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Release of Radioactive Materials and Buildings from Regulatory Control

A Status Report

NEA No. 6403

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 28 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, the Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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

FOREWORD

The NEA Working Party on Decommissioning and Dismantling (WPDD) brings together senior representatives of national organisations who have a broad overview of decommissioning and dismantling issues through their work as regulators, implementers, R&D experts or policy makers. The European Commission (EC) and the International Atomic Energy Agency (IAEA) take part in the work of the WPDD. This broad participation aids the co-ordination of activities in international programmes.

This status report presents the results of a questionnaire survey undertaken by the WPDD during 2006. The aim of the survey was to obtain an overview of current radiological clearance practices (i.e. release from the relevant atomic law) for materials and buildings. Information was collected from nine OECD/NEA member countries on the following topics:

- the legal context for clearance, including clearance levels;
- facility-specific assessments;
- the extent of clearance at a particular site;
- radionuclide vector/radiological fingerprints;
- averaging criteria; and
- clearance/release procedures.

This report provides up-to-date information on an array of approaches to clearance. It should be of particular help to those planning the implementation of a clearance procedure, such as that for decommissioning a nuclear facility.

Acknowledgement

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1. INTRODUCTION

While clearance or release of materials and buildings of nuclear installations from radiological control is also relevant for operating nuclear installations, it has emerged as an important option for the management of material from decommissioning of nuclear installations. Extensive experience is available from dozens of decommissioning projects worldwide.

Therefore, advice prepared by the Working Party on Decommissioning and Dismantling (WPDD) of the OECD Nuclear Energy Agency (NEA) is expected to be beneficial for those nuclear installations that are planning for the implementation of a clearance procedure, e.g. in preparation of decommissioning, by providing up-to-date information on various issues concerning clearance, reflecting the results of a questionnaire survey circulated among relevant decommissioning projects and authorities in the NEA member countries. This status report on release of materials and buildings follows the publication of a status report on the release of sites [OECD, 2006a], published in 2006.

The report is structured in the following way:

- Section 2 provides basic considerations on clearance, including the radiological concept and factors affecting the decision on clearance.
- Section 3 provides information on the derivation of clearance levels, ranging from basic considerations on clearance options from the radiological models used to calculate clearance levels from initial dose constraints (usually, a dose criterion of 10 µSv/a is used) to examples of clearance levels. This section also discusses the important question of dealing with radionuclides of natural origin, especially in building material, and its segregation from radioactivity originating from the licensed practice.
- Section 4 discusses the implementation of the clearance process, including the initial characterisation of the material, the appropriate measurement techniques, the determination of the nuclide vector, performing clearance measurements, and the final statement of compliance with clearance criteria.

- Section 5 presents alternatives to clearance, such as the near-surface disposal of very low-level radioactive waste.
- Section 6 contains the conclusions.

2. BASIS FOR CLEARANCE

2.1 The radiological concept for clearance

The concept of clearance is defined by the International Atomic Energy Agency (IAEA) as the removal of radioactive materials or radioactive objects within authorised practices from any further regulatory control applied for radiation protection purposes. Conceptually, clearance is closely linked to exemption, which means the determination by a regulatory body that a source or practice need not be subject to some or all aspects of regulatory control on the basis that the exposure (including potential exposure) due to the source or practice is too small to warrant the application of those aspects. However, clearance can be seen as the process of relinquishing regulatory control, while exemption is the process of deciding that no regulatory control is necessary from the outset.

Clearance is based on the concept of triviality of exposure, generally taken to mean:

- the radiation risks to individuals caused by the practice or source be sufficiently low as to be considered trivial;
- the collective radiological impact of the practice or source be sufficiently low as not to warrant regulatory control under the prevailing circumstances; and
- the practices and sources be inherently safe, with no appreciable likelihood of scenarios that could lead to doses above dose limit.

In quantitative terms, this is generally related to the stipulation that the effective dose expected to be incurred by any member of the public due to cleared materials is of the order of 10 μSv or less in a year.

It is implicit in the concept of clearance that materials, once cleared, are subject to no further regulatory restriction or control. Consequently, cleared waste may be treated as normal waste; and materials cleared for reuse or recycling may be sold or transferred to any other party and used for any purpose without being considered to be radioactive.

This, however, does not preclude the concept of clearance for a specific purpose, often referred to as “conditional clearance”, i.e. the case where a certain condition has to be fulfilled before the act of clearance has been completed. Examples for "conditional clearance" are clearance of metal scrap for melting only (i.e. not for direct reuse), clearance of buildings for demolition only (i.e. not for reuse), or clearance of material for disposal on (conventional) landfill sites. After this condition has been fulfilled, the material is also subject to no further regulatory restriction or control.

Because of the fact that exemption and clearance are closely related, there have been some discussions as to whether one set of radionuclide-specific values should be used to allow both:

- exemption of materials to be regulated;
- clearance of materials already regulated.

In this respect, the International Commission on Radiological Protection has made the following statements in its draft recommendation [ICRP, 2006]:

> "While the activity levels applied to the application of regulatory requirements (exemption) might be different from those applied the release from regulatory requirements (clearance), because, for instance, the imposition of regulatory requirements on materials may require more regulatory resources than are freed by releasing materials from those requirements (clearance), such an approach has the advantage of simplicity; one set of values would be easy to apply and could be interpreted as a definition of a radioactive material, including radioactive waste, for regulatory purposes. There are, however, counter arguments. The values for clearance are being derived on the basis of different assumptions and sometimes for a different purpose than those derived for exemption. A consequence of choosing one set of values is likely to be selection of the lowest of those available. Nevertheless, there may be a case for choosing one set of values for clearance levels: a plethora of levels, each specific to a material or industry, will lead to confusion. Another tempting possibility was to use a specified fraction of the established exemption levels as a generic clearance level."

The ICRP considers having just one set of values for both clearance and exemption has the advantage of simplicity but bears the danger of simply choosing the lowest available value from the various sets of clearance and exemption levels for each nuclide. The alternative of using different sets of clearance levels for clearly defined clearance options (see Section 3.1) – which are differentiated from exemption values – has been implemented in nearly all countries where clearance is an established practice. Experience from NEA member countries shows that, in general, different sets of values are used for exemption and for clearance.

2.2 Differences between clearance of materials and clearance of buildings

While the basic concepts are the same for clearance of materials and clearance of buildings, there are important differences in the implementation of clearance of materials and clearance of buildings.

- Unconditional clearance of materials requires mass specific clearance levels and for those materials with a measurable surface also surface specific clearance levels in order to limit the surface activity (release of dust etc.). In addition, clearance levels for material have to take account of all possible exposure pathways and radiological scenarios for reuse and for recycling.
- Clearance of buildings, on the other hand, needs to take account of a much more limited set of exposure scenarios. Clearance levels for buildings are usually expressed as surface specific activity levels (relating to the activity on and beneath the surface). Radiological scenarios must distinguish between reuse of the buildings and demolition without reuse.

This implies that in some circumstances scenarios and radiological models for the clearance of buildings might be considerably more realistic, i.e. refer to an actual situation that can be envisaged for the use of the building after clearance. It may even be worthwhile to consider case-by-case approaches for clearance of buildings, particularly in those circumstances where a building shall be reused for a specific purpose. This generally will allow using less restrictive requirements than those resulting from purely generic approaches. The reason is that the radiological evaluation of a specific situation (the scenarios and exposure pathways) can be tailored to the actual conditions, while generic assessments need to take into account a large variety of conceivable situations.

2.3 Factors affecting the decision for clearance (technical, economic, regulatory, social)

Clearance of materials is a decision normally taken for logistic and/or economic considerations.

- Logistic reasons: In cases where no repository is available, the decommissioning material requiring treatment as radioactive waste needs to be segregated from the large quantities of material that may be reintroduced into the normal material cycle. Otherwise, uneconomically large interim storage capacities would need to be built to accommodate large material quantities, rendering a safe enclosure of the nuclear facility – instead of its dismantling – less expensive.

- Economic considerations: In cases where a repository is available or where a repository is planned and (preliminary or final) repository acceptance criteria exist, clearance is often the less expensive option. The costs for conditioning and packaging into waste containers suitable for the repository and the repository fees usually exceed the costs for segmenting, decontamination and clearance by far.

The technical means for clearance measurements are commonly available and have proven to be effective. Today, factors influencing clearance are mainly:

- the provisions within the regulatory framework of a particular country concerning clearance (clearance options, clearance levels, restrictions to certain materials or certain pathways etc.);
- the availability and cost of final disposal sites for VLLW;
- public opinion on clearance and the attitude of the general public and of certain industrial sectors (like the metal working industry) towards the origin of such material;
- the total amount of material which arises (currently and in the near future) from the nuclear sector, in particular the existence of large decommissioning projects with a high material volume requiring clearance;
- other, mainly country-specific factors.

Such factors are further discussed in the Appendix to this report.

3. DERIVATION OF CLEARANCE LEVELS

3.1 Clearance options

3.1.1 Overview

Clearance/release of metals, other materials and buildings are governed by the same fundamental principles, though applying different approaches and detailed provisions for application in practice. This becomes obvious already from the nature of the clearance levels: surface contaminated metals require surface specific and mass specific clearance levels, bulk materials such as building rubble requires mass specific clearance levels only, and building surfaces (floors, walls, ceilings) require surface specific clearance levels or mass specific clearance levels in combination with the definition of penetration depth. In addition, other details will be different, like the averaging criteria (for small metal objects, large building surfaces, large quantities of rubble), specifications for the measurement methods (such as contamination monitors, in situ gamma spectrometers, sampling with laboratory measurements) and use of statistical measurements. Furthermore, different approaches may be allowed depending on the destination of a specific type of material, i.e. clearance of metals for any use, for melting only, or for disposal.

A set of clearance procedures together with suitable clearance levels pertaining to a specific type of material and a specific destination is often referred to as “clearance option”. The following list of clearance options takes into account practical experience from various NEA member countries. The first part of this list includes options for unconditional clearance, while the second part lists options for clearance for a specific purpose. In this latter case, the number of possible radiological scenarios (see Section 3.2) is generally more limited than for unconditional clearance, leading to higher clearance levels for the specific purpose. It should be noted that not all clearance options have been implemented in each country.

1. Unconditional clearance[1] of:
    a) solid materials and of liquids[2] for reuse, recycling or disposal (the most general clearance option);
    b) large quantities of building rubble and soil (an option that should be treated separately from Option 1(a), as clearance of several 10 000 Mg of building material involve radiological scenarios not relevant to small quantities);
    c) buildings for reuse or demolition (i.e. with no restriction on the future fate of the building).

2. Clearance of:
    a) solid materials for disposal on landfills or by incineration as well as of liquids for disposal by incineration;
    b) buildings for demolition (i.e. with the restriction that the building needs to be demolished and may not be reused as a workplace occupied by other than radiation workers);
    c) metal scrap for melting (i.e. melting in any conventional foundry that does not need to possess a nuclear license).

The extent to which all or some of these clearance options are implemented in a particular country varies according to various circumstances, such as the overall amount of material eligible for clearance, the conventional waste regulations, political decisions. The actual implementation may take place on the basis of country-specific evaluations or on the basis of international recommendations. Important recommendations of international bodies in this context are the following:

- European Commission:
    - Recommendations on clearance of metals – Radiation Protection No. 89 [European Commission, 1998].
    - Recommendations on clearance of buildings and building rubble – Radiation Protection No. 113 [European Commission, 2000a].
    - Recommendations on unconditional clearance – Radiation Protection No. 122 part I [European Commission, 2000b].

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[1] In addition, release/clearance of sites of nuclear installations would also constitute a clearance option in this respect. This is, however, dealt within a separate status report [OECD, 2006].

[2] This only refers to clearance of liquids e.g. turbine oil for reuse, not to authorised discharges of waste water.

- International Atomic Energy Agency:
  - Application of the concepts of exclusion, exemption and clearance – Safety Guide RS-G-1.7 [IAEA, 2004].
  - Related documents describing the derivation of clearance levels [IAEA, 2005].

Many countries have based at least part of their clearance regulations on these documents, which are therefore taken as reference for the following discussions.

3.1.2 Clearance options for metals and other materials

The following clearance options for metals and other solid materials can be distinguished:

- unconditional clearance of metals for direct reuse, recycling or eventually disposal;
- clearance of metals for melting in a conventional foundry (i.e. not for direct reuse);
- unconditional clearance of other materials (e.g. building rubble) for direct reuse, recycling or disposal;
- clearance of other materials for disposal only (i.e. not for recycling or reuse).

The unconditional clearance options are dealt with in the European Commission (EC) Recommendation RP 122 part I and in the IAEA RS-G-1.7. The various options for metal recycling are covered by EC Recommendation RP 89. Recycling or disposal of building rubble is treated in EC Recommendation RP 113.

3.1.3 Clearance options for buildings

The following clearance options for buildings can be distinguished:

- clearance of buildings for reuse (or demolition);
- clearance of buildings for demolition only.

These two clearance options are dealt with in EC Recommendation RP 113.

3.2 Radiological modelling

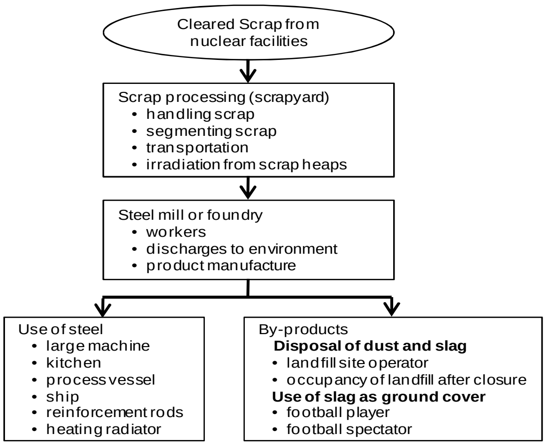
The basis for the derivation of clearance levels are radiological models, as a direct measurement of the resulting individual doses (in the order of 10 μSv/a) is impossible. Therefore, a number of models have been developed and applied over the last decades in a number of countries and by international organisations like the IAEA, the EC and the NEA. These models link the residual mass specific, surface specific or total activity on or in various kinds of materials or on building surfaces to the resulting dose for relevant groups of exposed people (workers and general public).

This section gives a small overview of the types of models that are currently in use or have been used for the derivation of existing clearance levels. It is obvious that this overview cannot present radiological models for all countries included in the Appendix. However, the models used in the EC Recommendations RP 89, 113 and 122 Part I are outlined in the following subsections.

3.2.1 Radiological model for clearance of metals

Figure 3.1 provides a schematic representation of the pathways and scenarios included in the radiological model for clearance of metals, as used in the EC Recommendation RP 89 [European Commission, 1998]. This model covers all steps from processing the released scrap by melting to the use of the steel and the use or disposal of by-products.

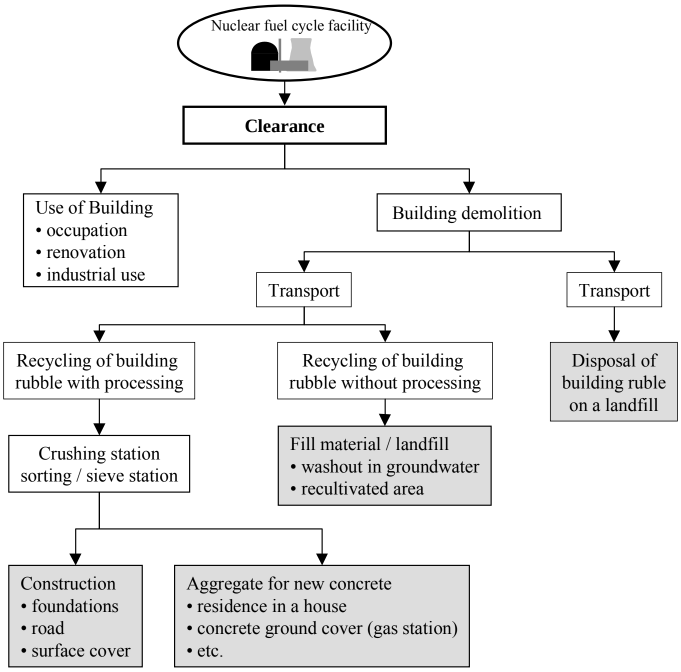
Figure 3.1 **The radiological model for clearance of metals according to EC Recommendation RP 89** [European Commission, 1998]



3.2.2 Radiological model for clearance of buildings and building rubble

Figure 3.2 provides a schematic representation of the pathways and scenarios in the radiological model for clearance of buildings and of building rubble, as used in EC Recommendation RP 113 [European Commission, 2000]. This model covers all steps from building demolition to recycling with or without processing or disposal of the building rubble, covering also the transport in between, as well as the reuse of the building for industrial purposes, and covering also the necessary renovation work.

Figure 3.2 **The radiological model for clearance of buildings and building rubble according to the EC recommendation RP 113** [European Commission, 2000]



Radiological model for unconditional clearance

Figure 3.3 provides a schematic representation of the pathways and scenarios in the radiological model for unconditional clearance, as used in the EC Recommendation RP 122 Part I [European Commission, 2000b]. These scenarios correspond to generic, enveloping situations covering all relevant exposure pathways rather than actual working conditions or actual exposure situations for members of the public. “Enveloping” means that the parameter values in the various scenarios have been chosen in such a way as not to underestimate doses at typical workplaces where workers could come into close contact with the cleared materials or for situations where members of the public could handle such material or remain in its vicinity for a prolonged time. For reasons of conservatism, and to take account of the results of the recommendations RP 89 and RP 113, the clearance levels of RP 122 Part I have not only been based on the generic scenarios shown in Figure 3.3, but values from RP 89 or RP 113 have been taken over in those cases where that value was smaller (i.e. more restrictive) than the value calculated from the RP 122 Part I scenarios. This ensures that the values of RP 122 Part I can indeed be used for any type of unconditional clearance, including, for example, large quantities of building materials or of metal scrap.

Figure 3.3 **The scenarios for unconditional clearance according to the EC Recommendation RP 122 part I** [European Commission, 2000b]

Scenarios for inhalation. • Worker. • Member of the public.	Scenarios for external irradiation. • Worker on landfill. • Transport. • Member of the public in house built with recycled building rubble.
Scenarios for ingestion. • Direct ingestion, worker. • Direct ingestion, child.	Scenario for skin contamination. • Worker in dusty environment.

International harmonisation

Clearance is an act carried out by the authorities in specific countries, but it also has international implications, in particular due to possible transboundary movement of materials and international trade. This means that the question on international harmonisation of clearance levels, in particular those for unconditional clearance, has to be raised. In recent years, the issue of international harmonisation has been discussed e.g. at larger conferences, such as the NEA Workshop in Rome in September 2004 [OECD, 2004].

Numerous national and international working groups have undertaken comparisons of sets of clearance levels, e.g. the German Strahlenschutzkommission (Commission on Radiological Protection), which published its results in 2005 [Strahlenschutzkommission, 2005]. The conclusion of this and other publications is that some convergence of the models and values over the past 5 to 10 years can be observed, and that it is not essential for clearance levels to be exactly equal among various countries. The numerical values of clearance levels may differ as long as the differences are not significant. A criterion for this may be that the clearance levels for key radionuclides such as ^{50}Co, ^{137}Cs, ^{90}Sr, ^{241}Am are of the same order of magnitude. This is the case, for example, for German levels for unconditional clearance and those of the EU recommendation RP 122 Part I [European Commission, 2000b] and the IAEA Recommendation RS-G-1.7 [IAEA, 2004]. Reasons for differences in sets of clearance level values are often different assumptions in the models caused by national or regional circumstances, including specificities of the material cycle, transport distances and industrial safety requirements. These factors influence the choice of scenarios and scenario parameters in the radiological scenarios and therefore the calculated clearance levels. From the answers provided by NEA member countries in response to the questionnaire, no significant differences in the choice of the dose criterion (10 µSv/a individual dose) that forms the basis for the calculations could be observed.

3.3 Clearance levels

Clearance levels that have been calculated with the radiological models presented in Section 3.2 are summarised in Table 3.1 for a set of radionuclides. These radionuclides are relevant in reactor and fuel cycle facilities and represent various groups of nuclides, such as weak beta emitters (^{3}H, ^{14}C, ^{63}Ni, strong beta/gamma emitters as activation and fission products (^{60}Co, ^{137}Cs), strong beta emitters (^{90}Sr), and alpha emitters of different origins (^{235}U, ^{241}Am, ^{239}Pu).

The first two rows of Table 3.1 relate to unconditional clearance from the two recommendations RP 122 part I of the European Commission [European Commission, 2000b] and RS-G-1.7 of the IAEA [IAEA, 2004]. Both documents contain a set of rounded clearance levels that are based on different scenarios and assumptions, but resulting in quite similar values. RS-G-1.7 has a slightly more conservative tendency, as these values are not merely meant as unconditional clearance levels, as is pointed out in the following:

> "The Safety Guide includes specific values of activity concentration for both radionuclides of natural origin and those of artificial origin that may be used for bulk amounts of material for the purpose of applying exclusion or exemption. It also elaborates on the possible application of these values to clearance."

The third row of Table 3.1 provides the clearance levels from RP 89 [European Commission, 1998] for metal scrap for melting. In comparison with the values from RP 122/I, they are generally the same or larger, indicating that a smaller and therefore less restrictive set of scenarios has been used. Similar observations apply to clearance levels for building rubble, shown in the fourth row of Table 3.1. These values are closer to those of unconditional clearance, as they also apply to large quantities and therefore need to be more conservative in nature.

The last two rows of Table 3.1 provide clearance levels for buildings from RP 113 [European Commission, 2000]. As they are expressed in Bq/cm², no direct comparison with the other sets of values is possible or meaningful. It can, however, be observed that the values for clearance of buildings for demolition only (i.e. where any reuse would not be permitted) are generally higher or equal to those for clearance without restrictions, i.e. for reuse or demolition.

Table 3.1 **Overview of clearance levels calculated with the radiological models presented in section 3.2 for selected radionuclides**

Purpose	^{3}H	^{14}C	^{63}Ni	^{60}Co	^{137}Cs	^{90}Sr	^{235}U	^{241}Am	^{239}Pu	Unit
Unconditional clearance, RP 122/I	100	10	100	0.1	1	1	1	0.1	0.1	Bq/g
Unconditional clearance, RS-G-1.7	100	1	100	0.1	0.1	1	-	0.1	0.1	Bq/g
Metal scrap for recycling or reuse, RP 89	1,000	100	10,000	1	1	10	1	1	1	Bq/g
Building rubble, RP 113	100	10	1,000	0.1	1	1	1	0.1	0.1	Bq/g
Buildings for reuse, RP 113	10,000	1,000	10,000	1	1	100	1	1	0.1	Bq/cm²
Buildings for demolition only, RP 113	10,000	10,000	100,000	1	10	100	10	1	1	Bq/cm²

3.4 The case of natural radionuclides for buildings and building rubble

As clearance refers only to the activity originating from licensed practices, radionuclides of natural origin in building materials, such as those from the U and Th decay chains and ^{40}K, need not be taken into account when performing clearance measurements. This matter is of particular relevance in cases where the licensed practice included radionuclides that are also present in building materials, e.g. in U conversion or enrichment plants or in fuel fabrication facilities. Clearance levels are intended to be applied only to the radionuclides from the practice. This means that applying them to the sum of the fraction originating from the practice plus the fraction present in building material would constitute a severe conservatism, making clearance measurements inapplicable in most cases. This is a quite similar issue to clearance/release of sites where, for example, ^{137}Cs can be present from the licensed practice on this site as well as from Chernobyl fallout.

However, it is often difficult in practice to distinguish between the origins of such nuclides. As clearance regulations are related only to the radioactivity originating from the licensed practice, either natural radioactivity has to be screened out using the results of spectrometric measurements, or the count rate of contamination monitors or bulk monitors has to be appropriately reduced.

Experience has shown that the actual contents of natural radionuclides may vary considerably even within one batch of concrete, i.e. within a quantity of material where a more or less homogeneous distribution might have been expected. This makes it difficult to determine an appropriate background count rate to be deducted when performing measurements with contamination monitors on building surfaces, or with bulk monitors for building rubble. For this reason the numerical value for such a count rate for natural background subtraction will usually have to be set cautiously to a comparatively low value for measurements with handheld contamination monitors, in order not to underestimate the remaining part of the artificial contamination, which has to be accounted for in the clearance procedure. Obviously, this approach may introduce a substantial amount of conservatism into the clearance procedure.

This drawback can be avoided by a strategy relying on measurements on building surfaces with (collimated) *in situ* gamma spectrometry. In this case, the subtraction of natural background can be performed directly in the gamma spectrum. This method can also be used for building rubble in suitable containers, e.g. waste drums or boxes that are rotated during the measurements.

A further complication arises when naturally occurring radionuclides and radionuclides used in the licensed practice are the same, as e.g. in fuel production plants. In such cases it may be necessary to investigate the composition of the concrete and bricks of which the building was constructed, including samples from the quarries where the concrete constituents had been extracted. In the case of a nuclear installation where the contamination consists almost entirely of uranium and/or thorium, the clearance procedure has to rely on sampling and laboratory analysis rather than on surface contamination measurements, as the contribution of the “artificial” contamination, i.e. that originating from the practice, compared to the “natural” activity already present in the building material is so small that it usually cannot be distinguished by direct measurement.

3.5 Interdependence between the clearance levels and the quantity of material to be cleared

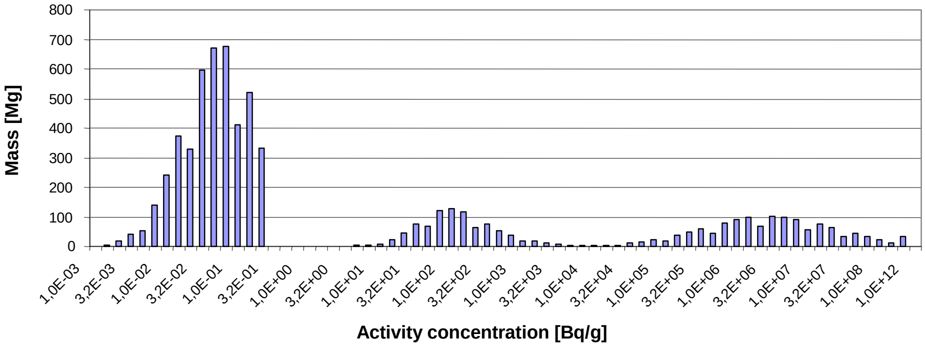
A country introducing new clearance levels or revising existing levels may take sets of clearance levels as recommended by international bodies, as introduced in Sections 3.2 and 3.3, or may develop its own sets of clearance levels. In any case, an issue will arise of the degree of conservatism that is put into the models and of the material quantities that will be eligible for clearance. The choice of clearance levels may have very large effects on the cost of material management, which in turn is one of the highest cost items in any decommissioning project.

In this context, it is a trivial observation that the quantity of material that can be cleared will increase when the clearance levels are raised. However, there is no linear dependence for metals, building rubble or buildings, for the following reasons:

- The starting point in these considerations is the overall distribution of activity on the material or in the building prior to any decontamination. This distribution can usually be approximated by one log-normal distribution or a superposition of two or three log-normal distributions. The lower values usually originate from airborne ("background") contamination that is present nearly everywhere in the controlled area of a facility, the higher values can be attributed to media contamination, e.g. spills, leakages, sprays and, in the case of metallic material from reactors, activation. An example is shown in Figure 3.4.
- Because of the form of log-normal distributions, it is clear that there is a range of values of the specific activity where changes in clearance levels will affect large amounts of material (around the maximum of the distribution), while in the tail range of the distribution only small material quantities will be affected. This means that raising clearance levels for key nuclides from 0.5 Bq/g to 1 Bq/g has a much higher effect than raising them from (an already high value of) 5 Bq/g to 10 Bq/g.
- The number of decontamination steps to reach clearance levels is also a relevant parameter. Usually it will not be possible to decontaminate (metallic) material from any initial contamination level down to free release or clearance levels in a single step. It is usually more appropriate to use at least two steps, one for the highly contaminated fraction, bringing the material down to intermediate or low values, and the second one for decontamination to clearance levels. It is, however, very significant in the overall economic considerations if a third decontamination step becomes necessary (if the clearance levels are lowered) or if the last decontamination step has to run longer to comply with lower clearance levels.
- Similar considerations apply to measurement methods, which require increasingly greater effort when the clearance levels are lowered below a certain range.
- Cost considerations regarding clearance have always to be viewed in the context of the costs for final disposal in a repository. Lowering clearance levels below a certain range and thus increasing the effort required to reach these values and to demonstrate compliance with them would eventually result in rendering clearance more expensive than disposal.

- Raising clearance levels above a certain range would have little or no effect on the overall costs for material management, as there is an activity range where the amount of material falling into this range is comparatively small and would require some treatment in any case, e.g. because of very inhomogeneous contamination or even the presence of hot spots.

Figure 3.4 **Theoretical distribution of the quantities of metallic materials from a large NPP during decommissioning as a function of the activity ranges – superposition of three log-normal distributions, prior to decontamination** [Nüsser *et al.*, 2001]



It is evident that the current unconditional clearance level values for the most relevant radionuclides (^{60}Co, ^{137}Cs) are in the same range (0.1 … 1 Bq/g) also in which the activities of large quantities of metallic (and other) materials prior to decontamination are also located. This means that it is worthwhile from an economic point of view to define further clearance options for specific purposes (e.g. clearance of metals for melting, clearance of any type of material for disposal or incineration – see Section 3.1) allowing the use of dedicated and therefore higher clearance levels, thus significantly reducing the effort in preparing this material for clearance.

4. IMPLEMENTATION OF THE CLEARANCE PROCESS

4.1 Initial characterisation

The initial characterisation of a facility for the purpose of clearance is of high importance for a smooth and efficient clearance process afterwards. Depending on the type of facility, different characterisation strategies are pursued and different measurement methods are applied. The initial characterisation is also the basis for planning the extent of decontamination, the strategies for clearance measurements and other important aspects of the overall clearance process.

The initial characterisation usually pursues the following aims:

- identifying areas where protective measures are necessary, i.e. respiratory protection because of the presence of radionuclides with high inhalation dose coefficients, shielding because of high dose rates;
- gaining an overview of the spatial distribution and degree of the contamination; and
- identifying which nuclides are present in the contamination and with which percentages.

The measurement methods to be applied for these analyses are usually the following:

- Dose rate meter

  The dose rate distribution is usually determined first in order to gain the necessary information for health physics considerations. Dose rate measurements can also be used to identify “hot spots” (areas of elevated contamination).

- Material samples with laboratory analysis

  Material samples that are subsequently evaluated by laboratory gamma spectrometry or – if necessary – that are analysed for hard-to-measure nuclides after radiochemical separation provide the most accurate information, but this information is limited to a small area. Analysis of material samples is, however, necessary for developing nuclide vectors (Section 4.2).

- Surface contamination monitors

  Surface contamination monitors allow the determination of pure surface activity with a sufficiently high beta emission. Such instruments allow quick scanning of areas for screening purposes, but do not provide any information on the nuclide composition of the activity.

- *In situ* gamma spectrometry

  A method that is rapidly gaining importance both in measurements during the initial characterisation and in clearance measurements is the *in situ* gamma spectrometry. This method allows a gamma spectrum from an entire room (if applied without collimation), or from a limited area on a building surface or a component (if applied with collimator), to be obtained in a short to medium measurement time.

- Wipe tests

  As wipe tests can only detect the removable fraction of the contamination and as they can be applied only on a limited range of surfaces (e.g. not on building surfaces without decontamination coating), the use of wipe tests is usually limited to health physics measurements, where they may serve as a sensible method to detect the presence of, for example, alpha emitting nuclides. They can provide information on the nuclide distribution but need to be complemented by sampling for the determination of correlation factors (see below) or nuclide vectors (Section 4.2), as the transfer factor varies for different chemical elements.

Using the results of these measurements and sampling methods, an important aspect of the characterisation phase is to establish correlation factors between easy-to-measure (gamma emitting) nuclides and hard-to-measure nuclides like alpha or weak beta emitters from full analysis of samples using radiochemical methods. In facilities where hard-to-measure nuclides of radiological significance are present, but only to a limited extent, e.g. nuclear power plants with alpha contamination from fuel failures during the operational period, it is important to derive their abundance rapidly from measurements of key nuclides like ^{60}Co and ^{137}Cs. Correlation factors are therefore derived from statistical evaluations of a medium to large number of samples that have been analysed for the relevant hard-to-measure nuclides.

A further aspect that has to be addressed during the characterisation phase is the determination of the penetration depth on building surfaces: The initial characterisation of buildings requires the determination of the penetration depth of contamination into the building surfaces. Deeper penetration is usually analysed by taking drilling cores that are segmented into slices of appropriate thicknesses for analysis by gamma spectrometry and/or for other nuclides after radiochemical separation. A more shallow penetration can be determined more easily by taking material samples through chiselling and collecting the dust of one layer in a suitable container, e.g. a bag. Skilled personnel can remove layers of a predefined surface in thicknesses of about 1 mm. This procedure can be repeated a number of times to get a depth profile over the first few millimetres of a concrete surface.

When combining the methods described above into a strategy for the initial characterisation and when determining how many samples and measurements should be made, one has to take into account the following aspects:

- Expected contamination situation

  The contamination situation that has to be expected depends on the type of the facility and its operation history. Leading nuclides present in contamination in light-water reactor facilities are usually ^{60}Co and ^{137}Cs with minor amounts of fission products like ^{90}Sr and eventually alpha emitting nuclides from fuel defects. Nuclide compositions in reprocessing plants may vary extensively, with ^{137}Cs and ^{241}Am being among the most important nuclides. Fuel element production facilities show basically the same nuclide composition as the fuel, with a number of trace elements present if U from reprocessing or MOX has been produced.

- Economic considerations

  The effort spent in carrying out a good and comprehensive initial characterisation has to be balanced against the savings for a smooth clearance procedure afterwards. Experience shows of the benefit of having as much information as possible about the radiological situation within a facility. A firm and comprehensive database will greatly facilitate the strategy selection for clearance measurements and other decisions to be taken during the clearance procedure.

- Safety considerations

  The possibility of the presence of alpha emitters in the contamination especially in reactor facilities is often greatly underestimated during planning for decommissioning and during the early stages of the radiological characterisation. As the price for a full analysis of material samples for alpha emitting nuclides is significantly higher than for gamma measurements, it is tempting to deduce the absence of alpha emitting nuclides simply from the absence of ^{241}Am peaks in the gamma spectrum. However, a meaningful analysis is only possible by measurements after radiochemical separation. Such measurements are inevitable from a health physics perspective.

Examples for a thorough initial characterisation process are available from many nuclear installations undergoing decommissioning. Among the answers provided to the questionnaire, an illustrative example has been provided *inter alia* for the Eurochemic reprocessing plant in Belgium, in which the implementation of a pilot project for testing the assumptions relevant for clearance is described. During this pilot phase, two small storage buildings for end products from reprocessing were dismantled to verify the assumptions made in a previous paper study on decommissioning, to demonstrate and develop dismantling techniques and to train personnel. Both buildings were emptied and decontaminated to background levels. They were demolished and the remaining concrete debris was disposed of as industrial waste and green field conditions restored. The main conclusions of this pilot decommissioning project suggested that, in future, emphasis should be put on the automation of concrete decontamination, and the decontamination of metal components. Other nuclear installations have made use of – in some cases extensive – characterisation schemes to establish the amount of activity from hard-to-measure nuclides, realistic correlation factors with key nuclides and realistic estimates of the penetration depth in building surfaces.

The use of measurement techniques addressed above is also described in more detail in Section 4.7 of the Appendix.

4.2 Determination of nuclide vectors

A nuclide vector (often referred to as "radiological fingerprint") is represented by the list of radionuclides that are present in the contamination together with the activity percentages. An example for a typical nuclide vector in the contamination on metallic items in nuclear power plant with light-water reactors with slight alpha contamination could be the following:

$$({}^{60}\mathrm{Co}, {}^{137}\mathrm{Cs}, {}^{90}\mathrm{Sr}, {}^{241}\mathrm{Am}, \alpha_{\mathrm{rest}}) = (52\%, 39\%, 5\%, 1\%, 3\%)$$

Usually, those nuclides present in the contamination that have a negligible radiological significance are not included in the nuclide vector. In the example above, ^{63}Ni or ^{55}Fe, although well correlated to the activity of ^{60}Co, would usually be left off the list as they have a negligible radiological importance, i.e. very high clearance levels (Section 3.3) in relation to the leading nuclides ^{60}Co or ^{137}Cs.

A nuclide vector implicitly contains the concept of correlation factors. In the example above, the typical correlation factor between the hard-to-measure nuclide ^{90}Sr and ^{137}Cs would be 0.13 as the ratio of 5% and 39%.

A prerequisite for establishing nuclide vectors is that a sufficiently large set of samples has been analysed for relevant radionuclides, i.e. for all those that can be measured by gamma spectrometry, plus those for which a radiochemical separation is necessary. Experience shows that a data set for calculating a nuclide vector should comprise at least 10 samples and, if possible, 20 or more. There are various methods to calculate the percentages for the radionuclides in the nuclide vector:

- The activity percentages for the nuclides to be included in the nuclide vector are calculated from the averages of the percentages of the samples.
- The activity percentages for the nuclides to be included in the nuclide vector are calculated from a procedure that takes account of the radiological relevance of the radionuclides in question, assigning a higher weight to those with a high radiological relevance (i.e. those with a small clearance level). This results in a conservative, i.e. enveloping, nuclide vector.
- The activity percentages for the nuclides to be included in the nuclide vector are calculated from the distributions of the percentages measured for the samples by taking, for example, the 95% percentile values and re-normalising the resulting vector to 100% total activity contents. Such a method puts greater emphasis on the fact that there are – in some cases very large – variations of the activity percentages of the sample set from which the nuclide vector is derived.

A number of sophisticated statistical methods have been introduced in the derivation of nuclide vectors, e.g. methods for testing whether a set of samples actually forms a statistical entity from which a meaningful nuclide vector can be derived.

In the clearance procedure, a nuclide vector is used to calculate the percentages of the relevant nuclides from measurement results giving only the total (alpha, beta or gamma) activity, as in measurements using contamination monitors that show only total beta activities. Such a result can then be used to check whether an actual measurement complies with clearance levels by inserting the calculated activity percentages into the summation formula:

$$\sum_{i=1}^{n} \frac{a_i}{C_i} \leq 1$$

Where: n : number of radionuclides present in the nuclide vector
a_i : specific activity of radionuclide i (in Bq/g or Bq/cm²)
C_i : clearance level of radionuclide i (in Bq/g or Bq/cm²)
A sum smaller or equal than 1 indicates compliance with the clearance levels.

Examples for procedures for deriving nuclide vectors have been provided by several countries in the responses to the questionnaires. A very comprehensive approach is reported from the United Kingdom. The United Kingdom Atomic Energy Authority (UKAEA) derives a unique radiological fingerprint (nuclide vector) for every situation where a variation in isotopic composition is possible. This often results in a single facility having numerous fingerprints. The methodology for fingerprinting is determined on a case-by-case basis underpinned by guidance developed for the nuclear industry in the United Kingdom. In practice, this is achieved by physical sampling with subsequent laboratory analysis and reporting. Typically at Harwell/Winfrith the radio-nuclides encountered during decommissioning might include percentage compositions of: ^{241}Am, ^{14}C, ^{134}Cs, ^{137}Cs, ^{60}Co, ^{55}Fe, ^{63}Ni, $^{238\text{-}241}$Pu, ^{90}Sr, ^{3}H and ^{234}U, ^{235}U, ^{238}U.

An approach is described by Germany where the concept of nuclide vectors is also extensively used. The process of determination of the nuclide vector is implemented on a site-specific basis. In this way, best account of the operating history and specific features of the installation are taken. Usually, the nuclide vector is not just taken as the arithmetic average of the percentages of nuclides found in the radiological characterisation, but is shifted towards the conservative side to allow for variations of the percentages in actual measurements. The nuclide vector is the basis for all subsequent measurements during the clearance procedure.

A synopsis of the various approaches to use nuclide vectors or radiological fingerprints is given in Section 4.5 of the Appendix.

4.3 Clearance measurements

A number of established and well-applied techniques are available for all kinds of clearance measurements. This section provides a short overview; more information can be found, for example in the report [OECD, 2006b] of the NEA Radioactive Waste Management Committee. An overview of methods used for clearance measurements is provided in Section 4.7 of the Appendix and are further addressed in Section 5.4 of the Appendix. Almost all answers provided in response to the questionnaire have addressed the use of measurement techniques and have described their application to specific purposes, e.g. measurements of metallic parts, of building rubble or of building surfaces.

Wipe tests

As wipe test provide information only of the non-fixed contamination, they can be used only as an auxiliary tool in the early stages of the characterisation of the material or of the (coated) building surfaces. The results of the wipe tests are usually mainly for health physics purposes, i.e. to determine the amount and composition of contamination that might be re-suspended during dismantling and decontamination work and the need to wear respiratory protection. Wipe tests, however, cannot be used for determining the radionuclide composition of the contamination present on surfaces. In exceptional cases, they may be used for screening purposes, e.g. checking the presence of alpha emitting nuclides.

Sampling

Sampling and subsequent analysis in a gamma spectrometer as well as analysis of hard-to-measure nuclides are commonly used during the radiological characterisation of materials and buildings installation. Samples from metallic items as well as from walls and floors serve to determine the radionuclide composition of the contamination for deriving nuclides vectors (See Section 4.2) as well as for determining the spatial distribution of the activity levels.

There are many sampling techniques available, including surface sampling, material samples both for metals and building surfaces, core drilling and volume samples mainly for building surfaces. A further technique that can be used at ceilings or walls of buildings is shown in Figure 4.1. A milling head scrapes off the surface layer, and the material is collected in a beaker from which it can be transferred into a suitable sample container for measurement.

Taking samples from building surfaces not only from a single depth but also from successive layers or segmenting drilling cores into slices allows measurements to be performed for various depths, thus being able to establish the penetration of the activity into building material.

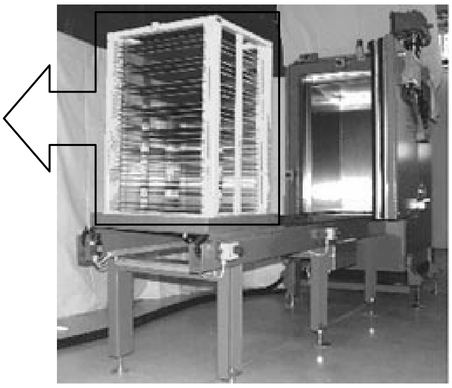
Figure 4.1 **Taking samples at concrete surfaces with a power drill with milling head and a beaker to collect the powder (left); transferring the powder to a measurement container** (right) (pictures from [KWW, 2004])

Bulk monitors for metal scrap, building rubble and other bulk materials

Bulk monitors (or release measurement facilities) of the type shown in Figure 4.2 are widely used for measurement of metal scrap, building rubble and various other types of material. The high throughput makes them ideal for releasing larger quantities of metal scrap, building rubble and other bulk materials arising during the decommissioning phase. The containers (usually boxes having a volume of 0.5 m^3 or more) are filled with several 100 kg (up to about 1 Mg) of the material and are measured for usually less than 1 minute in the measurement chamber where the integral gamma flux is detected by e.g. 24 detectors in 4π geometry. The throughput of these devices can reach several tens of Mg per work shift.

As bulk monitors (as shown in Figure 4.2 in their most widely used form) are capable only of measuring the total gamma component, it is crucial to know the appropriate nuclide vector by which the counts delivered by the instruments can be related to volume or mass specific activity values of the radionuclides present (by Section 4.2).

Figure 4.2 **Bulk monitor by RADOS[3], shown with calibration dummy and open measurement chamber**



Surface contamination monitors

Surface contamination monitors, mostly large area proportional counters or plastic scintillators such as the one shown in Figure 4.3, are widely used in measurements on metal surfaces or building surfaces during preliminary measurements (i.e. for radiological characterisation) as well as during clearance measurements.

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[3] RADOS Technology GmbH, Hamburg – a company within the Synodys group. http://synodys.com/portal/

Figure 4.3 **The contamination monitor CoMo 170 by S.E.A.**[4] **with plastic scintillator**

Proportional counters can be particularly useful for many clearance applications. They exist in two main forms: (i) as a thin-window gas flow or refillable detectors, being used for alpha and beta radiation monitoring, and (ii) as sealed xenon-filled counters, which have a thicker window (and therefore are insensitive to alpha radiation) but which have a useful response to low energy X-rays. In addition, they are not susceptible to magnetic fields and will identify the presence of high beta or gamma fields by showing a high count rate in the beta channel.

Scintillation detectors are used for surface contamination monitoring of alpha, beta, low-energy gamma, and X-ray radiation and, for these purposes, thin layers of scintillation material are used. Scintillation detectors are also often used in measurements of bulk gamma radiation contamination. For this application thicker scintillators with larger volumes are used. However, scintillation detectors are susceptible to magnetic fields and may be unreliable in high radiation fields.

In situ *gamma spectrometry*

Collimated *in situ* gamma spectrometers consist of HPGe (high purity germanium) solid-state detectors surrounded by circular shielding elements that restrict the sensitivity of the instrument to a cone shaped region (Figure 4.4) Such instruments allow the measurement of gamma radiation from surfaces and from the volume underneath (the depth depending on the gamma energies of the radionuclides in question and on the material properties, usually between a few cm for metal and several 10 cm for soil or loose building rubble and high-energy gamma emitters).

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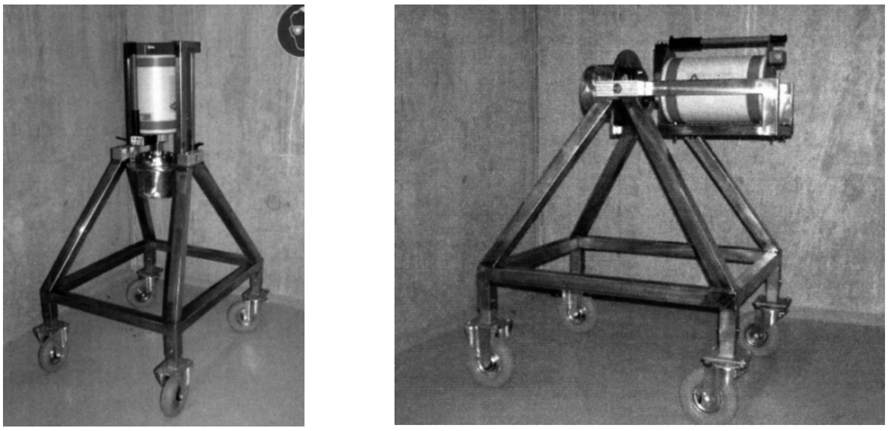
[4] S.E.A. Strahlenschutz-, Entwicklungs- und Ausrüstungsgesellschaft; Dülmen, Germany. www.nuklear-medizintechnik.de/

Figure 4.4 ***In situ* gamma spectrometer in a frame for floor and wall measurements (Canberra)**



As the collimator restricts the angle through which gamma quanta can enter the detector, the measurement results can be attributed to a certain area or a certain volume allowing quantitative measurements of surface or mass specific activities. By varying the opening angle (aperture) and/or the distance between the instrument and the surface, the area and/or the volume from which gamma quanta are registered can be adjusted. Such instruments are widely used where large areas have to be cleared like building surfaces or land. The collimator and distances are usually set in such a way that the area covered by the instrument is in the range of 1 m² or a few m².

4.4 Compliance with regulatory requirements

Materials or buildings that are to be cleared generally have to comply not only with the clearance levels pertinent to the clearance option in question (see Section 3.1). In addition, other requirements, such as mass restrictions, types of materials, first destination of the material after clearance, have to be fulfilled.

In the answers provided in response to the questionnaire, the use of averaging criteria has been addressed by a number of countries. The following evaluation is a condensation of the more extensive overview provided in Section 4.6 of the Appendix.

Averaging masses

The averaging mass describes the quantity of material over which a measurement may be averaged, i.e. by which the number of becquerels determined from a single measurement may be divided to yield mass specific activities (Bq/g or Bq/kg).

Metals

Averaging masses for metals are usually chosen in the range of 100 kg up to several 100 kg. This corresponds to the quantity that a waste drum or a box used for bulk monitoring can hold. The self-absorption in this mass is still at an acceptable level, especially when ^{60}Co or ^{137}Cs are the main contaminants.

Building rubble and other bulk material

Averaging masses for building rubble are usually chosen in the range of a few 100 kg up to 1 Mg. Similar considerations apply as for metal scrap. If the measurement device can measure only quantities smaller than the averaging mass, several measurements may be combined until the averaging mass is reached.

For a number of practical applications in clearance procedures, higher masses have been applied, especially if the contamination on the material is more or less homogeneous. In such cases, it is usually practicable to apply averaging masses of up to 10 Mg or a truck load.

Averaging areas

The averaging area describes the area of material or building surface over which a measurement may be averaged, i.e. by which the number of becquerels determined in a single measurement may be divided to yield surface specific activities (Bq/cm² or Bq/m²).

Metals

Averaging areas for metals are usually chosen in the range of several 100 cm² up to 1 m². In many cases 1 000 cm² is used. This corresponds to the range of sizes of the windows of surface contamination monitors.

Buildings

Averaging areas for buildings are usually chosen in the range of 1 m² or several (up to 10 m²), which corresponds well to measurements with in collimated situ gamma spectrometers. Often a smaller averaging area is applied when the building will be cleared for reuse, thereby ensuring that the residual contamination will not exhibit peak values that could affect persons working in the building after clearance for a longer time in a small area.

Larger areas are applied for clearance for demolition, as in this case the average contamination (and not a localised value) plays the dominant role. In a number of practical applications involving clearance procedures, much larger areas have been applied, especially if the contamination on the walls and floors is supposed to be homogeneous, e.g. following a general decontamination of the walls. In these cases, averaging is usually performed over one connected building surface, such as an entire ceiling, wall or floor area.

5. ALTERNATIVES TO CLEARANCE (RECYCLING, DISPOSAL AS VLLW, INTERIM STORAGE)

5.1 Technical, economic and social factors

5.1.1 Overview

In many countries, clearance is not considered a viable option for all or part of the material originating from the nuclear sector, e.g. for the large amounts of material arising from decommissioning of nuclear installations. In these cases, other waste management approaches need to be used, instead of or in addition to clearance. These include:

- recycling in the nuclear sector,
- disposal of (otherwise clearable) material as VLLW on specific disposal sites,
- interim storage for decay.

These approaches need to be considered and evaluated carefully for a specific country, especially when they are not intended as complementary to clearance, but as a substitute for clearance. Many countries have introduced additional pathways for dealing with material for which compliance with clearance levels cannot be demonstrated, e.g. melting of metal scrap in dedicated licences foundries in Germany and Sweden, with the possibility of subsequent recycling within the nuclear sector as in Germany, or specific disposal sites for VLLW in France, Spain (under development) or Sweden. The only NEA member country with a significant nuclear programme that has chosen not to introduce the concept of clearance and to rely on alternatives is France. The driving factors for this decision and a comparison for clearance are outlined in Section 5.2. Other factors for introducing alternatives to clearance are discussed below.

5.1.2 Technical factors

Although technically feasible, demonstrating compliance with clearance levels may not be straightforward in all cases, especially for nuclide vectors with high abundances of hard-to-measure nuclides. An example for such material is metal scrap from fuel cycle installations with varying nuclide vectors where the effort for characterisation and measurements can be extremely large. In such cases, it may be much easier to use alternative methods such as melting in a dedicated foundry for which the necessary effort for characterisation is significantly smaller.

In addition, depending on the clearance options that are available in a particular country, there may be a large quantity of material that falls above clearance levels but cannot be conditioned as radioactive waste, not only because of economic considerations, but also because it would not meet acceptance criteria for a final repository or because there is not enough space in a (planned or existing) repository. Examples are contaminated soils from nuclear sites for which it is hard to reach extremely low moisture contents, or building material from demolition of nuclear installations that would by far exceed available repository space.

5.1.3 Economic factors

Economic considerations are often closely linked to the technical factors described above. A pathway that is technically not viable or that would require significant additional technical effort is usually also not economic. However, economic considerations have to take account of the costs for alternatives. A number of cost studies have been done comparing the costs for clearance with the costs for waste conditioning and disposal in repositories. In countries with (planned or operating) deep geological repositories, and therefore with high costs associated with final disposal, e.g. Germany, clearance is in general the least expensive option. In countries with VLLW repositories that can accommodate waste that would be cleared in other countries, the costs for clearance and for disposal in a VLLW repository will be balanced at some point, making only clearance of material with lower contamination levels economically feasible.

5.1.4 Social factors

The view of the public towards clearance differs between countries. There are NEA member countries where the aspect of recycling, i.e. of re-introducing materials that otherwise would have to be discarded as radioactive waste, is appreciated, while in other countries the appropriateness of the models used for the derivation of clearance levels (see Section 3.2) and the values themselves (see Section 3.3) are questioned, as well as the potential dangers of even trivial doses (see Section 2.1). In any case, pursuing a range of alternatives, as addressed in Section 5.2, can help in putting the concept of clearance into context. Such an approach should incorporate the provision of a well-founded information campaign on clearance to the general public.

France does not pursue a clearance policy, citing social factors as a primary reason, e.g. there is a concern that negative connotations about clearance can have a negative impact on the public opinion about nuclear power in general.

5.2 Comparison of alternatives to clearance

From the alternatives to clearance listed in Section 5.1, the use of dedicated VLLW repositories has the greatest potential and can accommodate the largest quantity of materials, especially building rubble and soil, which cannot be cleared or cannot be recycled. Recycling within the nuclear industry may soon reach saturation and is mainly limited to certain types of metal scrap, while interim storage for decay requires the construction of storage facilities and an administrative act to release the material at the end of the storage period. In comparison to other types of repositories in engineered near-surface structures for LILW or deep geological sites for LILW or HLW, VLLW repositories are inexpensive both in construction and in operation.

In general, the overall costs for clearance and for VLLW disposal are of the same order of magnitude, making a further comparison worthwhile, while the costs for disposal in a geological repository are about one order of magnitude higher (See Box 1) [Avérous, 2004].

The above discussion underlines that there are economically viable alternatives to clearance, but that they have to be judged in the context of the existing nuclear programme and of the general waste management strategy. The discussion also shows that clearance is in the long run a very inexpensive option that is worthwhile implementing and pursuing, especially in countries where dedicated surface repositories for VLLW would not be accepted by the general public.

Box 1

A recent paper by Avérous (2004) concluded:

For a clearance strategy, cost is almost proportional to the waste volume. Segregation of materials is very labour-intensive but management after clearance is easy, can be dealt with on a local basis with low transportation costs and disposal costs.

For a VLLW disposal strategy, the initial investment cost is high, but costs associated with VLLW decrease rapidly with the total amount of waste, as fixed costs are dominant.

In a country that has an important decommissioning program of an important nuclear programme (i.e. VLLW amounts of several 100 000 t to some 1 000 000 t):

- if it is possible to create one or some VLLW disposal sites, it is economically preferable not to rely on clearance, because of its intense labour costs that do not allow to gain on volume, but to rely heavily on VLLW gross segregation and dedicated elimination. This will be facilitated by a joint organisation of the licensees or the concentration of the facilities within a few companies (e.g. France);
- if a surface ILW disposal is available, it is an option worthwhile considering economically, but care has to be taken in that case of the availability issue: an open ILW disposal is an asset for all operating facilities;
- if no surface disposal can be created (e.g. Germany), clearance is obviously by far the preferable option from the economics point of view.

If a country is considered that has only a small nuclear program, amounts of VLLW produced by decommissioning will be small:

- if a surface disposal facility already exists for some reason, it is probably the best solution at a marginal cost;
- if no surface disposal exists, clearance is economically the best option.

This discussion shows that economic reasoning and optimisation can lead to the choice of either the clearance or the disposal strategy for VLLW from decommissioning.

6. CONCLUSIONS

This report provides up-to-date information on the release of materials and buildings from regulatory requirements (clearance), providing an overview of the current situation with the aim of assisting member countries that are planning the implementation of a clearance procedure, e.g. in preparation for decommissioning. In general, clearance has developed to a very mature concept allowing the swift and safe determination of compliance with clearance criteria on nearly all materials (metals, building rubble, cables, plastics etc.) and building surfaces. However, there are differences in the ways in which clearance is dealt with in the regulatory framework in various countries and in which clearance has been implemented at various decommissioning projects.

The radiological concept of clearance is defined by the IAEA as the removal of radioactive materials or objects within authorised practices from any further regulatory control, applied for radiation protection purposes, by the regulatory body. It is generally based on the concept of triviality, of which constraining individual doses potentially resulting from clearance to a range in the order of 10 µSv/a is the most important one for practical purposes.

There are a number of possible clearance options for unconditional clearance as well as for clearance for a specific purpose. International guidance on these issues is available from the European Commission, for example, while numerous regulations exist in various countries. Clearance levels have been derived on an international scale, promoting international harmonisation of clearance, as well as on a country-specific scale in many NEA member countries. Acceptable agreement between clearance levels for key nuclides like ^{60}Co and ^{137}Cs has been achieved for unconditional clearance, i.e. the clearance levels fall within one order of magnitude, while the scattering of values can be much larger mainly for radionuclides of minor radiological significance.

The implementation of the clearance process is generally complex and requires good planning in order to avoid high costs in the implementation phase. The variety of measurement devices suitable for the initial characterisation as well as for measurements for determining compliance with clearance levels is large and comprises surface contamination monitors and *in situ* gamma spectrometry, and bulk monitors as the most commonly applied measurement techniques, as well as dose rate meters, extraction of material samples with laboratory analysis, wipe tests and other auxiliary techniques mainly used during the characterisation phase. The establishment of correlation factors between easy-to-measure gamma emitting nuclides and hard-to-measure nuclides like alpha or weak beta emitters, the determination of nuclide vectors as well as the determination of the penetration depths for building surfaces are also important tasks to be carried out during the characterisation phase.

Measurement techniques such as bulk monitors for containers or drums with metal scrap, building rubble and other bulk material allow the swift measurement of even larger amounts of material. *In situ* gamma spectrometry, especially when used with a collimator, permits the measurement of large areas of building surfaces in a reasonable time, while at the same time being able to detect gamma emitting radionuclides that have penetrated into the building surface by up to a few centimetres. It is evident therefore that measurement techniques are available for all types of clearance measurements. However, there is some potential for further developments, such as using instruments with increased detector surfaces or detectors with smaller outer dimensions that allow measurements in otherwise inaccessible parts of buildings, e.g. narrow gaps.

A comparison of clearance and other material management options, like disposal of the material as very low-level waste on dedicated VLLW disposal sites and the disposal of the material as radioactive waste in near-surface or deep geological repositories, reveals that the costs for clearance and for VLLW disposal are comparable, and both options are about one order of magnitude less expensive than disposal in a repository. Clearance and disposal as VLLW on dedicated disposal sites may thus be regarded as two generally equivalent options.

In conclusion, clearance or the release of materials and buildings from regulatory requirements has become an indispensable part of the material management in the nuclear field. Current efforts are therefore directed more towards refinement of processes and techniques to enhance applicability than on the development of totally new approaches. While international harmonisation of clearance still plays a role, it must be recognised that harmonisation of the current sets of clearance levels and clearance regulations has been achieved to a large extent. Further steps in this direction should therefore be considered with great care.

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Appendix

BACKGROUND INFORMATION AND EVALUATION OF THE QUESTIONNAIRE ON CLEARANCE

1. Introduction

This Appendix contains background information derived from the Questionnaire on the release of materials and buildings, sent to selected decommissioning projects in NEA member countries.

It presents the questionnaire itself in Section 2. Section 3 provides an overview of the completed questionnaires. Section 4 presents and compares the data that have been gathered from these answers, while a first evaluation is done in Section 5.

2. Presentation of the questionnaire

The "Questionnaire on the Release of Materials and Buildings" has been prepared by the WPDD (Working Party on Decommissioning and Dismantling) of the OECD/NEA in the first half of 2006 in order to get an overview of current practices in clearance (i.e. release from the relevant atomic law) of materials and buildings. It has subsequently been sent to selected nuclear power plants and fuel cycle installations undergoing decommissioning or in operation to get information on the following topics:

- legal context of clearance, including clearance levels,
- facility specific assessments,
- extent of clearance at a particular site,
- radionuclide vector/radiological fingerprint,
- averaging criteria,
- clearance/release procedure.

This choice of questions pursues the aims of providing up-to-date information on the use of clearance and clearance levels and their application in various member-countries. The legal context is also included, but this is not the focus, as many other publications deal with legal aspects. The value of this report lies in the focus on the application of clearance in practice. This is particularly emphasised by providing information on the averaging criteria that can be used during the measurement activity, on the measurement methods and their application, on the possibility to perform site-specific assessments by which clearance levels that are particularly tailored to the nuclear facility or site in question are derived etc.

3. Overview of the completed questionnaires

Answers to the questionnaire described in Section 2 were received from the following countries and decommissioning projects:

- Belgium: two answers have been received from Belgium, one with a broader scope pertaining to the decommissioning of the Eurochemic reprocessing plant and of the research reactor BR3, the other particularly to the Eurochemic reprocessing plant.
- Czech Republic: the answer describes the clearance procedures used at the NPPs Dukovany and Temelín.
- Finland: the answer pertains to the practice of clearance at the NPP Olkiluoto with an overview of clearance in Finland in general.
- Germany: the answer provides a general overview pertaining to all types of nuclear installations in operation and in decommissioning, with an emphasis on NPPs undergoing decommissioning.
- Japan: clearance is discussed with respect to the Tokai Atomic Power Station and the Japan Research Reactor No. 3 (JRR-3).
- The Netherlands: clearance regulations as applied to the NPP Dodewaard.
- Slovak Republic: clearance regulations applicable in the Slovak Republic are presented, with particular emphasis on the NPP A-1, Jaslovske Bohunice.
- Spain: the Spanish clearance regulations as applied by ENRESA at the NPPs Vandellós 1 and José Cabrera as well as at the research installations PIMIC are presented.
- Sweden: clearance regulations for Sweden are described. Reference is made to the decommissioning of the Active Central Laboratory (ACL) in Studsvik.
- United Kingdom: clearance regulations for the United Kingdom with particular emphasis on the sites at Harwell and Winfrith are provided.
- United States: the NRC perspective on controlling the releases of solid materials is presented.

The clearance regulations discussed in the answers to the questionnaire are generally of a generic type, i.e. independent of a specific installation, but clearance itself is exercised mainly at NPPs, in particular those undergoing decommissioning. Table 3.1 provides an overview of the type(s) of nuclear installations to which the answer pertains as well as of the type of clearance regulation presented for that country. More details to the clearance regulations are provided in Section 4.1.

Table 3.1 **Overview of the type of nuclear installations and the type of clearance regulations presented in the answers to the questionnaire**

Country	**Type of nuclear installation**	**Type of clearance regulation presented**
Belgium	• Belgoprocess (Dessel): Decommissioning of Eurochemic reprocessing plant. • SCK-CEN (Mol): Decommissioning of research reactor BR3 (PWR 10.5 MWe).	Generic regulations for clearance.
Czech Republic	• NPP Dukovany (4 blocks of VVER 440/213): in operation. • NPP Temelín (2 blocks of VVER-1000/320): in operation.	No specific clearance.
Finland	• NPP Olkiluoto (2 blocks of BWR) in operation until ~2040. • Interim storage for SF. • Underground storage for LILW.	Generic regulations for clearance, applicable to all nuclear installations in Finland.
Germany	All types of nuclear installations (NPPs, RRs, fuel cycle facilities, laboratories etc.).	Generic regulations for clearance, applicable to all nuclear installations.
Japan	• Tokai Atomic Power Station (Magnox type, 166 MWe, operation 1966-98, under decommissioning) • Japan Research Reactor No.3 (JRR-3) – RR Heavy water moderated/cooled, Unat; 10 MWth, remodelled in 1990, in operation – clearance of concrete from remodelling.	Clearance of metals from Tokai Atomic Power Station is first case of clearance application in Japan.

Table 3.1 **Overview of the type of nuclear installations and the type of clearance regulations presented in the answers to the questionnaire** (Cont'd)

Country	**Type of nuclear installation**	**Type of clearance regulation presented**
The Netherlands	Decommissioning of NPP Dodewaard (BWR, 58 MWe; operation 1969-97, now in SE).	General regulation, decree as part of the Nuclear Energy Act.
Slovak Republic	NPP A-1 Jaslovske Bohunice (HWGCR, operation 1972-77).	General regulation.
Spain	• NPP Vandellós 1 in latency period, Level 2 • NPP José Cabrera in Transition Stage, preparation for total and prompt dismantling • PIMIC site: RR, several nuclear installations.	Regulations pertaining mainly to the NPPs and research reactor in decommissioning.
Sweden	Studsvik: – Active Central Laboratory (ACL); – Ventilation and filter building (ACF).	General regulations.
United Kingdom	Five UKAEA sites, in particular sites at Harwell, Winfrith, various research reactor and nuclear research establishments.	Description of the UKAEA procedures.
United States	NRC-licensed facilities: example of NPP Big Rock Point (75 MWe BWR, operation 1962-97), operated by Consumers Energy.	General regulations.

4. Data from decommissioning projects and countries

4.1 Legal context of clearance/release from control

This section provides an overview of those parts of the legal framework of the various countries that directly applies to or regulates clearance. Where available, the sources where clearance levels are listed are also identified.

Table 4.1 **Overview of the clearance regulations presented in the answers to the questionnaire**

Country	**General basis**	**Regulations for clearance contained in**
Belgium	Royal decree of July 20th 2001 ("General regulations regarding protection of the population, the workers and the environment against the hazards of ionising radiation").	Articles 18 and 35.2 Clearance Level (CL) in appendix, taken from RP 122.1.
Czech Republic	Act No. 18/1997 Coll. (Atomic Act) Implementation Decree No. 307/2002 Coll. on radiation protection.	Decree No. 499/2005 CL in Decree No. 307/2002 Coll. based on IAEA BSS 1996 and RP 122/I. CL not applicable since 2006, instead case by case decisions by SÚJB.
Finland	YVL-guide 8.2 of Finnish Radiation and Nuclear Safety Authority (STUK).	YVL-guide 8.2, sect. 3.
Germany	Radiation Protection Ordinance of July 2001 many guidelines and rules, e.g. DIN 25457.	Sect. 29 RPO CL in Appendix III Table 1 RPO.
Japan	Law for regulation of nuclear source material, nuclear fuel material and reactors clearance system introduced in 2005 in regulatory framework.	RS-G 1.7 values adopted in the Law.
The Netherlands	Nuclear Energy Act.	Decree as part of the Nuclear Energy Act. Clearance and Exemption levels are equal.
Slovak Republic	Public Health Act No. 126/2006 Government Regulation No. 345/2006 Coll. on Basic Safety Requirements for Health Protection of Workers and Population Against Ionising Radiation.	Government Regulation No. 345/2006 Coll. CL given for five radiotoxicity classes of radionuclides.

Table 4.1 **Overview of the clearance regulations presented in the answers to the questionnaire** (Cont'd)

Country	**General basis**	**Regulations for clearance contained in**
Spain	Regulation of Nuclear and Radioactive Installations (RD 1836/1999). Decree Royal 833/1988 on regulations of hazardous wastes and Law 10/1998 on waste. Law 54/1997 on radioactive waste.	CL defined individually, based on IAEA TECDEC 855 for Vandellós 1; for new projects on EU RP 122/I conditional CL for metals on EU RP 89 and for buildings on RP 113.
Sweden	General regulations SSI FS 1996:2: Regulations on the Discharging of Goods and Oil from Controlled Areas in Nuclear Plants (with additional specific conditions).	Formerly: IAEA TECDOC 855 now under revision, to adopt latest recommendations of EC and IAEA. for melting at Studsvik: EC RP89. for building: case-by-case basis, EC RP113.
United Kingdom	Nuclear Installations Act 1965 Radioactive Substances Act 1993. Waste Man. Licensing Regulations 1994. Environment Protection Act 1990 (non-rad. waste).	Health and Safety Policy Exchange Meeting (HASPEM) Document – Report on Radioactive Clearance Monitoring Substances of Low Activ. Exemption Order also taking account of EC recommendations RP 117 (RP89) and RP 113.
United States	10 CFR 20 – public dose limit, disposal procedures NUREG-1640, NUREG-1761.	NUREG-1640 "Radiological Assessments For Clearance Of Materials From Nuclear Facilities"; values have been approved by the United States National Academy of Sciences (IAEA RS-G-1.7, ANSI-N13.12-1999 used as additional guidance). Currently, case-by-case decisions issued by NRC.

4.2 Clearance levels

4.2.1 Overview

This section provides an overview of the numerical clearance levels together with their range of application. In order to provide a meaningful and yet clear comparison of these values, a number of radionuclides have been selected which represent the various groups of radionuclides as follows:

- ^{3}H, ^{14}C: weak beta emitters with special environmental behaviour;
- ^{63}Ni: weak beta emitter with high abundance in many NPPs (similar properties as ^{55}Fe);
- ^{60}Co, ^{137}Cs: important activation and fission products in NPPs and other nuclear installations;
- ^{90}Sr: strong beta emitter with high abundance in various types of nuclear installations;
- ^{235}U: alpha emitter, representing the nuclear application of U;
- ^{241}Am, ^{239}Pu: important alpha emitters of high abundance in the alpha contamination in various types of nuclear installations.

In order to indicate the origin of the clearance levels, the following abbreviations have been used:

- RP89: European Commission: “Recommended radiological protection criteria for the recycling of metals from the dismantling of nuclear installations”, Radiation Protection No. 89, Luxembourg 1998.
- RP113: European Commission: “Recommended radiological protection criteria for the clearance of buildings and building rubble from the dismantling of nuclear installations”, Radiation Protection No. 113, Luxemburg, 2000.
- RP122/1: European Commission: “Practical Use of the Concepts of Clearance and Exemption – Part I: Guidance on General Clearance Levels for Practices; Recommendations of the Group of Experts established under the terms of Article 31 of the Euratom Treaty”; Radiation Protection No. 122, Luxemburg, 2000.
- EUBSS: Basic Safety Standards of the European Union; Council Directive 96/29/Euratom laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation; Official Journal of the European Communities, L 159, Vol. 39, 29.06.96.

- TD855: IAEA: “Clearance Levels for Radionuclides in Solid Materials: Application of Exemption Principles”; IAEA-TECDOC-855, Vienna, 1996.
- RSG1.7: IAEA: “Application of the Concepts of Exclusion, Exemption and Clearance”, Safety Standards Series No. RS-G-1.7, Vienna, 2004.
- Reg: a regulation that is specific to the country in question, for more details (See Section 4.1).
- ss: site specific approach.
- Col. 4/5/6/8/9/10/10a: is taken from the German Radiation Protection Ordinance (StrlSchV) containing sets of clearance levels.

4.2.2 Numerical values

A comparison of the numerical values in the following tables has to be made with caution. The reason is that the scope of the clearance options for which these clearance values have been designed may differ. The clearance values have been grouped into the following tables:

- Table 4.2 Overview of mass specific clearance levels for metals which are cleared unconditionally (i.e. for reuse, melting or possibly disposal) or which are cleared for melting only.
- Table 4.3 Overview of surface specific clearance levels for metals which may be used in addition to the mass specific clearance levels presented in Table 4.2 or may be used as the single decision criterion for clearance.
- Table 4.4 Overview of mass specific clearance levels for building rubble.
- Table 4.5 Overview of surface specific clearance levels for building surfaces.

Table 4.2 **Overview of mass specific clearance levels for any type of clearance or for clearance of metals** (in Bq/g)

Country	**^{3}H**	**^{14}C**	**^{63}Ni**	**^{60}Co**	**^{137}Cs**	**^{90}Sr**	**^{235}U**	**^{241}Am**	**^{239}Pu**	**Origin**
Belgium	100			0.1	1	1	1	0.1	0.1	RP122/1
Czech Republic			300	0.3	0.3					reg, ss
Finland	10	10	10	1	1	1	0.1	0.1	0.1	reg
Germany	1 000 1 000	80 80	300 10 000	0.1 0.6	0.5 0.6	1 9	0.5 0.8	0.05 0.3	0.1 0.2	Col.5 Col.10a
Japan	100	1	100	0.1	0.1	1	-	10	0.1	RSG1.7
The Netherlands	10^{6}	10^{4}	10^{5}	1	10	100	10	1	1	EUBSS*
Slovak Republic	3 000	300	3 000	0.3	0.3	3	0.3	0.3	0.3	reg
Spain	3 000 100 1 000	300 10 100	3 000 100 10 000	0.3 0.1 1	0.3 1 1	3 1 10	0.3 1 1	0.3 0.1 1	0.3 0.1 1	TD855 RP122/I RP89
Sweden	0.5 Bq/g for beta/gamma emitters						0,1 Bq/g for α emitters			
*for ingots***	1 000	100	10 000	1	1	10	1	1	1	RP89
United Kingdom	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	reg(SOLA)
United States*	530	310	21 000	0.2	0.6	18	0.7	0.2	0.3	reg

* calculated from Table 2.1 of NUREG-1640.

** for ingots from Studsvik melting facility; condition: remelting as assumed in RP 89.

Table 4.3 **Overview of surface specific clearance levels for any type of clearance or for clearance of metals**
(in Bq/cm²)

Country	**^{3}H**	**^{14}C**	**^{63}Ni**	**^{60}Co**	**^{137}Cs**	**^{90}Sr**	**^{235}U**	**^{241}Am**	**^{239}Pu**	**Origin**
Belgium	0.4	0.4		0.4	0.4	0.4	0.04	0.04	0.04	reg
Czech Republic	-	-	-	-	-	-	-	-	-	
Finland	40	40	40	4	4	4	0.4	0.4	0.4	reg
Germany	100	100	100	1	1	1	1	0.1	0.1	Col.4
Japan	-	-	-	-	-	-	-	-	-	
The Netherlands	-	-	-	-	-	-	-	-	-	
Slovak Republic	3 000	300	3 000	0.3	0.3	3	0.3	0.3	0.3	reg
Spain	4	4	4	0.4	0.4	0.4	0.04	0.04	0.04	reg
Sweden	4	4	4	4	4	4	0.4	0.4	0.4	reg
United Kingdom	4	4	4	4	4	4	0.4	0.4	0.4	reg
United States*	2 600	1 600	10^{5}	1	3	83	4	1	1.5	reg

* calculated from Table 2.1 of NUREG-1640.

Table 4.4 **Overview of mass specific clearance levels for clearance of building rubble** (in Bq/g)

Country	**^{3}H**	**^{14}C**	**^{63}Ni**	**^{60}Co**	**^{137}Cs**	**^{90}Sr**	**^{235}U**	**^{241}Am**	**^{239}Pu**	**Origin**
Belgium	100			0.1	1	1	1	0.1	0.1	RP122/1
Czech Republic	300		300	0.3	0.3					reg ss
Finland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
Germany	1 000 60 1 000	80 10 2 000	300 300 3 000	0.1 0.09 4	0.5 0.4 10	2 2 2	0.5 0.4 10	0.05 0.05 1	0.04 0.08 1	Col.5 Col.6 Col.9
Japan	100	1	100	0.1	0.1	1	-	10	0.1	RSG1.7
The Netherlands	-	-	-	-	-	-	-	-	-	
Slovak Republic				0.2	0.2	2	0.2	0.2	0.2	reg
Spain	62	10	1 200	0.09	0.4	1.5	0.34	0.09	0.08	RP113
Sweden	5	5	5	5	5	5	0.5	0.5	0.5	dump
United Kingdom	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	reg(SolA)
United States*	150	83	4 800	0.03	0.2	7	0.3	0.3	0.3	reg

* calculated from Table 2.1 of NUREG-1640.

Table 4.5 **Overview of surface specific clearance levels for clearance of buildings** (in Bq/cm²)

Country	**^{3}H**	**^{14}C**	**^{63}Ni**	**^{60}Co**	**^{137}Cs**	**^{90}Sr**	**^{235}U**	**^{241}Am**	**^{239}Pu**	**Origin**
Belgium	0.4	0.4		0.4	0.4	0.4	0.04	0.04	0.04	reg
Czech Republic	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
Finland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
Germany	1 000 4 000	1 000 6 000	1 000 10 000	0.4 3	2 10	30 30	1 10	0.1 3	0.01 2	Col.8 Col.10
Japan	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
The Netherlands	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
Slovak Republic	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
Spain	3 800 3 800	2 800 5 800	18 000 37 000	0.36 2.9	1.5 12	34 34	1.3 10	0.34 2.8	0.29 2.3	RP113
Sweden	10 000	10 000	100 000	1	10	100	10	1	1	as RP113 demolition
United Kingdom	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
United States*	42 000*	24 000*	10^{6}	10	45	1 900	80	80	90	reg

* calculated from Table 2.1 of NUREG-1640.

4.2.3 Dose criterion and concepts

All clearance levels presented in this section have been derived on the basis of a 10 µSv/a individual dose – the only exception are site specific clearance levels applied in the United States which may be based on ~20 µSv/a. The clearance levels have been taken directly from international recommendations or have been derived on the basis of radiological models.

There is general agreement that the numerical values of clearance levels need to be lower than or equal to the values of exemption values as laid down in Appendix I Table A of the Basic Safety Standards of the European Union or Table I-I of the Basic Safety Standards of the IAEA. In their answer, The Netherlands point out an important issue concerning the relation of both sets of levels:

> "General regulation [*for clearance*] is laid down in a decree, which is part of the Nuclear Energy Act and which stipulates that clearance and exemption levels are the same in the Netherlands. The clearance/ exemption levels are the same as proposed in the Euratom Basic Safety Standards, but a few radionuclides such as ^{60}Co and ^{226}Ra are decreased with a factor of ten.
>
> It is considered conceptually wrong to use different values for the same materials when bringing these outside regulatory control. This is important for all situations where reuse and/or recycling should be considered. So not only in dismantling projects also in normal scrap dealing/handling. In the judgement whether material is radioactive or not, both the clearance activity criterion and the activity concentration criterion have to be met."

4.3 Site specific derivation of clearance levels

A site specific derivation of clearance levels is a reasonable approach if either no (generic) clearance levels for the particular material exist in a country or if the existing clearance levels are not applicable for some reason. In the derivation of site specific clearance levels it is usually possible to take account of the characteristics of the site, the material quantities and pathways, the working conditions, the geological and hydrogeological circumstances and the average contamination level. Table 4.6 provides an overview of whether site specific assessments and derivations of clearance levels are possible and, if so, provides examples from various countries.

Table 4.6 **Overview of site specific derivation of clearance levels**

Country	Possibility of site specific assessments	Examples for site specific assessments
Belgium	Not carried out.	–
Czech Republic	No.	–
Finland	No, same rules apply for both NPP sites.	–
Germany	Yes, general regulation for site spec. assessment in RPO, actual implementation depends on case.	Many different sites, mainly for buildings, building rubble, sites (soil); have to take account of material characteristics, waste stream, characteristics, environmental conditions etc.
Japan	No.	–
The Netherlands	not allowed.	–
Slovak Republic	No, as clearance levels are so conservative that only one set of clearance levels is recommended for all kinds of cleared materials.	–
Spain	Possible, need to be approved by the Regulatory Body CSN.	None carried out yet; have to take account of different types of materials (origin, geometry, radionuclide vector) and environmental radiological conditions.
Sweden	Yes.	Clearance of U contaminated waste for deposition on a municipal dump site.
United Kingdom	No, procedures are applied uniformly at all five UKAEA sites.	–
United States	Yes, usual approach. Case-by-case decisions are used by NRC.	NPP Big Rock Point: basis 20 µSv/a; calculated mass specific CL ~0.3 Bq/g.

4.4 Masses of materials and buildings to be cleared

The overviews of the quantities of metals to be cleared in Table 4.7 and for building rubble and buildings in Table 4.8 are based on different premises. In countries where no decommissioning projects are yet carried out, the figures refer to estimates of the total masses to be treated in the future. In countries where reference is made to a specific decommissioning project, the figures refer to that particular project. In countries with a generic approach with many ongoing decommissioning projects, the figures refer to the average annual masses to be subjected to a formal clearance procedure.

Table 4.7 **Overview of metal quantities to be cleared**

Country	Metals	Comment
Belgium	726 Mg: (79% of total mass) 2 390 Mg (95% of total mass)	From Eurochemic reprocessing plant from BR3 RR.
Czech Republic	~114 000 Mg for NPP Dukovany ~105 000 Mg for NPP Temelín	Masses presumed to be non-radioactive. no decommissioning project exists.
Finland	N.A.	no decommissioning project exists.
Germany	Several 1 000 Mg per year.	Annual quantity for formal clearance procedure from various decommissioning projects.
Japan	Estimates for BWR, PWR and GCR available, e.g. 30 000 Mg for 1 100 MWe BWR.	
The Netherlands	several 1 000 Mg.	NPP Dodewaard only (clearance only after safe enclosure).
Slovak Republic	~10 000 Mg during decommissioning.	
Spain	7 500 Mg ferrous scrap 86 Mg non-ferrous scrap 370 Mg other materials	
Sweden	Metal scrap: 53 Mg for recycling 119 Mg for melting at Studsvik	For ACL and ACF facilities.
United Kingdom	~10 000 m^3 for disposal	From Winfrith site.
United States	Topic not mentioned in the answer to the questionnaire.	

Table 4.8 **Overview of building rubble quantities/building surfaces to be cleared**

Country	Building rubble/buildings	Comment
Belgium	654 Mg (34% of total mass) 23 936 Mg (99% of total mass)	From Eurochemic reprocessing plant from BR3 RR.
Czech Republic	~560 000 Mg for NPP Dukovany ~440 000 Mg for NPP Temelín	Masses presumed to be non-radioactive. no decommissioning project exists
Finland	N.A.	No decommissioning project exists.
Germany	building rubble: several 1 000 Mg up to a few 10 000 Mg per year buildings: depending on progress of decommissioning projects.	Building rubble (before building demolition) from various decommissioning projects, depending of progress.
Japan	estimates for BWR, PWR and GCR available e.g. 500 000 Mg for 1 100 MWe BWR	
The Netherlands	about 50 000 Mg	NPP Dodewaard only (clearance only after safe enclosure).
Slovak Republic	~180 000 Mg during decommissioning	
Spain	1 962 Mg concrete 136 000 m² building surfaces	
Sweden	~ 20 000 Mg from building demolition	For ACL and ACF facilities.
United Kingdom	~30 000 m³	From 75 buildings at Winfrith site.
United States	NPP Big Rock Point: ~38 000 Mg for disposal in a licensed landfill	In the answer to the questionnaire, topic only mentioned with respect to sample NPP.

4.5 Radionuclide vectors

This section provides an overview of the use of the concept of radionuclide vectors (also called nuclide vectors, “fingerprints” etc.). This concept is useful in cases where the measurement techniques used to demonstrate compliance with clearance criteria are not spectroscopic and/or cannot detect the activities of all relevant radionuclides. The activity percentage of radionuclides which are or might be present on the surfaces or in the walls/floors is determined before the release measurement takes place. It is a particular aim of establishing a radionuclide vector to determine the activity ratios between radionuclides which are easy to measure such as ^{60}Co or ^{137}Cs and those which are hard to measure like alpha emitters, pure beta emitters such as ^{90}Sr. The radionuclides that are easy to measure are often referred to as “key nuclides” because the activity of the other nuclides is derived from them.

While some measurement techniques are capable of identifying the radionuclides (e.g. ^{60}Co, ^{137}Cs) from the characteristic gamma energies they emit during decay, a large number of radionuclides that need to be taken into account cannot be identified *in situ*. Furthermore, the amount of resources needed to determine the nuclide composition of the contamination each time a measurement is carried out make this approach unrealistic in practice.

Therefore, the concept of nuclide vectors or of correlation factors is used in many cases of clearance. Table 4.9 provides an overview of the way in which nuclide vectors are used in clearance procedures.

Table 4.9 **Overview of the use of the concept of nuclide vectors (NV) and the methods to establish nuclide vectors**

Country	Use of NV concept or correlation factors	Method to establish NV
Belgium	Yes.	From sampling.
Czech Republic	Concept not used until now.	–
Finland	NPP Olkiluoto: fingerprint is established from operational waste.	waste samples, analysed with gamma spectrometry
Germany	yes, regularly details in DIN 25457	varies; based on sampling results no general method prescribed usual key nuclides ^{60}Co, ^{137}Cs for β/γ, ^{241}Am for α

Table 4.9 **Overview of the use of the concept of nuclide vectors (NV) and the methods to establish nuclide vectors** (Cont'd)

Country	**Use of NV concept or correlation factors**	**Method to establish NV**
Japan	Yes, e.g. guide of Atomic Energy Society of Japan (AESJ): "Monitoring for Compliance with Clearance Level", 2005.	No real experience with implementation of clearance.
The Netherlands	Yes (at NPP Dodewaard).	By sampling and *in situ* spectrometric measurements.
Slovak Republic	Yes.	Standard method: spectrometric measurements for easy-to-measure nuclides, for others, correlation factors are used.
Spain	NV established for NPP Vandellós I for general application, spent fuel pools, liquid effluent treatment, graphite	Radiochemical analyses, establishment of correlation factors.
Sweden	Yes.	β/γ emitting radionuclides from sampling and γ spectrometric measurements alphas correlated to ^{241}Am.
United Kingdom	Yes unique radiol. fingerprint is derived for each situation where isotopic composition varies.	Ref. document "Clearance and Exemption, Principles, Processes and Practices, for Use by the Nuclear Industry - A Nuclear Industry Code of Practice" often ^{3}H has very high abundance (99%)
United States	Topic not mentioned in the answer to the questionnaire.	Topic not mentioned in the answer to the questionnaire.

4.6 Averaging criteria

This section provides an overview of the averaging criteria that are applied for clearance measurements. Table 4.10 provides an overview of averaging criteria for metals, which are in some countries expressed in terms of averaging masses for measurements in bulk monitors (usually several 100 kg) and/or in terms of averaging areas for measurements with surface contamination monitors (usually on the order of 1 000 cm²). Table 4.11 provides a similar overview for averaging masses for bulk measurements of building rubble and averaging areas for measurements of building surfaces.

Table 4.10 **Overview of averaging criteria for metals and other solid items**

Country	Averaging masses	Averaging areas
Belgium	–	Corresponds to the measurement area of instrument, usually 50 – 100 cm².
Czech Republic	Not used in releasing material.	Not used in releasing material.
Finland	300 kg, in addition: in partial masses of 30 kg max. 10-times CL.	1 000 cm²
Germany	300 kg	1 000 cm²
Japan	In general 100 kg 10 Mg if max. concentration < CL and average concentration << CL	
The Netherlands	In general: average over single items not yet specified for NPP Dodewaard.	In general: average over single items not yet specified for NPP Dodewaard.
Slovak Republic	1 Mg for homogeneous volume activity 0.3 Mg for non-homog. volume activity (Non-homogenous activity can exceed CL three times, general activity limit averaged over 1 Mg must be kept.).	1 m² for homogeneous surface activity 0.1 m² for non-homogeneous surface activity (Non-homogenous activity can exceed CL three times, general activity limit averaged over 1 m² must be kept.).
Spain	200 kg	N.A.
Sweden	Not specified, often averaging over one item.	N.A.
United Kingdom	Determined on case by case basis no intention for deriving a standard.	Determined on case by case basis no intention for deriving a standard.
United States	Topic not mentioned in the answer to the questionnaire.	Topic not mentioned in the answer to the questionnaire.

Table 4.11 **Overview of averaging masses for building rubble and averaging areas for buildings**

Country	**Averaging masses for building rubble**	**Averaging areas for buildings**
Belgium	Mass of batch from which a representative sample is taken.	Corresponds to measurement area of instrument, usually 50 – 100 cm².
Czech Republic	Not used in releasing material.	Not used in releasing material.
Finland	N.A.	N.A.
Germany	300 kg when using uncond. clearance levels according to App. III Tab. 1 Col. 5 RPO 1 Mg when using CL acc. to Col. 6.	1 m² when building is re-used several m² up to whole areas/whole rooms when building is demolished.
Japan		
The Netherlands	Not yet specified for NPP Dodewaard.	Not yet specified for NPP Dodewaard.
Slovak Republic	1 Mg for homogeneous volume activity 0.3 Mg for homogeneous volume activity (Non-homogenous activity can exceed CL three times, general activity limit averaged over 1 Mg must be kept.).	Topic not addressed in the answer to the questionnaire.
Spain	N.A.	On the order of 1 m².
Sweden	Not specified.	1 m².
United Kingdom	Determined on case by case basis no intention for deriving a standard.	Determined on case by case basis no intention for deriving a standard.
United States	Topic not mentioned in the answer to the questionnaire.	Topic not mentioned in the answer to the questionnaire.

4.7 Clearance/release procedure

Table 4.12 provides an overview of specific features of the clearance/release procedures which are applied in the various countries as well as of the main measurement techniques which are routinely used. It is not the aim to describe the entire clearance/release procedures as such.

Table 4.12 **Overview of the characteristics of clearance/release procedures**

Country	Procedure	Measurement techniques
Belgium	Details established by operator of nuclear installation two independent surface contamination measurements for metals and on building surfaces. Clearance must be approved by the operator's Health Physics Department and by an independent recognised inspection body.	Surface contamination monitor sampling and lab analysis.
Czech Republic		Characterisation by sampling and lab analysis hand-held contamination monitors, *in situ* gamma spectrometry, bulk monitors.
Finland	Scrap from NPP Olkiluoto classified in three categories: clean/low surface cont./high surface cont.	Surface contamination monitor dry and acid wipe tests.
Germany	Well established, mainly at decommissioning projects; details established by operator of nuclear installation record keeping required rigorous QA, e.g. routine control measurements of independent experts on behalf of the authorities penetration depth at building surfaces established e.g. from bore samples.	Metals: hand-held contamination monitors, bulk monitors building rubble: sampling and lab analysis; bulk monitors, *in situ* gamma spectrometers buildings: hand-held contamination monitors, *in situ* gamma spectrometers.
Japan	Checks carried out by competent authority.	Surface contamination monitors of various types specific measurement device for trays or baskets penetration depths at building surfaces determined by sampling.
The Netherlands	No specific information for NPP Dodewaard.	Mostly hand-held contamination monitors.

Table 4.12 **Overview of the characteristics of clearance/release procedures**
(Cont'd)

Country	**Procedure**	**Measurement techniques**
Slovak Republic	Each item measured homogeneity of activity in drums/containers is checked QA procedure for measurements.	Hand-held contamination monitors clearance measurement facility (in transportable ISO container) = bulk monitor, gamma spectrometric system.
Spain	QA by internal reviews of clearance measurements and independent lab analyses.	Metals: hand-held contamination monitors, box counters with spectrometric detectors, sampling and lab evaluation, large gate monitors at exits of sites buildings, rubble: *in situ* gamma spectrometry (ISOCS), sampling and lab evaluation.
Sweden	QA by internal quality control and inspections by SSI penetration depth at building surface established, for ACL/ACF < 1 mm.	Metals: hand-held contamination monitors, smear samples, gamma spectrometric measurements on whole item or of samples buildings: hand-held contamination monitors, smear samples and gamma spectrometric measurements (ISOCS). Assumed penetration depth: 1 mm for 80% of the activity and 10 mm for 20% of the activity.
United Kingdom	QA by internal reviews of clearance measurements within UKAEA penetration depth at building surface determined from sampling.	Hand-held contamination monitors, *in situ* gamma spectrometry, sampling and lab evaluation large portal monitors for checking trucks as final re-assurance check.
United States	Release of material with volumetric radioactivity from reactors possible if no activity from licensed practice above background levels is detected record keeping required.	Guidance given in NUREG-1761 "Radiological Surveys for Controlling Release of Solid Materials" detection capabilities in Regulation Guide 1.86.

4.8 *Alternatives to clearance*

Questions on alternatives to clearance, such as the use of special disposal sites for very low-level waste, recycling in the nuclear industry, and interim storage for decay, have also been included in the questionnaire. The answers are summarised in Table 4.13.

Table 4.13 **Overview of alternatives to clearance**

Country	**Special disposal sites for VLLW**	**Recycling in nuclear industry**	**Interim storage for decay**
Belgium	No.	Used in some cases, melting in facilities in other countries.	(only materials with short half-lives, e.g. medical sector).
Czech Republic	No.	Not practised, not planned for decommissioning projects.	Currently not considered.
Finland	No.	No.	At Olkiluoto site for large components to decay to disposal or clearance levels.
Germany	No.	Yes, e.g. at Siempelkamp (Germany) or Studsvik (Sweden); ongoing.	Yes, e.g. at interim storage facility of NPP Greifswald.
Japan	No.	No.	No.
The Netherlands	No.	–	–
Slovak Republic	No. category of VLLW not specified.	No.	Performed for radionuclides with half-life < 60 days.
Spain	Under development at the El Cabril disposal site (up to 130.000 m^3) for waste with less than ~100 Bq/g β/γ.	72 Mg of contaminated scrap has been shipped to Duratek (United States).	No.

Table 4.13 **Overview of alternatives to clearance** (Cont'd)

Country	Special disposal sites for VLLW	Recycling in nuclear industry	Interim storage for decay
Sweden	Shallow land burial in Studsvik, at NPPs Forsmark, Oskarshamn, Ringhals; max. 300 kBq/kg of nucl. with $T_{½} > 5a$, <1‰ α SFR-1: near-surface geological LILW repository at Forsmark.	Option not used.	Storage of ingots from the melting facility at Studsvik until clearance possible.
United Kingdom	No.	No.	No holding of material limited to 3 months before authorisation from Environment Agency is required.
United States	Tiered concept proposed: 1. Disposal in Environmental Protection Agency or State regulated landfills; 2. Re-use in a pre-defined set of uses (specifically concrete in road bed construction and re-use of tools and equipment); or 3. Other disposition paths, if supported by a case-specific analysis and approval of proposed procedures.	Topic not mentioned in the answer to the questionnaire.	Topic not mentioned in the answer to the questionnaire.

5. Evaluation of the data

5.1 Practice of clearance/release

In general, the answers to the questionnaire showed that the release of metals, building rubble or buildings from radiological control is treated by all countries as *clearance* in the sense defined by the IAEA. This means that release of metals, building rubble or buildings is associated with a trivial individual dose, for which most countries use 10 µSv/a as a reference. Only the United States mention a dose of 20 µSv/a as the reference for deriving clearance levels. However, this dose value is also to be considered trivial and therefore corresponds to the concept of clearance.

This agreement concerning the release of metals, building rubble or buildings is in contrast to the clearance of sites where the dose range used to derive clearance levels varies from 10 to about 300 µSv/a.

5.2 Clearance levels

The numerical values of the clearance levels have been derived from a number of international recommendations and country specific studies. When comparing the values in the different tables in Section 4.2, the following observations can be made:

- Table 4.2: mass specific clearance levels for metals: some countries use only a single set of clearance levels for metals, i.e. for unconditional clearance (any purpose), while other countries have performed studies in which clearance levels for melting have been derived. In the latter case, the cleared metal must not be directly reused because this might lead to higher exposure. In Germany, both sets of values can be applied, depending on the decision of the operator. When comparing the sets of clearance levels for unconditional clearance, there is generally good agreement between the values for the most relevant nuclides (^{60}Co, ^{137}Cs, ^{90}Sr, and alpha emitters), while larger differences are observed for the weak beta emitters, especially ^{3}H and ^{14}C.
- Table 4.3: The comparison of the surface specific clearance levels for metals shows much larger differences for the most relevant nuclides (^{60}Co, ^{137}Cs, ^{90}Sr, alpha emitters) than the mass specific ones. The reason may be that these values have not been taken over in all cases from studies or from international recommendations but have been taken from the existing regulatory framework without adapting them to the radiological models describing clearance.

- Table 4.4: As for metals, there are different sets of mass specific clearance levels for building rubble or buildings, depending on the destination of the material. In general, there are unconditional clearance levels and clearance levels for disposal of the material on a conventional landfill. Germany has even introduced to sets of unconditional clearance levels, one for quantities of less than 1 000 Mg/a per waste producer, the second one for larger quantities.
- Table 4.5: Only a small number of countries have derived clearance levels for building surfaces. In the European countries, the values have been taken over directly from the recommendation RP 113 of the European Commission, while the United States has derived its own values.

5.3 Relation between clearance levels and exemption values

The only country that has pointed out that there are no fundamental differences in the concepts of clearance and exemption and that therefore clearance levels and exemption values should be numerically equal is the Netherlands. The line of reasoning is as follows:

> *"It is considered conceptually wrong to use different values for the same materials when bringing these outside regulatory control. This is important for all situations where reuse and/or recycling should be considered."*

The other countries treat clearance and exemption as two different concepts as laid down in the Basic Safety Standards of the IAEA or the European Commission. In particular, the fact that exemption levels have been designed for small or moderate quantities of the order of a few Mg make them unsuitable for use for large quantities arising for example from decommissioning of nuclear installations. This is the reason why those countries that have clearance levels in place either use international recommendations (see Section 4.2 for an overview) or have derived such levels in country specific studies.

5.4 Measurement techniques

Considerable agreement between the measurement techniques can be observed between the various countries. Common measurement techniques are the following:

- For preliminary measurements, like establishing nuclide vectors or correlation factors (See Section 5.5), the commonly used technique is sampling and laboratory analysis with gamma spectrometric methods and radiochemical analysis. In addition, *in situ* gamma spectrometry is used.

- For final release measurements, surface contamination monitors, in situ gamma spectrometry, bulk monitors of various types as well as sampling and laboratory analysis have often been mentioned. The instruments currently available provide a wide choice of options.

Particular problems with measurements have not been mentioned.

5.5 Use of nuclide vectors (Fingerprints) or correlation factors

The concept of establishing correlation factors between easy to measure key nuclides such as ^{60}Co, ^{137}Cs etc. for β/γ emitting nuclides and ^{241}Am for α emitting nuclides and hard to measure nuclides such as ^{90}Sr, ^{63}Ni, ^{3}H, ^{14}C, other α emitters is widely used. In some countries, this concept is further developed to nuclide vectors by which the activity percentages of all nuclides that are present in contaminated or activated material are fixed, based on measurements on a sufficient number of samples. While the use of correlation factors is essential and is good for cases where, for example, in situ gamma spectrometry is used as a measurement method, the use of nuclide vectors also allow a correct interpretation of measurement results where only the total β or γ activity is measured.

5.6 Clearance procedures

The description of the clearance procedures was treated quite differently in the various answers to the questionnaire. In general, no basic problems with carrying out clearance measurements have been mentioned. It has been emphasized that a number of quality assurance measures are in place, such as performing internal review procedures or carrying out independent measurements by experts acting on behalf of the competent authorities.

5.7 Clearance and international trade

The issue of the interdependence of clearance and international trade has only been touched by the United States, opting for internationally agreed clearance levels. This aspect should be considered in the light of the fact that most clearance levels being applied to metals (which is the material type with the highest potential for international trade) are in good agreement. Furthermore, the residual activity on cleared items is generally well below the relevant mass or surface specific clearance levels, being usually less than 30%, and in most cases even below 10%, of the clearance levels. This means that it is highly unlikely that a cleared item would ever be considered as radioactive in another country.

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