Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Author: Robert A. Meck

2013:14

Approaches used for Clearance of Lands from Nuclear Facilities among Several Countries

Evaluation for Regulatory Input

Report number: 2013:14 **ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

SSM perspektiv

SSM har nyligen beslutat om föreskrifter om friklassning av material, lokaler, byggnader och mark vid verksamhet med joniserande strålning (SSMFS 2011:2). Föreskrifterna innehåller bland annat krav på att tillståndshavare, vid avveckling av verksamhet med joniserande strålning, ska vidta åtgärder som möjliggör friklassning av lokaler, byggnader och mark. Föreskrifterna innehåller nuklidspecifika friklassningsnivåer i becquerel per m2 för lokaler och byggnader men ger ingen upplysning om vilka friklassningsnivåer som ska tillämpas vid friklassning av mark. Istället anges att SSM ska besluta om friklassningsnivåer för mark i det enskilda fallet och att tillståndshavaren ska upprätta ett kontrollprogram för den provtagning och de mätningar som avses genomföras för att visa att friklassningsnivåerna uppfylls.

Under kommande år avser SSM att utveckla föreskrifter och eventuellt även allmänna råd om friklassning av mark som kan ha förorenats med radioaktiva ämnen till följd av verksamhet med joniserande strålning, till exempel drift av kärnteknisk anläggning. Som underlag för detta arbete, och för att bidra till utvecklingen i Sverige av robusta metoder för provtagning, friklassningsmätning och utvärdering av resultaten, har SSM låtit genomföra den studie som redovisas i denna rapport. I rapporten görs en utvärdering av olika metoder och angreppssätt som tillämpas i några utvalda länder för att uppnå friklassning av markområden där kärnteknisk verksamhet bedrivits. De olika metoderna och angreppssätten analyseras med avseende på ett flertal olika aspekter.

Studien fokuserar på frågan om hur det på ett tillförlitligt och transparent sätt kan visas att angivna friklassningsnivåer innehålls. (Den amerikanska term som används för friklassningsnivåer för mark är DCGL, derived concentration guideline levels.) SSM avser att arbeta vidare med frågan om vilka friklassningsnivåer som ska gälla i Sverige och vilka metoder som bör tillämpas för att visa att nivåerna inte överskrids. En utgångspunkt i detta arbete är att friklassningsnivåer kan variera från fall till fall beroende på de lokala förutsättningarna och den förutsedda fortsatta användningen av marken, till exempel odling eller industriell användning (ofta kallat "green field" respektive "brown field"). Detta utesluter dock inte att generella, vägledande friklassningsnivåer för mark kan komma att inkluderas i kommande föreskrifter (nya föreskrifter eller revidering av SSMFS 2011:2).

Studien har genomförts av Robert (Bob) A Meck vid Science and Technology Systems, LLC, USA. Bob Meck har lång erfarenhet av arbete vid den amerikanska kärnkraftmyndigheten Nuclear Regulatory Commission (NRC), bland annat gällande friklassning av material och landområden. Bob Meck ledde NRC:s arbetsgrupp och var en av huvudförfattarna till MARSSIM-manualen, vilket är en av de metoder som utvärderas i denna rapport.

SSM har inte dragit några definitiva slutsatser av studien. Istället välkomnas kommentarer och förslag som kan bidra till utvecklingen av brett accepterade standarder och robusta, transparenta metoder för friklassning av mark. Kommentarer och förslag kan skickas per e-post till registrator@ssm.se eller henrik.efraimsson@ssm.se, eller med vanlig post till Strålsäkerhetsmyndigheten, 171 16 Stockholm.

SSM perspective

SSM has recently established new regulations for clearance of materials, rooms, buildings and land (SSMFS 2011:2). The regulations specify that license holders for practices involving ionising radiation shall take measures after the cessation of the practice to achieve clearance of rooms, buildings and land. The regulations state nuclide specific clearance levels in becquerel per m2 for rooms and buildings, but give no information on levels to be used for the clearance of land. Instead, it is stated that SSM shall decide on clearance levels on a case by case basis and that the license holder shall develop a control program for the methods and procedures to be used in clearance monitoring.

In the coming years, SSM intends to develop regulations, and possibly also guidance, on clearance of land that may be contaminated due to practices involving radioactive substances, such as the operation of nuclear facilities. As a basis for this work, and to support the development of robust procedures for performing clearance measurements and showing compliance with clearance levels for land, SSM has initiated the study presented in this report. The study evaluates methods and approaches used in different countries to achieve clearance of land where nuclear activities have been carried out (also called site release). The different methods and approaches are analysed using a broad variety of attributes.

The study is focused on the issue of showing compliance with given clearance levels for site release (also called derived concentration guideline levels, DCGL:s). SSM intends to continue working on establishing such clearance levels in Sweden. As a starting point, SSM foresees that levels applied will depend on the features of the specific site and on the expected future use of the land, for example farming or industrial use (i.e. green or brown field, respectively). This does however not exclude that general clearance levels for guidance may also be included in regulations (new regulations or a revision of SSMFS 2011:2).

The study has been conducted by Dr Robert (Bob) A Meck, Science and Technology Systems, LLC. Bob Meck has long experience in the field from working with the US Nuclear Regulatory Commission (NRC) on, inter alia, regulations and procedures for clearance of materials and land. He was the NRC lead for and one of the major contributors to the MARSSIM manual, one of the procedures assessed in the present study. SSM has not drawn any definitive conclusions from the present study. Instead, comments and suggestions are invited to facilitate the process of developing commonly accepted standards, as well as robust, transparent procedures for clearance of land areas in the future. Comments and suggestions may be send by e-mail to registrator@ssm.se or henrik.efraimsson@ssm.se, or by post to SSM, 171 16 Stockholm, Sweden.

Project information

Contact person SSM: Henrik Efraimsson

Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Author: Robert A. Meck, Ph.D
Science and Technology Systems, LLC / Bethesda, Maryland, USA

2013:14

Approaches used for Clearance of Lands from Nuclear Facilities among Several Countries

Evaluation for Regulatory Input

Date: September 2012
Report number: 2013:14 **ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

Contents

Summary

This report compares specific information from several countries on the processes and methods used to demonstrate compliance with clearance levels for site release. Knowledgeable key experts in France, Germany, Spain, the United Kingdom (UK) and the United States (US) provided information sources from their respective countries. A significant amount of additional information was found on authoritative and official web sites. The clearance criteria in all of these countries generally result in a dose or risk equivalent to the range of a one-in-one-million to one-in-ten-thousand chance of a fatality in a year. Also, there are significant variations of the approaches to and guidance for implementing the demonstration of compliance with the clearance criteria.

Making a comparison of clearance implementation guidance used in different countries is complicated, because it needs to look at - in addition to technical aspects of measurements - other aspects such as regulatory culture, stakeholder input, and level of prescriptiveness. In order to cover this wide range of aspects and to make the comparison between countries, the guidance from each country was assessed based on ten chosen attributes. For most, if not all, the approach taken for an attribute in the guidance has trade-offs in the expected outcomes. For example, more flexibility can delay finality, and the more prescriptive guidance can expedite implementation and regulatory reviews. In the end, the regulatory authority or authorities must determine the approach for developing the implementation guidance in the context of their present and anticipated future situations. An effective and efficient method for the development process is to structure the development of the guidance with the Data Quality Objectives method. In any case, development of guidance can build or use directly from established guidance that has proven to be effective, efficient, widely used and results in a technically sound decision on clearance. The main examples of such guidance are MARSSIM and EURSSEM.

List of Acronyms and Abbreviations

/a	Per annum or per year
AEA	US Atomic Energy Act as amended
ALARP	As Low As Reasonably Practicable
ANSI/HPS	American National Standards Institute/Health Physics Society
ASN	Autorité de Sûreté Nucléaire [*French* Nuclear Safety Authority]
AtG	Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz - AtG) [*German* Act on the Peaceful Utilisation of Atomic Energy and the Protection against its Hazards (Atomic Energy Act)]
AWE	UK Atomic Weapons Establishment
BNFL	British Nuclear Fuels, Ltd.
CEA	Commissariat à l'énergie atomique et aux énergies alternatives [*French* Atomic Energy and Alternative Energies Commission]
CIRIA	The Construction Industry Research and Information Association
CSN	Consejo de Seguridad Nuclear [*Spanish* Council of Nuclear Safety]
DCGL	Derived concentration guideline level
DIN	Deutsches Institut für Normung [German Institute for Standardisation]
DOE	US Department of Energy
DQO	Data Quality Objective
EA	UK Environment Agency
EC	European Commission
ENRESA	Empresa Nacional de Residuos Radiactivos SA [*Spanish* National Company of Radioactive Waste, Incorporated]
EPA	US Environmental Protection Agency
EURSSEM	European Radiation Survey and Site Execution Manual
HSA	Historical Site Assessment
HSE	UK Health & Safety Executive
HSE NII	UK Health & Safety Executive Nuclear Installations Inspectorate
L	Location of measurements
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment
MARSAS	Multi-Agency Radiation Survey and Assessment of Sub-surface Soils
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	Minimum detectable concentration
MWe	Mega-Watts electric
N	Number of measurements
NDA	UK Nuclear Decommissioning Authority

NGO	Non-Governmental Organizations
NPP	Nuclear Power Plant
NRC	US Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
PSG	Project Steering Group
RMC	Ready Mixed Concrete
SADA	Spatial Analysis and Decision Assistance
SAFEGROUNDS	SAFety and Environmental Guidance for the Remediation of contaminated land on UK Nuclear and Defence Sites
SD:SPUR	Site Decommissioning: Sustainable Practices in the Use of Resources
SITF	Shopfitting Independent Training Forum
SLC	Site Licence Companies
SSK	Strahlenschutzkommission [*German* Commission on Radiation Protection]
SSM	Strålsäkerhetsmyndigheten [Swedish Radiation Safety Authority]
Sv	sievert
UK	United Kingdom
UKAEA	United Kingdom Atomic Energy Authority
US	United States of America
WPDD	*OECD Nuclear Energy Agency* Working Party on Decommissioning and Dismantling

1. Introduction

1.1. Background and purpose

The Strålsäkerhetsmyndigheten (SSM) [Swedish Radiation Safety Authority] has authorized the development and publication of this report to compile and analyse information on approaches used for the final status survey by several counties for the clearance of lands from nuclear facilities. Clearance of buildings, materials, equipment, and mines are beyond the scope of this report.

The development of implementation guidance is complex, because it depends on more than the technical aspects of modelling clearance levels and measuring them. For the guidance to be effective, efficient, and widely accepted, it needs to be in the context of the regulatory culture, stakeholder input, and have an appropriate level of prescriptiveness, among other things.

The purpose of this report is to describe, compare and evaluate the pros and cons of different methods for radiological characterisation of land areas after decommissioning of nuclear facilities. Specifically, methods used in France, Germany, Spain, the United Kingdom (UK), and the United States (US) are included in this analysis. The subsection below outlines the approaches for obtaining the relevant information and the bases for the evaluations. The following subsection provides descriptions of the general approach and its attributes for each country. The comparisons and evaluations are in Section 3, and they are followed by the section on considerations for developing regulations and guidance for site release. The last sections are comprised of concluding remarks, acknowledgements and references.

1.2. Attributes used for evaluating country-specific approaches

The evaluation of the guidance from each country was based on the following ten attributes which were considered important aspects of the clearance process for land:

- *Regulatory basis*—statement of regulatory requirements; specific or general connection to regulations. Typical questions: Exactly what are the legal requirements as stated in the law? Is the guidance specifically related to the various topics of the regulation or does it generally refer to the law without addressing the specific aspects?

- *Scope*—general or specific; includes instrumentation and uncertainties; entire process or limited to clearance approval; surfaces and sub-surfaces; etc. Typical questions: There are numerous complex tasks that are interrelated required to verify that the criteria have been met for release from radiological control. These requirements include the underlying mathematics, evaluation of uncertainties, instrument calibration and sensitivity, etc. How thoroughly do the regulations and guidance address the wide range of tasks for implementation?

- *Applicability*—general description of processes or specifically addresses how to demonstrate compliance with the criteria for release from radiological controls, i.e., clearance. Typical questions: How explicitly do the regulations and guidance provide details to the users or are they generally referred to with an implied case-by-case evaluation to follow?

- *Flexibility*—prescriptive or outcome based; implementation of specific procedures results in clearance by authorities or case-by-case reviews required; various interpretations of the requirements possible; ability to modify requirements. Typical questions: Are all cases generally reviewed against consistent criteria or is each one considered individually anew? Do the legal requirements permit interpretation, and do they have provisions for exceptions? Does the guidance allow for the development of different approaches?

- *Transparency*—explicit and detailed descriptions of processes; adequate clarity to allow reproduction of results. Typical questions: Are the documents produced to demonstrate compliance detailed enough to allow an independent party to reproduce the results and conclude that the clearance criteria have been met?

- *Roles and responsibilities of parties involved*—specific requirements by authorities; responsibility of facility operators; role of various implementers of clearance procedures; role of various stakeholders. Typical questions: Are clear lines of responsibility and authority established by the requirements and guidance? How are decisions made for implementing procedures? Is the person who makes the decision also an implementer? Is there a final single authority that clears the facility or is it a concurrence of several authorities?

- *Quality program*—control of processes and documentation. Typical questions: How can an independent third party verify that procedures were correctly followed and documented? Do the requirements and guidance require a quality program?

- *Detail of measurement descriptions*—types of instruments, calibration, use of radionuclide vectors, uncertainty calculations. Typical questions: Do the measurement descriptions in the requirements or guidance sufficiently call for enough detail to enable a qualified third party to repeat the results?

- *Mathematical approaches*—rigorous or general technical defensibility; explicit or general detail of mathematical procedures. Typical questions: How do the requirements or guidance ensure that the conclusions from the measurements are technically sound and defensible, mathematically?

- *Available assessment tools*—statistical software applications for clearance; data logging of measurements; mapping software. Typical questions: Do the requirements or guidance indicate available assessment tools for statistical software applications? If so, do they cover a broad range of measurement techniques?

While there may be additional attributes that could be evaluated, the above list was considered sufficient for the purposes of this report. Clearly, the evaluation of these attributes is based on the detail and applicability of the collected information and on expert judgment. The collected information is the result of diligent efforts to get accurate, current, information from authoritative sources in each of the countries compared in this report. Naturally, the evaluations may be subject to modification, based on authoritative new information.

1.3. Methods used to gather information

Professional network referrals identified subject matter experts in each of the five countries who were then contacted. The contacts provided electronic documents or online links to the publicly available information. The online links often led to additional world-wide-web searches and more information. In addition, some information was provided by private communication in e-mails. Other experts provided electronic proceedings of a conference or symposium. A significant fraction of the source information was available only in French, or in German, or in Spanish. Translations of these documents to English enabled a reasonable and sufficient understanding of the concepts as well as the methods and procedures. The information sources and a summary of their contents are listed in Section 2 on a country-by-country basis.

2. Demonstration of compliance with clearance levels for site release—approaches by country

This Section specifies the evaluated reports on a country by country basis. The reports are identified and briefly described in general terms. Descriptions focus on topics applicable to a comparison and contrast with the attributes stated above in Section 1.2.

2.1. France

2.1.1. General Approach

The regulatory basis for site clearance comes, at least in part, from two acts, a decree, and a policy. Specifically, they are:

- Act No. 2006-686 of 13 June 2006 on the transparency and security in the nuclear field—generally, this Act empowers the Autorité de Sûreté Nucléaire (ASN) [Nuclear Safety Authority] to regulate the operations of the nuclear industry [1];
- Act No. 2006-739 of 28 June 2006 program on the sustainable management of materials and radioactive waste—this Act provides regulations for the management of radioactive wastes. Its definitions include:
    - A radioactive substance shall include any substance containing natural or artificial radionuclides, the activity or concentration of which warrants a radiation-protection control; and
    - Radioactive waste shall include any radioactive substance for which no further use is prescribed or considered [2]
- Decree No. 2007-1557 of November 2, 2007 relating to nuclear installations and control under the Nuclear Safety of transport of radioactive substances—this Decree addresses the timing and processes of decommissioning, among other things [3];
- ASN Policy for dismantling and decommissioning of nuclear facilities in France - April 2009—this Policy refines the requirements on timing and processes for decommissioning, among other things [4].

In general, the ASN guides appear to allow great flexibility of the approaches and processes that nuclear installations are required to address in a comprehensive list of required topics. Unlike some other national approaches, the French approach to clearance is woven into the entire operation and final-status, including financial, decommissioning and dismantlement, and handling of waste. They facilitate this overview approach with the concept of zoning—the separation of conventional materials from materials with associated radioactivity from the installation’s operation. As a consequence, each installation may be different in the details on how to arrive at the final-status, but, at the same time, each is required to address the same topics.

Guide de l'ASN n°14 : Méthodologies d'assainissement complet acceptables dans les installations nucléaires de base en France [Acceptable Methods of Complete clean-up of Nuclear Facilities in France] [5]—The basic processes for clearance of nuclear facilities in France are dependent upon the identification of waste zones. In contrast to the approach of several countries, this guide is focused on the radioactive waste and the non-radioactive waste. The approach is that decontamination and decommissioning a nuclear facility requires management of radioactive and non-radioactive waste. A nuclear facility requiring clean-up for decommissioning can be viewed as a waste management project. Radioactivity on facility surfaces and in depth of materials may be viewed as waste to be removed. The parts of the facility that fit this potential to contain radioactivity associated with the operation of the facility constitute the zone that serves as the first line of defence.

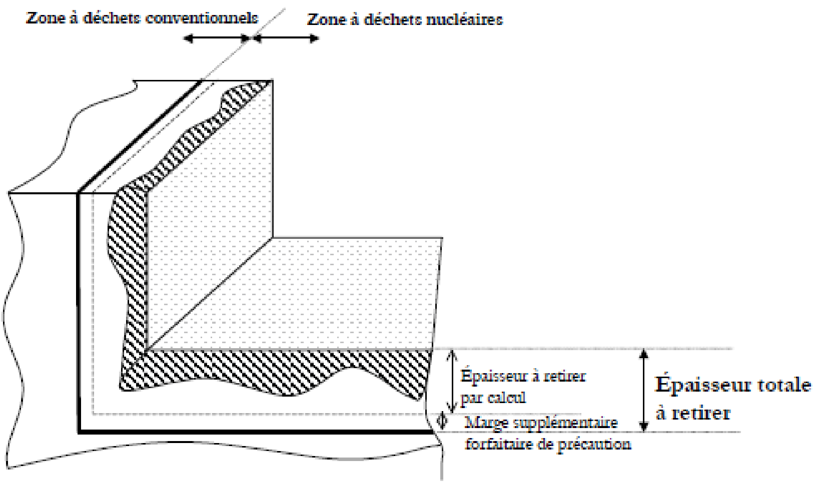


Figure 1. Illustration of the zone of the first and second lines of defence: The wide black line separates the zone of conventional waste from the zone of nuclear waste. The total thickness to be removed consists of the calculated thickness to be removed plus Φ, the flat-rate, precautionary supplemental margin. Figure 1 from *Guide de l'ASN n°14*.

This guide emphasizes that a comprehensive overview must be taken to quantify the zone. Simple *ad hoc* measurements are not enough. Within this first line of defence, there can be four categories of potential and physical characteristics of radioactivity and their respective treatments.

Table 1. Categories of potential and physical characteristics of radioactivity and their respective treatments.

Category	Radioactivity	Treatment
Category 0	no surface radioactivity or activation	no treatment
Category 1	demonstrated or suspected radioactive contamination of radioactive dust or aerosol	treatment of a very thin surface
Category 2	areas with proven or suspected radioactive liquid contamination	treatment remove the thickness in the defined area with suspected or proven liquid radioactive contamination
Category 3	surface activated or contaminated with penetrating radioactivity	treatment case-by case

Surface layers are removed to a calculated depth plus an additional depth as a precaution to ensure that what is left is conventional waste (cf Figure 1 above). This is the zone that is second line of defence and is where non-radioactive or conventional waste may be generated. Care must be taken to ensure that the conventional waste does not contain radioactivity above background levels. A third line of defence is the monitoring of the conventional waste as it leaves the facility. There is always the flexibility to change the zone of a part of the facility on a case-by-case basis. There is not a universal clean-up level threshold. The manager makes the determination of the objective concentrations in consideration of the potential impacts. However, risk has to be taken into account.

Guide de l'ASN n°6 : Mise à l'arrêt définitif, démantèlement et déclassement des installations nucléaires en France [Setting the decision of final dismantling and decommissioning of nuclear facilities in France] [6]**—**This guide addresses the administrative aspects of final closure of a nuclear installation in France, after which there are no further radiological controls, i.e., clearance. The guide details the topics required in a decommissioning plan and in an appendix addresses final issues, such as the environment, radiation protection, waste and zoning, etc. It states that it is the responsibility of the operator to plan and ensure that all hazardous waste, including radioactive waste, is removed. The IAEA Safety Guide No. WS-G-5. 1 *Release of Sites from Regulatory Control on Termination of Practices* [7] is cited as an example of internationally accepted and best practices as a context for this guide.

Commissariat à l'énergie atomique et aux énergies alternatives (CEA) [Atomic Energy and Alternative Energies Commission] **—**CEA is a French government-funded technological research organisation. A prominent player in the European Research Area, it is involved in setting up collaborative projects with many partners around the world. CEA has developed geostatistics software adapted to radioactive waste categorization, and it has been validated on more than 100 sites. CEA and Geovariances, in a partnership, developed Kartotrak™, which is the name of the commercial software version that provides an integrated workflow from in-situ characterization to final control after remediation. It precisely maps the radioactivity at each step of the characterization sequence. The software can also map the confidence intervals of measurements. A Geographic Information System tailored to radiological needs constitutes the heart of the platform; it is complemented by several modules aiming at sampling optimization (Stratege), data analysis and geostatistical modelling (Krigéo), real-time monitoring (Kartotrak-RT) and validation of clean up efficiency (Pescar) [8] [9] [10; 11].

2.1.2. Description of Attributes

- *Regulatory basis*—The regulatory instruments listed above in Section 2.1.1 provide a regulatory framework for decommissioning, waste disposition, and a final judgement on the status of the facility. The ANS guides give details on the general approaches for implementation. There is considerable flexibility in the implementation left to the judgment of the facility operator, but the details of the implementation must be documented in the decommissioning plan and approved by the regulator, ASN. Thus, within the framework, the implementation and final judgment are on a case-by-case basis.

- *Scope*—The scope of the reviewed documents covers the general administrative processes of decommissioning from start to finish, especially with the timing requirements for implementation. The reviewed documents did not specifically address the details of how conventional waste is verified to be not a radioactive substance under the definition in the Act addressing radioactive waste. For example, no guidance was found specifying instrument performance requirements or evaluation of uncertainties. The ANS Policy states: "The final state achieved upon completion of the dismantling operation must be capable of preventing or sufficiently limiting the risks or disadvantages which could be presented by the dismantled facility and its site in terms of public health and safety or protection of the environment, taking into consideration, in particular, the anticipated re-use of the site or buildings. This objective must be fixed and based on the scientific and technical knowledge available at the time;" and, "In terms of the dosimetric impact of the facility and of its site after dismantling, operators' objectives are justified in relation to national and international best practices, in particular the guide developed by the IAEA on this subject." [4]

- *Applicability*—The information reviewed generally addressed that a final judgment on the facility status would be made. However, the details of how the final judgment is to be made appear to depend on the satisfactory completion of the decommissioning plan. The technical basis for the judgment, such as acceptable uncertainty and dose rates, apparently can vary on a case-by-case basis.

- *Flexibility*—Within the administrative and timing framework for decommissioning set out by the regulatory requirements and guidance, the details of implementation appear to be highly flexible. The flexibility is a result of the case-by-case approach which can lead to various interpretations of the requirements and a potential ability to modify requirements for a specific facility.

- *Transparency*—Except for the administrative and timing details of the overall framework, the reviewed documents did not address explicit and detailed descriptions of the processes. However, documentation of the entire decommissioning plan is required and files are to be publically available. Investigation of the transparency of clearance on a facility-by-facility basis is beyond the scope of this report.

- *Roles and responsibilities of parties involved*—The general and some specific requirements by authorities and responsibility of facility operators are reasonably explicit in the reviewed documents. Beyond the overall role of the facility operator, the roles of various implementers of clearance procedures and processes are not addressed. The requirement to include various other stakeholders is addressed. The ASN Policy includes a statement that statutory procedure for obtaining authorization to decommission requires consultation between the relevant parties: the public, the public authorities concerned (national or European) and the local information commission. In order to facilitate the mission of local information commissions, and, in particular, to enable them to return their opinions on the file under proper conditions, ASN recommends that operators form an active partnership with them during the final shutdown and dismantling authorization application procedure [5].

- *Quality program*—The documents reviewed did not specifically address quality control of processes. The public availability of the entire decommissioning plan may indirectly provide quality control feedback if there is a mechanism to do so. No information was found on the data quality requirements of measurements used to make decisions.

- *Detail of measurement descriptions*—The details of the measurement implementation were not found in the general guidance documents reviewed. It seems likely these details may be found in the site-specific plans. However, the review of site-specific plans is beyond the scope of this report.

- *Mathematical approaches*—Requirements and guidance from ASN apparently do not indicate specific mathematical approaches to provide the technical basis for clearance of nuclear facilities. Rather, they recommend the best available technology. In support of using the best available technologies, CEA actively conducts research as demonstrated in the Échantillonnage et Caractérisation II [Sampling and Characterization II] symposium in April 2010. Exactly on this topic, Nadia Perot presented comparisons the method of Wilks with the Sign test and the Wilcoxon Rank Sum tests as described in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) from the U.S. [12] [13]. MARSSIM is described below in Section 2.5.

• *Available assessment tools*— CEA and Geovariances, in a partnership, developed Kartotrak™, which is the name of the commercial software version that provides an integrated workflow. In addition there are other statistical software applications for clearance; data logging of measurements; mapping software, etc.

2.2. Germany

2.2.1. General Approach

The regulatory basis for clearance of nuclear facilities in Germany lies in the German Radiation Protection Ordinance [11]. The clearance criteria are prescribed in comprehensive detail by this Ordinance. The clearance values of Annex III Table 1 Column 7 of the German Radiation Protection Ordinance have been based on a detailed study after consultation within the German SSK (German Commission on Radiation Protection) [14].

Decommissioning of nuclear installations routinely ends with leaving structures in the ground, e.g. those of foundations below a depth of, e.g., 2 m. However, the authorities usually require radiological assessment and clearance of these structures by the operator (with the approach usually used for clearance of buildings, i.e. sampling, in situ gamma spectrometry, surface contamination monitors or something like that). This means that above-ground, there will usually be green-field, but below grade, structures may remain [15].

Green-field is, however, no requirement by any part of the regulatory framework in Germany. It is usually chosen for practical reasons for NPPs and fuel cycle installations, as nobody could make reasonable use of these buildings afterwards. This is not the case for research reactors, as those are often located inside institutes or large hospitals, where just the rooms are decontamination and cleared, while the building structure is left standing for subsequent use. This is even more relevant for clearance of radionuclide laboratories which often are used afterwards as "normal" laboratories [15].

Summing up: All large NPPs and fuel cycle installations have been decommissioned to green field (for the reason given above), i.e. NPPs Niederaichbach (KKN), Heißdampfreaktor Großwelzheim (HDR), and Versuchsatomkraftwerk Kahl (VAK) and the U fuel cycle facilities at Hanau. Buildings of the larger research reactors, e.g. at PTB Braunschweig (FMRB), Berlin (BER), DKFZ Heidelberg (HD-I, HD-II) and others have been left standing for further use, while the RRs at Juelich (FRJ-1) has been fully dismantled to green field [15].

DIN-25457-7: 2008-1, Aktivitätsmessverfahren für die Freigabe von radioaktiven Reststoffen und kerntechnischen Anlagenteilen - Teil 7: Bodenflächen [Activity measurement methods for the release of radioactive waste materials and nuclear facility components - Part 7- ground areas]

(DIN) [16] —This standard applies to land surfaces only and excludes buildings. It applies to radioactivity from the regulated operations of the nuclear facility. It uses preliminary surveys and process knowledge to plan the measurements. It has a statistical approach for using the measurements and deciding the compliance with clearance criteria.

The DIN mentions that preliminary investigation may be necessary to identify the kinds, relative concentrations, and spatial distributions of the radioactivity. Not much detail is given on the procedure or the specific items that are needed. The focus of the DIN is the demonstration that the survey unit meets radiological clearance criteria.

The DIN has useful flow diagrams that illustrate the sequence of the procedures and the decision points. The area that the decision applies to is categorized in the DIN by one of three categories as listed in Table 2 below.

Table 2. Categories of areas according to their potential concentrations of radioactivity from the facility.

Category	Radioactivity
Category 1	concentrations may exceed the clearance levels
Category 2	concentrations are below clearance levels
Category 3	no indication that radioactivity from the nuclear facility is or has been present

The DIN provides a procedure for clearance of soil that has radioactivity at depth. Layers of soil are removed and measured, and the remaining soil at the survey unit is measured again. If there is radioactivity remaining that exceeds the clearance levels, then the process is repeated until the survey unit meets the clearance criteria. The last layer removed may be used as backfill if it is below the clearance level. This DIN references other German standards to provide detailed guidance on specialised topics, such as instrument calibration and sensitivity.

2.2.2. Description of Attributes

- *Regulatory basis*—The German Radiation Protection Ordinance [11] provides comprehensive, detailed, and prescriptive requirements for clearance of nuclear facilities. The requirement is dose-based. It requires that clearance does not cause any member of the public to be exposed to an effective does more than on the order of 10 µSv in a calendar year thereafter. Its Annexes provide extensive tables of radionuclide concentrations that can be considered to meet this dose-base clearance requirement. The requirements are clearly stated. In addition, the DIN [16] provides detailed procedures for how to implement compliance with the regulatory requirements;

- *Scope*—The DIN addresses a broad range of topics encountered in the processes encountered in finally authorising clearance. It also clearly limits its scope to ground surfaces and radionuclides that are from the licensed operation of the facility. Areas to be cleared are categorised according to their potential to exceed the clearance levels and processes are adapted to the categorisations. It cross-references related standards that address more specifically measurement methods, scrap metal, buildings, and building rubble. It includes the relationships of grid size to the effective detection areas of the instruments. There are sections specifically addressing areas for averaging measurements, nuclide vectors, statistics for demonstrating compliance, and documentation of the processes. Surface area and mass are addressed, as well as, methods for handling of sub-surface radionuclides and helpful flow diagrams for making decisions;

- *Applicability*—The DIN specifically addresses the authorisation of clearance for ground surfaces at nuclear facilities that do not involve intervention as a result of their operations and is well-focused on this end-point. (Intervention as used here is in the same sense as used by IAEA. An example would be an accident resulting in the potential for unacceptable exposures.) It is broadly applicable to all such facilities;

- *Flexibility*—Both the Radiation Protection Ordinance and the DIN are prescriptive in nature. Upon request, the authority may find that the dose-based requirement for clearance may be met in a specific situation by the use of different criteria, e.g., different radionuclide concentrations. [See Part 2, Chapter 2, Section 9, §29 (2).] Notable flexibilities arise in the DIN for areas of statistical treatment of log-normally distributed radionuclide concentrations and also for the level of detail in implementation plans;

- *Transparency*—Most technically qualified persons should be able to produce or reproduce results from the explicit and detailed descriptions of processes. Documentation or plans to receive authorisation for clearance could be anything from the entire suite of volumes comprising the decommissioning project down to the single "safety report", where the whole project is summarised in short. However, the final step of such a project need not be documented there, as this could be changed or decided by the operator during the course of the project with a separate license [15].

- *Roles and responsibilities of parties involved*—The roles of the competent agencies are included in the AtG. Roles of the authorities are specified and requirements upon the operator of the facility are clear, and persons performing various functions must be qualified. In terms of stakeholders from the public or groups, the German Atomic Energy Act (AtG) [17] requires that decommissioning be licensed; however, the requirement for a public hearing may be waived. [See Chapter 2, §7 (3) (4).];

- *Quality program*—Various Safety Standards and guides require control of processes and documentation and details of measurement descriptions including types of instruments, calibration, and use of vectors. The documents reviewed did not address a structured quality program for implementation of the measurements and assessment of the data;

- *Detail of measurement descriptions*—The DIN, as used in this report, is actually part seven of a suite of standards. Included in this suite are other parts that detail measurement of alpha, beta, and gamma radiations. There are other German standards that address in-situ gamma spectrometry for measurement of radionuclide-specific environmental contamination; detection limit and limit of detection for nuclear radiation measurements. Illustrative examples are included.

• *Mathematical approaches*—There are specific statistical instructions, with examples, in the DIN that describe a method to calculate the number of samples needed to confirm that clearance requirements have been met with 95% probability. The method uses the binomial distribution and the calculation of a calculation of the confidence interval with the inverse F-distribution. The DIN requires that if measurements exceed the clearance level, the adjacent grid areas be measured and perhaps the survey unit be placed in Category 1. There is also flexibility to use other distributions, and an annex provides a procedure for using a log-normal distribution to make the decision.

• *Available assessment tools*—No statistical software applications for clearance; data logging of measurements or mapping software was mentioned in the reviewed documents.

2.3. Spain

2.3.1. General Approach

There are fewer cases of decommissioning in Spain. Spanish guidance appears mostly to use methods and procedures adopted by international organisations and other countries, such as from the European Commission (EC) and the US. Summaries of the available documents are below, but first, a brief description of the Spanish regulatory structure and status of decommissioning provides context for the reviewed documents. The following information was reported online by the World Nuclear Association, and it summarises key governmental organisations that relate to decommissioning in Spain:

In 1980 the Consejo de Seguridad Nuclear [Council of Nuclear Safety] (CSN) was set up to take over both nuclear safety and radiological protection matters. The CSN was changed in 2007, following an incident in 2004 at Vandellòs-2, and the scope for penalties increased. Licensing is under a 1964 law (amended) and 1999 regulations by the Economic Ministry, advised by CSN and Ministry of Environment. Empresa Nacional de Residuos Radiactivos SA (ENRESA) [National Company of Radioactive Waste, Incorporated] was established in 1984 as a state-owned company to take over radioactive waste management and decommissioning of nuclear plants.

Vandellòs 1, a 480 MWe gas-graphite reactor, was closed down in mid-1990 after 18 years operation, due to a turbine fire which made the plant uneconomic to repair. In 2003 ENRESA concluded phase 2 of the reactor decommissioning and dismantling project, which allows much of the site to be released. After 30 years Safestor, when activity levels have diminished by 95%, the remainder of the plant will be removed.

In April 2006 the 142 MWe Jose Cabrera (also called Zorita, Figure 2 below) plant was closed after 38 years operation. Dismantling the plant will be undertaken over six years from 2010 by ENRESA. The total cost is estimated at EUR 135 million. About 4% of the plant's constituent material will need to be disposed of as radioactive waste; the rest can be recycled, including 43 tonnes of internal components [18].

Figure 2. José Cabrera (Zorita) nuclear power plant. Source: Google images.

Buildings & Site Release and Reuse the Spanish Regulator's View—In 2002, there were no general clearance standards available in Spain and release criteria had been authorised only on a case by case basis. Radiological criteria for the partial release that were being considered for the Vandellòs 1 nuclear site were proposed in the "Site Restoration Plan" submitted by ENRESA to the CSN. The dose release criterion (100 μSv/a) was translated into corresponding derived concentration guideline levels. The radiological surveys were to be conducted to demonstrate compliance with the derived concentration limits. These limits were based on the MARSSIM approach and included the planning, implementation, assessment and decision making phases required for a final status survey [19].

In 2007, CSN established the release criterion 100 μSv/a for release of nuclear installation sites, published as Instruction IS-13 on the Radiological Criteria for the Release of Nuclear Installation Sites [20].

The American National Standards Institute Standard/Health Physics Society, *Characterization in Support of Decommissioning Using the Data Quality Objectives Process* (ANSI/HPS N13.59-2008) [21] has been applied in specific projects in Spain, although it is not so far an official recommend-dation of the CSN [22]. This Standard elaborates the section in MARSSIM on the characterization survey, which is prior to the final status survey.

Guía de Seguridad 4.2, *Plan de Restauración del Emplazamient*, [Safety Guide 4.2, Site Restoration Plan] CSN—In 2007, CSN published guidance on the implementation of the final radiological study, among other things [23]. The guidance very closely follows the Data Quality Objectives as described in MARSSIM, but in a more general manner. The main points of the guidance are as follows:

- The release methodologies derive from previous performances in which the “release units” (in Spanish UL) and the “release levels” (in Spanish NL) are defined, and are supported as well as a quality assurance (QA) plan. The methodology includes the following stages:
  - Definition of the decision framework;
  - Definition of QA goals that are required for the results and system of measurements;
  - Design and planning of the measurements;
  - Equipment specifications and measurement methods;
  - Analysis and evaluation of results;
  - Decision making process.

The guidance elaborates on the recommendations for each of the key points above. The safety guides are non-obligatory technical documents by which the CSN provides guidance for the parties affected by the standards in force, with a view to orienting and facilitating the application of such standards [24].

2.3.2. Description of Attributes

- *Regulatory basis*—An apparently complete accounting of the regulatory framework is contained in a report entitled, *Nuclear Legislation in OECD Countries*. The legal foundations are given in two Royal Decrees, 1522/1984 and 1349/2003. The first gave ENRESA the responsibility of radioactive waste in Spain, and the second governs the activities and funding of ENRESA. A recent act, Act 11/2009, established that, among other things, decommissioning is exclusively the state’s competency and the management is commissioned to ENRESA. ENRESA reports to the Ministry of Industry, Tourism and Trade via the Secretariat of State for Energy. The CSN, also created by Law, has among its tasks the control and surveillance of the waste at facilities and the performance of the activities carried out by ENRESA. The mission of CSN is about nuclear safety and radiation protection matters [24]. According to CSN Safety Guide 4.2, it is the responsibility of ENRESA to state the clearance levels in its Site Restoration Plan. No dose criterion was found in the reviewed documents;

- *Scope*—CSN Safety Guide 4.2, which is non-obligatory, thoroughly addresses the entire process of the final radiological study in general terms and specifies that details should be included, such as instrumentation, calibration, detection sensitivities, and uncertainties, as well as other details;

- *Applicability*—Section 7 of the CSN Safety Guide 4.2, is directly applicable to identifying the processes and details needed to reach the point of authorisation of clearance;

- *Flexibility*—The reviewed documents allow a great deal of flexibility and appear to be oriented to clearance on a case-by-case basis;

- *Transparency*—The criteria used to decide that a site can be cleared were not found in the documents reviewed. It is not clear what would ensure that a Site Restoration Plan submitted by ENRESA would result in approval or disapproval. While there may be clear criteria in practice, they are not readily available for review, and thus, a technically qualified person could not reproduce the results or the decision basis without additional information;

- *Roles and responsibilities of parties involved*—The roles of authorities are very well established and clear. The roles of the various implementers of the final radiological study for the facility were not found. Nothing in the reviewed documents mentioned a role for members of the public or of organisations in the clearance process. However, the autonomous communities do have opportunity for input;

- *Quality program*—CSN Safety Guide 4.2 clearly emphasises the value of a quality program to control of processes and documentation, and to ensure the validity of the data used in demonstrating that the final radiological study is technically sound;

- *Detail of measurement descriptions*—By reference to US and international guidance, the Spanish guidance provides a detailed list of the required topics to be addressed describing the measurements to be made.

- *Mathematical approaches*—The details of the statistics needed to demonstrate that clearance criteria in the Site Restoration Plan were met apparently are left for ENRESA to describe and defend. No specific guidance on accepted statistical approaches was found in the reviewed documents;

- *Available assessment tools*—There was no mention of statistical software applications for clearance, data logging of measurements, or mapping software in the reviewed documents.

2.4. UK

2.4.1. General Approach

The Energy Act 2004, enacted by Parliament, established a public corporation, the Nuclear Decommissioning Authority (NDA) [25]. In 2005, the Health and Safety Executive (HSE) published its radiological criterion for the delicensing of a nuclear facility. For practical purposes, HSE will consider the satisfactory demonstration of a risk from radionuclides above background less than one in a million would normally mean the site could be allowed to be delicensed. HSE is of the view that doses to members of the public of the order of 10 µSv or less per year broadly equates to the 1 in a million per year ‘no danger’ criterion. In addition, such doses are consistent with other legislation and international advice relating to the radiological protection of the public [26]. HSE followed its criterion in 2008 with its guidance document, *Guidance to Inspectors on the Interpretation and Implementation of the HSE Policy Criterion of No Danger for the Delicensing of Nuclear sites.* In it, MARSSIM is listed and briefly described in Appendix A as a useful resource for measurement guidance [27]. Otherwise, no specific guidance for how to demonstrate compliance with the radiological criteria for delicensing was found in the reviewed documents.

As part of the restructuring of the UK civil nuclear industry in 2007, NDA set up Site License Companies (SLCs) to carry out decommissioning and commercial operations across its twenty sites. The SLCs, as the enduring entity, employs the workforce on the sites they manage. The management of the SLCs is contracted out to different Parent Body Organisations, which are owned by private companies. According to the NDA Strategy effective April 2011, to delicense a site, the regulatory framework requires proof that radioactive contamination is reduced to a level suitable for any foreseeable future use. NDA will discuss the implications of this with Government and Regulators as part of ongoing dialogue about proportionate restoration and regulation. On a site-by-site basis, the delicensing plan appears to remain flexible and subject to modification as the Site End State is approached [28].

Development of decommissioning guidance in the UK is approached broadly with a wide variety of stakeholders, whose input appears to be integral to the process of delicensing a site. The Construction Industry Research and Information Association (CIRIA) has a nuclear decommissioning network, SAFESPUR. SAFESPUR provides the opportunity for the nuclear supply chain to discuss the latest developments in both radioactive contaminated land and the management of assets and decommissioning wastes. SAFESPUR was set up in 2006 to work with the SAFEGROUNDS and SD: SPUR Learning Networks, a resource, accessible through the internet, to share supplier good practice for nuclear and defence sites. SAFEGROUNDS stands for SAFety and Environmental Guidance for the Remediation of contaminated land on UK Nuclear and Defence Sites. “SD: SPUR” stands for Site Decommissioning: Sustainable Practices in the Use of Resources. The initiative was developed to establish through dialogue safe, socially, economically and environmentally sustainable practices in the use of resources arising from the decommissioning of nuclear sites.

This initiative was funded by the member organisations of Shopfitting Independent Training Forum (SITF) (Atomic Weapons Establishment (AWE), British Energy, British Nuclear Fuels, Ltd. (BNFL) and United Kingdom Atomic Energy Authority (UKAEA)), the Ready Mixed Concrete (RMC) Environment Fund and the Health & Safety Executive Nuclear Installations Inspectorate (HSE NII or HSE). The initiative, or project, was guided by a Project Steering Group (PSG) comprising operators of nuclear licensed sites, Government departments and agencies, and non-governmental organisations. The network uses participatory approaches to develop and disseminate good practice guidance for the management of radioactively and chemically contaminated land on nuclear and defence sites in the UK.

SAFEGROUNDS documents below are guidance developed by committee or stakeholder dialogue. They are intended for use by site owners, site operators, contractors, governmental departments, local authorities, regulators, NGOs [Non-Governmental Organizations], and other groups within the public. SAFEGROUNDS documents have no legal standing and, thus, are not binding. They propose a case-by-case approach to contaminated land management with stakeholder involvement. This will include assessment of the impact of any waste arising to avoid unacceptable transfer of risk from one area or group to another.

CIRIA W27 SAFEGROUNDS: Approach to managing contaminated land on nuclear-licensed and defence sites—an introduction, May 2009.**—**This report explains in detail the historical and regulatory context of nuclear installations and the approach to management and decommissioning. This report has a glossary with many terms [29].

CIRIA W30 SAFEGROUNDS: Good Practise Guidance for Site Characterisation, Version 2 2009.**—**The HSE policy, developed after extensive consultation, is that it would be unreasonable to require a licensee to demonstrate "no danger" by demonstrating that the site is completely free of all activity. The policy concludes that, after termination of licensable activities on a site and following rigorous decontamination and clean-up, the residual risk from any radiological hazard remaining on site should be in line with HSE's views on "broadly acceptable" risks and the concept of reducing risks to be ALARP[1] [30].

SAFESPUR Meeting 12Jan2011—The NDA reported Site Strategic Specifications are being developed for each site; these set out what is to be achieved but are not prescriptive about the means of achieving it [31].

*Model Procedures for the Management of Land Contamination, Contaminated Land Report 11 (CLR 11) Environmental Agency 2004***—**This Environmental Agency (EA) report is a comprehensive discussion of detailed consideration for management of sites, including verification that planned remediation has been met. It also has a list of resources with brief descriptions of them for further detail. It states that identification of uncertainties is an essential step in risk assessment. Some uncertainties can then be reduced, for example by obtaining better data or refining models to improve their validity. All uncertainties need to be noted: some uncertainties can be quantified, for example by providing statistical confidence limits, while others may need more qualitative characterisation such as setting high, medium or low degrees of confidence on information or judgements. The overall aim is to ensure that the quality of information used and the overall degree of confidence associated with the analysis of that information

[1] "ALARP" is short for "as low as reasonably practicable". Reasonably practicable involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which we expect to see workplace risks controlled. http://www.hse.gov.uk/comah/alarp.htm Accessed 19 September 2011.

provides a robust basis for decision making. Explicit implementation procedures and statistical tests are not included [32].

Clearance and Exemption Principles, Processes and Practices for Use by the Nuclear Industry: A Nuclear Industry Code of Practice, Clearance and Exemption Working Group; Nuclear Industry Safety Directors Forum, July 2005—This Code of Practice is not, in itself, a working level procedures document. It is aimed at those responsible for formulating organisational policy and developing working level procedures. It provides specific details, in a generic manner, to readily develop site-specific working procedures. This code defines Sentence or Sentencing as that step of the clearance process at which the decision is made that an article or substance is clean, excluded, exempt or radioactive. However, its scope appears to be limited to materials and equipment and does not include lands [33]. The details of procedures at specific sites may be more explicit. For example, a supplemental paper apparently from the Dounreay Site, based on the source URL, entitled, *Clearance and Exemption Principles, Processes and Practices for Use by the Nuclear Industry: Supporting Paper 2 Procedures and Methods of Statistical Sampling and Analysis*, provides specific guidance on the use of statistical tests and methods to determine the number of samples needed to ensure a specified confidence level [34].

The Bradwell site serves as an example of a specific approach to implementation. The environmental consultant RSK, working with Magnox's Waste Management team, developed a 'paper of principle' to use as a discussion paper with the regulators for the revised strategy. The revised strategy builds on the Nuclear Industry Code of Practice [33] and incorporates the European Radiation Survey and Site Execution Manual (EURSSEM) [35] and the MARSSIM [13] approach. The project also delivered a strategy document that builds on paper of principle providing detail on each stage of the revised strategy. A Bradwell Site Characterisation Plan was also prepared which specifically evaluated the Bradwell site with regard to the revised strategy [36].

2.4.2. Description of Attributes

- *Regulatory basis*—UK regulations for clearance of lands from nuclear installations appear complicated and multi-layered. Complicated because the Energy Act 2004 is the enabling law, and it specifies a "no danger" criterion for clearance, which from a literal and scientific view is impossible to attain. Thus, the regulatory agencies needed to find a finite level of risk that could be considered to be of "no danger" from a policy standpoint. A licensee's application must include an assessment of dose and risk to the public following delicensing. The assessment is to demonstrate that any reasonably foreseeable future use the land presents "no danger" of a risk of a fatality to the public in excess of 1 in a million per year. The standing policy is consistent with international recommendations. Further, agreements from at least HSE NII and EA appear to be required for delicensing, i.e., clearance. In addition, stakeholder agreement to the plan for the Site End State appears to be an essential step in the delicensing process.

Multi-layered because NDA, a non-departmental public body established by the Energy Act 2004, takes ownership for decommissioning of an installation, but sets up SLCs to carry out decommissioning and commercial operations. Further, the management of the SLCs is contracted out to different Parent Body Organisations, which, in turn, are owned by private companies;

- *Scope*—The implementation guidance is general, and the actual implementation appears to be developed on a site-specific basis;

- *Applicability*—There are general descriptions of processes and topics to specifically address, but the specifics on how to conduct the verification of the Site End State for delicensing apparently is left to the details of the Site End State Plan.;

- *Flexibility*—The details for implementing delicensing appear to be highly flexible. Not only are they developed on a site-specific basis, but apparently they can be progressive during the decommissioning processes and finalised shortly before the survey for verification of the Site End State;

- *Transparency*—Beyond the general descriptions of the elements of the delicensing process, the site-specific plans likely are where transparency can be examined. As seen in the case of Bradwell, the bases of the strategy and site characterisation plan can be comprehensive;

- *Roles and responsibilities of parties involved*—From the documents reviewed and in general, there may be overlapping specific requirements by authorities and blurred responsibilities of facility operators, various implementers of clearance procedures and the role of various stakeholders. These roles and responsibilities seem likely to evolve as the site-specific strategy and plans develop;

- *Quality program*—The reviewed documents did not address a structured quality program. It is possible that descriptions of a quality program could be found in the site-specific strategy and plan. However, the review of site-specific plans is beyond the scope of this report;

- *Detail of measurement descriptions*—The details for measurements were not found in the general documents reviewed. The guidance seemed to point the general direction for the site operators to use resources, but did not provide definitive guidance. However, in the case of Bradwell, the EURSSEM was specifically referenced, and it, in turn, contains explicit detail of measurement descriptions in the entire process. Thus, it may be that the site-specific plans are or can be amply detailed.

- *Mathematical approaches*—In the general case, acceptable mathematical approaches were not found in the reviewed documents. However, in a specific case, apparently from the Dounreay site, rigorous, technically defensible and explicit mathematical procedures were found;

• *Available assessment tools*—The reviewed documents included a single reference to statistical software applications for clearance, data logging of measurements, and mapping software in a paper entitled, *Development of Software Tools for Supporting Building Clearance and Site Release at UKAEA* [37].

2.5. US

2.5.1. General Approach

The principal enabling law that authorises the Department of Energy (DOE), the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) is the Atomic Energy Act (AEA) as amended (42 U.S.C. 2011-2296). This Act is the fundamental U.S. law on both the civilian and the military uses of nuclear materials.The AEA requires the management, processing, and utilization of radioactive materials in a manner that protects public health and the environment. The AEA requires that source, special nuclear, and byproduct materials be managed, processed, and used in a manner that protects public health and the environment. Under the AEA and Reorganization Plan No. 3 of 1970, EPA is authorized to issue federal guidance on radiation protection matters as deemed necessary by the Agency or as mandated by Congress. This guidance may be issued as regulations, given that EPA possesses the authority to promulgate generally applicable radiation protection standards under Reorganization Plan No. 3. For example, under AEA authority EPA promulgated its environmental radiation protection standards for nuclear power operations in 40 CFR Part 190. In brief, the EPA issues generally applicable federal guidance. The NRC and some States regulate the non-military uses of radioactivity. The military uses of radioactive materials are regulated by the DOE. See [38] for the full text of the AEA and other Federal laws applicable to the regulation of radioactive materials.

The DOE, EPA, NRC, and the US Department of Defense endorse the processes and methods in MARSSIM for demonstrating compliance with clearance criteria for surfaces of structures (buildings, etc.) and lands with radionuclides from licensed operations. The clearance criteria are assumed to be risk or dose based, which, in turn, are translated into measurable radionuclide concentration levels. The scope of MARSSIM does not include specifying the radionuclide concentration levels. MARSSIM is a technical report, and as such, is non-binding. However, the above named author agencies readily accept demonstrations of compliance that use MARSSIM. A separate report, Multi-Agency Radiation Survey and Assessment of Sub-surface Soils (MARSAS), is a planned supplement for MARSSIM. Some preliminary work that uses free geospatial statistics software, Spatial Analysis and Decision Assistance (SADA) has been done for MARSAS applications [39]. SADA has a module for the implementation of MARSSIM, also.

The scope and purpose of MARSSIM needs to be understood to provide the context for this evaluation and comparisons in this report. The focus of MARSSIM is the final status radiological survey. In the context of MARSSIM, the final status survey is the collection of radiological measurements that demonstrate that the clearance criteria have been met in a technically sound manner and are acceptable to the regulators. "Technically sound," in this context includes taking into account the combined uncertainties of calibrations and measurements as well as their associated statistics.

Therefore, MARSSIM is for a technical audience having knowledge of radiation health physics and an understanding of statistics as well as experience with the practical applications of radiation protection. Understanding and applying the recommendations in MARSSIM requires knowledge of instrumentation and measurement methods as well as expertise in planning, approving, and implementing radiological surveys. Certain situations and projects may require consultation with more experienced or specialized personnel (e.g., a statistician). However, the technical audience will find thorough and detailed explanations of the methods and processes in MARSSIM.

Facility decommissionings have used MARSSIM to arrive at different facility configurations for clearance. For example, in the US the Trojan nuclear power plant was cleared with buildings still standing. The Maine Yankee nuclear power plant clearance end result was a "green field." Both of these decommissionings used MARSSIM for the entire decommissioning. MARSSIM has detail on preliminary investigations, including a Historical Site Assessment (HSA), a scoping survey, a characterization survey, and remediation-support surveys. The end-point of MARSSIM is the final status survey, which is the survey that is designed to demonstrate that the survey units meet clearance criteria. MARSSIM emphasizes in several processes, decision points where consultation and agreement with the regulatory authority is highly recommended, e.g., the decommissioning survey plan and the remediation approaches. Such communications tend to avoid rework and lead to clearance more efficiently, even if the technical approach is sound from the beginning.

MARSSIM processes and methods are divided into four phases:

- Planning
- Implementation
- Assessment
- Decision-making.

The list and subsections below provide brief descriptions of key concepts and terms in MARSSIM, and a flowchart follows that illustrates the processes in each of the four phases above. Terms that are used in all of these phases and in the overview flowchart in Figure 3 include:

- *Classification* is separating *survey units* by the estimated concentration and distribution of radioactivity from the facility. There are four classifications of which concentrations can range from none, i.e., not impacted by facility radioactivity, to likely to exceed the criteria concentration levels;

- *Survey unit* is the area upon which measurements are made to support a disposition decision, e.g. clearance or other action for that area;
- *N* is the number of measurements;
- *L* is the location of the measurements;
- *MDC* is the minimum detectable concentration;
- *DCGL* is the derived concentration guideline level. This is the radionuclide-specific concentration corresponding to a dose-based criterion for clearance. The DCGL:s are derived from site-specific or conservative modelling of relevant exposure scenarios.

Planning—Planning is a large part of the processes, because it includes everything before data acquisition begins. The HSA collects and evaluates information from various sources to be used as input for the planning and design of radiological surveys. MARSSIM addresses four types of surveys that may be needed, including the final status survey. All four surveys require planning and design. The types of surveys are the scoping survey, characterization, remediation-support, and final status surveys, and they are for sites with surface soil and building surface contamination.

MARSSIM requires two analyses in parallel. One is based on the average level of radioactivity in the survey unit. The other is for single measurements that exceed the clearance level. These are called "elevated measurements." The clearance level in MARSSIM is assumed to be based on dose. Elevated measurements are related to the dose by modelling of appropriate scenarios and are scaled to an area in which the clearance dose criteria would not be exceeded. Thus, in MARSSIM measurements above the clearance concentration level may be allowed if the area is small enough that the clearance dose criteria would not be exceeded.

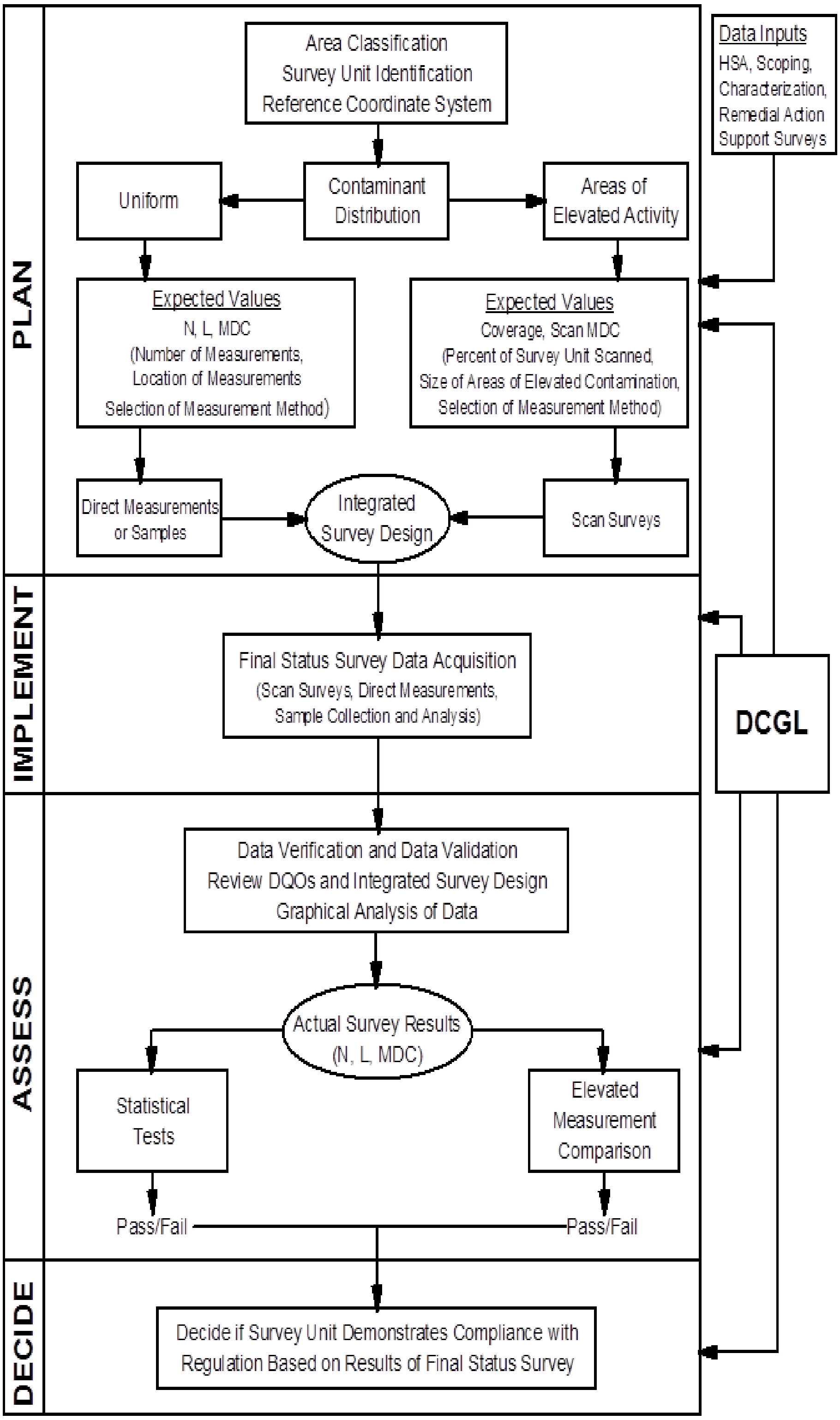
In addition, the planning phase includes establishing the Data Quality Objectives (DQOs) to ensure that the data to be collected are of sufficient quality and quantity for the decision to be made, which is usually, "Have the clearance criteria been met?" Quality Assurance and Quality Control procedures need to be established in the planning phase to ensure that the DQOs are met [40].

Implementation—Implementation includes not only conducting surveys and collecting data, but also integrating field and laboratory methods and instrumentation, and interfacing with radiation laboratories.

Assessment—The assessment phase includes statistical hypothesis testing. Usually, the null hypothesis that is to be rejected is, "The clearance criteria were not met." Thus, rejecting the null hypothesis means the alternate hypothesis is accepted and the criteria were met. MARSSIM has two parallel null hypotheses to reject. One is for diffusely distributed radioactivity with relatively uniform concentrations, and the other is for small areas of elevated levels of radioactivity. Both null hypotheses have to be rejected to satisfy a dose-based criterion. MARSSIM recommends nonparametric statistics. One of the primary advantages of the nonparametric tests is that they involve fewer assumptions about the data than their parametric counterparts. If parametric tests are used, (e.g., Student's t test), then any additional assumptions implicitly made in using them should be verified (e.g., testing for normality). The test for normality may require taking more samples than the nonparametric test requires. The assumptions of any statistical test should include checking the assumptions for that test. Finally, the interpretation of statistical data should be documented.

Decision-making—Based on the interpretation of the statistical data, the null hypothesis is either rejected or not. If the DQOs, which were established in the planning phase, are met, then a technically sound decision can be made, as planned, for the disposition of the survey unit, e.g. it is cleared or other actions are required, such as remediation.

Figure 3. Flowchart overview of MARSSIM process phases: Plan, Implement, Assess, and Decide.



2.5.2. Description of Attributes

• *Regulatory basis*—The regulatory bases for decommissioning are a patchwork of legal requirements made by EPA, DOE, NRC, and the States. Specific requirements of the regulatory agencies that co-authored MARSSIM are explicitly presented in Appendix C of MARSSIM. EPA does not license the use of radioactivity, but has the authority to restrict use of sites and require clean-up to risk levels generally in the range of one-in-a-million to one-in-ten-thousand for a fatality. It has translated risk levels to concentrations based on various radiological dose-to-risk models that are not consistent with each other and several which supersede others. For exposures from radionuclides on lands and structures, it generally considers 150 µSv/a at the upper limit of the acceptability range.

DOE guidance for complying with their requirements for release of real property, lands, buildings and their fixtures, state a constraint of 250 µSv/a to a member of the public plus ALARA for consistency with the requirements of the NRC. The guidance also references MARSSIM for measurements in the final status survey [41].

NRC regulations specify the radiological criteria for license termination as 250 µSv/a plus ALARA to a member of the public. If it can be shown that there is no other exposure from a licensed source, the dose of 1 mSv/a to a member of the public plus ALARA may be approved for license termination [42]. States generally follow the same criteria. In practice sites may have to demonstrate that 150 µSv/a would not be exceeded for a member of the public, because State and local governments also comply with EPA requirements. NRC issues Regulatory Guides to provide guidance for an acceptable method to comply with its regulations. Other methods may be acceptable if the licensee provides substantial bases to support it. MARSSIM is referenced frequently in the NRC guidance for planning and implementing the demonstration of compliance.

• *Scope*—The clearance implementation guidance in MARSSIM is comprehensive and provides specific details with illustrative examples. It addresses instrumentation and uncertainties. All processes from planning through the final decision are addressed with the emphasis on the final status survey. Surfaces of buildings and lands are included in the scope; sub-surfaces of lands more than 15 cm are out of scope. The root zone for modelling dose to concentrations of radionuclides is assumed to be 15 cm deep.

• *Applicability*—MARSSIM specifically addresses verification that radiological clearance criteria have been met, given the concentration levels of radionuclides to measure;

• *Flexibility*—MARSSIM methods and processes are non-binding, and other alternative methods may be used to comply with clearance criteria. They are endorsed as methods and processes that the regulatory authorities find acceptable to verify compliance. As such they are prescriptive, but generally applicable to a variety of final states of the site, e.g., green field or structures remaining;

- *Transparency*—The descriptions are explicit and detailed with illustrative examples. Most technically qualified persons should be able to the reproduce results of reports based on MARSSIM;

- *Roles and responsibilities of parties involved*—The guidance states specific responsibilities of a planning team for the design and implement-tation of the surveys. A different team may perform the analysis. The decision may be made by still another team or individual. There are a number of places where consultation with the regulatory authorities, and perhaps other stakeholders, is recommended;

- *Quality program*—Data Quality Objectives are the foundation of the MARSSIM methods and processes. With them are associated quality assurance and quality control programs to ensure the data are of sufficient quality and quantity to make a technically sound decision in the end;

- *Detail of measurement descriptions*—The details of measurement descriptions for the final status survey are comprehensive, detailed, and illustrated by examples in MARSSIM [13]. The details of surveys and data leading up to the final status survey are outlined, but perhaps better covered in the EURSSEM [35].

- *Mathematical approaches*—Rigorous mathematical approaches are essential for ensuring that the implementation, data analysis, quantified combined standard uncertainty, and the decision are technical sound and defensible. The statistical approach is to use the non-parametric Wilcoxon Rank Sum test or the Sign test to calculate the number of samples needed and to verify that the desired Type I error rate is met. For data logging data sets random samples are taken from the data to make the statistical samples. These tests have an underlying assumption that the measurements are spatially independent. Geospatial statistics account for spatial correlation but are not included. The explanations in MARSSIM are explicit and accompanied with illustrative examples;

- *Available assessment tools*—SADA has a MARSSIM module and also has mapping software [39]. Several software programs are available for download as tools for MARSSIM, including a guide through the MARSSIM processes named COMPASS [43].

3. Comparison and evaluation by attributes of characterisation approaches

The following sections review, compare and evaluate the attributes of the various approaches among the countries examined. It is obvious that each country has the goal of clearing sites with an acceptable level of risk to the public and environment, and they are each capable of reaching the goal. Nevertheless, the different approaches have trade-offs that are noteworthy.

3.1. Regulatory basis

The regulatory bases examined for the five countries in this report reveal regulatory cultures that make a spectrum of approaches to clearance; they may be reflective of the situations and respective cultures of the countries themselves. These regulatory cultures may be used as examples to demonstrate the trade-offs between the timely and cost-effective efficiency of generally applied guidance in comparison with the wide acceptance of implementation processes with end states that are specifically and flexibly tailored to each site. Authorities who are developing guidance may consider these trade-offs as an optimisation exercise, the solution of which will best suit their present and anticipated needs. The discussion below expands on how generally applied guidance provides clarity on what is expected and acceptable and how it can reduce the burden on regulatory authorities and facility operators. In comparison, specifically and flexibly tailored guidance can include input from many stakeholders and result in wider acceptance of the processes and the end state.

Ultimately, all the reviewed regulatory bases have the goal of an acceptable risk outcome. Legislatures or regulatory authorities must judge and define the acceptable risks. Internationally, there is a variety of criteria used for residual risk due to remaining radioactivity after clearance of land. In Europe, several countries use criteria corresponding to about a one-in-a-million risk of fatality. In the US there is some vagueness because the application of ALARA can result in different end state risks, but they generally are in the one-in-a-million to one-in-ten-thousand risk of a fatality.

3.2. Scope

The French scope is classifying waste as either conventional or nuclear waste. To do this, the French ASN no. 14 guide requires detailed process knowledge augmented, as necessary, by radiological surveys. The guidance applies to both lands and building structures. This approach roughly parallels the MARSSIM process to determine if a survey unit is non-impacted, i.e., conventional, not associated with radioactivity from the operation of the facility. Conversely, if it is impacted, a historical site assessment, a scoping survey, and characterization survey may be necessary to assess how much remediation is necessary. However, the French guidance appears to focus on the administrative aspects of clearance and the details of the implementation is the responsibility of the site manager, within the administrative guidelines.

In contrast, the German DIN is limited to the implementation of measurement methods required to clear lands, but not buildings. It is prescriptive in its guidance on instrumentation, the design of grids for measurement, and the statistics for determining the number of samples to measure, and the confirmation of the level of confidence of the results. The level of prescriptive detail ensures that facility operators know how to implement the guidance and how to report it. Reports that adhere to the guidance could be readily reviewed by regulatory authorities without needing additional detail. The scope of this DIN is well defined, and it references additional standards to provide details of various aspects directly related to implementation of this DIN. Taken together, the German standards are comprehensive for conducting the final status survey.

The Spanish CSN Safety Guide is comprehensive in scope for the final radiological survey in general terms and specifies a thorough list of details that must be included. It is non-binding, but an adequate outline and useful to facility operators. By making use of the methods developed by the EU and MARSSIM, the Spanish approach can result in high-quality, technically sound clearance processes with a clearly defined scope for the final status survey.

The scope of government-issued UK documents reviewed appeared to only address the overall risk and levels of radionuclides that would be considered to be of “no danger.” NGO documents addressed best practices, but the guidance for actual implementation appear to be left to the site operator.

In the US, MARSSIM, a non-binding technical report authored by four government agencies, is widely used for the demonstration that clearance criteria are met. This demonstration is made with the final status survey. The design of the final status survey is based on the survey unit’s classification, which, in turn, is based on the potential to exceed the clearance criteria. The scope of MARSSIM is comprehensive, and includes initial planning, implementation, assessment, and decision-making.

3.3. Applicability

The respective German and US implementation guidance documents are similar in their level of detail and are directly applicable. In MARSSIM there are three classifications of survey units with the potential to have radioactivity from the facility, and non-impacted is the term equivalent to the DIN Category 3 and the French Category 0. Both procedures base the density of sampling measurements on the categorizations or classification. It is not clear whether the DIN or the German Ordinance specifies the maximum size of the area for which the decision for clearance is made. An area of 100 m^2 is used in the example. The German guidance reviewed specifically and directly addresses implementation of the measurements for clearance. It is designed to be clearly applicable and has illustrative examples.

In comparison, the Spanish guidance efficiently uses by reference MARSSIM-based guidance, which is directly applicable to implementation and verification of clearance measurements. In the UK the guidance appears to mostly address administrative matters such as timing of processes. UK guidance has general descriptions of processes and topics to be specifically addressed. The details of implementation in the UK, as in France and Spain, are developed on a site-specific basis.

The approach of French guidance, which regards the clearance of lands as a matter of distinguishing conventional waste from radioactive waste, is not explicit on the details of implementation of this distinction. The documents reviewed appeared to focus on administrative matters such as timing and processes, rather than implementation and verification of measurements. Apparently, the implementation details are left to the site manager to decide. However, the guidance specifies hazardous waste must be quantified. International best practices are offered as context for implementation of the distinction between conventional and radioactive waste. Thus, there possibly could be technically sound plans for implementation on a site-specific basis. The guidance states that there is not a universal clean-up level threshold. At least conceptually, this leaves the possibility of a range of end results when the land is cleared. The kernel of the matter is that one cannot measure zero radioactivity for conventional waste as this has no signal to measure. What is possible to state is the sensitivity with which the measurements were made and the level of combined uncertainty attained; that is, in common language, “How well did you look, and how confident are you?”

3.4. Flexibility

The French and UK guidance documents permit the more flexibility than those from Germany, Spain, and the US. The French guidance appears to be the most flexible, because there is no universal clean-up threshold, and the site manager apparently decides on the implementation details. The UK guidance and implementation are also quite flexible, because it is site-specific, incorporates consideration of stakeholder input, and remains dynamic in time depending on changing information during the decommissioning. In Spain, CSN issues technical instructions to all parties within scope that are binding when published in the *Official State Gazette*. In addition, CSN issues non-binding safety guides aimed at orienting and facilitating application of the standards. The guidance from Germany and from the US applies to all sites in general. The German and the US guidance each allow flexibility in the approaches within the framework. The German case is less flexible, because the clearance level for each nuclide is specified in the Ordinance. The US case allows site-specific modelling to establish the radionuclide concentrations that correspond to the dose-based clearance criteria. They also allow alternative statistical approaches if there is substantial justification and it is approved by the regulatory authority.

3.5. Transparency

The US MARSSIM processes, methods, and implementation are explicit, detailed, and comprehensive with in its scope; hence it is the most transparent of the clearance guidances reviewed. Next is the German DIN. It, too, is explicit, detailed, and comprehensive within its scope. However, the DIN is written as a standard and has few detailed explanations or examples.

General guidance from France, Spain and the UK are not as transparent as the US and German cases, because the details are in the site-specific plans and documents of implementation. Site-specific survey plans for clearance could be transparent. However, it is possible that the degree of transparency among the site-specific plans and implementation documents may be variable, also. Inspection of the collection of individual site-specific plans from these countries is beyond the scope of this report.

3.6. Roles and responsibilities of parties involved

From the high-level laws and regulations view, the roles and responsibilities of agencies and the facility operators are reasonably clear for all countries. In fact, the guidance from some countries, especially France, Spain, and the UK, is heavily weighted to the administrative aspects, including the descriptions of processes and their timing. The guidance from the UK appears to incorporate the input of stakeholders, including NGOs, to a greater degree than the other countries. The German AtG specifies that the on-site personnel must be appropriately qualified. In some cases the public hearing of German licensing process for decommissioning may be waived. The US guidance was the only one that indicated the roles of on-site or operator planning and decision-making. It also indicated key points of the planning and implementation where consultation with the authorities could be productive and efficient.

3.7. Quality program

Quality programs are the central theme of the US guidance. The DQO’s are the basis of the planning, implementation, assessment, and decision-making. Quality Assurance and Quality Control programs ensure that the data used for decision-making are of sufficient quality and quantity to make the decision technically sound and defensible. Consistent with the approach of MARSSIM, the Spanish guidance also clearly calls for a quality program to control of processes and documentation, and to ensure the validity of the data used in demonstrating that the final radiological study is technically sound

Guidance from the remaining countries, France, Germany, and the UK, apparently rely on the professional expertise of the implementers at the facility and the thoroughness of the regulatory authorities reviewing the documentation. A structured quality program can improve the overall efficiency of arriving at a clearance decision for both the operator and the regulatory authorities. From a human resources point of view, a required quality program may seem like an unnecessary collection of additional efforts. In fact, the documentation of quality processes provides traceability of errors when they are discovered. In addition, the documentation from a quality program provides defensibility long after the individuals who conducted various parts of the clearance are gone.

3.8. Detail of measurements descriptions

The US, German, and the EURSSEM guidance are all strong on the details of measurement descriptions. In the case of Germany, comprehensive guidance is spread across a collection of German standards. The US guidance is perhaps the most explicit within the description of the final status survey. The German guidance provides reasonably detailed descriptions of methods for measurements. The EURSSEM provides information and guidance on strategy, planning, stakeholder involvement, conducting, evaluating and documenting radiological, environmental and facility (surface) surveys based on best practices for demonstrating compliance with dose or risk-based regulations or standards, remediation, reuse, short-term and long term stewardship on radioactively contaminated and potentially radioactively contaminated sites and/or groundwater. EURSSEM guidance appears to be the most comprehensive and has sufficient detail for a technically qualified person to reproduce results from this guidance. By reference, the Spanish guidance uses US and international guidance to adequately describe the measurement processes. The descriptions of measurement processes in France and the UK appear to be relegated to the site-specific plans for clearance and were not reviewed within the scope of this report.

3.9. Mathematical approaches

The reviewed documents from France, Germany, and the US had general approaches for the mathematical tools to demonstrate compliance with clearance criteria. Perot from France compared the Wilcoxon Rank Sum Test and the Sign Test, which are used in MARSSIM, with the method of Wilks. In addition there is a French promotion of geospatial techniques [12].

The German DIN specifies using the binomial distribution to determine the number of samples needed and the inverse F-distribution to calculate the confidence interval in an iterative process. It also provides guidance for an alternate log-normal distribution of radionuclide levels.

MARSSIM uses either the Wilcoxon Rank Sum Test or the Sign Test in parallel with other tests of the measurement data. These are used for hypothesis testing of the median, as a surrogate for the mean. These tests do not depend on the underlying distributions, such as normal or log-normal. MARSSIM specifies a triangular grid, rather than the square grid specified in the DIN. MARSSIM states that mathematically the probability of finding an elevated measurement is greater with a triangular grid and scanning measurements. Central to ensuring a technically sound decision, MARSSIM emphasizes the combined standard uncertainty [44]. MARSSIM does not address geospatial measurements. However, a readily available software tool, SADA, has a MARSSIM module and has geospatial capabilities.

The DIN standard uses an iterative process to determine the number of samples needed from the binomial distribution. The situation is that either a measurement is below the equivalent of the clearance level or it is not. The confidence level of the results of the measurements can be calculated with an inverse F-distribution. The treatment of uncertainties in the DIN appears to be limited to the calculation of the confidence interval of the measurements. However, a comprehensive treatment of all the uncertainties was not found.

The Wilks method investigated by Perot is for tolerance intervals, as contrasted to confidence intervals. This method is not a test of hypotheses method. It is a nonparametric way of estimating a probability interval. The number of samples needed is obtained from table values. Inputs are 1) the proportion of the population to be bounded, 2) the confidence level, and 3) the rank of the observations to be used as the tolerance limits. From the information reviewed, it is not clear how the use of this method can be used to make a clearance decision.

In the statistical tests mentioned above there is a common underlying assumption that measurements of samples of the radioactivity are random and independent spatially. Site-specific information, such as the HSA, may indicate that this assumption is not necessarily valid. For example, a known radioactive liquid spill or a predominate wind direction at a site could concentrate the radioactivity in a “footprint.” In MARSSIM this situation is addressed by additional tests for elevated measurements and posting plots. Posting plots are a visual representation of the structure of the data. Values of measurements are marked on a map indicating the location of each measurement. From a posting plot one can evaluate the assumption that the data are randomly distributed in the survey unit. For example, concentration of high measurements in a relatively small area would be an indicator that the data are not randomly distributed in the survey unit. An important alternative approach is also available as noted below.

Advances in data logging and computer software programs have enabled geospatial analyses. This technology can map thousands of measurements onto a survey unit and develop a map of radioactive footprints. If γ-spectroscopy is used to make measurements in conjunction with the data logging and geospatial analysis, it can be used to distinguish natural radioactivity from radionuclides resulting from the facility operations. Thus, if naturally occurring radioactivity is excluded from the clearance criteria, the facility operator can avoid a significant cost for its clean-up.

With the exception of MARSSIM, the detailed incorporation of the combined standard uncertainty was not found in the reviewed documents. The defensibility and technical soundness of the final status survey is questionable without quantification of the combined standard uncertainty incorporated in the planning, implementation, and analysis.

3.10. Available assessment tools

The Spatial Analysis and Decision Assistance (SADA), a no-cost, independent software development project, has led to a similar result as the French developed Kartotrak™ by CEA and Geovariances, in a partnership. Both use geostatistics as an analytical basis. SADA does have a MARSSIM module. SADA is a freeware product internationally recognized in the area of environmental decision support, geostatistics, uncertainty analysis, sample design, and risk assessment. Beyond that, it is an on-going research and development project conducted within a university and government environment where new methods or models are encouraged.

Development of SADA has been extremely transparent with published verification plans and the contributions of numerous experts from a wide array of national institutions (universities, labs, etc.). In the upcoming versions of SADA, there is a movement toward open source (hopefully with interactions with the Open Geospatial Consortium) permitting other modellers to add their methods without large encumbrances. The author of SADA would personally discourage organizations from the idea of "choosing" a software package. He prefers the "toolbox approach" where modellers, decision makers, etc. have access to many good tools each with their own strengths and weaknesses [45]. An excellent report on how to use SADA for subsurface radioactivity surveys and analysis has been recently published. The report integrates MARSSIM and another model, Triad, using a substantial and continually advancing set of tools including spatial analysis, modelling, and the geographic information system community. At the core of this application is the generation of a “Contamination Concern Map.” This map focuses on the likelihood of exceeding a decision criterion at a local scale and directly addresses uncertainty in volume extent and location [46].

In addition, there are several other programs available for the implementtation of the US guidance [43]. It is likely that some of these tools can be adapted to the statistical assessments of sites in other countries. An internet search did not reveal available software for implementation of the DIN. It is noted that the inverse F-distribution function is available on Microsoft Excel© software.

3.11. Summary and conclusions

The observations made in the previous subsections are summarized in Table 3 below. These previous subsections examined how the site clearance processes are actually implemented and verified. It is clear that there are wide-ranges of approaches for each attribute among the countries. For some countries, the guidance and even the regulatory basis are clearly prescriptive. That is, by carefully following specific instructions, step-by-step, the site will be cleared. In other countries, the guidance is based on the final outcome or objective with the demonstration of compliance that is subject to approval.

In some cases, the case-by-case approach may result in different end states from site to site within a country, while in others; the end state is relatively uniform throughout the country. For example, part of these differences can be attributed to the differing regulatory criteria. The criteria are varied and are based on dose, risk, or the outcome of case-by-case analyses.

One may conclude that a variety of approaches and even different criteria can be implemented and provide for an acceptable outcome and end-state. However, it is not implied that the approach and criteria used in one country would be equally successful if used in another country. It seems likely that there are important societal and governmental considerations that provide the context for successful clearance, and accounting for these national considerations likely has contributed to the differences observed in this report.

Table 3. Country-by-country summary of attributes of guidance reviewed for implementation and verification of the final survey for clearance of land at nuclear facilities.

Attribute	France	Germany	Spain	UK	US
Regulatory basis	No [residual] activity or concen-tration of which warrants a radiation-protection control	Order of 10 µSv/a and tables of concentra-tions	Release criterion 100 µSv/a	By policy, “no danger” law met by ≤10^{-6} risk	Multiple, with risks from 10^{-6} to 10^{-4} /a, and doses ranging from 150 to 250 µSv/a plus ALARA
Scope	General processes, timing for waste types	Ground surfaces, facility radionu-clides, mass, sub-surface	Entire measure-ment process generally addressed; details case-by-case	General guidance, case-by-case	Compre-hensive for clearance surveys, for surfaces of lands and structures
Applicability	Case-by-case basis	All facility ground surfaces, not intervention	Generally identified processes and details for measure-ments	General guidance, case-by-case	Specifically addresses verification that clea-rance criteria are met
Flexibility	Highly flexible, case-by-case	Prescriptive and dose-basis allows flexibility	Highly flexible, case-by-case	Highly flexible, case-by-case	Very highly prescriptive in scope; non-binding
Transparency	Not explicit, case-by-case	Explicit and detailed	Not explicit, case-by-case	Not explicit, case-by-case	Very transpa-rent and detailed with examples
Roles and responsibili-ties of parties involved	General requirements including consult with relevant parties	Law specifies authorities’ and operator’s require-ments; roles of other stake-holders not found	Clear roles of authorities; implement-ers’ roles not found	Possible overlapping authorities, responsibiliti es, unclear stakeholder roles seem to evolve during processes	Guides user to form quality, planning, implement-ing, decision teams; consultation with stake-holders, authorities
Quality program	Not found	Not found	DQO process is a basis	Not found	DQO process is the basis

Attribute	France	Germany	Spain	UK	US
Detail of measurements descriptions	Not found	Explicit and detailed; comprehen-sive combined with other standards	Very detailed by reference to US and international guidance	Not found, case-by-case	Very explicit, detailed, and comprehen-sive, examples included
Mathematical approaches	Not found as a specific application	Explicit and detailed	Not found	Not found	Very explicit detailed robust methods, geospatial not covered
Available assessment tools	Geospatial and data logging software	Not found specific to clearance	Not found	Data logging and mapping software	Several programs for MARSSIM geospatial included

4. Considerations for developing regulations and guidance for site release

The previous section indicates some of the pros and cons of different approaches to developing regulations and guidance for clearance of sites. Clearly, there are trade-offs among the various approaches. Depending on the regulatory culture of a country, especially in the matter of clearance from nuclear facilities, pros in one country may or may not be as attractive in the next country. Success and acceptance of regulations and guidance need to take account of the regulatory culture and require a very clear understanding of what is to be accomplished, and how to do it in a durable and defensible way. The subsections below address trade-offs found with the various approaches of the regulatory framework and the desired involvement of stakeholders. Keeping in mind the initial decisions on the regulatory framework and stakeholder involvement, the next subsection describes how the DQO process may be used to develop the regulations and the guidance. In practice, working through the DQO process almost always reveals the need to revise the initial decisions on the regulatory and stakeholder approaches. Thus, it should be expected that the application of the DQO process is an iterative one.

4.1. Regulatory framework

Most regulatory frameworks are built up over time, and from time to time could benefit from or require a revision. The less prescriptive regulatory frameworks that are based on a well-considered risk or dose, either of which are non-zero, tend to require revision less frequently as those that are highly prescriptive. The less prescriptive ones tend to require more regulatory effort in review and inspection to ensure the risk or dose criteria are met and technically defensible. The more prescriptive regulations are likely to require less regulatory effort for reviews and inspections once the criteria are well-established. However, when new risk or dose information becomes established, the prescriptive parts of the regulations could require change. For example, if dose coefficients or risk estimates change, acceptable concentrations of radionuclides for clearance in regulations may require change by legislation or other time-consuming and costly means.

A single authority that regulates clearance appears to be more efficient for both the authority and the facility operator. Uniformity of the criteria from the authority also provides clarity. Overlapping authorities and blurred directions can lead to costly multiple reviews, inspections, and re-work of clearance processes. In the case of the US, clearance approval from one agency can lead to disapproval by another agency. Non-nuclear power facilities in the US have different criteria than the nuclear power facilities for clearance. In addition, in the US nuclear power facilities a "non-detectable" criterion for clearance can cause a facility to be in violation of policy, if a more sensitive detection method is used subsequently.

Accordingly, clearance implementation guidance that applies generally to nuclear facilities and is prescriptive enough to be readily accepted by the regulatory authority can be most efficient for both the authority and the facility operator. Sufficient detail and defensibility can be prescribed and pre-approved. For example, with complete and detailed pre-approved procedures, including quality assurance and quality controls, the operator is informed about exactly what to submit to the authority. In addition, the authority does not have to review and evaluate the submission as a special or case-by-case situation.

4.2. Stakeholder involvement

With the great advances of information access, came wide-spread and ready communication among stakeholders of many interests. Governments of the countries reviewed in this report have recognized that stakeholder input is necessary. The use of stakeholder input has improved the communication and acceptance of clearance in some cases, but not in others. There is more than one way to approach widened awareness. Stakeholder involvement can provide valuable insights and information. However, it can also be time-consuming and expensive. This is an optimisation exercise that can factor in consideration of the source, kind, timing, amount, funding, and empowerment of the inputs.

For example, if a prescriptive regulation or guidance development is considered, then the stakeholder input needs to be part of the development and acceptance, before the regulation or guidance is finalised. In comparison, if the development of the final survey plan is progressive throughout the decommissioning, then parallel stakeholder input could provide continuing valuable input necessary for broad acceptance. These examples are not mutually exclusive; both approaches could be used.

In any case, the authority should make clear the ground rules for stakeholder input. The ground rules should include acceptable modes of input, rules of input during public meetings or hearings, and time limits for input. There should also be transparency concerning how the stakeholder input will be considered. In short, the authority should maintain its authority, but accept non-frivolous input in an open, considerate manner.

4.3. Applying the DQO Process in the development of clearance regulations and implementation guidance for the SSM

In practice, the DQO Process can be used in a general sense to solve a broad range of problems—many of which are not even mathematical. In the sub-sections below, the DQO Process is applied to developing decommissioning guidance by the SSM.

4.3.1. Identification of the problem to be solved

SSM is about to develop regulations for clearance of lands at nuclear facilities. There is also a need for the development of guidance for the Swedish industry on how to implement the regulations. This report is a comparison of several clearance implementation approaches used in five countries. A use of this inter-country comparison report is to find an optimum set of implementation attributes for use by both SSM and the Swedish industries. Thus, the problem to be solved may be stated:
"SSM needs to develop optimised regulations and guidance for implementation of clearance of lands at nuclear facilities."

The expected outputs of this step are:

- A list of the planning team members and identification of the decision maker;
- A concise description of the problem;
- A summary of available resources and relevant deadlines for the guidance development.

4.3.2. Identification of the decision to be taken

"Has SSM developed optimised guidance for implementation of clearance of lands at nuclear facilities?" The previous sentence is the identification of the decision to be taken. It may seem simplistic after the identification of the problem to be solved has been identified. It is important, because its answer, yes or no, identifies if the overall task has been completed. The steps in the subsections below reveal that arriving at this yes or no answer is not simple, because decisions of optimisation for each attribute considered must be made. Criteria and judgments have to be made to decide when optimisation has been reached for each attribute.

The expected output from this step is a decision statement that links the principal study question to possible solutions of the problem.

4.3.3. Identification of required inputs to make the decision

First, the regulatory culture in Sweden needs to be taken into account as an input to the decision. In this report, the following aspects of regulatory cultures have been identified: prescriptive processes and procedures applied to all; topics to address applied in general, a policy that defined what would be considered in compliance with the law and implementation details that are site-specific and dynamic to fit the progress of decommissioning.

Prescriptive guidance, such as is found in the German DIN, enhances uniformity of the inputs to the decision and the uniformity of cleared lands. Regulatory reviews can also be standard, and, as a result, decisions may be made readily. In this way the regulatory burden of the facility operator and the review and decision process of the authority can be more efficient. In other regulatory cultures there may be a structure and reasons to address implementation of clearance on a site-specific basis.

Identification of the relative importance of input from stakeholders outside the SSM and the facility operators needs to be made. The kinds of input, the amount, the frequency, responses to their input, if any, qualifications for stakeholders to provide input all need to be considered and decided in the planning stage. These decisions need to be harmonious with the regulatory culture.

The ten attributes of clearance implementation examined in this report may or may not be comprehensive enough for the needed optimised guidance—or they may need to be modified. In any case, the inputs to the decision should take into account those attributes that are sufficient for the SSM and facility operators to review or implement the demonstration of compliance with clearance criteria in a defensible and comprehensive manner.

The expected output of this step is a list of informational inputs needed to resolve the decision statement.

4.3.4. Definition of study boundaries

One of the study boundaries in this report is the exclusive focus on clearance of lands at nuclear facilities. For example, buildings were not included. Naturally occurring radioactivity and intervention situations are likely not to be included in the guidance. The guidance may need to limit the types of instrumentation used for field measurements. Laboratory protocols for measuring samples may be out of scope for the guidance. There may be a limited types of statistical assessments addressed. Archival methods for documentation of the clearance demonstration may be out of scope or addressed elsewhere. These are examples of some of the considerations that can clarify the scope, and thus the study boundaries.

The expected output of this step is a list of any conceptual or practical constraints that may interfere with the full implementation of the guidance development.

4.3.5. Development of a decision rule

This step addresses how to decide if the answer to the decision, as identified above is yes or no. Unlike in a case where a numerical tool, such as statistics, can be used, in this qualitative case other tools must be found or developed. In this case, the decision rule is best developed for each attribute. For example, develop the optimum level of transparency for guidance on the implementation of clearance. The optimum transparency of the guidance is not necessarily a single level for all facility lands. For example, it could need to be adjusted to the level of risk for the specific site. More risk at a site could require more transparency for the guidance. These cases could be addressed in an annex.

The expected output of this step is an “if...then...” statement that defines the conditions that would cause the decision maker to choose among alternative actions. That is, if the answer to the decision question in subsection 4.3.2

above is “No,” then what alternative actions will be taken? If the answer is “Yes,” what is the next step?

4.3.6. Specification of limits on decision errors

A decision error in this qualitative case would be an error of deciding the guidance was adequately comprehensive and finding omissions later. It would be an error to decide that the guidance was clear and implementation was readily done and intended users did not understand or use it correctly. Another error would be the decision that the guidance was optimised when it was shown in practice to be not optimal. The key to this step is for SSM to decide what it wants to review from the facility operators and how much flexibility is allowed.

The expected outputs of this step are not so quantitative that numerical values for decision errors can be specified. Nevertheless, a "comfort region" should be identified where the consequences of decision errors are relatively minor.

4.3.7. Optimisation of the design for obtaining data

In the case of development of clearance implementation guidance, the data are the required inputs for making the decision in subsection 4.3.3. The optimal way of getting those inputs is likely from one or more references for the specific input data. Some references may be expert persons, while others may be written documents that have proven effective and efficient with use, such as MARSSIM or EURSSEM.

5. Concluding remarks

The SSM has inherent regulatory functions that cannot be delegated. These include judging the optimal guidance attributes for implementation of surveys to demonstrate compliance with clearance criteria. The guidance approaches for clearance of land used in five countries have been reviewed and compared. For the regulator, the task is one of multi-dimensional optimisation. Key dimensions to optimise include: protection of the public and the environment, clarity, acceptance, efficiency, and cost. With this report SSM has obtained up-to-date information to use and judge, on an attribute-by-attribute basis, which of these approaches most closely addresses the needs in Sweden.

It is emphasised that it is not necessary to develop implementation guidance totally anew. Using guidance that has already been developed and proven to be effective, efficient, and useful in real cases can readily be adopted or modified by SSM. The approach of referring to established guidance such as MARSSIM or EURSSEM has been practical for authorities and facility operators in the US, in Spain and at Bradwell nuclear power plant in the UK. The potential benefits of using guidance by reference include:

- Reduced effort by the regulatory authority—namely, SSM;
- Reduced cost to the regulatory authority;
- Prompt issuance for timely use by the facility operators and SSM;
- Clarity of the methods and processes to ensure compliance with clearance criteria;
- Reduced rework by the facility operator resulting in reduced overall costs.

6. Acknowledgements

Thank you to individuals who provided contacts, information, and personal input to this interim report, including:

Jean-Guy Nokhamzon, CEA, Member of OECD/NEAWPDD Regulation (France);
Jean-Jacques Peraudin, Geovariances Industry (Sales manager of geostatistics software) (France);
Stefan Thierfeldt, Brenk Systemplanung, GmbH Industry (Consultant for Decommissioning and Clearance) (Germany);
José Luis González Gómez, Department Head, International Relations, ENRESA Regulation (Spain);
Alejandro Rodríguez Fernández, Manager of Operations, ENRESA Regulation (Spain);
Julia Lopez de la Higuera, Waste and Clearance Regulation, CSN (Spain)
Henrik Efraimsson, SSM (Sweden);
Shelly Mobbs, Radiological Assessment expert, Eden Nuclear and Environment Industry (U.K.);
Larry Boing, Manager, Special Projects & Decommissioning SME, Argonne National Laboratory Industry (U.S.);
Jean-Claude Dehmel, Senior Health Physicist, Regulation (Decommissioning specialist) Nuclear Regulatory Commission (U.S.);
Tom Hanson, MARSSIM Consultant, Ameriphysics, LLC Industry (U.S.);
Thomas Meek, U.K. Decommissioning Implementation Consultant Industry (U.S.);
Robert Stewart, Author-programmer SADA, Oak Ridge National Laboratory Industry (U.S.);
Carlos E. Corredor, Health Physicist, US Department of Energy (US).

7. References

[1] **Autorité de Sûreté Nucléaire (ASN) [Nuclear Safety Authority].** *On Transparency and Security in the Nuclear Field.* Paris : ASN, 2006. ACT No. 2006-686 of 13 June 2006.

[2] **ASN.** *Program on the sustainable management of materials and radioactive waste.* Paris : ASN, 2006. Act No. 2006-739 of 28 June 2006.

[3] **Ministre d'Etat.** *Decree No.2007-1557 of November 2, 2007 relating to nuclear installations and control under the Nuclear Safety of transpor of radioactive substances.* Paris : Ministry for Ecology, Sustainable Development and Spatial Planning, 2007. Official Journal no. 255 of 3 November 2007 page 18026 text no. 3.

[4] **ASN.** *ASN's Policy on Dismantling and decommissioning of nuclear facilities in France.* Paris : ASN, 2009. Version 0.v3 .

[5] **ASN.** *Méthodologies d'assainissement complet acceptables dans les installations nucléaires de base en France.* Paris : ASN, 2010. Projet de guide de l'ASN n° 14 • Version du 21/06/2010.

[6] **ASN.** *Mise à l'arrêt définitif, démantèlement et déclassement des installations nucléaires de base en France.* Paris : ASN, 2010. Guide de l'ASN n° 6 • Version du 18/06/2010.

[7] **IAEA.** *Release of Sites from Regulatory Control on Termination of Practices.* Vienna : International Atomic Energy Agency, 2006. IAEA Safety Standard Series No. WS-G-5.1.

[8] *French CEA's Site cleanup methodology and related applications.* **Dubot, D. and Attiogbe, J.** Idaho Falls : American Nuclear Society, 2010. Decommissioning, Decontamination, and Reutilization Topical Meeting. 2010.

[9] **Geovariances.** Kartotrak Brochure. *Kartotrak.* [Online] [Cited: November 22, 2011.] http://www.geovariances.com/en/IMG/pdf/kartotrak-brochure.pdf.

[10] *Geostatistical Methods for Radiological Evaluation and Risk Analysis of Contaminated Premises.* **Desnoyers, Y., Chilès, J.-P., Jeannée, N., Idasiak, J.-M., Dubot, D.** Bucharest : Nuclear Energy Romanian Association – AREN, 2009. International Symposium on Nuclear Energy "The Nuclear Power – A New Challenge".

[11] **Bundesamt für Strahlenschutz (BfS).** *Ordinance on the Protection against Damage and Injuries Caused by Ionizing Radiation.* Saltzgitter : Bundesamt für Strahlenschutz (BfS), 20 July 2001, last Amendment of 13 December 2007. Safety Code.

[12] *Eléments de statistiques pour le démantèlement et la gestion des déchets.* **Perot, Nadia.** Montpellier : CETAMA/CEA, 2010. Sampling and Characterization II.

[13] **Department of Defense, Department of Energy, Environmental Protection Agency, Nuclear Regulatory Commission.** *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Revision 1.* Washington : Nuclear Regulatory Commission, 2000. Technical. NUREG-1575, Rev.1; EPA-402-R-97-016, Rev. 1; DOE/EH-0624, Rev. 1.

[14] **Thierfeldt, S., et al.** *Stillegung von Kernanlagen-Freigabe von Bodenflächen kerntechnischer Standorte Endbericht zu Vorhaben SR*

2271. Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit. Aachen : Brenk Systemplanung, GmbH, 2000.

[15] **Thierfeldt, Stefan.** *Two questions re: German case-by-case decommissioning plans.* [interv.] Robert A. Meck. Aachen, July 14, 2011. e-mail.

[16] **Deutsches Institut für Normung e.V. (DIN).** *Aktivitätsmessverfahren für die Freigabe von radioaktiven Reststoffen und kerntechnischen Anlagenteilen – Teil 7: Bodenflächen.* Berlin : DIN, 2008. [Activity measurement mehtods for the release of radioactive waste materials and nuclear components-Part 7: (Nuclear) sites]. DIN 25457-7.

[17] **Bundesamt für Strahlenschutz.** *Act on the Peaceful Utilisation of Atomic Energy and the Protection against its Hazards (Atomic Energy Act).* Salzgitter : Bundesamt für Strahlenschutz, 23 December 1959, as amended and promulgated on 15 July 1985, last amendment by the Act of 31 July 2011.

[18] **World Nuclear Association.** Nuclear Power in Spain. *World Nuclear Association.* [Online] [Cited: 11 26, 2011.] http://www.world-nuclear.org/info/inf85.html.

[19] *Buildings& Site Release and Reuse: The Spanish Regulatory's View.* **Revilla, J. L.** Karlsruhe : Nuclear Energy Agency, Radioactive Waste Management Committee, 2002. Topical Session on Buildings & Sites Release and Reuse. pp. 50-57. NEA/RWM/WPDD(2002)8.

[20] **CSN.** Instruction IS-13 on the Radiological Criteria for the Release of Nuclear Installation Sites.

[21] **American Standards National Institute (ANSI).** *Characterization in Support of Decommissioning Using the Data Quality Objectives Process.* New York : ANSI, 2008. Standard. ANSI/HPS N13.59-2008.

[22] **Lopez de la Higuera, J.** June 13, 2012. e-mail to Henrik Efraimsson.

[23] **CSN.** *Plan de Restauración del Emplazamiento [Site Restoration Plan]* . Madrid : CSN, 2007.

[24] **OECD.** *Nuclear Legislation in OECD Countries: Regulatory and Institutional Framework--Spain.* Paris : OECD, 2010.

[25] **Parliament of the United Kingdom.** legislation.gov.uk. *legislation.gov.uk.* [Online] [Cited: November 29, 2011.] http://www.legislation.gov.uk/ukpga/2004/20/section/1.

[26] **Health and Safety Executive (HSE).** HSE Criterion for Delicensing Nuclear Sites. *Health and Safety Executive.* [Online] May 2005. [Cited: November 29, 2011.] http://www.hse.gov.uk/nuclear/delicensing.pdf.

[27] **HSE.** Guidance to Inspectors on the Interpretation and Implementation of the HSE Policy Criterion of No Danger for the Delicensing of Nuclear sites. [Online] August 2008. [Cited: November 29, 2011.] http://www.hse.gov.uk/nuclear/delicenceguide.pdf.

[28] **Nuclear Decommissioning Authority (NDA).** NDA-Strategy-Effective-from-April-2011. [Online] March 2011. [Cited: November 29, 2011.] http://www.nda.gov.uk/documents/upload/NDA-Strategy-Effective-from-April-2011-full-colour-version.pdf.

[29] **D. Collier prepared by Faulkland Associates and Enviros.** *SAFEGROUNDS: Approach to Managing Contaminated Land on Nuclear Licensed and Defence sites--an Introduction.* London : CIRIA , 2009. CIRIA W-27.

[30] **Towler, P.** *SAFEGROUNDS: Good Practise Guidance for Site characterisation, Version 2.* London : CIRIA, 2009. CIRIA W30.

[31] **Hill, Marion.** Nuclear Decommissioning: where we are, priorities and challenges. *SAFESPUR.* [Online] January 12, 2011. [Cited: December 1, 2011.] AMEC, Warrington, 12 January 2011. http://www.safespur.com/pdf/Note%20of%20SAFESPUR%20Decomm%20Meeting%20Jan11%20v2.pdf.

[32] *Model Procedures for the Management of Land Contamination.* Environmental Agency. Almondsbury : **Environmental Agency**, 2004.

[33] **Clearance and Exemption Working Group (CEWG).** Clearance and Exemption Principles, Processes and Practices for Use by the Nuclear Industry: A Nuclear Industry Code of Practice. [Online] 1.01, August 2006. [Cited: December 1, 2011.] http://www.cewg.safety-directors-forum.org/code/Uncontrolled-Issue-1.01-Nuclear-Industry-Code-of-Practice-Aug-2006.pdf.

[34] **Unknown.** Clearance and Exemption: Principles, Processes and Practices for Use by the Nuclear Industry. [Online] [Cited: December 1, 2011.] http://www.dounreay.com/UserFiles/File/archive/Waste%20plants/Waste%20Clearance%20and%20exemptions%20summary%20paper%202.pdf.

[35] **Co-ordination Network on Decommissioning of Nuclear Installations.** *European Radiation Survey and Site Execution Manual (EURSSEM).* s.l. : European Commission (EC), 2009.

[36] **RSK.** RSK. *Operational and Decommissioning Sites.* [Online] [Cited: December 1, 2011.] http://www.rsk.co.uk/sectors-complete-1728/nuclear-complete-1737/nuclear-case-studies/operational-and-decommissioning-sites.html.

[37] *Development of Software Tools for Supporting Building Clearanceand Site Release at UKAEA.* **G. Jessop, M. Pearl.** Karlsruhe : NEA, 2002. TOPICAL SESSION ON BUILDINGS & SITES RELEASE AND REUSE Karlsruhe. pp. 15-38. NEA/RWM/WPDD(2002)8 JT00135892.

[38] **US NRC.** About NRC. *US Nuclear Regulatory Commission.* [Online] March 31, 2011. [Cited: December 2, 2011.] http://www.nrc.gov/about-nrc/governing-laws.html.

[39] **University of Tennessee, Knoxville.** Spatial Analysis and Decision Assistance. *Spatial Analysis and Decision Assistance.* [Online] [Cited: December 2, 2011.] geospatial software with MARSSIM module. http://www.tiem.utk.edu/~sada/index.shtml.

[40] **US Environmental Protection Agency (USEPA).** *Guidance on Systematic Planning Using the Data Quality Objectives Process.* Washington, DC : USEPA, 2006. Technical Report. EPA QA/G-4 EPA/240/B-06/002.

[41] **US Department of Energy (US DOE).** *RADIATION PROTECTION OF THE PUBLIC AND THE ENVIRONMENT.*

Office of Health, Safety and Security. Washington, DC : s.n., 2011. DOE Order. DOE O 458.1, Chg.1, Chg. 2.

[42] **US NRC.** *Radiological Criteria for License Termination.* [prod.] National Archives and Records Administration Office of the Federal Register. Washington, DC, USA : s.n., January 22, 2008. Code of Federal Regulations: Title 10 Energy, Part 20, Subpart E. 10 CFR Part 20, Subpart E, 20.1402.

[43] **Oak Ridge Institute of Science and Education (ORISE).** MARSSIM Tools. *MARSSIM Tools.* [Online] [Cited: 12 7, 2011.] Several software programs for download. http://www.marssim.com/Tools.htm.

[44] **International Organization for Standardization (ISO).** *Guide to the Expression of Uncertainty in Measurement.* Geneva : International Organization for Standardization (ISO), 1995. ISO Guide 98.

[45] **Stewart, Robert.** [interv.] Robert Meck. July 27, 2011. e-mail communication.

[46] **US NRC.** *A Subsurface Decision Model for Supporting Environmental Compliance.* Rockville, Maryland : US Nuclear Regulatory Commission, 2012. p. 97. NUREG/CR-7021.

2013:14

The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

Strålsäkerhetsmyndigheten
Swedish Radiation Safety Authority

SE-171 16 Stockholm
Solna strandväg 96

Tel: +46 8 799 40 00
Fax: +46 8 799 40 10

E-mail: registrator@ssm.se
Web: stralsakerhetsmyndigheten.se