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Releasing the Sites of Nuclear Installations

A Status Report

NEA No. 6187

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 WPDD addresses the current views of NEA member countries and is intended to be of service to them with the goal to strengthen overall visibility of decommissioning as an activity that is attracting growing attention.

The WPDD keeps under review the policy, strategic and regulatory aspects of decommissioning of phased-out nuclear installations in view of the ultimate goal of releasing facilities and sites from regulatory control. The intention is to examine decommissioning commonalities and differences internationally and to identify a common basis for moving forward.

Release issues were discussed at a topical session on “Materials Management” held in Paris on 5-7 December 2001. The WPDD then held a topical session in June 2002 on “Buildings & Sites Release and Re-use” in Karlsruhe, Germany. In 2003 a questionnaire was sent to nuclear power plant decommissioning projects in OECD/NEA member countries to obtain data and information on this comparatively young type of release from radiological control, to get an overview of the dose criteria and the release criteria that are used and to learn which measurement techniques for verification of compliance with the release criteria are preferred.

A task group was established at the WPDD meeting in November 2003 to prepare a status report on release of sites based on the information from the topical sessions and the questionnaire. The report was submitted to the WPDD at its November 2005 meeting and approved for publication in spring 2006.

Status reports of the WPDD are intended to summarise existing knowledge and experience on a given subject in order to provide concise, “digested” information to those who are interested in obtaining a quick overview over a subject without reading through an extensive number of specialised papers from conferences, seminars or other types of meetings. Status reports are not only directed at decommissioning experts, such as regulators, implementers and R&D experts, but also an interested audience including politicians, decision makers and the general public.

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1. SUMMARY OF KEY POINTS

The following key points regarding the release of sites of nuclear installations have been derived from this status report:

- **The release of sites of nuclear installations is one of the last steps in the decommissioning of nuclear facilities but has so far only been implemented in a limited number of cases.**

  Release of sites have been practised only in a limited number of decommissioning projects, and the overall experience is much more limited than with clearance of materials and buildings as most decommissioning projects have not yet advanced to a state where release of the site becomes imminent or because the sites are, or will be, re-used for nuclear activities. The release of sites is only a mature practice in those countries with a number of completed decommissioning projects.

- **The appropriate authority in a country where release of sites shall be implemented needs to make a decision on the appropriate dose criterion which shall be used.**

  A number of countries have carried out release of sites successfully by using different dose criteria, ranging from the trivial dose range (~ 10 µSv/a) up to a larger fraction of the individual dose limit of 1 mSv/a (~ 100 to 300 µSv/a). Different models for the derivation of suitable release criteria have been applied. Modelling takes account of all relevant pathways, i.e. external irradiation, inhalation (dust), direct and secondary ingestion (soil, water, food) and other pathways if appropriate. There seems to be far less need for an international harmonisation of release criteria and approaches for sites than for the clearance of materials, as release of sites has no impact on international trade.

- **A plan for the release and final radiation survey of the site needs to be developed well before the release measurements.**

  The plan must demonstrate how it will be assured that the site complies with the release criteria. It must comprise the identification of the radiological contaminants, the classification of the impacted areas, the methods and performance criteria used to conduct the survey, and the definition of the number and location of measurements or samples. The subtraction of the background activity is an important issue as soil contains non-negligible amounts of radionuclides of the natural U and Th decay chains as well as ^{40}K.

- **Appropriate techniques for release measurements of sites in combination with statistical approaches are available.**

  Suitable techniques are: *in situ* gamma spectrometry, contamination monitors (for sealed surfaces), dose rate measurements or cobalt coincidence monitoring, as well as sampling in combination with laboratory measurements. Release measurements can be applied easily to cases where a substantial amount of gamma emitting nuclides is present in the radionuclide vector, but can cause a much higher effort for cases where alpha emitters or other nuclides which are hard to measure are present. Averaging areas for the release of sites are generally chosen in the range of several 10 m² up to 100 m².

- **Underground soil contamination must be taken into consideration in the release of sites.**

  Release criteria and survey methods are generally developed for surficial residual radioactivity (in the upper 5-15 cm of soil). If residual radioactivity (non-negligible amounts) has penetrated to a depth greater than this range, this should be taken into consideration when performing the radiological modelling and when developing the final survey plan.

2. INTRODUCTION

Release from radiological control of sites of nuclear installations is usually one of the last steps in the decommissioning phase of nuclear installations. It has been practised only in a limited number of decommissioning projects, and the overall experience is much more limited than with clearance of materials and buildings as most decommissioning projects have not yet advanced to a state where release of the site becomes imminent or because the sites are, or will be, re-used for nuclear activities.

Therefore, advice prepared by the WPDD of the OECD/NEA might be beneficial for a number of decommissioning projects where planning for release of sites will start or already has started. While the report *Release of Sites of Nuclear Installations – Evaluation of a Questionnaire Issued by the WPDD of the OECD/NEA and Other Background Information* [1] has presented technical information, more general guidance prepared by the WPDD would be needed.

This paper is structured in the following way:

- Section 3 provides the basic considerations which have to be taken into account when a decision on the release of sites is to be made. It emphasises the role of the concepts of clearance and release which may both be applied to the release of sites.
- Section 4 provides guidance on the derivation of release criteria.
- Section 5 presents aspects of the implementation of release of sites, like the determination of nuclide vectors, an overview of measurement techniques, methods to deal with measurements on very large surfaces like statistical evaluations, background subtraction etc.
- Section 6 discusses the issue of underground contamination.
- Section 7 contains the conclusions.

For reasons of simplicity, hereafter the term “site” shall mean any site of a nuclear installation or a place where a licensed use of radionuclides has taken place.

3. THE BASIS FOR THE RELEASE OF SITES

3.1 Overview

Sites of nuclear installations or other places where a licensed use of radionuclides has taken place may be released from control by the nuclear regulatory authorities. Release is based on demonstration that no residual radioactivity above release levels is present on the site. In principle, this can be performed

- by carrying out measurements on the sites to be released;
- by a systematic and careful evaluation of the operating history and thus of the contamination history of the site and by demonstrating that no contamination could have been deposited on the part of the site to be released;
- by a combination of both approaches.

When contamination measurements need to be carried out, certain prerequisites have to be fulfilled which usually comprise:

- availability of appropriate release criteria for nuclear sites in the particular country in general or specific release criteria which have been derived for the site in question;
- availability of measurement methods for demonstration of compliance with these release criteria;
- provisions for deducting or taking proper account of the fallout and the natural radioactivity which will be present on the site or which may have penetrated into the material of the site;
- provisions for performing measurements on large areas of land;
- availability of a suitable scheme for implementation and verification of these measurements.

Furthermore, the appropriate authority in a country where release of sites shall be implemented needs to make a decision on the appropriate dose criterion which shall be used. As the decision on the dose criterion is a fundamental aspect in the whole approach to release of sites, the following parts of this section discuss the release of sites in the context of the concepts of clearance and release in connection with the respective ranges of dose criteria pertaining to both concepts.

3.2 The radiological concepts for clearance and release

The International Atomic Energy Agency (IAEA) has defined various concepts for the clearance of material and the release of sites from regulatory control. In the current context, the concepts of clearance and release are applicable.

3.2.1 Clearance of materials as defined in the IAEA BSS [2] *and IAEA Safety Guide RS-G-1.7* [3]

The Basic Safety Standards (BSS) [2] provide a general definition of clearance:

> "*Removal of radioactive materials or radioactive objects within authorized practices from any further control by the Regulatory Authority.*"

The Safety Guide RS-G-1.7 [3]

> "*Clearance is defined as the removal of radioactive materials or radioactive objects within authorized practices from any further regulatory control by the regulatory body. Furthermore, the BSS state that clearance levels "shall take account of the exemption criteria specified in Schedule I and shall not be higher than the exemption levels specified in Schedule I or defined by the regulatory body". A footnote indicates that "Clearance of bulk amounts of materials with activity concentrations lower than the guidance exemption levels specified in Table I-I of Schedule I may require further consideration by the regulatory body".*

In summary, the BSS provide radiological criteria to serve as a basis for the derivation of clearance levels but provide no definitive quantitative guidance on clearance levels. The activity concentration values developed in the following section for use in making decisions on the exemption of bulk materials may find use by regulatory bodies as a basis for the clearance of such materials.

The requirement that "clearance shall take account of the exemption criteria specified in Schedule I" of the BSS [2] means that:

1) the radiation risks to individuals caused by the practice or source be sufficiently low as to be considered trivial – this is further substantiated by the requirement that the effective dose expected to be incurred by any member of the public due to the practice or source is of the order of 10 µSv or less in a year;

2) the collective radiological impact of the practice or source be sufficiently low as not to warrant regulatory control under the prevailing circumstances; and
3) the practices and sources be inherently safe, with no appreciable likelihood of scenarios that could lead to doses above dose limit.

In summary, clearance of materials is linked to a constraint for the effective dose in the range between 10 µSv/a and several 10 µSv/a.

3.2.2 Release of sites as defined by the IAEA

The radiological concepts for clearance of materials and release of sites are different. While clearance requires the associated doses to be in the trivial dose range as discussed above, release of sites may be associated with higher individual doses. Material can enter trade and therefore should comply with clearance criteria, which are in the order of 10 µSv/a [2]. However, land remains in place, and the degree of certainty of potential future uses of the land is higher that the certainty associated with the use of material after they are released from regulatory control. Thus, it is reasonable to allow a larger fraction of the individual dose limit, i.e. dose constraint for the release of sites (in the range of 100 µSv/a up to a few 100 µSv/a) than for release of material (in order of 10 µSv/a) [4].

3.2.3 Differences between release of sites and clearance of materials

The release of sites and the clearance of materials or buildings are inherently different as the latter can be moved (even buildings will eventually be demolished) while the former is essentially immobile (the possibility of removing soil from a site has to be considered but is not the main issue for release of sites). It has therefore been international consensus for a long time to treat the release of materials or buildings with the concept of clearance. Such an approach is in accordance with the precautionary principle: limiting the potential dose from clearance of materials or buildings to the trivial dose range will automatically exclude the possibility that any person might ever receive significant doses in cases where the cleared material might inadvertently be used for different purposes than assumed in the radiological models.

There is no unanimous opinion on whether the same criterion should be used for the release of land as for clearance of materials (10 µSv/a) or whether more flexibility should be allowed, leaving countries more freedom. Some countries have used dose values up to 250 µSv/a, others prefer 100 µSv/a, a few even go to 10 µSv/a for sites. After all, material can be traded across borders, land cannot. Compliance with 10 Sv/a in all cases might be a waste of effort;

there are many types of installations which certainly could meet e.g. 250 µSv/a quite easily, while cleanup to a standard of 10 µSv/a would create additional effort which may not be justified by the reduction of potential individual dose.

The NEA RWMC Regulatory Forum has distributed a document which collates the national regulatory positions in the area of removal of regulatory controls and includes a summary of the national positions. The national positions are up to date to April 2004 [5].

3.3 Optimisation in the release of sites

For the release of a site, the dose release criteria (the effective dose to a member of a critical group) may be optimised below the dose constraint of a few hundred µSv/a (~ 100 to 300 µSv/a) up to a trivial dose range (~ 10 µSv/a). There is a lower level of the region of optimisation for site release of the order of 10 µSv/a below which it is unlikely that significant expenditures to reduce the excess risk to an average member of the critical group of future site occupants would be warranted on radiological protection grounds.

The two approaches for the dose criterion, i.e. the trivial dose range (~ 10 µSv/a) or a larger fraction of the individual dose limit (~ 100 to 300 µSv/a) can both be justified for site releases.

Therefore, it might currently be prudent to allow countries this flexible approach until more experience will be gained with site releases. A flexible approach offers the possibilities for application of the ALARA or optimisation principle and making best use of available resources.

4. DERIVATION OF RELEASE LEVELS

4.1 Radiological modelling

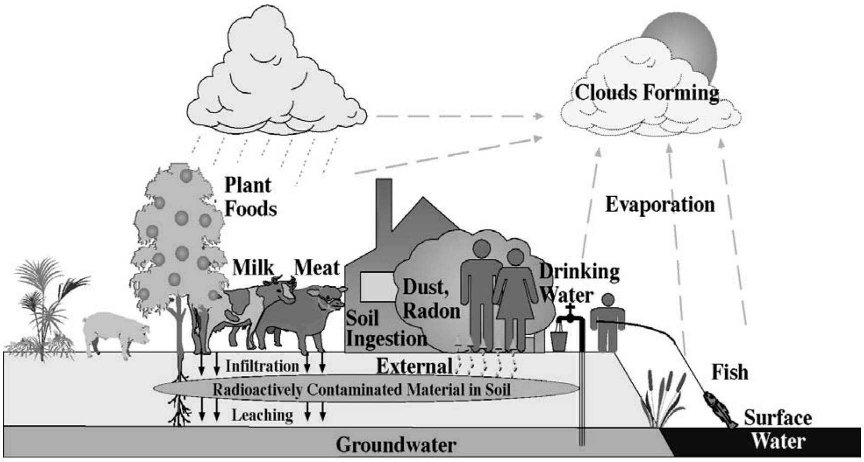
Release levels are usually derived on the basis of radiological models which in turn consist of scenarios describing a multitude of exposure situations and pathways. Considerable experience has been gained with deriving such levels over the last decades.

In general, radiological pathways and scenarios and the combination of all such pathways and scenarios, the radiological model, establish a link between the hypothetical doses to members of the public (including non-radiation workers working on the site to be released) and the residual radioactivity which may remain in the soil or on the site. Further distinction is made between cases where site specific evaluations are used and general approaches e.g. where a country establishes generic release levels for sites which can be used nation-wide:

- Site specific approaches will usually concentrate on a smaller number of exposure pathways and scenarios which are tailored to the conditions of the site. Site specific models will take account of site specific parameters, like the size of the site, the exact nuclide vector, known details of the future use of the site, meteorological, hydrological and other parameters relating to the site etc.
- Generic approaches need to accommodate a larger number of different sites the details of which are not known a priori and can therefore not be incorporated into the models. Generic models have to include all pathways and scenarios which might become relevant for any site in the country or in the region for which the derived release/clearance levels shall be valid. Such models therefore may have a tendency towards the conservative side when compared with site specific approaches.

The models which have been used in a number of countries usually contain scenarios which cover all exposure pathways. A general overview of such pathways is given in Figure 1.

Figure 1. **Pathways used in the RESRAD Code** [6]



The radiological models are used to calculate release levels for a number of radionuclides which are or are deemed to be relevant for the release measurements. Table 1 gives an example of truly generic release levels in Germany which can be used for any nuclear site for contamination depths of up to 10 cm. The pathways and scenarios which have been taken into account for the derivation are quite similar to those shown in Figure 1. Table 2 provides generic values for sites in USA according to NUREG-1757 [7].

Table 1. **Examples of release levels for sites in the German Radiation Protection Ordinance (Strahlenschutzverordnung)** [8] **– Values relate to soil**

Radionuclide	Release level [Bq/g]	Radionuclide	Release level [Bq/g]
^{3}H	3	^{137}Cs	0.06
^{14}C	0.04	^{131}I	0.2
^{55}Fe	6	^{242}Pu	0.04
^{60}Co	0.03	^{241}Am	0.06

Table 2. **Examples of release levels for sites in the USA (NUREG-1757)**

Radionuclide	Release level [Bq/g]	Radionuclide	Release level [Bq/g]
^{3}H	4.1	^{63}Ni	78
^{14}C	0.44	^{137}Cs	0.41
^{55}Fe	373	^{239}Pu	0.08
^{60}Co	0.14	^{241}Am	0.08

The differences in the release levels given in Tables 1 and 2 relate to the different dose release criteria used in Germany (10 µSv/a) and USA (250 µSv/a).

It should also be noted that the RESRAD code [6] with its excellent implementation, description and quality assurance has become a quasi-standard for site release over the past years in a number of countries. This can be gathered from the fact that it has been applied not only in the US but also in Spain and that many operators of decommissioning projects are checking their approaches against RESRAD results.

4.2 Unconditional release vs. restrictions on land use after release

While generic release levels as presented in Section 4.1 need to take account of all radiological pathways that might pertain to a nuclear site in that particular country and parameters need to be adjusted to the conservative side, site-specific modelling may take advantage of the fact that the potential exposure conditions for a specific site can be determined much better. The derivation of release levels using site-specific models can therefore be an important approach in countries where no generic release levels for sites are available. Tables 3 and 4 give examples of release levels for two nuclear sites which have been derived using site-specific approaches.

Table 3. **Release levels for the Cintichem site (USA) derived with the RESRAD program** [6] **– Values relate to soil**

Radionuclide	Release level [Bq/g]	Radionuclide	Release level [Bq/g]
^{54}Mn	0.1	^{109}Cd	2
^{55}Fe	20,000	^{134}Cs	0.07
^{60}Co	0.03	^{137}Cs	0.1
^{90}Sr	0.6	^{152}Eu	0.07
^{99}Tc	17	^{238}U	0.8
^{110m}Ag	0.03	^{241}Pu	1

Table 4. **Release levels which have been proposed for the release of the site of NPP Vandellós 1 (Spain) – Values relate to soil**

Radionuclide	Release level [Bq/g]	Radionuclide	Release level [Bq/g]
^{3}H	1.25E+02	^{125}Sb	4.63E+00
^{14}C	3.19E-01	^{134}Cs	9.38E-01
^{59}Ni	2.21E+02	^{137}Cs	3.27E-01
^{63}Ni	1.00E+02	^{152}Eu	4.57E-01
^{60}Co	4.95E-01	^{154}Eu	1.01E+00
^{90}Sr (^{90}Y)	1.52E-01	^{239}Pu	8.43E-01
^{94}Nb	9.23E-02	^{241}Am	8.22E-01

If the derivation of site-specific release levels rely on the exclusion of certain scenarios, like exclusion of groundwater pathways and use of this groundwater for drinking purposes as shown in Figure 1, it must be assured that the reasonably foreseeable land use will not include those scenarios until a time when radioactive decay has lowered the residual radioactivity to a sufficiently low level. If the site complies with the appropriate release criteria when a reasonable set of possible future uses have been considered, the site should be released for unrestricted use, which is the preferred option. If this is not feasible, the site may still be released after remediation for restricted use. In case of restricted use the restrictions should be designed and implemented to provide reasonable assurance of compliance with the dose constraint for as long as they are necessary. The restrictions should serve to exclude or prevent the exposure pathways leading to doses higher than the value of the dose constraint. Release of sites for restricted use generally required ongoing institutional involvement and control to implement the necessary restrictions.

The question remains, however, under which part of the regulatory framework such a restriction could be achieved. There are two basic possibilities:

a) The restriction of land use after release of the site is controlled by the nuclear authority, i.e. the same body which was responsible for the nuclear installation. This, however, means that the site will remain under some kind of nuclear licensing regime which might be unfavourable for the future site development in the conventional industrial sector.

b) The restriction of land use is recorded in the land title register. It would then be the responsibility of the authorities competent in the building law together with the land registry office to ensure that the restrictions are complied with. This is a common procedure which is applied for any real estate where rights or titles are to be preserved. In this case the nuclear authorities would only have to ensure that the appropriate restriction is entered in the land title register.

The question of whether a site may be released with restrictions on its later use should be determined on a site-specific level.

4.3 Partial site release vs. total site release

Some sites may be released using a phased approach. This means that a substantial part of the site will be released prior to the end of institutional control of the whole site, e.g. for settling new (non-nuclear) companies there or for reducing the size of the licensed nuclear site. Such a situation may occur when one reactor is decommissioned to green-field at a multi-block NPP site where the other units remain operational, or at a large nuclear site where some part of the land is not necessary due to changes in the nuclear programme.

The difference between radiological modelling for the release of the entire site and that for the partial site release is that the residual contamination remaining in the licensed site may affect the potential dose on the part to be released. This aspect needs to be taken into account when developing reasonable scenarios for partial site release.

4.4 Is international harmonisation required?

International harmonisation would always be of great benefit in gaining public confidence in the release standards used. However, harmonisation of release criteria might not be of great importance for sites because in this case international trade is not involved – as opposed to clearance of metal scrap or building rubble.

Yet, it might be beneficial for the acceptance of site release to have at least some guidance from international bodies how appropriate modelling should be carried out. Similar experience has been gained with international recommendations on clearance of metal scrap, buildings, building rubble etc. which have been issued by the European Commission for the EU Member States. Although these recommendations have been transposed into national legislation only in a small number of Member States, these recommendations serve as benchmarks in other countries for comparison with the national approaches. Therefore, international guidance on radiological modelling setting minimum standards might be a step worthwhile considering.

5. IMPLEMENTATION OF RELEASE OF SITES

5.1 Development of the plan for the final survey and the categorisation of sites

When the release of a site becomes imminent, a plan for the release and the final radiation survey needs to be developed. This plan must demonstrate how it will be assured that the site complies with the release criteria. On the basis of the site characterisation, the plan should identify the radiological contaminants and classify or categorise the impacted areas by their potential or probability for residual radioactivity. The plan also needs to establish the methods and performance criteria used the conduct the survey and define the number and location of measurements or samples necessary to ensure that the collected data will be sufficient for statistical analysis.

One of the most important steps in developing the final radiation survey plan is to establish a categorisation of the entire site according to the operating history and/or the likelihood of contamination. This is a reasonable approach to direct efforts for decontamination and for measurements to those parts which have the highest potential for contamination. A variety of categorisation schemes has been proposed. The following scheme is taken from the MARSSIM recommendations [7]. It is compatible to a number of approaches used at other site release projects.

Class 1 Areas: areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiation surveys) above the release criteria. Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete solid pieces of material and high specific activity.

Class 2 Areas: areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the release criteria. To justify changing the classification from Class 1 to Class 2, there should be measurement data that provides a high degree of confidence that no individual measurement would exceed the release criteria. Other justifications for reclassifying an area as Class 2 may be appropriate based on site-specific considerations. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form, 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of buildings or rooms subjected to airborne radioactivity, 5) areas handling low concentrations of radioactive materials, and 6) areas on the perimeter of former contamination control areas.

Class 3 Areas: any impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of residual radioactivity at a small fraction of the release criteria, based on site operating history and previous radiation surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Class 1 areas have the greatest potential for contamination. These areas therefore require the highest effort for release (highest number of sampling/ measurement points etc.). Table 5 gives an overview of the density of measurements which might be required on the three classes.

Table 5. **Recommended survey coverage for land and areas (from [4])**

Area classification	Surface scans	Soil samples
Class 1	100%	Number of data points from statistical tests; additional measurements may be necessary for small areas of elevated activity
Class 2	10 to 100% – systematic & judgmental	Number of data points from statistical tests
Class 3	Judgemental	Number of data points from statistical tests

5.2 Determination of nuclide vectors

Radionuclides present on the surfaces of the site or in the top layer of soil of the site need to be measured, e.g. by one of the methods described in Section 5.4, in order to demonstrate compliance with the release criteria as described in Section 4. 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 which need to be taken into account cannot be identified *in situ*. Furthermore, it would be a large waste of resources to determine the nuclide composition of the contamination on or in a site each time a measurement is carried out.

Therefore, the concept of radionuclide vectors (also called nuclide vectors, “fingerprints” etc.) is useful. The activity percentages of radionuclides which are or might be present on or in the site 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 like ^{60}Co or ^{137}Cs and those which are hard to measure like alpha emitters, pure beta emitters like ^{90}Sr etc. The radionuclides which are easy to measure are often referred to as “key nuclides” because the activity of the other nuclides is derived from them.

When establishing a nuclide vector, i.e. the list of activity percentages of all radionuclides to be taken into account on that particular site, radiological considerations need to be taken into account. The nuclide vector needs to be designed in a conservative way, i.e. the activity of the nuclides which are not directly measured must not be underestimated.

5.3 Subtraction of background

The subtraction of the background activity is an important issue as soil contains non-negligible amounts of radionuclides of the natural U and Th decay chains as well as ^{40}K. In addition, land has been exposed to fall-out which usually may be subtracted as well as it does not originate from the practice which has been carried out on the site.

5.4 Measurement techniques

5.4.1 Overview

A considerable number of different measurement techniques are available for site release measurements, as described below. The detection limits of many techniques are low enough to allow for rapid and significant measurements. There is therefore no need for totally new techniques although of course the development continues.

Measurements for site release need not cover the entire surface. A reasonable measurement density can be derived from statistical considerations, as described in Section 5.5. Furthermore, the measurement density will also depend on the category of the surface as described in Section 5.1. Such an approach can be combined with any of the measurement techniques described in the following.

There are measurement techniques which can detect the contamination on or in the soil or surface cover of the site directly or *in situ*, while other techniques rely on sampling and evaluation of the samples *ex situ* in a laboratory. Most direct measurement techniques can be applied for cases where the nuclide vector contains a sufficient amount of gamma or beta emitting radionuclides. For areas with substantial amount of alpha emitters or other radionuclides which are hard to measure and which cannot be correlated to an easy-to-measure radionuclide as described in Section 5.2, sampling may be the only reasonable approach.

5.4.2 Direct measurement techniques

5.4.2.1 In situ gamma spectrometry

The *in situ* gamma spectrometry is a non-destructive measurement method which detects the gamma emitting radionuclides on sealed surfaces or in the top layer of the soil down to a depth of several 10 cm, depending on the gamma energies of the radionuclides, on their spatial distribution and on other factors. This measurement technique discriminates the energies of the gamma radiation and can therefore be used for identification of the radionuclides present. It can also be used for detecting radioactivity beneath shielding layers.

The *in situ* gamma spectrometry can be applied in the usual uncollimated way where no spatial resolution of the activity distribution is possible and only the integral activity value can be derived, or in a collimated way where suitable shielding (the collimator) screens out radiation outside the opening angle of the collimator, limiting the measuring area to e.g. 1 m^2, depending on the opening angle and the height in which the spectrometer is placed above ground.

5.4.2.2 In situ total gamma measurement

The surface of the site is scanned by a detector which is sensitive to gamma emitting radionuclides. All gamma emitting radionuclides are measured integrally, i.e. no distinction between the radionuclides can be made. The activities of single radionuclides can be calculated from the measured integral activity using the percentages given in the previously established nuclide vector.

Total gamma measurements may be performed on sites where a sufficient amount of gamma emitting radionuclides is present, where the nuclide vector is established and where the penetration depth is not too deep.

5.4.2.3 Contamination monitors

Contamination monitors are sensitive to beta/gamma and/or alpha radiation. Because of the short length that beta particles travel in air and the extreme short distances for alpha particles, it is essential that the activity is located on the topmost layer. This method is therefore only applicable on smooth, dry and sealed surfaces, while it is generally inapplicable on open soil.

5.4.2.4 Other techniques

A variety of other techniques is available, ranging from dose rate measurements which rely on the increase of dose rate with respect to background to CCM (cobalt coincidence monitoring) which is sensitive nearly only to the radionuclide ^{60}Co. The overview given here is therefore far from complete, indicating that for nearly each measurement task a suitable technique is available.

5.4.3 Measurement techniques based on sampling

While the techniques described in Section 5.4.2 measure the activity *in situ*, i.e. on the spot, other of approaches need to rely on taking samples and analysing them *ex situ* in a laboratory. Those approaches are particularly relevant for cases where alpha or pure beta emitting radionuclides are present. Samples may also be taken as validation measurements for the measurement techniques described above. The large effort for taking and analysing samples prohibits extensive use of this approach in cases where other, direct measurement techniques are applicable.

Another variant of sampling is excavation of the soil of a site in layers down to a predetermined depth and measuring the excavated soil in release measurement facilities (measurement chambers surrounded by large proportional detectors which are sensitive to gamma radiation). If the excavated soil falls below predetermined limits, it can be considered in compliance with the release criteria and may be filled back to its previous place, assuming that the soil beneath it will have still lower activity concentrations. If it is above those predetermined limits, the soil is removed. Such a process has been successfully applied at areas of medium size at a number of mainly fuel cycle facilities.

5.4.4 Averaging areas

When activity measurements are taken it must be defined to which area they relate. A measurement with e.g. a collimated *in situ* gamma spectrometer measures an area of the order of 1 m². Measurements with such a technique would therefore give an indication of the variation of activity levels from one m² to the next. It is, however, not necessary to know the variation on this scale. Radiological evaluations for site release show that only the knowledge of activity concentrations averaged over much larger areas are relevant. Therefore, the so-called averaging area is introduced.

For the measurement techniques as described above, averaging areas which are reasonably large (100 m² to 10 000 m²) and are thus adapted to the issue of site release are applicable. This has been demonstrated by several countries which have even introduced such averaging areas in their national legislation (e.g. Germany). These averaging areas match in particular the approach of *in situ* gamma spectrometry combined with statistical approaches.

The application of large averaging areas requires that the activity is sufficiently homogeneously distributed. The potential or suspicion for the presence of “hot spots”, i.e. high-active particles on the site, would require using an appropriately smaller averaging area.

5.4.5 Room for improvement

Because of the complexity of the measurement process and the statistical evaluation, it might also be a reasonable approach to develop international standards for the application of these techniques. International standards for similar measurement techniques like e.g. the standard ISO 7503 on the evaluation of surface contamination have fostered harmonisation in the application of measurements and have influenced national standardization projects.

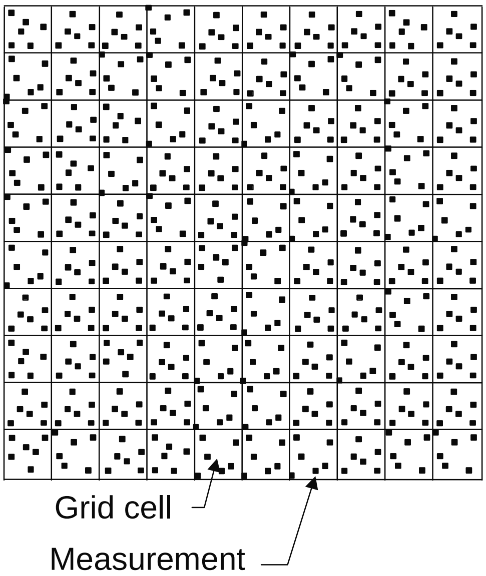
5.5 Statistic evaluations and data assessment

As it is not desirable to carry out measurements on the entire surface area of the site to be released, there must be statistical criteria to decide which percentage of the area needs to be measured and how reliable the result then is. Such statistical evaluations depend on many factors, like the measurement technique, the likelihood of contamination, the desired confidence level etc. There is a variety of approaches which have been used for deriving appropriate measurement densities at various site releases, some starting from quite simple statistical considerations while others use a refined and iterative approach that can deal with changing activity concentrations.

A common feature of all these approach is that the derived measurement density is on most surfaces far below 100%. Figure 2 gives an idea of such a measurement scheme where the total area is divided into 100 grids, each of which corresponds to the averaging area of 100 m². Six measurements per grid cell (1 m² measurement area) are carried out according to a random selection of measurement spots. The measurement density would thus be 6% in this example. Actual release measurements have used approaches with similar grid sizes and measurement densities.

The data which has been acquired during the release measurements needs to be assessed and subjected to quality assurance procedures. Those methods depend to a large extent on the measurement scheme, the measurement method and other requirements. Examples are given e.g. in [7].

Figure 2. **Example of a measurement pattern with a given number of measurements per grid cell. The grid cell may be 100 m^2, the measurement area 1 m^2. The total area would then be 10 000 m^2.**



6. SITES WITH UNDERGROUND CONTAMINATION

Release criteria and survey methods are generally developed for surficial residual radioactivity (in the upper 5–15 cm of soil). If significant amounts of residual radioactivity have penetrated to depth deeper than this range, this should be taken into consideration when performing the radiological modelling and when developing the final survey plan.

In such cases, the first step is usually to determine the penetration depths of the contaminants. The penetration depth may significantly vary over the site. In addition, it will also vary with the properties of the chemical elements of which the contamination consists, like K_d values by which the solubility and therefore the movement in the soil is determined. If the penetration depth is high, it may be a sensible approach to determine the depth down to which the soil has to be removed until the release criteria are met for each single area (grid cell) of the site separately. In this way, the amount of material which needs to be excavated is minimised. Underground contamination can also become an issue when in the past sediments of ditches carrying effluents have been removed and put somewhere else on the site, possibly covering them with soil of no or lesser contamination on top, thereby reversing the natural gradient of activity distribution. In those cases, good knowledge of the site history is of extreme importance.

7. CONCLUSIONS

The release of sites of nuclear installations or places where a licensed use of radionuclides has taken place is a mature practice in those countries with a number of advanced or completed decommissioning projects. Appropriate techniques for measurements combined with statistical approaches which allow calculating the measurement density in accordance with the contamination level of the site are available. Release measurements can be applied swiftly for cases where a substantial amount of gamma emitting nuclides is present in the radionuclide vector, but can cause a much higher effort for cases where alpha emitters or other nuclides which are hard to measure and which cannot be correlated to easy-to-measure nuclides. In the latter case, the release measurements have to rely to a great extent on sampling and laboratory analysis.

A number of countries have carried out release of sites successfully by using different dose criteria, ranging from the trivial dose range (~ 10 µSv/a) up to a larger fraction of the individual dose limit of 1 mSv/a (~ 100 to 300 µSv/a). In addition, different models for the derivation of suitable release criteria have been applied. As a site is essentially immobile after its release, there seems to be less need for an international harmonisation of release criteria and approaches than e.g. for the clearance of metal scrap, of building rubble etc. which may be transported across borders and for which an international harmonisation seems to be desirable. It might therefore be prudent to watch more projects that include release of sites to see whether a common approach can be extracted, and to decide on the necessity of harmonisation with respect to release of sites when more experience will be present.

8. REFERENCES

[1] Release of Sites of Nuclear Installations – Evaluation of a Questionnaire issued by the WPDD of the OECD/NEA and Other Background Information, NEA/RWM/WPDD(2005)10.

[2] International Atomic Energy Agency: International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Standards, Safety Series No. 115-I, Vienna, 1994.

[3] International Atomic Energy Agency: Application of the Concepts of Exclusion, Exemption and Clearance; Safety Guide RS-G-1.7, Vienna 2004.

[4] International Atomic Energy Agency: Release of Sites from Regulatory Control upon Termination of Practices, Draft Safety Guide, DS 332.

[5] Removal of Regulatory Controls for Materials and Sites. National Regulatory Positions. RWMC Regulators' Forum (RWMC-RF)**,** Paris, September 2004, NEA/RWM/RF(2004)6.

[6] RESRAD: User's Manual for RESRAD, 2003.

[7] NUREG/EPA/DOE: Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM); NUREG 1575-Rev. 1, 2002.

[8] Verordnung über den Schutz vor Schäden durch ionisierende Strahlung (Strahlenschutzverordnung) – Bundesgesetzblatt (Federal Law Gazette), G 5702, 26 July 2001, No. 38, p. 1714.

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