of the case histories illustrate that it is not

only feasible to safely release materials, but also cost beneficial. The expanded use of clearance standards has resulted in less need to specifically address the human health effects related to both unconditional and conditional clearance standards.

- Material recycling standards need to be further developed within the broad context of health risks from radioactivity in the environment. Although not specifically addressed in this report, TGRRM anticipates that the reuse of soils, and other non-traditional recyclable materials, will be more important in the future, and advocates for development of an international standard for conditional reuse or release of these materials.
- Overly conservative assumptions should be avoided in developing unconditional clearance standards to address the release of all types of materials to unknown destinations. The IAEA has proposed a single set of “unconditional” clearance levels¹ that represent a conservative, common denominator across wide ranging release situations. These proposed unconditional clearance levels may be overly conservative when exposure pathways are limited, such as, scenarios where drinking water or direct exposure conditions are not a practical concern. In these cases, conditional clearance levels that are suitably protective for public health can better optimise recycle and reuse of materials. More specific understanding of what uses are allowed for conditionally cleared materials would allow the use of less conservative criteria than for unconditional clearance, by incorporating more precise estimates of the range of parameter uncertainty, and specific conditions for how the material will be handled before considering any further margin of safety. Conditional clearance is regulated in the European Basic Safety Standards through a set of general clearance requirements, and approval is required through national competent authorities. However, by referring to RP 89 or RP 113, members could eliminate the need to perform additional assessment of radiological impact when applying for conditional clearance for the recycling of metals and concrete, respectively.
- The continued evolution of radiation detection instrumentation, with increased measurement sensitivity, provides greater certainty of achieving conditional and unconditional clearance standards. However, very conservative clearance standards may pose challenges even to state-of-the-art instrumentation. The establishment of regulatory requirements for clearance should take such practical aspects into account.
- Two key drivers for the development of recycling routes are the lack of availability of disposal facilities, and the comparison of the costs between recycling options and disposal options. In some countries, general policies exist which create pressure to ensure limited disposal capacities are preserved as rare resources while in others, policies exist to minimise the number of new disposal facilities. The implementation of best available techniques for reuse and recycle of any material can, in some cases, bring significant cost-savings compared to direct disposal alternatives.

Stakeholder acceptance of recycling and reuse of materials is a significant challenge to the successful recycle and reuse of materials from the decommissioning of nuclear facilities. As witnessed in some countries, greater involvement of regulators in communicating directly with recyclers and the public, to address stakeholder concerns and validate that regulated clearance of materials is warranted, can lead to enhanced trust and alignment of objectives. This may provide a pragmatic approach in identifying, resolving or preventing issues, and result in a more efficient working relationship among key groups in the clearance and recycling process.

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Annex A. Co-operative Programme on Decommissioning (CPD)

The International Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking of a limited number of organisations mainly from NEA member countries. The objective of the CPD programme that was launched in 1985 is the exchange and sharing of information from operational experience in decommissioning nuclear installations that is useful for current and future projects. Initially consisting of 10 decommissioning projects in eight countries, the programme has since grown to the present number of 70 projects (40 reactors and 30 fuel cycle facilities) in 14 NEA member countries, one non-member economy and the European Commission.¹

The projects in the programme have a broad range of characteristics and cover various types of reactors and fuel facilities. Also, all phases of decommissioning – from active dismantling to safe store and to completed decommissioning back to “green field conditions” – are represented.

The programme is implemented by a Management Board representing the participating organisations and a Technical Advisory Group (TAG) for the information exchange between the individual decommissioning projects. A Programme Co-ordinator provides secretariat services to the TAG and is the interface to the Management Board and the NEA Secretariat.

Decommissioning projects have benefitted from the information exchange framework provided by the CPD. This framework is valuable in ensuring that the safest, most economic and environmentally friendly options for decommissioning are employed. For some members who have less experience in this area, the benefit in not having to go through an expensive learning and development programme is invaluable.

The information exchange includes biannual meetings of the TAG during which the site of one of the participating projects is visited, and where positive and less positive examples of the decommissioning experience are openly exchanged for the benefit of all. If needed, the TAG convenes task groups to work on topics of interest, such as the Task Group on Recycling and Reuse of Material (TGRRM) which has carried out the present study and prepared this report.

Over the 30 years of experience of the Co-operative Programme on Decommissioning, and in particular through the information exchange and review within the TAG, it has become evident that:

- decommissioning can and has been done in a safe, cost-effective and environmentally friendly manner;
- the evolution of technologies have demonstrated their effectiveness in performance improvements in all aspects of conducting decommissioning projects;
- the upkeep and maintenance of design, construction and operational records can significantly enhance performance through all stages of a decommissioning project;

1. As of 31 December 2016.

- in the absence of waste disposal facilities, interim waste storage facilities with integrated waste processing facilities can effectively be used to keep all levels of waste streams moving and avoid delays to project schedules;
- clean-up of material for recycle and reuse or disposal as conventional waste is cost effective, environmentally friendly and generally receives positive public opinion;
- prompt decommissioning is increasingly becoming the strategy of choice due to advantages in overall cost and greater public acceptance.

The programme reports to the NEA Radioactive Waste Management Committee (RWMC) and has strong ties to the NEA/RWMC Working Party on Decommissioning and Dismantling (WPDD). Reports providing basic information on the participating projects, their modus operandi and summarising the experience accumulated through the project are as follows (in chronological order):

- NEA (1991), "Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects", Report from the Task Group on Decommissioning Costs.
- NEA (1996), *The NEA Co-operative Programme on Decommissioning – The First Ten Years 1985-95*, OECD, Paris.
- NEA (1996), *Recycling and Reuse of Scrap Metals – A report by a Task Group of the Co-operative Programme on Decommissioning*, OECD, Paris.
- NEA (1999), *Decontamination Techniques used in Decommissioning Activities – A report by the NEA Task Group on Decontamination of the Co-operative Programme on Decommissioning*, OECD, Paris.
- NEA (2006), *The NEA Co-operative Programme on Decommissioning – A Decade of Progress*, OECD, Paris.
- NEA (2006), *Radioactivity Measurements at Regulatory Release Levels: A Task Group Report of the Co-operative Programme on Decommissioning*, OECD, Paris.
- NEA (2006), "Comprehensive Report of the Task Group on Activity Measurements at Release Levels", NEA/RWM/CPD(2006)2.
- NEA (2011), "Twenty-five Years of Progress – The Last Five Years: 2006 through 2010", NEA/RWM/R(2011)3.
- NEA (2011), "Decontamination and Demolition of Radioactive Concrete Structures – A report of the NEA Co-operative Programme on Decommissioning (CPD)", NEA/RWM/R(2011)1.
- NEA (2011), "Remote Handling Techniques in Decommissioning – A report of the NEA Co-operative Programme on Decommissioning (CPD)", NEA/RWM/R(2011)2.
- NEA (2014), *Nuclear Site Remediation and Restoration during Decommissioning of Nuclear Installations: A report by the NEA Co-operative Programme on Decommissioning (CPD)*, OECD, Paris.

Experience has already shown that beginning the discussions on technical details between implementers at CPD before having a dialogue with regulators and policy makers may significantly change key factors towards successful, safe and efficient decommissioning of nuclear installations in the future. This also shows that the increasing importance of the exchange between key players in decommissioning is now being recognised for the future success of the nuclear industry.

The current CPD Agreement is valid from 2014 to 2018.

For more information visit: www.oecd-nea.org/jointproj/decom.html.

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Recycling and Reuse of Materials Arising from the Decommissioning of Nuclear Facilities

Large quantities of materials arising from the decommissioning of nuclear facilities are non-radioactive per se. An additional, significant share of materials is of very low-level or low-level radioactivity and can, after having undergone treatment and a clearance process, be recycled and reused in a restricted or unrestricted way. Recycle and reuse options today provide valuable solutions to minimise radioactive waste from decommissioning and at the same time maximise the recovery of valuable materials. The NEA Co-operative Programme on Decommissioning (CPD) prepared this overview on the various approaches being undertaken by international and national organisations for the management of slightly contaminated material resulting from activities in the nuclear sector. The report draws on CPD member organisations' experiences and practices related to recycling and reuse, which were gathered through an international survey. It provides information on improvements and changes in technologies, methodologies and regulations since the 1996 report on this subject, with the conclusions and recommendations taking into account 20 years of additional experience that will be useful for current and future practitioners. Case studies are provided to illustrate significant points of interest, for example in relation to scrap metals, concrete and soil.