CHANCE project

(Contract Number: 755371)

STUDY OF SOCIAL AND ETHICAL ASPECTS OF INNOVATIVE WASTE MANAGEMENT

DELIVERABLE (D6.3)

Work Package 6

Author(s): Hietala, M.

Reporting period 2: 01/11/2018 – 31/06/2020

Date of issue of this report: **28/05/2020**

Start date of project: **01/06/2017** Duration: 48 Months

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 755371;

Dissemination Level		
PU	Public	X
CO	Confidential, only for partners of the CHANCE project and EC	

History chart			
Status	**Type of revision**	**Partner**	**Date**
Draft	Initial version	SCK-CEN	20/01/2020
Draft2	Reviewed	ANDRA/ RWM	28/04/2020
Final		SCK-CEN	28/05/2020

Reviewed by
End User Group: Amy Shelton (RWM)

Approved by
The Executive Board

© CHANCE

TABLE OF CONTENTS

ABBREVIATIONS

© CHANCE

CRDS	Cavity Ring-Down Spectroscopy
CoRWM	Committee on Radioactive Waste Management
DAD	Decide, Announce, Defend
EUG	End-User Group
FP7	Framework Programme 7
GDF	Geological Disposal Facilities
HLW	High Level Waste
IAEA	International Atomic Energy Agency
LLW	Low Level Waste
ILW	Intermediate Level Waste
InSOTEC	(International) Socio-Technical Challenges for implementing geological disposal
NIMBY	Not In My Back Yard
RWM	Radioactive Waste Management
SNF	Spent Nuclear Fuel
STS	Science and Technology Studies
VLLW	Very Low Level Waste
WAC	Waste Acceptance Criteria
WMO	Waste Management Organization
WP	Waste Packages

© CHANCE

1. Introduction

The CHANCE project aims to address the characterization of conditioned radioactive waste. The characterization of fully or partly conditioned radioactive waste is a specific issue because unlike for raw waste, its characterization is complicated by the need for non-destructive techniques and methodologies. There are different and varying reasons for this: 1) conditioned waste may no longer be in its initial form (e.g., due to incineration); 2) conditioned waste is typically embedded or surrounded by a matrix; and 3) conditioned waste may contain wastes that come from different primary sources and therefore the radiological spectrum might become more complex. Characterization issues within CHANCE encompass both physico-chemical characterization and radiological characterization.

The first objective of the CHANCE project is to establish at the European level a comprehensive understanding of current conditioned radioactive waste characterization and quality control practices across a range of different national radioactive waste management (RWM) programs, based on inputs from end-users members such as Waste Management Organizations and storage operators. CHANCE will focus on the following waste forms (IAEA classification):

- Very Low Level Waste (VLLW);
- Low Level Waste (LLW);
- Intermediate Level Waste (ILW);
- High Level Waste (HLW).

The second objective of CHANCE is to further develop, test and validate techniques already identified that are expected to improve the characterization of conditioned radioactive waste, namely those that cannot easily be dealt with using conventional methods. Specifically, the work on conditioned radioactive waste characterization technology will focus on:

- **Calorimetry** as an innovative non-destructive technique to reduce uncertainties on the inventory of radionuclides;
- **Muon Tomography** to address the specific issue of non-destructive control of the content of large volume nuclear waste;
- **Cavity Ring-Down Spectroscopy** (CRDS) as an innovative technique to characterize outgassing of radioactive waste.

The present report focuses on activities from Work Package 6 (Task 6.2) related to the first objective of the CHANCE project, and in particular, the establishment of an overview of the socio-technical and ethical issues associated with the waste characterization process in view of the final disposal of radioactive waste. To collect information of these issues on a country level, a questionnaire was designed and distributed to operators of radioactive waste disposal in Europe through the CHANCE project End-User Group (EUG).

© CHANCE

This document presents an analysis of socio-ethical and technical frameworks of radioactive waste characterization practices and policies based on answers to the questionnaire by members of the EUG. The questionnaire was also used to understand the requirements and methodologies for the characterization of conditioned radioactive waste used in different national contexts (Bucur et al., 2019).

The questionnaire consisted of 18 questions on key parameters required for characterization; technologies/methods commonly used for the characterization of conditioned waste; waste acceptance criteria applied and the possibilities of their harmonization in Europe; specific problematic issues for the characterization of conditioned radioactive waste; current R&D needs and the potential of on-going R&D programs on conditioned radioactive waste characterization; potential applications of R&D actions included in CHANCE; and the socio-ethical and technical issues associated with the waste characterization process. 12 respondents from the EUG and the CHANCE WP2 members, from Belgium, France, Italy, Germany, Poland, Romania, Spain, Sweden and UK answered to the questionnaire. Seven of these were from national waste management organizations and five were from research institutes.

Some key findings that emerge from the analysis of responses to the questionnaire highlight, perhaps unsurprisingly, the centrality of safety (Landström and Bergmans, 2012) as the underlying value and the driving factor for radioactive waste characterization. Additionally, the diversity of existing waste characterization and management practices between, and within, different national contexts; the importance, and in some cases the difficulty, of retaining and managing knowledge and data; and, finally, a broadly shared understanding of radioactive waste characterization as a mainly technical issue.

These findings are the focus of section 4, while the following two sections will discuss existing social scientific work on RWM and the methods used in this study. The last section of the report will offer some final discussion points and conclusions.

2. Social scientific takes on radioactive waste management

Social scientific literature on RWM has mainly focused on the geological disposal of radioactive wastes, in particular on risk perception and communication (e.g. Perko et al., 2012; Seidl et al., 2013; and Skarlatidou, Cheng, and Haklay, 2012), issues around the governance (e.g. Chilvers, 2007; Di Nucci, Brunnengräber, Isidoro Losada, 2017), as well as public and stakeholder participation (e.g. Lehtonen, 2010; Mackerron and Berkhout, 2009; Strauss, 2010). This focus, especially on governance and participation, reflects the so called participatory turn in RWM (Bergmans et al., 2015), which in turn reflects the acknowledgement by decision-makers and nuclear waste management organizations of the importance of 'social aspects' and citizens' involvement in RWM. This acknowledgement stems, on one hand, from the

© CHANCE

politicization of nuclear power in the 1970s (Solomon and Andrén, 2010) and on the other, from the recognition in the 1990s that the so called 'decide, announce, defend' (DAD) approach (the development of policy behind closed door by the government, the nuclear industry and selected scientists) was ineffective and only resulted in opposition (Mackerron and Berkhout, 2009). WMOs, policy makers and other nuclear proponents routinely viewed this opposition as a 'NIMBY' (Not In My Back Yard) reaction, with all of its negative connotations. Researchers have since reflected that self-interest or irrational fear, often associated with NIMBY, are too simplistic explanations for opposition (Bergmans et al., 2015). Rather, negative reactions should be understood as stemming from WMO neglect of the social aspects of RWM, but also from a neglect of non-technoscientific problem definitions – such as differences in the perceived need and importance of geological disposal technologies (Bergmans et al. 2008). Potential host communities perceive and conceptualize disposal projects and technologies from their own lived experience and local knowledge (Felt and Wynne, 2007), and these conceptualizations and understanding might contradict the technoscientific logics underpinning the long-term management of radioactive waste management.

Where DAD privileged 'sound science' as the foundation for policy making, siting controversies led to a recognition that while sound science is necessary, it alone is an insufficient basis for decision making. The subsequent turn to a more participatory approach to RWM has aimed at developing trust (and consent) through transparent and open procedures, working with communities and democratizing RWM. Nonetheless, it has been argued that public participation has had a limited impact on RWM (e.g. Durant, 2015; Blowers and Sundqvist, 2010). One limitation of participatory processes has been the persistent separation of the so called 'social' from the 'technical' aspects of RWM. Where publics have been invited to deliberate on the social aspects, technical aspects tend not to be opened for deliberation. Rather they are generally brought to the public arena after technical experts have defined problems and solutions to those problems (Bergmans et al., 2015). This separation of the social and the technical is not unique to RWM, but is emblematic of the so called linear model of innovation that traces a clear trajectory from innovation to implementation and impact. This model has been critiqued in social science literature, because it fails to acknowledge the complexity of innovation processes (Owen at al., 2013), but also because "the linear model is very hard to find anywhere, except in some descriptions of what it is supposed to have been" (Edgerton, 2004: 32). This latter observation is also reflected in some of the responses to the questionnaire (see section 4.2.2). Within the received answers, innovation and radioactive waste characterization are, on one hand, described as 'complex, collective and dynamic' processes (Owen et al., 2013). On the other hand, they are, nonetheless, perceived as processes taking place in isolation from the broader society and broader societal concerns, and not as something that publics should be debating on. Rather, societal actors, including potential host communities, are left to coalesce around and debate on the so called social and politics aspects of siting and hosting geological disposal facilities (GDFs) (Gregson, 2012), such as community

© CHANCE

benefits and/or compensation that hosting a GDF can bring to a community. In contrast to this situation, it has been argued in social scientific literature that participatory processes should, indeed, address social aspects, such as access to and transparency of information, acceptance and trust, but also how these matters *connect to technical aspects in sociotechnical combinations*, such as RWM and/or the implementation of geological disposal (e.g. Bergmans et al., 2015).

The notion of the 'sociotechnical' emerges from the field of Science and Technology Studies (STS), where an extensive research tradition has demonstrated the close interconnections between society ('the social') on one hand, and science and technology on the other ('the technical') (e.g. Callon, 1984; Fisher, 2007; Latour, 2005). STS literature suggests that what happens in the 'technical' sphere influences, and is influenced by, what happens in the 'social' sphere. Thus the social and the technical are understood as inherently interlinked and inseparable, and cannot be studied in isolation. For instance, technological innovation includes innovation of decision-making processes, identities, institutions and social roles that adapt and are adapted to the technological object. In other words, what goes on within an innovation process is the mutual adaptation of a range of factors gathered together within a single process. Examining RWM through the lens of the sociotechnical can help to open up the science and technology underpinning RWM to clarify what kinds of social assumptions and values they contain, but also to tease out the effects science and technology may have on society.

The InSOTEC-program ((International) Socio-Technical Challenges for implementing geological disposal), funded and conducted under FP7, explicitly addressed geological disposal, and RWM more broadly, as a sociotechnical challenge (Bergmans and Schröder, 2012). In relation to geological disposal, the program identified safety, siting, reversibility of decisions/retrievability of waste, and the long timescales involved in geological disposal as sociotechnical challenges shared by a number of countries. For instance, safety has been positioned as the main socio-technical challenge for, and the first one to be addressed by national policies on, geological disposal (Landström and Bergmans, 2012). Initially the safety of geological disposal was envisioned to be achieved through the separation of humans and radioactive wastes, the social and the technical (Schröder, 2016). As was mentioned above, this technocratic approach, the configuration of safety as a technical problem that could be solved with sound science and engineering, led to public opposition and failed in a range of societal contexts and at different points in time (Landström and Bergmans, 2012). The failure led to a reconfiguration of the safety-making process. Instead of imposing GDFs on communities, voluntarism – the willingness of communities to host a GDF – was inserted into RWM policies and implementation processes in many countries, but also on the European level (EC, 2011). Although the connection between the social and technical processes is not always explicit in national policies, analytically they highlight the integration of the social and the technical (Landström and Bergmans, 2012). Another example of this integration and mutual influence of

© CHANCE

the social and the technical is waste classification. While there is an international classification scheme for radioactive wastes (IAEA, 2009), national differences in how specific materials are classified are evident. For example, different countries demonstrate different approaches to the management of spent nuclear fuel (SNF). Where Sweden treats SNF as waste and plans to emplace it in a geological disposal facility (GDF) in the future, the UK and France, for instance, have historically treated it as a resource and reprocessed it for plutonium and uranium, which has resulted in more diverse and complex radioactive waste inventories.

Thus, the categorization of materials (as waste or resource) is bound up with broader national practices and policies, for example about the nuclear fuel cycle (open or closed), the future role of nuclear within the energy mix, choice of fuels and so on. As such, these broader policies have direct consequences for RWM and regulatory practices. They influence radioactive waste inventories, and by extension waste storage and disposal arrangements (Hietala, 2018). What waste is (how it is classified, but also what it is composed of) has tangible sociotechnical consequences for political decision-making, and technical solutions and visions for the long-term management of radioactive waste. Nonetheless, what counts as waste and what should be done with it are questions that have not (generally) been opened up for public deliberation. Meanwhile, waste has similarly been decentered from social scientific inquiries that have focused on risk and the siting of disposal facilities (Strandberg and Andrén, 2009).

Yet, it has been argued that the invisibility of waste in participatory processes, including debates and discussions in potential GDF host communities, can be unconducive for the implementation of geological disposal (Gregson, 2012). It has been argued that “communities are unlikely to express a willingness to participate in a siting process unless they have a clear understanding of the waste inventory they may be asked to accept” (CoRWM, 2006: 145). It can and has been argued that radioactive wastes should be made more transparent to publics (Gregson, 2012). Even where waste inventories for disposal are clear, radioactive wastes remain difficult for publics to know because of their double sequestration from the public sphere. Firstly, because of radiological protection and security reasons, radioactive wastes are physically confined to hard-to-access nuclear sites. Secondly, they have become discursively contained in the realms of technical expertise. In part this is a result of processes that have generated and fostered broad technopolitical support for geological disposal. The focus of public discussions on implementing solutions to the radioactive waste problem have worked to decentralize the problem itself. What this means for potential host communities is that they are asked to host radioactive wastes and GDFs with potentially very limited knowledge of what the waste actually contains and is composed of, how decisions about waste matrices, packages and, ultimately, safety are made, and what kinds of logics underpin these decisions and makings. Instead, potential host communities rely on technoscientific representations that tend to simplify the description of radioactive wastes. The complexity of the wastes and the challenges in terms of characterization are therefore not so widely understood (Gregson, 2012). In other

© CHANCE

words, despite the participatory turn in RWM, generally, host communities and the general public have historically had little or no input to the definition and deliberations on the proposed technological solutions to radioactive waste issues or the broader societal consequences and impacts of those definitions and solutions might be. Rather, they may be treated as an audience to be convinced and to voice their supports for, technological solutions predefined by technical experts; and to trust the industry. In this way, potential host communities have been detached from the processes and issues of RWM and left to deal only with the narrowly defined 'social' aspects of the process (Bergmans et al., 2015).

Yet, even where national level consensus has been reached over RWM, the 're-heating' of debates and RWM politics on the local level has been well documented in social scientific literature (see e.g. Elam and Sundqvist (2011) for Sweden; Kari, Kojo and Litmanen (2009) for Finland; Di Nucci and Brunnengräber (2017) for France; Bickerstaff (2012) for the UK). In part this stems from the fact that national and local interests do not neatly align. Rather their relationship holds potential for conflict. For example, while a broad and abstract agreement that something should be done by radioactive waste exists (Vilhunen et al., 2019; Eurobarometer, 2008), on a more concrete level, and in the context of 'risk decision-making', ethical issues tend to come to the fore with the "most common problems revolving around assessment of what is 'fair', 'equitable' and how this is decided upon" (Cotton, 2009: 606). Indeed, social scientific literature on RWM and nuclear issues has focused on such ethical questions (e.g. Cotton, 2018; Shrader-Frechette, 2000, 2005; Taebi, 2017). It has, for instance, been argued that decisions about waste canister materials (e.g. steel or copper) are underpinned by ethical considerations that put differing emphasis on intragenerational (e.g. resource allocation/cheaper implementation cost of steel canisters) and intergenerational (e.g. the longevity of containment offered by copper) equity (Shrader-Frechette, 2000). Additionally, it has been suggested that the framing of risks host communities face in terms of national interests or the 'greater good' bypass local justice and rights (Cotton, 2018), while it has also been argued that focus on social acceptance of disposal technologies overlook questions about their ethical acceptability – the moral issues that relate to the implementation of these technologies (Taebi, 2017). For instance, when talking about intergenerational questions, it needs to be defined who the future generations implied in these questions are, and who gets to define how future generations are defined (ibid.).

The implementation of geological disposal is dependent on space, on a locality, and on the alignment of scalar politics (the local, the regional, the national). On one hand, then, broader problem definitions and decision processes are entwined with (local) ethical issues and justifications (Cotton, 2018). On the other, it has been argued that social acceptance and ethical acceptability of geological disposal solutions do not flow from the technology alone. Rather, what is important, is the inevitable dependency of host communities on institutions responsible

© CHANCE

for the implementation of geological disposal. Indeed, representatives of the Östhammar community that will host the Swedish GDF have pointed out that, when it comes to geological disposal, matters around procedural and substantive questions are equally important (cf. Schröder et al., 2012). Where substantive questions touch upon the implementation of nuclear waste disposal and the impacts of the disposal project will or might have on the local community, procedural questions refer to issues related to decision-making processes. They include questions such as how decisions are taken, and by whom; how safety is demonstrated and so on – and it is to this category that concerns around waste and waste characterization can be added.

Radioactive waste characterization and the development of characterization methods are implicated in and entwined with broader social and ethical concerns and frameworks, but they are also driven by (implicit) normative value judgements and assumption – all of which need to be carefully reflected on and opened up for discussion. Because of the impossibility for potential host communities, who will bear possible risks pertaining to final waste disposal (but also of interim storage), to gain first-hand experience and knowledge of radioactive waste and waste management practices, explicating the objectives of waste characterization, the knowledge and decision-making processes, and ethical justifications underpinning those practices is pertinent. This fosters transparency, and vitally, it has the potential to enable open and ongoing discussion and reflection of technical risks, which allows potential host communities to make informed decisions and choices about their possible involvement in the long-term management of radioactive waste.

3. Methods and Data

The analysis presented in this report is based on data collected through a questionnaire, in which respondents were expected to clarify and summarize RWM situations at the national level. The aim of the questionnaire thus was to trace the requirements and methodologies for the characterization of conditioned radioactive waste used in different national contexts, and to map socio-ethical and technical frameworks of radioactive waste characterization practices and policies.

The questionnaire consisted of 18 questions, some of which were open and some closed (see Appendix A). The questionnaire was emailed to CHANCE End Users Group (EUG) with the aim of gaining an overview of the end-users needs for the characterization of conditioned radioactive waste and to appreciate how EUG members foreground the requirement of waste characterization within their organizations in relation to the development of the national disposal program, and with respect to the importance of managing both the entire back-end of the nuclear fuel cycle as well as uncertainty.

© CHANCE

13 responses were received from the EUG and the CHANCE WP2 members, from Belgium, France, Italy, Germany, Poland, Romania, Spain, Sweden and UK. Eight of responses were received from national RWM organizations and five from research institutes. The questions and responses to them have been synthesized in CHANCE Deliverable 2.2 (Bucur et al., 2019). What is presented here is a more in-depth analysis of the socio-ethical and sociotechnical concerns and considerations related to the characterization of radioactive waste.

The data was analyzed using thematic analysis, which is the process of identifying patterns or themes within qualitative data. Unconnected to any specific epistemological or theoretical perspective, thematic analysis as a method is very flexible. Its aim is to identify important and interesting patterns in the data, which are then used to address the issue at hand. Good thematic analysis interprets and makes sense of data instead of just summarizing it. It has been argued that broadly, two distinct levels, semantic and latent, themes exist (Braun and Clarke, 2006). The former refers to the "explicit or surface meanings of the data … what a participant has said or what has been written", while the latter refers to the "underlying ideas, assumptions, and conceptualisations – and ideologies - that are theorised as shaping or informing the semantic content of the data" (ibid.: 84). Additionally, a distinction can be made between a top-down analysis driven by the specific research question(s) and a bottom-up analysis driven by the data. The analysis here is more bottom-up than top-down and driven by the collected data.

Open or emergent codes were used in the organization and coding of data (Glaser and Strauss, 1967). That is, there were no pre-set codes, but rather codes emerged from the data and were developed and modified throughout the coding process. After the initial stage of analysis, codes were examined and those that clearly fitted together were organized into broader themes, color-coded, and data associated to particular themes were collated into separate word files. Subsequently, data associated with the identified themes were read to ensure that data corresponded with and supported the themes under which they were organized. Finally, the 'essence' of themes was identified with an aim to reflect on how the themes interact and relate with the overall dataset as well as with the other themes that emerged from the analysis. The findings presented in the following section are the result of this iterative process.

All the data presented here are anonymized. Respondents to the questionnaire were asked to indicate the preferred level of recognisability by choosing one of three options: 'fine to publish the whole questionnaire with name', 'fine to publish the whole questionnaire anonymously', and 'just use the answers as part of a general overview/statistical analysis'. Since there was great variation between the different levels of anonymity, all data presented here are anonymized to protect identities and associations of those who chose to remain anonymous.

© CHANCE

4. Analysis

The characterization of radioactive waste is a core process in the safe management of radioactive waste, and ultimately the implementation of of a final disposal facility. As the characteristics and properties of radioactive waste inform the design of waste canisters and, together with the disposal site, the design of the whole disposal system, effective and accurate characterization of radioactive waste is, then, inherently tied to ideas about long-term safety. Unsurprisingly, then, safety is the underpinning theme that emerged from the analysis, as it is entangled with every aspect of RWM.

Safety, however, is not uniform or universal across different sites and contexts. Rather it is the result of localized practices (section 4.1) and complex processes (section 4.2.2). It is closely connected to entities such as Waste Acceptance Criteria that evolve and change over time (section 4.1.2), which creates particular challenges for RWM and waste characterization (section 4.3.1). Indeed, many of the issues and challenges regarding waste characterization relate to knowledge, knowing and the establishment of systems and methodologies of knowing. Knowledge and the processes of knowing are intimately tied to technoscientific confidence in the long-term safety of the disposal systems designed to contain radioactive wastes for several millennia. From this perspective the continuing separation of the social and the technical (section 4.2), and imaginaries of the linear relationship between technoscience and potential host communities (section 4.2.1) emerge as problematic, and demonstrate the limitations of the participatory turn in RWM.

4.1 Creating wastes for disposal

Waste Acceptance Criteria (WAC), were highlighted as being interlinked with policy decisions and waste classifications, disposal inventories and disposal sites, by all respondents. This came up in arguments against the harmonization of WAC across different countries, since, as one respondent observed, WAC are "based on safety assessment of a particular disposal facility and consequently are dependent on facility design and performance assessment, site characteristics, handling schemes and [it is difficult to] see how to harmonize them". WAC function as rules and guidelines for waste owners and managers in RWM. Decisions about what wastes are acceptable and accepted for disposal is defined with and through a broad range of parameters (e.g. heat generation, radionuclide content, radiological source term, dose rate, criticality/stability, gas content, presence of organic matter in waste, form, mechanical integrity etc.). There are two kinds of WAC. The first are applied at already operating storage or disposal facilities, while the second 'preliminary' WAC apply to disposal facilities that do not yet exist, but are expected to be operational in the future, such as GDFs for higher activity wastes.

© CHANCE

WAC, then, support an assessment of the disposability of radioactive wastes. They lay out the parameters within which wastes need to fit in order to be accepted into a disposal facility. By establishing these parameters for what can be disposed of in a facility, WAC perform boundary work (Gieryn, 1983). They cut through the waste inventory and create categories of inclusion and exclusion; wastes that are disposable and wastes that are not. At the same time, the boundaries and categories generated by WAC are not (necessarily) stable. WAC themselves are living entities, changeable in time and space, their evolution informed by technopolitical conditions and decision processes, such as tightening radiation protection rules and practices, and increasing knowledge of disposal sites. This changeability and the shifting boundaries of waste (acceptance/rejection and inclusion/exclusion), give rise to challenges pertaining to the implementation and design of disposal (and other RWM) solutions, as WAC remain in some senses, and in some cases, a moving target. The boundary work performed by and with WAC is saturated with ethical considerations (see below), but it is also entwined with probabilistic risk assessment and normative technoscientific assumptions about risk and safety. As such, as one respondent reflected, official WAC and stakeholder requirements for waste acceptance might juxtapose each other. Therefore, opening up space for (broader) reflection of the decisions and the guiding logics underpinning WAC, but also of the consequences of those decisions is necessary as they (may) have long lasting effects on the safety of geological disposal.

4.1.1 Localized safety making

In the questionnaire respondents were prompted to describe the most important radiological, chemical and mechanical (as well as other) parameters that radioactive wastes need to fit into in order to be deemed acceptable for disposal. The descriptions of parameters within these broader categories laid out by the questionnaire given by the respondents differed (although there were also similarities, see below) both in content and detail. However, the dependency of the WAC on local conditions; “on the facilities involved, strategic choices, design and advancement of the long-term management programme” was explicitly mentioned by all respondents in their answers to the questionnaire. The majority of respondents underlined that WAC as a mechanism for safety-making is intimately tied to specific contexts and conditions. Because of this they held that harmonizing, or aligning WAC, across different national contexts is not feasible. One respondent explicated, albeit in reference to the surface disposal of LLW, how deeply entwined with local conditions WAC are. They explained how “for a set of radionuclides critical for long-term safety” WAC can establish “limits per waste package, per disposal zone and for the whole disposal facility”. Likewise, another respondent described how WAC “are linked to the design of the facility, local constraints and also on the type of waste to be disposed”. WAC, then, are complex and highly localized.

© CHANCE

Indeed, this emphasis on locality in some of the responses to the questionnaire challenges, to an extent, official descriptions of final (geological) disposal as an intrinsically safe technology (e.g. Schröder, 2016; Schröder, Rossignol and van Oudheusden, 2016). Rather what emerges from the responses is a sense of complexity and the importance of local contexts, including sites, waste characteristics, volumes, and policies, in the making and implementation of safe disposal solutions (Hietala, 2018). Safety can be configured in multiple ways, and the above respondent observed that the "harmonization of the WAC seems impossible and would probably lead to an unjustified accumulation of constraints in several cases". Instead of automatically enhancing the safety of geological disposal, a number of respondents appear to perceive the harmonization of WAC potentially imposing general criteria on particular cases and contexts where they might not be relevant. Yet, this complexity tends to be reduced when respondents contemplate on relations and interactions between disposal projects and potential host communities. In contrast to the complexity many respondents attribute to WAC, waste characterization and RWM practices, they describe how host communities are presented a cleaned up image of RWM that aligns with the neat descriptions (of the safety) of disposal (see below).

However, where the majority of respondents agreed that the harmonization of WAC would not necessarily be appropriate, since circumstances vary between different countries/organizations, many supported closer cooperation between RWM actors around WAC. One respondent held that "parameters that affect general safety assessment" could be streamlined, while another observed that greater cooperation and knowledge exchange in relation to WAC could aid the implementation of (geological) disposal. They held that a "platform to exchange information between WMO's would be of great help to many organisations on how to attain certain requirements (i.e., on how to translate requirements into practical criteria, tests to be performed by the producers)". Another respondent, likewise, called for a "platform in which WMO's can freely discuss WACs, tests, measurement methods, calculation method evaluations". What these respondents seem to speak to is the need or desire to identify and share best practices around WAC through knowledge exchange. Indeed, one respondent directly linked cooperation with more effective RWM:

> A set of guides and rules elaborated by the specialists gathered around several international organisations, such as OECD-NEA, IAEA or technological platforms, have to be considered in order to enable a cooperation of different countries having the same or similar inventory of radioactive waste. In such a case, collaboration concerning the radioactive waste management of different countries and institutions would be more effective.

© CHANCE

While these respondents call for greater cooperation, another respondent observed that international guidance for WAC already exists. They held that “it is good to have guidelines or reference to already existing documents from e.g. IAEA that suggest what kind of WAC that normally should be addressed for different steps in the waste cycle on certain type of waste”. Thus, where the harmonization and imposition of harmonized WAC on diverse disposal contexts is seen as inappropriate, because of the reliance of WAC (and safety) on local conditions, respondents identified a need to establish more collaboration around WAC. From the respondents’ perspective, there is space, and in some cases need, for greater integration in waste characterization practices on the international level, similar integration has been called for on the national level (see also section 4.2.2)

4.1.2 Consequences of ‘acceptance’

As was noted above WAC are specific to a particular disposal facility and disposal site. WAC, and the notion of acceptance in particular, rest on technical principles and definitions of safety. Meanwhile, the criteria for acceptance can shift as a result of increasing knowledge of disposal sites as well as policy decisions. Regardless of how and if WAC change, they generate consequential realities that need to be visibilized and opened for reflection, as they are entwined with sociotechnical safety-making and ethical notions of fairness, intra and intergenerational justice.

WAC, by definition, exclude some wastes from (current) disposal (plans). As the flipside of waste acceptance, the implications of waste exclusion for long-term safety-making need to be reflected on; what are the (potential) consequences of rejecting some wastes from disposal? Generally, wastes that do not meet WAC are left in temporary storage facilities. One respondent explained that waste that does “not meet the WAC for the near surface repository has to be stored until the geologic disposal will be operational”. Another, similarly explicated that “waste that does not qualify for the repository [for waste with negligible heat-generating levels] is left in interim storages at various sites. … HLW and SNF, problematic and historical waste are left behind in short term, above ground interim storages at various sites”. Additionally, one respondent remarked that “activity levels are too high for surface disposal, but the volumes are too large for geological disposal. Characterisation is ongoing to classify the waste according to activity levels and as such optimise future management”.

On the whole, the management of wastes excluded from disposal has uncertainties. In part, this has to do with broader uncertainties related to long-term RWM – namely the lack of disposal sites and willing host communities. In part, however, these uncertainties relate to, and stem from, the apparent lack of long-term management plans and routes for these wastes. Overall, contemporary RWM practices hang on the discernible assumption that disposal solutions and

© CHANCE

facilities will become available. Disposal facilities may well become available in due time, but the assumption of their eventual availability does not necessarily sit easily with past experiences and the present situation where the implementation of geological disposal, for instance, has proven out to be a challenge. From an ethical perspective, then, deliberation and reflection on the (potential) consequences of the exclusions performed by WAC and how they might affect (potential) host communities needs to be opened up for deliberation.

The exclusion of wastes from disposal prolongs, as was already observed, the period necessary for storage. While some form of storage over a period of time is a necessary and an inevitable part of the nuclear fuel cycle, it has an ambiguous role in the management of wastes that do not meet WAC. For instance, SNF, in contexts where it is classified as waste, requires a cooling down period before disposal, the challenge with wastes excluded by WAC lies with the undefined period these wastes need to be stored for. By extension, there is uncertainty about the kinds of burdens ongoing, undefined storage might impose on communities where wastes are currently being stored. This is an ethical question that pertains also to wastes that meet WAC and will be disposed of in the GDF in cases where the implementation of geological disposal is prolonged or delayed. Ongoing storage, limits of existing storage capacity, and the potential need to implement new kinds of storage solutions are examples of the kinds of sociotechnical considerations with ethical implications that may need to be considered.

In particular, the potential need for continuing storage raises questions about the differing treatment and status of potential GDF host communities and communities that already have storage facilities in their area. In Europe geological disposal projects, generally, are based on a voluntarist principle, meaning disposal facilities cannot be “imposed” on communities if they are not willing to host them. Additionally, depending on the country context, (potential) GDF host communities are offered community packages/benefits for hosting a GDF.This does not necessarily apply to communities, where wastes are already stored as storage facilities are in within the bounds of already existing nuclear sites. Thus, considering that the longevity of interim storage needs is, in most cases, undefined, from an ethical perspective it needs to be asked what kinds of risks and burdens might ‘storage communities’ face – and whether, if the implementation of disposal solutions is significantly delayed – the differing treatment of GDF host and storage communities has just foundations.

Overall, as has been noted above, WAC are not set to stone, but are liable to change as disposal projects evolve. One respondent held that “based on the information accumulating during site characterisation, monitoring, or as a more adequate understanding of the important processes with impact on the disposal facility safety it [may be] concluded that the criteria for waste acceptance has to be modified”. Likewise, another respondent explained that the ‘modification of acceptance criteria’ has a number of repercussions on RWM. They noted that if WAC

© CHANCE

become "more restrictive, the question of already produced waste packages is … crucial", as their "adaptation [to the new WAC] may … be costly or difficult". Moreover, "when acceptance criteria become less restrictive, it is important to focus on edge effects that could occur. For example, a specific criteria (A) may have not to be monitored since a more constraining criteria (B) implied the respect of A. But a relaxation of B may induce that A has to be taken into account". Meanwhile, one respondent noted how shifting policy frames have impacted and tightened WAC for LLW and ILW disposal; "when [we] are dealing with the risk criteria for final disposals we have to meet the risk criteria 10^{-6}, earlier for it was a higher dose criteria (0,1 mSv per year as critical dose)". They added that more stable "policy decisions [w]ould be [beneficial] so that the circumstances and facts that have been decided do not change too much over time".

WAC, but also changes thereof, that stem from changing policy frames and increasing knowledge of disposal sites, have implications, among other things, on acceptable dose rates and the monitoring and measuring of parameters. Moreover, what the consequences of these changes and (potential) exclusions of wastes from planned disposal solutions might be and how they might play out on different timescales deserve consideration beyond the impact they have on RWM practices. The relationship between ongoing interim storage and local communities is one factor that needs reflection. Connected to this is the notion of hosting; when does a local community become a host community, and what might this change in status imply.

4.2 Configuring 'the social' and the 'technical' in waste characterization

As was noted above, RWM, including the implementation of geological disposal, is a complex process. This is reflected in the 'participatory turn' that has come to shape RWM policies as a response to the inability of technocratically driven processes to implement disposal solutions. This turn has been hailed for its potential to democratize RWM and disposal (e.g. Blowers and Sundqvist, 2010; Strauss, 2010), yet participatory processes in RWM have largely been confined to GDF siting, in particular to the benefits potential host communities might gain and the conditions they might have for hosting these facilities (e.g. Bergmans et al., 2015). Where disposal technologies have been opened up for deliberation, these deliberations have had little or limited impact on the core of disposal technologies and systems (Bergmans et al., 2012; Lehtonen, 2010). On one hand, the technopolitical consensus of geological disposal as the safest and most sustainable option available for the long-term management of radioactive wastes (EC, 2011; OECD/NEA, 2008) narrows down the scope of public discussions and the potential influence of these discussions. On the other hand, but relatedly, RWM continues to be a technical issue in which the broader society can have limited or no input (Blowers and Sundqvist, 2010; Gregson, 2012).

© CHANCE

This is equally the case with the characterization of radioactive waste. In the words of one respondent, radioactive waste characterization is “a very technical issue” in which “host communities are not involved … [but] they have the information available when they require”. Indeed, most respondents reported some forms of public engagement techniques and on the whole there seems to be an agreement that communication and transparency form an important part of RWM practices. One respondent, for instance, held that it is “important [for us] to have a transparent and clean image towards society that can induce positive thinking and trust” in RWM, yet they did not explicate how this might be achieved. Indeed, while it was not prompted by the questionnaire, it would be beneficial for RWM actors to reflect on what they mean and understand by public perception and/or acceptance, and how these understandings might shape their practices, the roles they envision for host communities in RWM and, more broadly, how they conceptualize the relationship between RWM and the broader society.

Overall, aside from two exceptions, most respondents envisioned a distance between host communities and radioactive waste characterization practices. This distance sits in contrast with calls made by some respondents for greater integration within RWM communities to manage the complexity of waste characterization and management. Present here is a strong imagination of the separation of the ‘social’ and the ‘technical’ aspects of RWM, and an imagination of linearity, both in terms of communication and innovation.

4.2.1 Imagining the social and the technical apart: host communities as audiences

In many of the responses to the questionnaire the relationship between radioactive waste characterization and society is seen as relatively straightforward. On one hand, host communities are treated as recipients rather than producers of information and one-way communication (see above quotes), and on the other, they are seen as beneficiaries of, and audiences to, innovation in RWM processes. One respondent expressed the opinion that “*any action to increase the safety* of stored or disposed of waste *will promote greater acceptance* by the public” (emphasis added). Overall, respondents shared the view that the relationship between technological developments in RWM and the public opinion of it is positive. Respondents were asked whether they considered that “continuous improvement of waste characterization by innovative methods can improve the perception of risks associated with waste disposal” (Appendix A, Q15). They all unanimously agreed with this view, and while the phrasing of the question might have invited particular kinds of answers, what emerges here is an assumption of an association between innovation, safety and public opinion. In simple terms, the imagination here is that innovation leads to greater safety provision, which in turn reduces public risk perception. In other words, discernible here is the linear model of innovation (see below), which has been criticized in much STS literature (e.g. Edgerton, 2004; Felt and Wynne, 2007; Owen et al. 2013). This linear imaginary can be seen to limit the scope of public

© CHANCE

engagement and participatory processes in RWM, as will be discussed below. As long as acceptability is seen to flow from innovation, it might be that the willingness of the RWM communities to engage with publics can remain limited in a number of cases.

What this suggests is the limited character of and extent to which the ‘participatory turn’ has taken place in RWM. Even where local communities and/or broader publics have been invited to deliberate on RWM questions, the extent to which publics have influenced these questions is narrow. In part this is, because participatory processes tend to be underpinned by the same linear imaginary that public involvement leads to broader support for technoscientific developments (Felt and Fochler, 2010). As geological disposal has solidified as *the* policy aim (instead of being considered as a possible means for achieving long-term safety), the influence of deliberations on the long-term management of radioactive waste is confined (Bergmans, Landström and Schröder, 2014). In part, the limited influence of the participatory turn stems the privileged status assigned to science and scientific knowledge in problem solving (Jasanoff, 2007). An imaginary where science invents RWM solutions, the nuclear industry applies them, and society conforms to and accepts them, is prevalent (see below) and it maintains an asymmetrical relationship between places, (potential) host communities and the RWM community. The former is positioned as a passive spectator and the latter as an active doer and implementer, and this shapes the role that host communities are ascribed and the ways in which RWM actors seek to interact with host communities. The positioning of (potential) host communities as audiences to and recipients of nuclear knowledge, tends to marginalize local “modes of knowing that are often pushed aside in expanding scientific understanding and technological capacity” (ibid.: 33). It misses an opportunity to complement science with the analysis of aspects of human existence, and ethical considerations, that science cannot easily illuminate.

Additionally, it means that waste acceptance as well as ‘public acceptability’ continue to be technoscientifically defined, as local communities are rendered an audience to attempts and efforts by the RWM community to realize safety and identify wastes acceptable for disposal. This is implied in a statement made by a respondent that “the [public] perception has to be that we use the most innovative means for the characterization process”. The respondent positions the application of innovative methods as a demonstration of the expertise and knowhow of their institution. What can be discerned here is an expectation that innovation and the application of state-of-the-art methods translates into trust in the institution and its ability to manage wastes in a safe way – or that it will, at least, shape publics’ perception of risk.

Indeed, most of respondents described the relationship between RWM and (potential) host communities through such a linear imaginary (innovation-safety-acceptability). Yet, the descriptions and levels of interaction between RWM and host communities varied from case to

© CHANCE

case, and differed from the characterization of public engagement as “PR” to speculations of the host communities potential role in waste characterization, which also conveys a more complex conceptualization of the relationship between host communities and geological disposal projects, and by extension long-term safety-making. Several respondents described the host community as a recipient of information. One respondent, for example, noted that “local authorities are informed” about potential issues at a waste storage site, while in another case the host community is described as being “informed yearly” about developments in RWM, while local concerns are dealt with through “different kind of meetings” – suggesting a more interactive approach, albeit no elaboration of the meetings, their form or scope, was offered. Finally, a respondent noted that while the host community is not involved in the waste characterization process, “they should be (and are) informed on the processes of waste characterisation, approval and acceptance. For the surface disposal project, local partnerships were formed to ensure permanent, long-term involvement and participation of the local communities”. On the whole, respondents described that present host communities were “aware” of their RWM activities, and that while they are not involved in waste characterization “they have the information available when they require”. Most descriptions of the relationship between RWM communities and practices on one hand, and host communities on the other fall in line with a linear imaginary, albeit some respondents additionally described methods of engagement beyond informing the host community.

In contrast, two respondents briefly weighed the possibility that host communities might have a role to play in radioactive waste characterization/management. One respondent mused that the host community “will probably also get a word in the radiological control of the barrels that will be placed in the disposal site”, thus speculating on direct host community involvement in RWM. Another respondent, more explicitly, reflected that host community conceptualizations of, for instance, the acceptability of wastes for disposal might not align with the assessments of the RWM community. They held that local expectations of waste characterization will be managed through community engagement practices as the siting process for a GDF moves forward. While, again there is little discussion of the ways in which local expectations might be engaged, there is nonetheless an explicit acknowledgement that a host community “may drive” waste characterization requirements in the future.

Respondents, then, envision different levels of engagement and inclusion of host communities in radioactive waste characterization and waste management processes. On the whole, however, respondents maintain a division between radioactive waste characterization practices and host communities who are, in most cases, expected to accept and align with the technoscientific radioactive waste communities’ future visions and plans for RWM. This, division between host communities and radioactive waste characterization practices, and by extension the separation between the ‘social’ and the ‘technical’ aspects of RWM may prove out to be a problematic.

© CHANCE

Descriptions of generally narrow engagement practices contrast with the respondents' identification of uncertainties pertaining to waste characterization. A number of respondents held, in the words of one respondent, that "the main uncertainties are social (public acceptance) and then political". A couple of respondents described social uncertainties in almost mystical terms. One respondent explicated

> We only try to manage technical uncertainty, the others [i.e. social, political, ethical] *are not under control*. Technical uncertainties are the only ones that we try to control/investigate. The most important source of uncertainty for us is the political one, but … talking about characterization uncertainties, I do not think that political, ethical and other [uncertainties apart] from technical uncertainty influence … characterization. (emphasis added)

Along the same lines another respondent held that "*political, societal and ethical uncertainties are unpredictable* … and generally not addressed by waste conditioners, inspectors and regulators, yet" (emphasis added). What emerges clearly here is the separation of the social and the technical. While political uncertainty, in the first quote, is positioned as the most important one, it is still envisioned apart from technical waste characterization. Similarly, in the latter quote this division is evident, as non-technical uncertainties are not envisioned, presently at least, as the responsibility of technoscientific actors. This speaks to the prevalence of the linear imaginary of innovation, where publics can/will be engaged when technical problems or challenges and solutions to them have already been defined by the technoscientific community. Additionally, non-technical uncertainties are described as unpredictable and as such contrasted with technical uncertainties, positioned as manageable or solvable. The labelling of non-technical uncertainties as unpredictable, coupled with one-directional flows of information can close down opportunities for addressing and understanding these uncertainties (de Saille, 2015).

4.2.2 Complex matters: technoscientific expertise and integration

This separation between host and RWM communities contrasts with a perceived need for greater integration and cooperation within the RWM community (see section 4.1.1). Moreover, where imaginaries of linear communication and innovation characterize the former relationship, respondents describe a more nuanced and complex relationship between technoscientific expertise and waste characterization, where the more social and technical aspects are inseparably entangled. In contrast to the perceived host community awareness of the "proper organization of the work and its adequate control, as well as proper management of radioactive waste produced", the diversity of practices, and the availability of expertise and knowledge (see also section 4.3) were raised as challenges within the RWM community.

© CHANCE

One respondent discussed how the WMO in their case needs to work with diverse waste producers, wastes and waste characterization techniques. They explained that the WMO "collects & treats [wastes] from diffuse [waste] producers. In this role, [we] manage various different ways of characterisation because of the different natures and ways of production [from] those different sources". The diversity of practices is illustrated by participants explicating how, for instance, characterization "method[s are] evaluated case by case", while similarly the "level of characterisation is often [decided] case by case". Waste characterization, here, emerges as not just a technical process, but as a process entailing layers of decision-making, expert judgement and justification about the appropriateness of methods and data. Alongside appropriate methods, respondents put significant emphasis on the availability of appropriate expertise. For instance, one respondent described how the development of characterization techniques and expertise are inseparable. They described how their institution "is currently developing new strategies and techniques for radioactive waste characterization in order *to improve the company know-how* and being up to date to the current technologies, *both in terms of analysis/data processing skills and in terms of equipment/instruments*" (emphasis added). Another respondent, similarly, posited that the development and adoption of new characterization methods requires their institution to both "develop its expertise on advanced characterisation methods and apply these methods in the characterisation of radioactive waste sent for disposal as well as for those that need to be stored until a disposal option will be available". Waste characterization, and ultimately the safety of disposal, are described by these respondents as dependent on available and institutionally situated expertise.

Waste characterization, here, is depicted as a sociotechnical challenge or processes. The entwinement of the technical parameters and expertise was highlighted by participants also in discussions of WAC. Respondents noted how RWM practices, expertise and WAC mutually shape each other. One respondent noted that WAC are in "continuous evolution owing to the accumulated experiences and the improvement of the available means". Conversely, another respondent explained how the evolution of WAC informs daily waste management practices, as "new rules must be implemented on the work floor … this can be a slow process even if there is a transition period. However, it is important that these changes are being implemented, otherwise the waste will no longer be accepted by [the WMO]". What these respondents describe is the iterative evolution of WAC based on both technological and methodological developments as well as increasing operational expertise and experience of (different) waste characterization methods. Broadly along similar lines, another respondent discussed challenges related to the characterization of already conditioned wastes and held that their institution has "no RD&D needs [on this front], this [challenge] should be solved by other means". Waste characterization and the development of waste characterization methods, then, like "patterns of innovation [is] more complex … with feedback loops, user-induced innovation, and societal developments rather than technological developments leading the way" (Felt and Wynne, 2007:

© CHANCE

21). Taking this line of thought further, it is from the co-evolution of technologies and expertise that claims about the characteristics of wastes and ultimately the safety of geological disposal flow.

Moreover, one respondent reflected that innovation in waste characterization methods needs to be worthwhile, and that it has little intrinsic value. They posited that new methods should not be adopted simply because they are available. Discussing the characterization techniques (Calorimetry, Muon Tomography and Cavity Ring-Down Spectroscopy) being developed within the remit of the CHANCE project, the respondent posited that their organization has "no plans for using those methods at the moment. They need first to [be] proven and validated before the possibility to be used and [they need to] bring sufficient value to the process". The adoption and application of new methods, then, is not a given, but relies on a judgement based on their demonstrated value in waste characterization. This judgement, in turn, influences not only the ways of knowing, but also the kinds of data that can be produced and is available for making decisions about the acceptability of waste for disposal, and ultimately for making the case for the safety of the disposal facility.

Consequently, technological development was described only as one aspect of waste characterization, and a number of respondents highlighted the importance of availability of knowledge and the sharing of waste characterization experiences. In line with the respondent positing that R&D is not an automatic or the only solution to addressing existing challenges in waste characterization, others called for greater integration of existing RWM expertise. One respondent called for "systematic international coordination/projects R&D", while another posited that "more integration between disciplines would be useful". Likewise, one respondent discussed the benefits of establishing an integrated and coordinated country-level approach to waste characterization. They described that in the current situation waste characterization projects are confined to particular institutions that address specific needs-driven challenges, and posited that the knowledge gained from these projects should be made broadly available, which is not necessarily the case at the moment.

> They held that it is currently difficult to learn from the experiences and developments that others have made. A coordinated approach would be beneficial to understand more about the techniques available, their applicability to various situations with the ability to gauge how well certain technique could address certain challenges.

© CHANCE

What emerges from these comments are descriptions of RWM practices as founded on available knowledge and expertise. Indeed, elsewhere, too, a respondent mused how "interaction and a good understanding between WMO and waste producer are necessary to obtain reliable characterisation".

This emphasis on expertise, integration, interaction and knowledge as the basis of RWM and confidence in waste characterization begins to illustrate the complex sociotechnical character of waste characterization and RWM more broadly (Schröder and Bergmans, 2012), and it directs attention to the contributions of organizations (rather than just technologies and techniques) and, in some cases, individuals (as will be discussed below) in the characterization of radioactive wastes. The discussions here have highlighted, on one hand, the limitations and, on the other, the importance of situated institutional expertise and knowledges that underpin the development and adaptation of waste characterization techniques as well as (routine) RWM practices. As these knowledges and expertise shape and influence the ways in which 'acceptance' and safety are conceptualized and discussed, opening up RWM decision processes to reflection – for instance through the collaboration called for by some respondents could foreground some of the normative, often implicit, assumptions that underpin RWM and are held by scientific authorities (Welsh and Wynne, 2013). On the other hand, where waste characterization seeks to generate and contribute to long-term safety-making by producing facts about wastes, the RWM community acknowledges the limits of their knowledge and safety-making endeavors and the presence of uncertainty and indeterminacy in long-term RWM (Hietala, 2018). While concerns about knowledge and integration illustrate the sociotechnical character of RWM, they also surface ethical questions about the adequacy of knowledge (what is 'good enough' knowledge), but also who get to decide when knowledge is 'good enough'? It can also be inquired whether the understanding of who gets to make these kinds of decisions shifts if/when the distribution of risks (and benefits) is take into consideration – and whether integration and collaboration should be extended to actors outside the RWM community.

4.3 Knowledge needs and practices

Knowledge and expertise, the availability of and access to knowledge and expertise, emerged as important themes and concerns from the questionnaire. One respondent raised the challenge of retaining institutional and industry-level expertise in the future and remarked how "in all nuclear fields, staff and recruitment potential is dangerously low". Knowledge maintenance and retention is a well-recognized challenge for the industry (IAEA, 2017), however, here, respondents focused on present challenges arising from historical RWM practices and the limited knowledge available on historical wastes. They listed additional waste characterization effort, higher costs, the need to recover information and knowledge among the consequences of historical RWM. Additionally, some respondents discussed how these consequences might affect the disposal system; how potential future changes in expectations and criteria (e.g. WAC,

© CHANCE

see also section 4.1) might inform RWM practices today, and finally some noted how working with radioactive materials and in radioactive spaces impose challenges (and sets limits) for characterizing and generating (detailed) knowledge about waste.

Knowledge and safety are dynamically related and this relationship is informed by what is judged to be important at a given time. Many respondents observed the, sometimes, tricky relationship between historical waste and WAC/current knowledge requirements. One respondent noted that historical waste need not align with current WAC, but rather "historical waste that has been conditioned before the establishment of WACs is accepted by "Historical WACs" that take into account the timeframe in which they were produced and the according quality, characterisation and documentation measures". Yet, contrastingly, most respondents seemed to agree with the view expressed by a respondent that "historical waste should meet the same criteria as well characterised "new" waste". Indeed, another respondent held that "historical waste have to be studied in order to know their [fit with] the repository WAC", and because "WAC has to be fulfilled at the required level" the characterization of historical wastes might lead to the "reconditioning or immobilization (of waste) in greater packages", while "extra barriers could be required" for their containment. In this way (increased) knowledge about wastes can reconfigure the disposal system and 'tighten' safety requirements. In contrast, other respondents discussed how the lack of knowledge influences safety requirements. One respondent observed how changing practices, standards and expectations impose challenges on RWM.

> The major difficulty is the characterisation of legacy waste packages (WP). [For] WPs produced after 1990 characterization was performed according to the principles of current production. For older WPs the quantities of fissile materials are estimated with large uncertainties. So the[re is a] need to significantly reduce these uncertainties, in order to avoid any overestimation of the safety conditions to apply for the design of the transport casks and for the design of the disposal site.

The overestimation of safety conditions – or the conservativeness of the safety margin – can render assessments of the disposal system's safety more difficult. Safety margins, as the distance between prediction and the point of failure, are ensured by the setting of conservative safety limits and maintain operating conditions below that limit (Gavrilas, n.a.; OECD/NEA, 2007), limits that are too conservative can introduce uncertainties and/or require further research. One respondent explained how limited knowledge of historical wastes requires "conservative assumptions to be made that might lead to higher disposal costs [as well as] RD&D efforts needed to demonstrate the safety of these conservative assumptions". Along the same lines, another respondent posited that "conservativeness is not the best option", and

© CHANCE

concluded that “the best one is the determination of actual content, [but] it requires much more effort”.

What surfaces from the above comments is the situated character of RWM and safety-making practices (section 4.1) as well as their evolution in time. Similarly what arises, or begins to arise, here is the role values and value judgements play, for instance, in attempts to characterize historical waste. The last respondent, above, for example held that investing (time, effort, money) in waste characterization is better than making conservative safety assessments. Or in other words, knowing is better than not knowing, for knowledge enables the broadly accepted “need to protect humans and the environment from the potentially adverse effects of radioactive wastes [that] is clearly recognized” (OECD/NEA, n.a.) to be better addressed. Indeed, one respondent drew a direct link between knowledge and safety, holding that

> more improvements have to be made concerning old legacy waste. [It is] very important to know the inventory in the waste packages before disposal in order to improve the long term accuracy for long term safety. And also to avoid the need for retrieval due to insufficient knowledge of the waste inventory.

Another respondent reflected on the relationship between knowledge, what kind of knowledge is produced, and present and future knowledge requirements. They weighed how the

> amount of information asked could be excessive at a given time. It’s always a balance between precautionary principle (not to have the information in the future when future knowledge demonstrate that this information is important) and the present absolute necessity that may concentrate money on a restrained field in the expectation to have more accurate information.

Where the former respondent directly connects knowledge and safety, the latter sees that the implementation of safe disposal solutions, including waste characterization, includes a balancing act between present and future needs. Another respondent, similarly, reflected on evolving needs for data and knowledge.

> The high amount of legacy waste that needs further characterisation, and the difficulties associated to this, proves that it is useful to characterise and document waste as well as possible the moment it is produced, even if the information is not deemed useful at that time since it might be required later.

In contrast to the previous respondent, here potential future needs are seen as a key driver for the scope of knowledge production. In other words, the impossibility of predicting future knowledge is here seen as necessitating detailed generation of information. Some respondents

© CHANCE

discussed the practical consequences of limited knowledge on the characterization of historical wastes. When waste documentation and records are not available, wastes can be characterized from samples. However, if the properties within wastes vary considerably, waste characterization becomes difficult, as representative sampling may be challenging (IAEA, 2007). A number of respondents raised the representativeness of sampling as an important matter. One respondent held that one challenge in sampling is judging "how representative sampling is in relation to the entirety of a waste package or a waste stream", while another posited that the "sample/location chosen are very important and have to be representative of waste". However, they also held that only limited "expertise of the representativeness of sample selection/quantity & number of samples collected" is available, linking back to the importance of epistemic and expert processes and judgements in RWM.

Underlying respondent observations about the importance of expertise and knowledge is a recognition that they can be lost relatively easily and rapidly (IAEA, 2017; Schröder, 2014). A respondent noted that while many "uncertainties due to limited knowledge of old wastes" are addressed through R&D efforts, more qualitative work, such as "interviews with people in the production/conditioning of waste" is also taking place. As the respondent above, they held that this kind of work "should be done as early as possible in order to have the greatest effect". Similarly, another respondent explained that both documentary research and "interviews of senior personnel and retired people to identify facts" are utilized in order to regain knowledge that is on the verge of being lost or that has already been lost within their institutions. As sense of urgency, then, exists with regards to data and knowledge management and preservation. On one hand this stems from the experience of how quickly knowledge can be lost (IAEA, 2017), while, on the other, the availability of knowledge is seen as directly connected to implementing safe disposal solutions.

Indeed, while issues around knowledge preservation and transmission have been explored with respects to communicating locations of and risks contained in GDFs to future generations (e.g. Benford, 2000; Sebeok, 1984), the shorter term knowledge preservation needs are increasingly a matter of concern and are beginning to be addressed (e.g. Schröder, 2014), but have on the whole been afforded less attention. Some of the challenges pertaining to historical wastes and their characterization thus connect to broader discussions on nuclear knowledge management, but also to calls for greater integration of practices and sharing of experience within the technoscientific radioactive waste community, which were raised in the previous section.

Finally, some respondents also discussed the limitations radioactivity places on knowledge production and the characterization of wastes. One respondent listed a number of R&D challenges their institution faces in relation to radioactive waste characterization. These included matters such as working in "challenging environments (remote access) … working on

© CHANCE

a nuclear site [and the] representativeness of sampling". Broadly along the same lines another respondent explicated that "technical problems in the characterization process … for high dose rate waste [include] low efficiency devices but high constraints due to radiological protection issues". They further explained that radiological protection concerns limit the ability to validate theoretical methods, which would enable their institution to "know in advance the degree of precision with the knowledge of all the parameters involved" in the analysis of the radiochemistry of wastes. Yet, they held, "in many cases we only are able to accept what the codes provide us and it was almost impossible to verify it by real samples due to radiological protection issues. By the validation proposed, we could know the real situation in a better way". Likewise another respondent held that "the difficulty is that [dose rate] measurements are made on final waste packages – with all biological protection (if needed) and filling materials". While waste characterization, as part of the implementation of disposal systems, ultimately aims at the generation of data to ensure the protection and safety of future generations, the same principles of protection and safety apply in the present set limitations to waste characterization practices, but also drive R&D needs, such as the development of remote access (i.e. robotics) that enables access to and work in radioactive or contaminated spaces. What emerges from these observations is a complex picture of expert knowledge and knowledge production processes. Where limited records and knowledge of historical wastes imposes challenges for waste characterization, further challenges are imposed on the aim to fulfil a recognized ethical need to protect future human generations and the environment from radioactive wastes (OECD/NEA, n.a.) by the radioactivity of wastes and the ethical principle and practice of protection set limits on the production of knowledge.

5. Discussion and conclusion

The questionnaire format can be problematic in exploring complex matters (Mason, 2004) such as the topic of this report, as standardized questions leave little room for further probing of the logics and understandings at play behind written responses. Nonetheless, some clear patterns and (shared) understandings emerged from the data, these include

- a picture of radioactive waste characterization as a complex sociotechnical process, which is accompanied by;
- a more technically driven imaginary of the relationship between radioactive waste characterization and (potential) host communities, and linking back to the first point
- challenges imposed on waste characterization and knowledge production practices by evolving RWM practices and WAC.

Starting with the second point, the presence of this technically driven imaginary of the interactions between RWM and society supports and is supported by linear conceptualizations of innovation and communication, and can be seen as reflective of the limits of the 'participatory turn' within RWM (Bergmans et al., 2015) and the voluntarist principle (EC, 2011) that can be situated within that turn. The participatory turn emerged out of the failures of

© CHANCE

a tradition of technocratically driven approaches, which were unable to advance the implementation of geological disposal. Yet, the limited engagement and the one-way informing of host communities described by many respondents here illustrate, to an extent, the limitations of this turn and can be conceptualized as a dis-invitation of host communities, and other social actors (and factors) described by some participants as uncontrollable and unpredictable, from RWM (de Saille, 2015).

Although the level of information and engagement with stakeholders in general will be commensurate with the stage of implementation/RWM practice, and will be based on a shared understanding what information they find useful, the highly technical process of waste characterization as it is frequently denoted nowadays, might result in only a limited role of stakeholders in the process. Yet, respondents simultaneously describe waste characterization as a complex sociotechnical interplay informed by situated decision-making about waste acceptance, the adoption of new characterization techniques, the representativeness of sampling and so on. Additionally concerns about the availability of expertise, lacking or limited historical waste data together with questions about the primacy of the present or the future, and around protection, as well as judgements about the sufficiency of data and methods are inseparably and intimately entangled with waste characterization practices.

In public discussions, publically available scientific and policy documents as well as in social scientific literature on RWM radioactive wastes are often peripheral. What is generally focused on are technological solutions and ways of managing wastes that tend to be presented as pacified and containable (Gregson, 2012). Likewise, epistemic questions pertaining to RWM tend to focus on the multi-millennial timespan of geological disposal (e.g. Ialenti, 2014; Schröder, 2016) rather than on wastes themselves. The discussions in this report begin to add some complexity to this picture as respondents raised and addressed questions about the knowledgeability of wastes; how are radioactive wastes known and rendered knowable, and; what limitations do wastes impose on generating data and knowledge about them. One respondent held that in their country's case R&D needs in radioactive waste management are related to questions such as "*how to assess* with non-destructive methods the radiological content and fissile mass content, *with an acceptable uncertainty*, compatible with the WAC for storage, transportation and final disposal?" (emphasis added). Another respondent, similarly, explicated that "the nature of what is measured is important. Do we … measure final package: [do we] minimize the number of objects to measure but [in so doing] augment the difficulties/uncertainties". How knowledge is generated, but also what it is generated about matters. What counts as (representative of) waste, is an open and contestable question that influence disposal solutions, and thus has long-term consequences, while also impacting shorter-term RWM practices.

© CHANCE

> WAC evolve constantly making new parameters important. The question then is how to fulfill these criteria for historical waste when in the past these criteria were not yet asked or important. *Are there measurement techniques to determine these parameters? What if you can't measure them? Is a best estimate enough?* (emphasis added)

These are important epistemological and ontological questions without any definitive answers. In whatever way these questions are answered, they have, by definition an ethical component, and an intergenerational reach as host communities will carry and live with the effects of those answers. From this perspective the notion of acceptance – with regards to both waste and 'the public' – deserves more attention. What needs to be reflected on and opened up are the normative assumptions held by the RWM community that underline both waste acceptance and public acceptance.

The RWM community can be regarded as an epistemic community (Haas, 1992). It has established practices, policy-relevant expertise, and a shared set of normative commitments that come in the form of "subjective judgements, influential social values, contestable assumptions and administrative procedures that are open to contingent framings and the tacit or deliberate exercise of power" (Felt and Wynne, 2007: 33). These commitments, that are not opened for deliberation, but rather are framed as 'neutral' and 'objective', form the basis for the choice waste characterization techniques, judgements about the validity of data and the definition of WAC that seek to ensure the conformity of waste to the disposal facility safety case (WENRA, 2014). The safety case itself is a collection of "scientific, technical, administrative and managerial arguments and evidence in support of the safety of a [disposal facility], covering [for example] the assessment of radiation risks and assurance of the adequacy and quality of all of the safety related work associated with the facility or activity" (IAEA, 2012:1). It includes a "systematic assessment of radiation hazards. The … quantification of radiation dose and radiation risks that may arise from the facility … under *normal* conditions and *anticipated* operational occurrences and in the event of accidents" (ibid.: 2, emphasis added).

The challenge with assessments such as the ones described above is that they focus on probable or known possible consequences of technologies. While, publics tend to focus on possible, but unknown consequences (Welsh and Wynne, 2013). Questioning whether unanticipated consequences can be handled is not the disputation of risk assessment, rather it can be seen as a desire to unpick and illuminate how decisions are made, what kinds of logics drive decision-making and assessments processes, what logics are excluded, and why. As such it links to the importance of procedural questions for host communities discussed in section 2 (see also Schröder et al., 2012). In contrast to this interest in the process of, essentially, safety-making, the respondents here described and envisioned host communities at a distance and as removed

© CHANCE

from RWM. Simultaneously, they anticipated public acceptance and risk perception to be improved by the outcomes of the process to which host communities, mostly, are not invited. This imaginary of *innovation* → *safety* → *acceptance* falls in line with the primacy of technoscience, characteristic of modern western society beyond RWM, in addressing complex (ethical) issues to which it can offer only partial answers (Jasanoff, 2007). For instance, the epistemological and ontological questions raised above are beyond the scope of technoscience, yet addressing these readily involves, in the words of a respondent, the consideration of "considering the last technico-scientific progress and experience accumulated in countries with more advances disposal programmes" (see also Jasanoff, 2007). Additionally, the imaginary of *innovation* → *safety* → *acceptance* sits in contrast to the other imaginary of *innovation* → *acceptance* → *safety* that respondents described in relation to RWM practices. It can be asked what might happen if the relationship between host communities (and/or broader publics) and RWM were conceptualized in terms of the latter imaginary. Situating public acceptance before safety as contributing to rather than deriving from safety (assessment) opens up space for reflection on what constitutes acceptance and/or safety, what normative commitments underpin certain kinds of understandings of acceptance and safety, and what kinds of ethical commitments and consequences can emerge and surface from these understandings.

Radioactive wastes are difficult to know both for publics and experts (see above; also Gregson, 2012). Because of their radioactivity they are sequestered and confined, which removes them from 'everyday life', but also renders their characterization difficult. In effect, this enforced distance means that the epistemological and ontological questions relating to waste faced by expert and host communities are similar, even if they operate at different scales. Including host communities in discussions regarding questions about the sufficiency of knowledge (i.e. what counts as 'good enough') and criteria acceptance can be beneficial in addressing deeply ethical questions with potential long-term consequences that technoscience alone is not well equipped to answer. As such, this opening up may well contribute to 'public acceptance', yet this requires that the underlying technoscientific assumptions about what constitutes (and/or fosters) public acceptance need to be subjected to reflection as well. These are questions to which social sciences have much to contribute and that are also worth greater social scientific scrutiny.

© CHANCE

List of References

Benford, G., 2000. *Deep Time: How Humanity Communicates Across Millennia*. New York: Harper Perennial.

Bergmans, A., and Schröder, J., 2012. *Review of initiatives addressing sociotechnical challenges of RWM & geological disposal in international programmes*. InSOTEC Report.

Bergmans, A., Elam, M., Simmons, P., and Sundqvist, G., 2012. Perspectives on Radioactive Waste Repository Monitoring: Confirmation, Compliance, Confidence Building, and Societal Vigilance. *Technikfolgenabschätzung – Theorie und Praxis*, 21(3), 22-28.

Bergmans, A., Sundqvist, G., Kos, D., and Simmons, P., 2015. The participatory turn in radioactive waste management: deliberation and the social–technical divide. *Journal of Risk Research*, 18(3), 347-363.

Bickerstaff, K., 2012. “Because we’ve got history here”: nuclear waste cooperative siting, and the relational geography of a complex issue. *Environment and Planning A*, 44, 2611-2628.

Blowers, A., and Sundqvist, G., 2010. Radioactive waste management - technocratic dominance in an age of participation. *Journal of Integrative Environmental Sciences*, 7(3), 149-155.

Braun, V. and Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2),77-101.

Bucur, C., Dodaro, A., Ferruci, B., Meskens, G., Ricard, D., Tietze-Jaensch, H., Thomas, P., Turcanu, C., 2019. *Synthesis of Commonly Used Methodology for Conditioned Radioactive Waste Characterization. CHANCE Report (D2.2).* [pdf] Available at: http://www.chance-h2020.eu/en/Deliverables.

Callon, M., 1984. Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. *The Sociological Review*, 32(S1), 196-233.

Chilvers, J., 2007. Towards analytic-deliberative forms of risk governance in the UK? Reflecting on learning in radioactive waste. *Journal of Risk Research*, 10(2), 197-222.

CoRWM, 2006. *Managing our Radioactive Waste Safely: CoRWM’s Recommendations to the Government*. [pdf] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/294118/700_-_CoRWM_July_2006_Recommendations_to_Government_pdf.pdf.

Cotton, M., 2009. Ethical assessment in radioactive waste management: a proposed reflective equilibrium-based deliberative approach. *Journal of Risk Research*, 12(5), 603-618.

Cotton, M., 2018. Environmental Justice as Scalar Parity: Lessons From Nuclear Waste Management. *Social Justice Research*, 31(3), 238-259.

De Saille, S., 2015. Dis-inviting the Unruly Public. *Science as Culture*, 24(1), 99–107.

© CHANCE

Di Nucci, M.R., and Brunnengräber, A., 2017. In Whose Backyard? The Wicked Problem of Siting Nuclear Waste Repositories. *European Policy Analysis*, 3(2), 295-323.

Di Nucci, M.R., Brunnengräber, A., Isidoro Losada, A.M., 2017. From the right to know to the right to object and decide. A comparative perspective on participation in siting procedures for high level radioactive waste repositories. *Progress in Nuclear Energy*, 100, 316-325.

Durant, D., 2015. Simulative politics: the case of nuclear waste disposal. *Environmental Politics*, 24(3), 442-460.

EC, 2011. *Council Directive 2011/70/EURATOM of 19th July 2011 Establishing a Community Framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste*. Brussels: European Commission.

Edgerton, D.E.H., 2004. The linear model did not exist. In: K. Grandin, N. Worms, and S. Widmalmn eds., *The science-industry nexus: History, policy, implications*. Sagamore Beach, MA: Science History Publications, 31–57.

Elam, M. and Sundqvist, G., 2011. Meddling in Swedish success in nuclear waste management. *Environmental Politics,* 20(2), 246-263.

Eurobarometer, 2008. *Special Eurobarometer 297: Attitudes towards Radioactive Waste*. [pdf] Available at: https://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_297_en.pdf.

Fisher, E., 2007. Ethnographic Invention: Probing the Capacity of Laboratory Decisions. *NanoEthics*, 1(2), 155-165.

Gavrilas, M., n.a. *A Framework for Integrating Risk and Safety Margins*. [pdf] Available at: https://www.nrc.gov/docs/ML0614/ML061420109.pdf.

Glaser, B.G., and Strauss, A.L., 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. London: AldineTransaction.

Gregson, N., 2012. Projected futures: the political matter of UK higher activity radioactive waste. *Environment and Planning A*, 44, 2006-2022.

Haas, P.M., 1992. Introduction: Epistemic Communities and International Policy Coordination. *International Organization*, 46(1), 1-35.

Hietala, M., 2018. *Making Distant Futures: Implementing Geological Disposal of Nuclear Waste in the UK and Finland*. PhD Thesis, University of Exeter. [pdf] Available at: https://ore.exeter.ac.uk/repository/handle/10871/33976.

IAEA, 2007. *Strategy and Methodology for Radioactive Waste Characterization. IAEA-TECDOC-1537*. [pdf] Available at: https://www-pub.iaea.org/MTCD/publications/PDF/te_1537_web.pdf.

IAEA, 2009. *Classification of Radioactive Waste. General Safety Guide No. GSG-1*. [pdf] Available at: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf.

© CHANCE

IAEA, 2017. *Knowledge Loss Risk Management In Nuclear Organizations. IAEA Nuclear Energy Series No. Ng-T-6.11*. [pdf] Available at: https://www-pub.iaea.org/MTCD/Publications/PDF/17-35661_PUB1734_web.pdf.

Ialenti, V.F., 2014. When Deep Time Becomes Shallow: Knowing Nuclear Waste Risk Ethnographically. *Discard Studies*. [online] Available at: https://discardstudies.com/2017/03/09/when-deep-time-becomesshallow-knowing-nuclear-waste-risk-ethnographically/.

Jasanoff, S., 2007. Technologies of Humility. *Nature,* 450(1), 33.

Kari, M., Kojo, M., and Litmanen, T., 2009. *Community Divided: Adaptation and Aversion towards the Spent Nuclear Fuel Repository in Eurajoki and its Neighbouring Municipalities*. Tampere: University of Tampere.

Landström, C., and Bergmans, A., 2012. Socio-technical challenges to implementing geological disposal: a synthesis of findings from 14 countries. [pdf] Available at:

Latour, B., 2005. *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford: Oxford University Press.

Lehtonen, M., 2010. Deliberative decision-making in Finland, France and the UK: Influence of mixed form of deliberation in the macro discursive context. *Journal of Integrative Environmental Sciences*, 7(3), 175-96.

MacKerron, G., and Berkhout, F., 2009. Learning to listen: institutional change and legitimation in UK radioactive waste policy. *Journal of Risk Research*, 12 (7-8), 989-1008.

OECD/NEA, 2007. *Safety Margins Action Plan - Final Report. NEA/CSNI/R(2007)9*. [pdf] Available: https://www.oecd-nea.org/nsd/docs/2007/csni-r2007-9.pdf.

OECD/NEA, n.a. *The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes: A Collective Opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency*. [online] Available at: https://www.oecd-nea.org/rwm/reports/1995/geodisp-entire-report.html.

Owen, R., Stilgoe, J., Macnaghten, P., Gorman, M., Fisher, E., and Guston, D., 2013. A Framework for Responsible Innovation. In: E. Owen, J. Bessant, and M. Heintz, eds., *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*. Chichester: John Wiley & Sons, 27-50.

Perko T., Zeleznik, N., Turcanu, C., Thijssen, P., 2012. Is Knowledge Important? Empirical Research on Nuclear Risk Communication in Two Countries. *Health Physics*, 102(6), 614-625.

Schröder, J., 2014. Preparing for the future The findings of the OECD-NEA RK&M project concerning the short term. [pdf] Available at: https://www.oecd-nea.org/rwm/rkm/constructingmemory/presentations/s1-01-Schroeder.pdf.

Schröder, J., 2016. Geological Disposal of Radioactive Waste: A Long-Term Socio-Technical Experiment. *Science and Engineering Ethics*, 22, 687-705.

© CHANCE

Schröder, J., Barbier, J-W., Bergmans, A., and Vandervelden, M., 2012. *Report of the InSOTEC Stakeholder Seminar n°1. Universitat Pompeu Fabra, Barcelona 21-22 March 2012*. InSOTEC Report (D-N°: 5.1).

Schröder, J., Rossignol, N., and van Oudheusden, M., 2016. Safety in long term radioactive waste management: Insight and oversight. *Safety Science*, 85, 258-65.

Sebeok, T., 1984. *Communication Measures to Bridge Ten Millennia. Technical Report prepared for Office of Nuclear Waste Isolation*. [pdf] Available at: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/16/010/16010244.pdf?r=1.

Seidl, R., Moser, C., Stauffacher, M., Krütli, P., 2013. Perceived Risk and Benefit of Nuclear Waste Repositories: Four Opinion Clusters. *Risk Analysis*, 33(6), 1038-1048.

Shrader-Frechette, K., 2000. Duties to Future Generations, Proxy Consent, Intra- and Intergenerational Equity: The Case of Nuclear Waste. *Risk Analysis*, 20(6), 771-778.

Shrader-Frechette, K., 2005. Mortgaging the Future: Dumping Ethics with Nuclear Waste. *Science and Engineering Ethics*, 11(4), 1-3.

Skarlatidou, A., Cheng, T., and Haklay, M., 2012. What Do Lay People Want to Know About the Disposal of Nuclear Waste? A Mental Model Approach to the Design and Development of an Online Risk Communication. *Risk Analysis*, 32(9), 1496-1511.

Strandberg, U., and Andrén, M., 2009. Editorial: Nuclear waste management in a globalised world. *Journal of Risk Research*, 12(7-8), 879-895.

Strauss, H., 2010. Involving the Finnish public in nuclear facility licensing: participatory democracy and industrial bias. *Journal of Integrative Environmental Sciences*, 7(3), 211-28.

Taebi, B., 2017. Bridging the Gap between Social Acceptance and Ethical Acceptability. *Risk Analysis*, 37(10), 1817-1827.

Vilhunen, T., Kojo, M., Litmanen, T., and Taebi, B., 2019. Perceptions of justice influencing community acceptance of spent nuclear fuel disposal: A case study in two Finnish nuclear communities. *Journal of Risk Research*, DOI: 10.1080/13669877.2019.1569094.

Welsh, I., and Wynne, B., 2013. Science, scientism and imaginaries of publics in the UK: Passive objects, incipient threats. *Science as Culture*, 22(4), 540–566.

© CHANCE

Appendix A: End User Group Questionnaire

The CHANCE project "Characterization of conditioned nuclear waste for its safe disposal in Europe" aims to address the specific issue of the characterization of conditioned radioactive waste to be disposed of in a dedicated repository. The project started on 1st June 2017 for a 4 years period.

The present questionnaire has been designed to gather as much information as possible about the important characterization requirements for conditioned radioactive waste to be disposed of in an appropriate repository in one of the European states. Information on CHANCE objectives and tasks can be found on the project website: www.chance-h2020.eu.

This questionnaire has been produced by CHANCE Work Package 2 to obtain a broad overview on the end-users needs for the characterisation of conditioned radioactive waste. It also includes questions pertaining to Work Package 6, related to underlying socio-technical and ethical frameworks of radioactive waste characterisation practices and policies. More specifically, these questions aim to appreciate how your organization perceives the activity of waste characterization in relationship with the evolution of your national disposal programme, in terms of importance with respect to the whole back-end of the fuel cycle, or in terms of uncertainty management within your organization.

The information collected will be used to identify:

- key parameters that need characterization;
- technologies/methods commonly used for characterization of conditioned waste;
- waste acceptance criteria applied and the possibilities of their harmonization in Europe
- specific problematic issues for the characterization of conditioned radioactive waste;
- R&D needs and potential on-going R&D programme on the topic of conditioned radioactive waste characterization;
- potential applications of R&D actions to be included in CHANCE;
- socio-technical and ethical issued associated with the waste characterization process.

A synthesis of commonly used methodologies for conditioned radioactive waste characterization and end-users requirements and concerns will be produced based on the questionnaire analysis. Also, the R&D needs on characterization of conditioned radioactive waste will be synthetized. The outcome of this analysis will additionally be used to refine the dissemination and communication strategy of the CHANCE project. Your answers to this questionnaire thus are vital for the CHANCE project in particular and for improving the characterization of conditioned nuclear waste for its safe disposal in Europe in general. We thank you very much in advance for your cooperation!

© CHANCE

This questionnaire consists of 18 questions and a guidance to answer these questions is included.

1.1 Personal Details
You name and surname:
Name of your organization:
Your role in the organization:
Email address:
Postal address:
Country:
If you are replying on behalf of a government, academic/research organisation, industry association, non-governmental organisation or any other type of organisation, please: - *specify the type of organisation* - *briefly describe your organisation, including scope and field of activity in relation to radioactive waste management*
Please indicate the preferred transparency level your answers must have by clicking directly on the corresponding boxes below: ☐ Fine to publish the whole questionnaire with name ☐ Fine to publish the whole questionnaire anonymously ☐ Just use the answers as part of a general overview / statistical analysis

© CHANCE

Q1. What types of radioactive waste, including spent fuel, are managed by your organization?

- *please specify the origins and the types of the waste you are managing*

- *you can adapt the table with waste classification according to the IAEA General Safety Guide No. GSG 1 to account for the classification scheme applied in your organisation/ country*

Waste type	Yes/No	Main origin	Comment
Very low level waste			
Low level & Intermediate level short-lived waste (category A)			
Low level & Intermediate level long-lived waste (category B)			
High level waste (category C)			
Spent fuel (category C)			
Other (eq. liquid waste)			

Q2. What is the option for storage / disposal of the radioactive waste and spent fuel in your country?

- *please specify the storage / disposal option for each waste category identified in Q1*

- *please specify the existing or planned facilities for radioactive waste storage and disposal in your country*

Waste type	*storage / disposal option*	*existing or planned facilities - storage*	*existing or planned facilities - disposal*
Low level & Intermediate level short-lived waste (category A)			
Low level & Intermediate level long-lived waste (category B)			
High level waste (category C)			
Spent fuel (category C)			

Q3. What are the waste acceptance criteria (WAC) for the storage / disposal facilities identified above in Q2 (operational and foreseen to be commenced in the future)?

© CHANCE

- *for each storage / disposal option please include the main parameters that have to be characterized:* - *Radiological parameters* - *Chemical parameters* - *Mechanical parameters*
Q4. Should WAC be harmonized across Europe? If so, how?
- *please express your personal point of view regarding the opportunity for WAC harmonisation* - *if you consider this harmonization as opportune, please you express your personal idea on how this can be done*
Q5. How do you deal with the fact that the WAC as well as the final disposal concepts are in constant evolution (techno-scientific progress, experiences, stricter attitudes …)?
- *how do you deal with the historical waste* - *do you have to characterize more (as required by the current WAC?)*
Q6. What methods are you applying in characterisation of conditioned radioactive waste?
- *please specify and give as much details as possible on the methods applied in your organization for radioactive waste characterisation (including characterisation of waste before its conditioning)* - *please specify how you correlate the so-called difficult to measure radionuclides with easy to measure nuclides* - *please specify if you correlate the chemo-toxicity with radio-toxicity of the waste* - *if you are complementing the measurement data with modeling/calculations, please specify and describe them specifying, if any, potential needs of codes' validation by National Control Authority*
Q7. What are the uncertainties associated to the methods you are currently using in radioactive waste characterisation?
- *please specify the levels of uncertainties for each method used in your radioactive waste characterisation* - *please specify the target level of uncertainties* - *what is the source of the uncertainty?* - *please specify your action(s) (if any) to decrease the uncertainty level in characterisation of conditioned radioactive waste*
Q8. Which other uncertainties (e.g. technical, conceptual, social, political, ethical) do you anticipate with regard to waste characterisation for safe disposal? Please list the three in your opinion most important ones. How do you deal with these uncertainties? Can they be managed?

© CHANCE

Uncertainties may relate to changes in the final disposal concept, regulation and/or policy, divisions of responsibilities, limits of knowledge, amounts of waste, societal incentives or pressures, financial constraints, safety/security protocols, among others. *For all three of the uncertainties you mention, can you please tell us:* *- what is the impact of each of these uncertainties on waste characterization is according to you (e.g. on the relationship between actors, operational safety, costs, …)* *- whether and how these uncertainties are dealt with at present(e.g. through various procedures, leaving the option of re-characterization, storing the waste in a certain manner, …)* *- any suggestions you may have on whether and how these uncertainties could be managed (e.g. new equipment, a political decision, involving other disciplines, reconditioning, flexible tariffs …)*
Q9. Do you have in your country / organisation waste categories *and/or waste forms* that do not have a dedicated option for disposal? If yes, are you characterising them?
- if you identified waste that do not have dedicated option for storage/disposal, please specify what are these waste categories *- please identify what are the potential limits for the acceptance of these waste categories in the existing or future disposal facilities* *- please specify what are the plans for managing these waste categories* *- if you are characterising these waste categories/forms, please specify what kind of measurements are you performing*
Q10. What are the major technical difficulties you encounter in characterising your conditioned radioactive waste?
- first please specify what are the conditioning methodologies and/or matrices used in your organisation *- please specify here any technical problems you face in the characterization process*
Q11. What are the R&D needs that could solve the difficulties identified in Q10?
- please identify what techniques/methods could complement the ones already used in your organisation/country to improve the level of radioactive waste characterisation?
Q12. Do you have an active R&D programme on radioactive waste characterisation?
- if yes, please specify what are the main topics addressed *- are you interested to be involved in R&D projects related to radioactive waste characterisation?* Yes
Q13. The CHANCE project will address and develop some specific techniques: Calorimetry, Muon Tomography and Cavity Ring-Down Spectroscopy (for details see www.chance-h2020.eu). Do you foresee an application of one of these techniques in your radioactive waste characterisation?
- if yes, please specify for what type of waste you could use these methods and how these methods improve the characterisation of your conditioned radioactive waste
Q14. In your country, who is in charge of characterization and who is in charge of control?

© CHANCE

- what organisation(s) are responsible for radioactive waste characterisation

- what organization is in charge with control

- how the characterisation and control processes are structured

- how these processes are follow up

Q15. What is the role of host communities in these processes?

- Do host communities (i.e. the local community where the waste is stored / (will be) disposed) have a role in waste characterization and/or control in your country?

- Should these communities have a role in waste characterization and/or control in your opinion and if so which one?

- How do you deal with the concerns of local communities, e.g. concerns about the content of the disposal facility?

- Do you think that continuous improvement of waste characterization by innovative methods can improve the perception of risk associated with waste disposal?

Q16. Which disciplines / fields of expertise / actors are involved in the characterization of conditioned waste in your country? Are there any missing in your opinion?

please specify:

- *disciplines, fields of expertise and actors involved in radioactive waste characterization*
- *missing ones, if any*

Q17. Why is waste characterization important for your organisation?
Please rate the importance of the following reasons from 'very high' to 'very low'

	Very high	High	Low	Very low
Verification of the declared inventory				
Improvement of characterization methods and techniques				
Operational safety				
Long term safety				
Economics (cost determination)				
Waste classification in view of disposal choices				
Optimisation of disposal concepts				
Stakeholder involvement				
Regulatory requirements				
Long term monitoring				
Retrievability				
Communication				
Documentation				
QM & incident management				
Other:				

© CHANCE

Comments (if any):
Q18. What lessons can be drawn from the waste characterization processes in your country?
Lessons can be either positive or negative. *You can compare with other countries, but this is not necessary.*
Open comments
If you have some comments either on CHANCE project or on this questionnaire that have not been addressed previously, please mention them here.

© CHANCE

Appendix B: List of Responding Organizations

Name of Organization	Type of Organization	Country
ANDRA	Waste Management Organization	France
CEA (Commissariat à l'énergie atomique et aux énergies alternatives)	Research Institution	France
ENRESA (Empresa Nacional de Residuos Radiactivos, S.A)	Waste Management Organization	Spain
FZJ (Forschungszentrum Jülich GmbH)	Research Institution	Germany
INCT (Institute of Nuclear Chemistry and Technology)	Research Institution	Poland
Nucleco	Waste Management Organization	Italy
ONDRAF/NIRAS	Waste Management Organization	Belgium
RATEN ICN (The Institute for Nuclear Research)	Research Institution	Romania
RWM (Radioactive Waste Management Limited)	Waste Management Organization	United Kingdom
RWMP (Radioactive Waste Management Plant)	Waste Management Organization	Poland
SCK•CEN (Belgian Nuclear Research Centre)	Research Institution	Belgium
SKB	Waste Management Organization	Sweden

© CHANCE