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Does technical risk dialogue entail socioeconomic valuation?

The case of scientific dispute over copper corrosion in a spent nuclear fuel disposal project

Tapio Litmanen, Matti Kojo, Mika Kari & Jurgita Vesalainen

Among the proponents of nuclear power, the project for the safe and secure disposal of spent nuclear fuel (SNF) in Finland is often deemed a success story. Opponents have had difficulties getting publicity for their claims about the risks of the project. Their most powerful arguments have been mostly ethical, but on technical issues the opponents have been in a weaker position in relation to the proponents. However, recently the risk of corrosion in oxygen-free water has become subject to scientific controversy, possibly threatening even the realisation of the final disposal of spent nuclear fuel (SNF) (Andersson 2014, p. 2; Wallace 2010). In Sweden, this issue has been intensively debated since 2007 (Andersson 2014; SNCNW 2013), but only recently has this debate taken off in Finland (Lempinen & Lempinen-Silvan 2011; Nurmi et al. 2012; Litmanen et al. 2012; FANC 2013; Klötzer et al. 2013).

While the main dispute is about the ability of copper canisters to resist corrosion in nearly oxygen-free geological conditions after the closure of the repository, there is also some controversy regarding other types of corrosion related to these canisters. The theme of copper corrosion has long since been addressed from a scientific perspective in the context of the Swedish KBS-3 method (King et al. 2002, p. 137). These canisters, containing SNF, are to be buried at a depth of approximately 500 metres in the bedrock, and surrounded by bentonite clay. The current scientific assumption is that copper corrodes at an extremely slow rate in such an environment and that no corrosion will take place in oxygen-free conditions (see e.g. King 2010; Posiva 2013, p. 434-436). However, as Andersson (2014) has indicated, this assumption has been challenged by experimental results of researchers working at the Swedish Royal Institute of Technology. The researchers are suggesting that, even in an oxygen-free environment, copper could corrode by taking oxygen from water molecules. This continuation of general corrosion could mean that the canister would not withstand the conditions prevailing throughout the 100,000-year foreseen lifetime of the final disposal, if the thickness of the copper were five centimetres as planned (Hultquist 1986; Szakálos et al. 2007). Despite Posiva's announcement in 2015 that the issue of copper corrosion had been brought to a conclusion and that the investigations have confirmed that copper will not be significantly corroded in oxygen-free conditions (Posiva 2015, p. 6), the scientific dispute is ongoing.

The focus of this article is on the risk dialogue over copper corrosion between the nuclear waste company, Posiva, and the Finnish Radiation and Nuclear Safety Authority, STUK, and the ways in which these organisations deal with the challenge that copper corrosion presents to geological disposal. The study of the copper corrosion dispute in the geological disposal of SNF[1] will shed light on how socioeconomic[2] evaluation[3] issues of a megaproject are intertwined both with institutional arrangements allowing and preventing evaluation and with technical risk dialogue, where socioeconomic evaluation is a hidden agenda not to be touched at the later stages of decision-making. Regardless of the seeming political neutrality of risk assessment, larger socioeconomic valuations frame the dyadic risk dialogue between the implementer and the regulator. Our aim is to illustrate 1) how technocratic risk assessment functions, but also 2) how this risk assessment is embedded in the broader societal-institutional setting, which to a large extent in itself predetermines the outcome. Conventionally risk assessment and safety regulation are assumed not to entail socioeconomic valuation, but on closer examination they can be seen to reflect changing societal-institutional goals. The collaborative arrangements between enterprise and supervising authority comprise a unique form of socioeconomic valuation as the goal is, in addition to safety, also to ensure that the megaproject is advancing according to the long ago set timetable without further problematising already established socioeconomic evaluation.

The structure of the article is as follows. First we discuss the Finnish regulatory culture in its institutional settings and the problematic nature of socioeconomic evaluation in the chosen case before reporting our methodological choices. The main empirical findings are presented in five sections covering each of the phases of risk dialogue studied, p. 1) Setting the stage (2003–2004), 2) Focus on future projections (2006–2007), 3) Intermingling of two processes (2009–2010), and 4) Crisis in the relationship (2012–2013). The final section of the paper discusses the findings and draws conclusions about whether the power to define the 'common good' is handed over to the parties of the risk dialogue.

Institutional settings behind the regulatory culture

Posiva's and STUK's risk dialogue takes place in legally and institutionally defined regulatory settings (Heinonen et al. 2014), which comprise at least two main elements: the Finnish Nuclear Energy Act (990/1987)[4] and Regulatory Guides on nuclear safety (YVL)[5]. In accordance with the Act, the power companies Teollisuuden Voima Ltd (TVO) and Fortum Power and Heat Ltd (FPH) are responsible for their own waste. For managing SNF, the power companies have established a joint company, Posiva, which is procedurally connected to STUK, because 1) STUK regulates the safety of the handling, storage and disposal of nuclear waste, 2) the authorities have issued reporting obligations to the producers of nuclear waste and STUK's role is to monitor companies, 3) STUK reviews Posiva's studies and technical plans for final disposal with the aid of other expert organisations and gives feedback to Posiva[6], 4) STUK conducts the safety review in each stage of the licencing process[7], 5) STUK is given powers of search and entry, access to records, power to take samples and install monitoring devices, power to require the operator to submit reports and the ability to give directions about the manufacture of equipment, 6) STUK can also require Posiva to make changes to the physical structure of a nuclear facility and to operating practices and procedures and 7) all STUK's regulatory costs are recovered from the licencees. (OECD 2008; Laaksonen 2006)

This institutionally defined, decades long, risk communication between the implementer and STUK has created a special relationship between the parties. Similarly as in Sweden

(Wärnbäck 2012; Wärnbäck et al. 2013), in Finland, too, the implementer and the regulator have been engaged in a series of conversations on the advancement of research, planning, and technical design related to disposal of SNF, and the interaction has affected their relationships (see also Elam and Sundqvist, 2009, p. 973). The Finnish regulatory framework and the relationship between the implementer and the safety authority are somewhat similar to those of Sweden, but there are also differences – mostly of historical origin (Wahlström 1999). In Finland the main actors have been in close dialogue before the construction licence application (CLA) authorisation process began, i.e. during the pre-licence phase (See Figure 1). As argued by Wärnbäck et al. (2013), close cooperation over a long period of time might change the way the actors perceive themselves and others, as well as how they formulate their goals and aims. Therefore the roles and responsibilities are not always as clear as claimed. For instance, Posiva's preliminary licence documentation submitted in 2009 (See Figure 1), required by the MEE, was perceived as an exercise for the actual licence application review by STUK (Heinonen et al. 2014, p. 3-4). In general, the aim of the exercise was to improve actual performance, in view of learning and reflection designed to potentially transform the regulatory approach or some aspects of it.

Even though it is difficult to identify pure national regulatory styles in Finland and Sweden (Wahlström 2007, p. 353; Melber & Durbin 2005), Finnish regulatory culture has been seen as flexible, development-oriented and, as such, oriented towards gradual learning and refinement (NEA 2003). Gradual learning refers to a process where the development of regulation is related to the current phase of decision-making, starting from very general principles and ending with the guidance applicable to a licencing review (NEA 2003, p. 12). The regulatory philosophy of gradual learning is characterised as one that provides plenty of opportunity for a constructive dialogue between the regulator and the implementer, which can be beneficial for the development of technical procedures, but also leaves room for interpretation and control by the authorities (NEA 2003, p. 12-13; see also Laaksonen 2006).[8]

This Finnish model of dialogue between implementer and regulators has been seen to require 1) strong social trust in the regulatory authorities and 2) a well-defined interaction process that ensures public confidence and ensures that decision-making in regard to licencing is not subsequently constrained or compromised in the legal or "quasi-judicial" sense (NEA 2003, 10). The Finnish nuclear regulation culture can also be characterised in Renn's (2008) terms by a mixture of fiduciary and consensual approaches (Renn 2008, p. 359); because of the close-knit relations of the prominent actors (STUK, the nuclear industry, and the MEE), little or no opportunity for public participation remains. Informal communication between the parties (Laaksonen 2006, p. 59-60) is significant as it creates an interactional culture and some sense of togetherness. In general, STUK has to balance between three sometimes conflicting roles in its regulatory tasks. STUK has the role of 1) expert, where dialogue, cooperation, self-criticism and reflectivity are important; it has a role of 2) authority, where independence, mediated control and perceptions are important; and it has 3) a public role where reporting, informing and openness are important (Reiman and Norros 2002, p. 188).

The time and place of socioeconomic evaluation of SNF geological disposal

Recently there has been much interest in studying emergent and prospective technologies from the perspective of social expectations and experiences (Konrad 2006; Geels & Raven 2006; Geels et al. 2007; Veerbong et al. 2008). Applying these kinds of socioeconomic evaluation perspectives to the study of nuclear power is rather difficult, because nuclear technology itself is not new and it is not evolving from an almost zero point straight to the markets. One option would be to follow current megaproject governance and evaluation approaches such as conventional rational evaluation schemes or megaproject pathologies approaches (Flyvbjerg et al. 2003; Flyvbjerg 2005) or their rivals such as the projects-as-practice approach (Sanderson 2012) or reflexive and learning-oriented evaluation[9] (Lehtonen 2014a). Instead of conducting any of these large scale socioeconomic evaluation exercises the aim of this paper is to contribute novel research on megaproject governance. As both Sanderson (2012) and Lehtonen (2014a) have indicated, megaprojects' project features are far from simple questions. Both authors have characterized megaprojects more as programmes of projects, networks or organic open systems with both substantive and institutional complexity and a multiplicity of rationalities all producing serious difficulties for the governance and also evaluations. As Lehtonen (2014b, p. 98) has indicated, the ambiguities related to 'the social' also produce problems for the socioeconomic evaluation. Besides conventional ways of measuring 'the social' through quantitative indicators there are also more qualitative elements, which escape efforts to objectify 'the social' (Lehtonen 2014a, p. 98).

One way to start deconstructing the socioeconomic evaluation of megaprojects in the field of nuclear technology is to focus on the element of time. Temporal dimensions of nuclear technology projects are huge due to the longevity of radioactive material. If we leave out ex post evaluation due to the long-term legacy[10] of SNF and concentrate on ex ante evaluation questions, we have to ask when ex ante evaluation is done. In the case of nuclear technology projects the socioeconomic evaluation is normally conducted in the planning and decision-making phases of these types of megaprojects. The Finnish case of geological disposal of SNF will illustrate how ex ante evaluation is a continuous and dynamic process despite the main actors' efforts to confine it to the crucial decision-making phases.

Due to the Finnish three step licencing process of nuclear facilities, socioeconomic questions are discussed mostly in the first phase, which is called Decision in Principle (DiP)[11]. During this decision phase socioeconomic issues are debated widely at different spatial levels, because, for instance, a proposed host municipality can use its veto right before the Government makes the decision and the Parliament ratifies the Decision in Principle. The DiP is seen as the Government's answer to the main political question, p. is the proposed nuclear facility in line with the overall good of society (The Nuclear Energy Act 1987/990, Section 1)[12]?

As Strauss (2011; see also Hokkanen 2007 and Kojo 2014) has indicated, the process of socioeconomic evaluation of the project is separated into two tracks. The first track is based on the Nuclear Energy Act and it is more decisive, because the socioeconomic consideration is the decisive criterion, whereas the second track is based on the Finnish Act on

Environmental Impact Assessment (EIA) Procedure[13]. The EIA Act gives citizens an opportunity to participate, but in a way which does not in real sense affect the decisions taken in track one. According to Strauss (2011, 150) the function of track two is to channel citizen participation into a smooth and efficient administrative process, which empties the critical potential of civil society and ensures that the overall goal of acceptance is reached in a quasi-democratic manner. Besides these two institutionally regulated socioeconomic evaluation tracks, also informal socioeconomic valuation by, e.g., the anti-nuclear movement can affect both the dominant socioeconomic evaluation outcomes and also the ongoing technical risk assessment and safety regulation activities.

Strauss (2011), who studied public participation in the siting of nuclear and hydro projects in Finland, has concluded that among politicians and authorities there has been a tendency to avoid politicisation of licencing and decision-making procedures. This has been the case especially after the acceptance of the DiP. Both STUK[14] and Posiva interpret that the political phase of the licencing procedure ended when the Finnish Parliament ratified the DiP in 2001 (Äikäs 2013; Isaksson 2007)[15]. The interpretation is that, after ratification of the DiP, the process, which leads towards a construction permit and operating licence, is essentially technical, and does not leave much room for political or socioeconomic consideration (Isaksson 2007, p. 177; Äikäs and Sundell 2014, p. 8–9).

Both STUK and Posiva seem to advocate a clear division between the ‘technical’ and the ‘political’. They frame the last two steps of the licencing procedure as forums for technical expertise, which in practice dismisses political considerations, leading to depoliticisation. During the second and third licencing phases the spectrum of socioeconomic issues to be taken into account in the evaluation is more concise as the decision is taken only by the Government on the basis of safety and technical considerations. The necessary prerequisite for issuing both construction and operation licences is a positive safety evaluation by the Finnish Radiation and Nuclear Safety Authority (STUK). In this sense socioeconomic issues are bracketed out from these decision-making phases, but the political reality is that, every time the Government handles nuclear facility applications, national political debates over the use of nuclear power proliferate.

Instead of analysing how different stakeholders present the socioeconomic impacts of the SNF disposal project and what kinds of results their socioeconomic valuation schemes produce in different phases of the project, this study focuses on dyadic risk dialogue[16] between the main actors of the SNF disposal project. The study design is quite similar to that of Wärnbäck’s (2012) extensive analysis of expert dialogue between the Swedish Nuclear Waste Company (SKB), the regulatory authorities, and the Government. We have chosen the actor-centeredness projects-as-practice approach which has three basic methodological components: 1) a micro-analytic focus upon the day-to-day activities of management practitioners and their meaning in a specific social setting; 2) a focus on the wide range of actors involved, both formally and informally engaged in a project; and 3) emphasis on the relevance and importance of emergent, non-programmed, work activities for an understanding of how a project develops (Sanderson 2012, p. 441). Our analysis focuses on the risk dialogue over copper corrosion between the nuclear waste company, Posiva, and the Finnish Radiation and Nuclear Safety Authority, STUK, and the ways in which these organisations deal with the challenge that copper corrosion presents to geological disposal. Whereas the project-as-practice approach emphasises the importance of analysing different actors involved in the project, our analysis highlights the country-specific features of the Finnish regulatory system of SNF disposal and the nature of the long-standing risk dialogue between the parties. Even though the Ministry of Employment and the Economy (MEE) has the general regulatory power in nuclear waste policy[17], the study of dyadic interaction between STUK and Posiva is important because these two organisations negotiate on risks regarding disposal of SNF and their risk dialogue is framed by the Finnish legislation. Though the project-as-practice approach stresses the need to put effort into analysing the relevance and importance of emergent, non-programmed work activities, our approach sticks more to institutionally channeled work activities, which can be interrupted by unplanned changes. Due to the research design, which covers a long time period, observing the day-to-day activities of management practitioners and their meaning construction in a specific social setting hasn't been possible. We concentrate solely on the official written exchanges of information, because even here there was plenty of material to examine (Litmanen et al. 2014, p. 13) and the minutes of the face-to-face interactions between Posiva and STUK weren't available for investigation purposes.

Data and method of the analysis

The empirical material of this study was obtained by examining core documents concerning the risk dialogue as part of the regulatory process between Posiva and STUK, namely the Research, Development and Technical Design (RTD) review process and the Construction Licence Authorisation (CLA) process. RTD related to the KBS-3 concept[18] has been underway for over 30 years[19], but there are still some uncertainties. As the KBS concept is originally Swedish, Posiva has been cooperating closely with its Swedish counterpart, SKB (Kojo and Oksa 2014). Because of the similarities in the technical plans and safety cases the two companies have had 'extensive research cooperation covering the whole disposal technology' (Posiva 2010a, p. 12-13).[20]

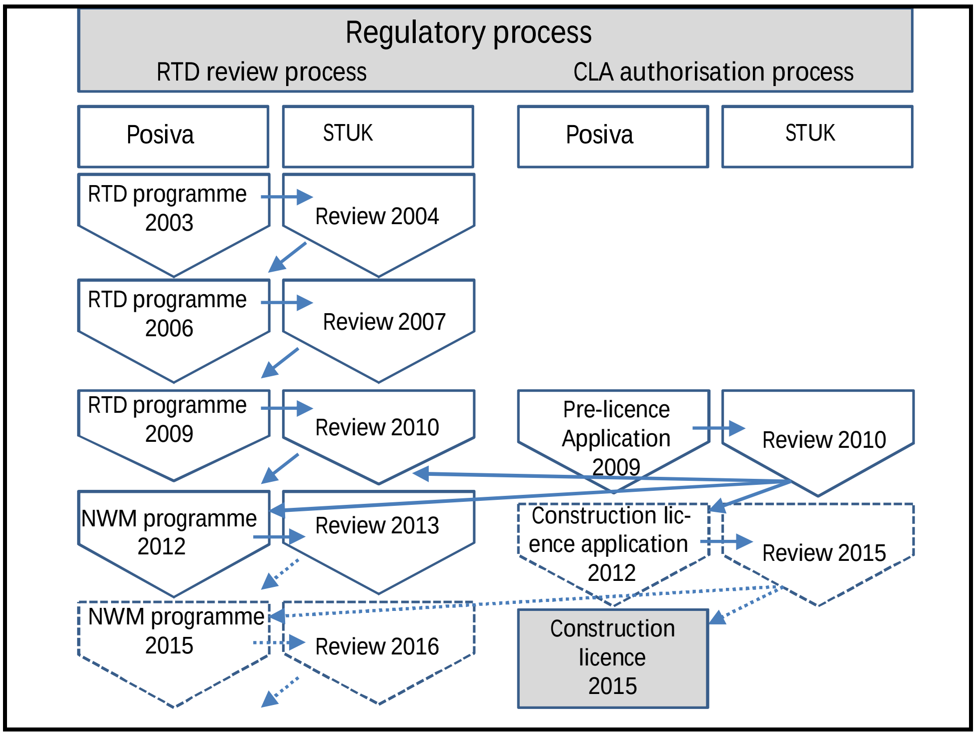
We examined Posiva's RTD programmes published in 2003[21], 2006 and 2009, and their successor, the Nuclear Waste Management (NWM) programme published in 2012[22]. The RTD programmes describe the progress as well as the management of the radioactive waste activities of Posiva for its owners, TVO and FPH, and for other stakeholders. Regarding the purpose of the reports an important change has taken place. The focus of the reports has been on the development of the SNF disposal programme, but the documents from 2003 to 2009 reflect the steps taken to prepare for the construction licence application and aim to show the feasibility of the repository (Posiva 2006, p. 11)[23]. Therefore the pre-CLA was also examined. This sample of data, which consists solely of the official written exchanges of information, can obviously only illuminate a part of a more complex picture of risk dialogue between the actors.

When examining STUK, we analysed the statements that the regulator submitted to the MEE concerning Posiva's reports. We also examined the appendices of the statements[24] that give more detailed background on the issues raised in the statements. In these documents, STUK, together with its subcontractors, evaluates the RTD efforts and the adequacy of the company's application material; comments on the planned research, development and technical design of the spent fuel repository system and the state of the application material; and makes recommendations regarding further development.

The analysis focused on copper corrosion, because the copper canister is one of the main barriers in the KBS-3 final disposal concept. In the data analysis, both copper corrosion and (if not specified) the corrosion issue in general were taken into account. However, forms of corrosion unrelated to copper (e.g. the corrosion of iron inserts, reinforcement materials or some of the metal parts of the fuel assemblies) were excluded from the research, as they did not fit into the frame of the present study.

The design of our study follows the sequence of the dialogue between Posiva and STUK (see Figure 1). We have investigated both the RTD review process and the CLA authorisation process as part of the regulatory process. The progress of Posiva's RTD on the possibility for an underground nuclear waste repository is influenced by the continuous exchange of information with STUK as well as the official statements of the authority (both indicated in the figure with arrows) that were developed on the basis of the RTD reports. The statements made by STUK were influenced by the risk communication conducted with Posiva. Statements by the MEE on the grounds of STUK's review statements are not included in the data and are not mentioned in Figure 1. As Figure 1 indicates, it was only after 2009 that the CLA review began to affect the RTD review process. STUK´s pre-CLA review influenced STUK's own 2010 RTD review and Posiva's new NWM-2012 programme. STUK's pre-CLA review also affected Posiva's 2012 CLA. The Finnish Government granted the licence to construct a SNF encapsulation plant and disposal facility at Olkiluoto in November 2015. The maximum disposal capacity of the facility is 6,500 tonnes of uranium (MEE 2015).

Figure 1. The flow of risk dialogue between Posiva and STUK as part of the regulatory process



Years 2003 and 2004: Setting the stage

The stage for the copper corrosion dialogue between Posiva and STUK was set in 2003, only two years after the first step of the authorisation process, and the ratification of the DiP by Parliament. In the RTD report of 2003, Posiva described their own and their co-operative research on corrosion, but also disclosed their thoughts concerning aspects needing further research. In addition to its own expertise, STUK hired external experts and the review of the RTD led STUK to demand further consideration, clarifications and research on several issues.

During this period there were many uncertainties identified regarding the issue of copper corrosion. Nevertheless, Posiva seemed to remain optimistic, while hoping for favourable results from future studies and improved insight into unclear matters related to copper corrosion. On the other hand, STUK (2004, p. 2) considered Posiva's RTD report of 2003 to be a general overview of the situation at that time and expected answers to many questions and concrete technological choices to be made in the near future.

With respect to the specifications of the canister for the isolation of SNF, Posiva (2003, p. 36) argued that canister design rests on the assumption that it is 'watertight and airtight, corrosion resistant and mechanically solid'. According to the company, a great deal of research conducted over 20 years by SKB as well as its counterpart and collaborator, Posiva, proved the suitability of copper. The organisation stated that 'available evidence supports' the claim that the canister can hold the waste for more than 100,000 years. Nevertheless, it simultaneously admitted the need for further research (Posiva 2003, p. 119).

At the time, Posiva and SKB together with Canadian partners were engaging in a joint project focussing on the development of a model enabling the prediction of long-term corrosion in sulphide-containing compacted bentonite. Posiva and its Swedish counterpart were also paying attention to such issues as general corrosion in oxygen-free and saline conditions, localised corrosion, the impact of redox conditions on corrosion, and the effects of methane and high-pH conditions on corrosion (Posiva 2003, p. 119-120).

Some of the above-mentioned issues are also presented in Posiva's RTD report. With respect to general corrosion in oxygen-free conditions and salinity, the company cites a couple of contradictory studies and concludes that the issue still needs further research in conditions as similar as possible to those of the repository. Further research is also needed on the possibility of localised corrosion that could cause an early failure of the copper shell. The impact of redox conditions on corrosion, with an unclear duration in the initial toxic period as well as estimates regarding the relevant chemical, electrochemical and microbiological processes, is recognised as another area of uncertainty (Posiva 2003, p. 120-121). Regarding the effects of methane, Posiva argued that, according to the literature reviewed, methane has no negative effect on copper (Posiva 2003, p. 121). Finally, with respect to the effects of high-pH conditions, Posiva (2003, p. 121) stated that a high pH would lead to the passivation of the canister surface, which would increase the stability of the canister, as well as its ability to prevent local corrosion. Although Posiva's 2003 RTD report provided a detailed overview in which the main issues regarding copper corrosion were thoroughly and logically addressed (Read 2004, p. 8), STUK and its reviewers made numerous comments, questions and requirements about further research concerning the challenge of determining the corrodibility of the copper canister. In relation to Posiva's estimate of the lifetime of the canister, Hänninen (2003, p. 2) highlighted that the isolation of the waste in the canisters for more than 100,000 years was a much longer timespan 'compared to the operation time of any other industrial product', while Apted et al. (2004, p. 11) believed that Posiva minimised numerous concerns. Therefore, Posiva was urged to consider, for instance, the manufacture of the canisters, the materials to be used, and their mechanical characteristics, in order to be able to address all forms of corrosion and other risks (Hänninen 2003, p. 2).

STUK, together with its reviewers, required more research on various issues and highlighted some aspects that Posiva should take into consideration. For example, Apted (2004, p. 10) noted that temperature might play a role in mineralogical alteration for some designs. Changes in volume due to the corrosion of the canister had to be taken into account while studying chemical interactions between the backfill and the buffer. Hänninen (2003, p. 2) agreed with Posiva that a thinner copper shell would be advantageous, but he also pointed out the need for proof that such a shell would withstand corrosion. STUK (2004, p. 5) pointed out that groundwater conditions were more prone to facilitate corrosion in the bedrock of Olkiluoto than in the operating waste cave, and this must be kept in mind when interpreting the results of copper corrosion research. Hänninen (2003, p. 8) and Apted et al. (2004, p. 11-12) demanded that the representative creep behaviour of the copper canister be tested to avoid canister corrosion. That said, Read (2004, p. 9) expressed his full support for the joint Posiva and SKB project, focussing on the development of 'a corrosion model for copper in sulphide media containing compacted bentonite'.

Years 2006 and 2007: Focus on future projections

During the second round of the dialogue the issue of copper corrosion gained both breadth and depth. The increased coverage of the corrosion issues in the RTD of 2006 indicated both increasing knowledge about the issue as well as remaining uncertainties. STUK recognised Posiva's efforts at enhancing its knowledge, but nevertheless identified weaknesses and pointed out areas in need of further research.

In this period the discussion between Posiva and STUK extended to considering the future prospects of and the possible concerns related to the long-term corrosion behaviour of copper in changing repository conditions. The increasing attention given to the issues of copper corrosion in Posiva's 2006 RTD report suggested that, during the three-year period, the company gained more information and clarity on the issues, but was simultaneously confronted with continuing uncertainties. STUK acknowledged the advances in Posiva's knowledge but once again required more information about certain issues related to the corrosion processes. STUK and its consultants deplored the lack of a coherent picture of the research, of evidence on the long-term properties of the canister design, and of research on the possibility of early failure of the canister due to creep or stress corrosion. Clarifications and further consideration of other matters were also required.

Posiva's 2006 RTD report delineated the requirements, reviewed the steps taken during the previous three years and outlined further RTD issues for the upcoming period. The document dwelled on 'technical performance of the disposal concept and of the engineering components in site-specific conditions'. Since the deadline for the submission of the CLA was approaching, the focus of this report shifted towards the 'operational and long-term safety of the system' (Posiva 2006, p. 11).

Posiva (2006, p. 49) had collected a substantial amount of knowledge regarding the corrosion of copper and argued that such potential forms of corrosion processes in repository conditions as general and local corrosion were already extensively studied, but information was still lacking on microbially induced corrosion. Stress corrosion cracking was deemed unlikely because of the low concentration of elements that induce stress corrosion cracking and the remarkably low corrosion potential values (Posiva 2006, p. 49, 197). In the report, Posiva (2006, p. 49-50, 71, 238) also described what it had learnt about the interaction between forms of copper corrosion mentioned earlier (including uniform and pitting corrosion) and the constantly evolving repository environment with a focus on oxygen-free, saline, chlorine and alkaline conditions, plus the effects of temperature and pH. Moreover, the possible impacts of alien materials on copper corrosion were considered in the report (Posiva 2006, p. 257).

In addition to the above-mentioned issues, Posiva paid attention to the changing repository conditions and to the expected corrosion processes during the planned lifespan of the repository. Posiva's examination took into account both the repository construction phases (e.g. early post-closure, the post-closure saturated phase) and climate change periods including e.g. permafrost and glacial melting (Posiva 2006, p. 196-201). Despite the lack of clear insight into upcoming changes, the document stated that the investigations carried out supported prior conclusions, which have tended to corroborate the hypothesis that the copper canister concept is safe and feasible (Posiva 2006, p. 208). However, because of numerous uncertainties connected to the long term corrosion in the repository environment Posiva (2006, p. 62) stated that it would continue to research the issue. In addition, the future RTD efforts of the company were to be directed towards the investigation of, for instance, corrosion in anoxic and saline conditions as well as compacted sulphide-containing bentonite (Posiva 2006, p. 50). Also, the company planned to continue studies on the potential for corrosion due to welding, as well as on the effects of acetates (Posiva 2006, p. 57-58, 140).

According to STUK (2007a, p. 2) and a group of external experts, it continued to engage in dialogue with Posiva in relation to research into the repository and the construction of ONKALO. The authority gave positive feedback on the reporting and technical development during the past three years but simultaneously identified weaknesses and areas for further investigation. STUK (2007b, p. 2) criticised the RTD report for failing to give a clear picture of the research and for a lack of evidence concerning the long-term properties of the canister design and argued that the risk of an early failure of the canisters due to creep or stress corrosion had received too little attention in the document. Other uncertainties had to do with the relationship between groundwater and copper corrosion (STUK 2007b, p. 4; Bath et al. 2007, p. 20). Moreover, further explanation was required regarding the worst-case scenario for copper corrosion caused by sulphate-reducing bacteria (Read et al. 2007, p. 30). Finally, Hänninen et al. (2007, p. 27) noted that there was a lack of information about stress corrosion cracking under reducing and oxidising conditions.

STUK and its reviewers required more RTD efforts on numerous copper-corrosion related issues. According to the authority, extensive research and mathematical modelling were still needed to ascertain the long-term durability of the technical barriers and special attention would need to be paid to the interaction between the copper canister and bentonite. STUK also stated that the processes affecting the corrosion behaviour of copper also had to be investigated (STUK 2007a, p. 2). Finally, STUK's subcontractors (Bath et al. 2007, p. 18-19, 20) asked for more investigation concerning the biogeochemical inputs into the engineered barrier system that impacts copper corrosion of the canister as well as the effects of sulphate on redox stability.

Years 2009 and 2010: Intermingling of two processes

At this stage the authorisation process brought up difficulties in the fairly simple regulatory review process. As indicated in Figure 1, the regulatory review process, i.e. the RTD review, was affected by the authorisation process, i.e. construction licence review. This intermingling of two processes increased STUK's criticism, causing it to become less self-evident than before that the CLA authorisation process would result in a positive decision to grant a construction licence.

In this period Posiva had to, in addition to its RTD report, also submit material for the so-called pre-construction licence application (pre-CLA) required by MEE. Interestingly enough, different perceptions of the pre-CLA by Posiva and STUK affected both of STUK's reviews. Finding the pre-CLA material lacking in many ways, STUK extended its criticism to the RTD report, looking at it in the light of its assessment of pre-CLA material. The criticism voiced by STUK was essentially two-fold. On the one hand it expected a more comprehensive approach from Posiva and on the other hand it still required more attention to questions of corrosion. STUK had expected a more holistic view in the pre-CLA. Therefore STUK's criticism was harsh. It deplored the lack of coherence, justifications and conclusions, but also Posiva's inability to keep up with its timetables.

Notably, at this time Posiva and STUK focused on almost the same themes related to copper corrosion as in earlier documents. This suggests that all the known strictly copper-corrosion related issues had probably been identified by that time. Nevertheless, Posiva's discussion of the corrosion behaviour of copper in the RTD of 2009 was more extensive than before and paid considerably more attention to comments made by STUK. However, in its statements STUK demanded a more comprehensive picture from Posiva and at the same time continued to demand answers to outstanding strictly corrosion-related questions before the next milestone – the CLA in 2012.

From STUK's comments it is painfully obvious that Posiva and STUK were not on the same page regarding the pre-CLA material. Posiva had submitted something like a compilation of research accomplished, whereas STUK, in turn, had been expecting a more holistic view on what Posiva would present later in the actual CLA, as it found Posiva's material lacking in coherence, justifications, and conclusions, and excessively concentrated on individual issues. STUK considered that some delayed and unfinished ongoing tasks had become critical to the schedule and stated that the RTD programme concurrently in review would be assessed with the findings of the pre-licence review in mind (STUK 2010a).

As one would expect, given that the pre-licence material[25] and RTD programme were submitted at roughly the same time, there were really no significant differences between these two materials in the ways that they addressed the strictly copper-corrosion related issues. In its last actual RTD programme report in 2009, Posiva (2010b, p. 13) dealt with the topic of the disposal of SNF generated by its owners and presented research as well as technical development and design work. For example, in the document, the company (Posiva 2010b, p. 292, 297-298, 309) discussed the significance of the bentonite buffer that would surround the copper canister, and protect it from corrosion as well as other risks. Moreover, in relation to the chemical composition of groundwater, Posiva (2010b, p. 302-304) considered the potential for chloride corrosion as well as the unfavourable impact of solutes and other corrosive agents on the copper canister. Corrosion processes due to the influx of oxygen into the repository along with glacial melt water were also taken into account in the research and formulation of safety scenarios (Posiva 2010b, p. 307, 358). In response to an earlier review by STUK, the document provided a discussion regarding various forms of copper corrosion (e.g. general corrosion, metal corrosion, localised corrosion, the inter-granular corrosion of copper in the welds, and microbially induced corrosion), and did so with reference to different phases of the disposal of the canister (Posiva 2010b, p. 356-357).

Posiva had also identified some areas of concern that still needed further research. Although the company deemed stress corrosion cracking to be unlikely under the expected conditions, it admitted to the remaining uncertainties with respect to evolving changes in climate as well as repository conditions (Posiva 2010b, p. 358-359). Posiva also stated that it would continue research on, for instance, possible material defects in the copper canister shell and weld as well as the adverse impacts of residual stresses that might increase the risk of stress corrosion cracking (Posiva 2010b, p. 208-209, 211-212, 239-240, 345-346, 358-359). Additionally, Posiva planned to investigate the potential for stress corrosion cracking due to the presence of oxygen, certain redox potential values, sulphide ions and sulphide impacts under anaerobic conditions (Posiva 2010b, p. 359, 362). With respect to canister evolution, the company said it was also going to study unlikely but possible scenarios related to uniform corrosion induced by sulphide ions (Posiva 2010b, p. 362, 411).

STUK and its reviewers acknowledged the substantial progress that Posiva had managed to make with respect to copper corrosion and other issues (STUK 2010b; STUK 2010a, p. 2). Nevertheless, the regulator still required some clarifications because it considered that the material provided was incomplete on numerous safety issues related to the canister's corrosion properties. Although Posiva's further analyses of copper corrosion indicated that SNF would be safely isolated for 10,000 years in the canister, STUK, once again, suggested taking into consideration the possibility of, for instance, some deficiently manufactured canisters that would not necessarily last for the required period (Hämäläinen 2010, p. 4). Furthermore, stress corrosion, copper corrosion in pure oxygen-free water as well as possible changes in the repository due to environmental conditions (e.g. groundwater or glacial melt water penetrating the repository) were safety issues that would require more research (Hämäläinen 2010, p. 5; Heinonen 2010, 10, 14, 22; STUK 2010b, p. 4).

STUK's broader criticism related to the inadequate extent of the safety analysis and lack of a plan to show how the performance targets would be reached and in some cases even how the targets would be established (2010b, p. 2-4). STUK considered that Posiva had a lot of work to do in order to improve the coherence of its presentation, notably of the conclusions and justifications. It noted that the schedule for the CLA was going to be very tight, as a sizeable part of the long-term research was to be done after 2012. STUK also stated that a situation in which safety-related research and conclusions were presented after the submission of the licence application could delay safety case review (2010b, p. 1-2, index p.18).

Years 2012 and 2013: Crisis in the relationship

At this stage, during the last regulatory review round before the CLA, earlier tensions between the parties increased. As in previous stages, here, too, the two processes, of regulatory review and authorisation (Figure 1), intersected with and affected each other, creating a somewhat confusing situation. Both the NWM 2012 programme and the official CLA were under review. In the NWM 2012 review process Posiva referred in many cases to material that was to be included in the CLA. The documents indicate that STUK was intensifying its criticism, because Posiva had not taken earlier criticism seriously enough. One of the important criticisms by STUK was Posiva's need for more time for some of its studies. It was estimated that some studies would be completed only after the CLA review by STUK. Thus STUK first rejected Posiva's NWM, and accepted it only after Posiva submitted clarifications and amendments based on STUK's initial review.

In this period the themes related to copper corrosion again remained much the same. In its first NWM report Posiva (2012) tried to respond to STUK's criticism by updating its safety plan with extra care, taking into account the feedback from STUK. In fact, Posiva claimed that it had compiled the comments into detailed lists accompanied by a plan on how it would take the comments into account. In the report, Posiva identified research work done, for example, regarding the suitability of the site, future evolution of the system, barriers and the canister (Posiva 2012, p. 34-35, 46-98, 120-170). The report was to include future plans up to 2015, but Posiva had chosen to make an account of plans up to 2018. The list of aspects needing further research still appeared extensive and included many issues similar to those that had been under investigation already; however, most of them were not strictly related to copper corrosion.

While the themes of the period had not really changed, the tone of STUK's criticism did as it considered that Posiva had not taken its earlier criticism seriously enough. STUK argued that although Posiva planned in many instances to continue its research on the basis of projects started earlier, in many of these cases Posiva had neither made clear their relationship and contribution to safety nor outlined a timeline for conducting these projects. Also, according to STUK, Posiva had overestimated the time available for Posiva to conduct its studies in order to complement the application afterwards. STUK stated that the report contained little information on long-term safety and that it had already criticised the RTDs of 2006 and 2009 for having been insufficient in this regard. STUK also reiterated its earlier criticism on the lack of a plan for implementing the measures needed to reach the performance targets. (STUK 2013, p. 1-5)

After STUK's statement Posiva complemented the NWM programme with more comprehensive plans regarding the schedules for the intended R&D. Regarding the issues concerning long-term safety, in its response Posiva frequently referred to material intended for the CLA. At the time, Posiva's CLA had already been submitted, but was expected to be supplemented while STUK was reviewing it. STUK deemed the amended NWM acceptable, but stated that the plans for ensuring long-term safety would have to be evaluated as a part of the CLA review[26].

Conclusions

In this study, we focused on the dialogue between the nuclear waste management company, Posiva Ltd, and the nuclear safety authority, STUK, with special attention to the copper corrosion issue, as one of the key challenges in the geological disposal of SNF. The starting point of the study was that technical risk dialogue is not apolitical or asocial, but rather takes place in institutional settings and therefore entails socioeconomic valuation.

Our empirical findings suggest that the need for a SNF repository pushes Posiva to adopt an optimistic view on safety issues, right from the first RTD report in 2003, yet the company admits its lack of knowledge on many aspects related to copper corrosion. The results suggest that Posiva's programmes evolved from a mere description of the situation towards more focused and extensive discussions. Meanwhile, the primacy of the ultimate safety of SNF disposal seems to determine how STUK frames the copper corrosion issue as a significant challenge to be dealt with in a way that leaves no room for error, but at the same time, as safe final disposal is seen as the goal, it supports Posiva in pushing ahead in its RTD work, giving credit for the company's advancements and identifying the areas that need further research.

Since the dyadic risk communication between the organisations is determined by the Finnish legislation, STUK exercised its right to demand information, while the implementer, Posiva, was compelled to comply with the requirements. Nevertheless, the organisations appeared to operate on an equal footing in that they both pursued the common goal of successful development of a safe repository for SNF. The results show that, under the normal steady flow of interaction, the risk governance process is oriented towards mutual learning and improvement; however, at the time of crucial decision-making, extra tensions come into the relationship. The mixture of two processes, the RTD review process and CLA authorisation process, opened the possibility of explicitly discussing socioeconomic issues when STUK rejected Posiva's NWM programme.

The results of this research support the assumption that long-lasting interaction between the implementer and regulator tends to shape the regulatory style. Both the existing literature on the Finnish nuclear regulatory culture and the case studied indicate that the regulatory culture is a mixture of a fiduciary and consensual approach due to the prominent roles of the main actors, STUK and Posiva, and the total absence of or very limited opportunity for public participation. The stepwise decision-making and implementation process also affected the regulatory process, which is also stepwise. The Finnish nuclear regulatory culture can be characterised as flexible, development-oriented and, as such, oriented towards gradual learning and refinement. This regulatory philosophy provides plenty of opportunities for a constructive dialogue between regulator and implementer, which can be beneficial for the development of technical procedures, but also leaves room for interpretation and control by the authorities. Ideally, the respective roles of the implementer and the regulator should be clearly defined and separate, but this study of long-standing interaction indicates that engagement in dialogue has transformed STUK's role towards greater attention to development, thus shifting STUK's input towards the advancement of the project, giving it a sort of consultative role. However, at the time of the pre-licence application and actual CLA STUK reviewed Posiva's RTD and pre-licence application more from the point of view of a regulator.

Even though the regulator may have enough regulatory power and it may enjoy powerful institutional status, the longstanding interaction may create convergence between the organisations. Wärnbäck et al. (2013) warn of the tendency of the values and priorities of implementer and regulator to converge over time due to prolonged social interaction. In the Finnish case, this rapprochement of values and priorities could be seen in the three RTD phases – those of 2003, 2006 and 2009 – but the analysis of the 2009 pre-CLA and NWM 2012 showed the withdrawal of STUK from a consensual regulatory style to a more independent and critical regulatory role, probably because of the intersection of two processes, namely the normal regulatory process RTD and the construction licence authorisation process. The diffusion of these two processes caused confusion for the implementer in 2009 as it produced a pre-CLA which did not meet the expectations of STUK. In the next phase, in 2012, STUK's increasing dissatisfaction with Posiva's work led to a crisis in the relationship. STUK rejected Posiva's NWM programme and accepted the new programme only after Posiva had provided a supplement. Yet, STUK underlined that the new NWM 2012 programme would once again be evaluated as part of the CLA review. The consensus and shared understanding achieved in earlier phases of interaction seemed to vanish in the pre-CLA and official CLA review processes.

Along with the regulatory culture, interesting questions concern the regulatory object. The study indicated that from 2003 to 2006 STUK's main regulatory object was the R&D process and the studies related to the advancement of the disposal project, whereas from 2009 to 2012, due to the approaching licencing procedure, STUK shifted its focus towards a broader understanding of safety. These two issues are of course connected, but during the regulation process the emphasis seemed to change.

Both Posiva and STUK state that the DiP ratified by Parliament in 2001 consolidated the dominance of the scientific-technical approach over socioeconomic evaluation. Both parties adhered to the view that the DiP closed the gates to political intervention, legitimating fiduciary regulation, with a few patrons obliged to make the 'common good' the guiding principle in their actions, and excluding public involvement (see Renn 2008, p. 358-361). A small number of company and regulatory directors were de facto given the freedom to define what was meant by the 'common good' or 'the good of the society'.

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STUK (2010b) Olkiluodon ja Loviisan voimalaitosten ydinjätehuollon tutkimus ja kehitystyön sekä teknisen suunnittelun ohjelma 2010–2012. [STUK’s statement on Posiva’s RTD-2009: “Nuclear Waste Management at Olkiluoto and Loviisa Power Plants Review of Current Status and Future Plans for 2010–2012”]

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[1] This article is based on the research group’s earlier publications (Nurmi et al. 2012; Litmanen et al. 2013; Litmanen et al. 2014) produced during the research programme International Socio-Technical Challenges for Implementing Geological Disposal (InSOTEC; see www.insotec.eu). The research programme was funded by the Seventh Framework Programme Theme [Fission-2010-1.1.2] [Research activities in support of implementation of geological disposal] (Grant agreement no: 269906). Particularly the research report on dyadic risk dialogue over copper corrosion (Litmanen et al. 2014) is utilised in the empirical sections of the article.

[2] In this paper we understand socioeconomic from a sociological perspective. Many authors have pointed out that there aren’t any uniform or consensual understandings of the term socioeconomic. The term has been used as an umbrella term for diverse and sometimes even antagonistic approaches. In his theoretical analysis Hellmich (2015) distinguishes two main trends of so-called socioeconomic research. According to him the first faction can be called economically oriented socioeconomics and the other can be labelled as more sociologically oriented socioeconomics. The first one has formed on the basis of its controversy with neoclassical economics and rational choice theory and the second draws its inspiration primarily from the intention to understand economic life as part of social life (Hellmich 2015, p. 2-4). This later is also how Etzioni (1991) and Swedberg (1995) see socioeconomics. They both emphasise that the economy is only a sub-system in the larger societal context and that socioeconomics refers to a general view of the economic process, which can ultimately be understood as an expression of an interaction between economic and social elements.

[3] In some cases the terms evaluation and valuation can be used interchangeably, because the meanings can overlap somewhat. With the term evaluation we refer more to the idea of institutionally regulated, rather careful, efforts at assessing the value of something or at assessing the consequences of some action. We also apply the terms ex-post and ex-ante evaluation, where the former refers to evaluation of completed activities and the later to anticipation and prediction of coming or ongoing activities. The term valuation is used to refer more to the societal or collective acts or processes of making value judgments about something or assigning the value of something.

[4] The legislation regarding nuclear activities in Finland includes three main instruments: 1) the Nuclear Energy Act 1987 (990/1987), 2) the Radiation Protection Act 1991 (592/1991) and 3) the Nuclear Liability Act 1972 (484/1972 & 588/1994) (OECD 2008). However, the legislation concerning nuclear energy was updated in 2008.

As part of the legislative reform, a number of the relevant Government Decisions were replaced with Government Decrees (GD). The Decrees entered into force on 1 December 2008. The Government Decision (478/1999) regarding the safety of the disposal of spent nuclear fuel, which particularly applied to the disposal facility, was replaced by the Government Decree 736/2008, issued on 27 November 2008 (Posiva 2012a, p. 15).

[5] These YVL regulatory guides are issued by STUK. The STUK mandate to issue detailed technical and administrative guidance is rooted in the Nuclear Energy Act.

[6] Posiva is obliged to prepare triennial programmes for research, development and technical design (RTD), which STUK must review. STUK must also publish an expert evaluation of the programme report. However, before it became obligatory, Posiva compiled the 2003 RTD voluntarily.

[7] For major nuclear facilities, including spent fuel storages and disposal facilities, the nuclear legislation defines a three-step authorisation process: 1) Decision-in-Principle: the Government makes the licencing decision, prior approval by the host municipality and ratification by Parliament are required; 2) Construction licence, issued by the Government, 3) Operating licence, issued by the Government. STUK is obliged to conduct the safety review in each of these licencing processes and the MEE prepares the licencing decisions.

[8] The example NEA gives is the reply STUK's former Director General Jukka Laaksonen gave to a question concerning the knowledge base of their review of the Decision-in-Principle (DiP) for the deep geological disposal project of radioactive waste. Laaksonen's pragmatic response was to point out that in the DiP stage, no definitive conclusion on the safety of the proposed disposal concept was required. Only a preliminary safety appraisal was needed stating that nothing had been found that would raise doubts about the feasibility of achieving the required safety level (NEA 2003, p. 12-13).

[9] In concrete terms the learning approach would mean 1) charting the network and its boundaries, 2) defining the accountability structures, 3) clarifying the goals and objectives of the network and, 4) exploring the role of evaluation and the evaluator in project governance (Lehtonen 2014a, p. 287).

[10] In a narrow sense socioeconomic expectations and evaluations are related to each project's life-cycle. The initial design lifespan of a nuclear power plant (NPP) is usually 30 to 40 years. Purely economic evaluation means financial depreciation of the investment in the plant and also the revenues and incomes returned by investments during the initial lifespan. Usually socioeconomic evaluation in the planning phase also includes indirect economic benefits in the local, regional and even in the national economy, but in the evaluation the actors should also focus on the expected impacts on socio-cultural factors such as quality of life, lifestyles and values. However, the long-term hazards from the radiotoxicity of the spent fuel extend the timescales to tens of thousands and even hundreds of thousands years. This risk of radiotoxicity requires isolation from the biosphere and produces huge problems with socioeconomic evaluation. The dilemma is how to anticipate such distant futures and assess socioeconomic impacts in a future which cannot imagined?

[11] The Finnish Nuclear Energy Act (990/1987, §) defines a three-step authorisation process consisting of 1) Decision-in-Principle (DiP) issued by the Government and ratified by Parliament, 2) the construction licence issued by the Government, and 3) the operating licence, also issued by the Government. As part of the procedure related to the first milestone, the DiP, which was issued in 2000, the Radiation and Nuclear Safety Authority (STUK) made a preliminary safety appraisal (Ruokola 2000). According to the Finnish timetable for nuclear waste management (originally set out in the Government's policy decision of 1983), the nuclear waste company Posiva submitted a CLA for a final repository for spent nuclear fuel (SNF), including a safety case, at the end of 2012 (cf. Posiva 2010c; Posiva 2012a, 2012b; Posiva 2013). The construction licence for a final disposal facility of spent nuclear fuel was granted in November 2015. Before that STUK conducted a safety appraisal of Posiva's CLA's safety case, as part of the procedure leading to the construction licence. According to the Nuclear Energy Act (990/1987, §55) STUK is responsible for the supervision of safe use of nuclear energy, and it participates in the processing of licence and operation applications.

[12] Indeed, in the Finnish legislation regulating nuclear power there is a general socioeconomic assessment principle. The Nuclear Energy Act (1987/990) defines clearly already in Section 1 that the objective is "To keep the use of nuclear energy in line with the overall good of society…" The crucial socioeconomic evaluation question of nuclear megaprojects in Finland tends to crystallise in the question: "Is this project in line with the overall good of society?"

[13] Within environmental impact assessment (EIA) socioeconomic impact assessment (SEIA) can have a formal status and standardised procedures. For instance the Mackenzie Valley Environmental Impact Review Board has defined that 'SEIA is the systematic analysis used during EIA to identify and evaluate the potential socio-economic and cultural impacts of a proposed development on the lives and circumstances of people, their families and their communities' (Mackenzie Valley 2007, p. 6). The impacts can be defined as potential changes caused by industrial development activities (Mackenzie Valley 2007, p. 6) or policy action (Michigan Sea Grant 2009, 23).

[14] STUK is obliged to control the safety of nuclear facilities in Finland. This control has two dimensions: 1) the evaluation of plans and analyses pertaining to the plant, and 2) the inspection of plant structures, systems and components as well as that of operational activity.

[15] STUK's former director Tero Varjoranta has described the importance of this DiP by saying that in the eyes of STUK, the DiP gave Posiva the additional dimension of a construction organisation, while its earlier role had been limited to research and development (Nikula et al 2012, p. 73).

[16] Dyadic risk dialogue is seen here as an interactional communicative co-construction, where 1) central institutional risk governance organisations define safety priorities, negotiate agendas for scientific-technological research programmes and advance a socio-technical project set out in official political decision-making, 2) the importance, relevance, sufficiency and validity of scientific research on the safety of SNF disposal plans are negotiated and co-produced, 3) certain aspects of scientific findings or technological risks are accentuated and others downplayed in order to gain the support of target stakeholders, convince the decision-makers, fulfil the priority set in advance for the overall project and reach governmental permission to implement the plans (Dewulf et al. 2004; 2009; Fairman et al. 2012; Risley 2011). Although there is a tendency to involve many stakeholders in risk-related decision-making, we share the view of those researchers who argue that the institutionalisation of risk governance has given risk professionals and expert organisations a powerful role in risk regulation (Renn 2008, p. 203-204; Beck 1992; OECD 2002). In many cases powerful expert organisations have significant power to frame issues and to conceptualise debates (Dewulf et al. 2009, p. 166). However, risk communication is not free of constraints, because it takes place within given institutional settings (Renn 2008, 215-217) and sociocultural contexts (Kasperson et al. 1988; Kasperson et al. 2001).

[17] The MEE decides on the principles and sets the timetables that the power companies follow. Construction permits and operating licences for nuclear facilities in Finland are issued by the Government, and the MEE receives applications and prepares decisions for the Government. This involves collecting and summarising the statements and views on the application, preparing the licence text with appropriate conditions, and presenting the case to the Government for decision. A prerequisite for any licence is safety (Laaksonen 2006, p. 50).

[18] The final disposal of SNF in Finland is based on the Swedish KBS-3 concept. The basic concept for the disposal of SNF rests on its encapsulation and emplacement in crystalline rock at a depth of about 500 m. Spent nuclear fuel is to be encapsulated in spheroidal graphite cast iron canisters that will have an outer shield made of copper. The surface of the canisters is to be protected by a clay buffer isolating it from the rock. The canisters are to be placed in individual deposition holes in deposition tunnels. Tunnels are to be backfilled with materials of low permeability and closed.

[19] The disposal concept proposed in the DiP application has been the focus of research and development work conducted in Finland over the past thirty years. The target schedule and the objectives were originally defined in the Government Decision of 1983: 1) Interim progress reporting in 1985 and 1992; 2) Preparedness for the selection of a disposal site by the end of 2000; 3) Preparedness for the construction licence application by the end of 2010; 4) Preparedness for the commencement of disposal operations as of 2020 (Ruokola 2000, p. 9).

[20] SKB and Posiva have also sought to jointly promote pan-European cooperation in the field of geological disposal. The technology platform "Implementing Geological Disposal" was established for enhancing the cooperation.

[21] The reason for focusing on the period 2003-2012 rests on two facts: 1) in 2003 the Ministry of Trade and Industry (MTI, nowadays MEE) decided to postpone the deadline for Posiva's construction licence application to the end of 2012 because it was expected that the timetable would be too tight for Posiva and, 2) in 2003 Posiva started to publish triennial RTD-programmes instead of annual reporting to the supervising ministry

TMI. According to the Nuclear Energy Act 1987 (990/1987) and the Nuclear Energy Decree, which regulate the nuclear waste management of Finnish nuclear power plants, the owners of NPP have to report at regular intervals to the TMI/ MEE how the companies in charge of SNF have planned to implement the nuclear waste management actions and its preparations. According to the Nuclear Energy Act Posiva was obliged to submit these reports yearly to the TMI/ MEE, but changes in the law in 2009 formalized the practice of Posiva and MEE starting from the year 2003. The MEE had given Posiva an opportunity to report on their research, planning and technical design every three years instead of annually.

[22] In Finnish YJH-2012 stands for 'Olkiluodon ja Loviisan voimalaitosten ydinjätehuollon ohjelma vuosille 2013–2015'. In English 'Nuclear Waste Management at Olkiluoto and Loviisa Power Plants: Review of Current Status and Future Plans for 2013-2015'. (NWM-2012; Posiva 2012c)

[23] The name of the triennial programme changed to the NWM programme following the amendment of the Nuclear Energy Act that entered into force in 2009.

[24] STUK's archive record numbers: 5/H48112/2009 tks2009 lausunto; Y811/123 tks2006 lausunto; Y811/43 tks2003 lausunto.

[25] As Heinonen et al. (2014) explain, the MEE required Posiva to submit preliminary (draft) licence documentation by the end of 2009. It is not known what originally triggered this improvisation in the official timetable, but STUK noted that the reasoning was 1) to have a regulatory review of the status of the construction licence application, 2) to use it as an exercise for the actual licence application review and 3) to test the review process, review organisation and assessment of preliminary safety case status (Heinonen et al. 2014, p. 3).

[26] STUK gave its statement regarding Posiva's construction licence application and safety case on the 11th of February 2015. It stated that 'The Olkiluoto encapsulation plant and disposal facility proposed by Posiva has been designed in such a way that the requirements on the nuclear and radiation safety during the operation of the facilities are fulfilled.' One of the tasks of STUK was to evaluate whether Posiva has the competence and expertise for the construction of the facility. STUK concluded that Posiva has a sufficient and extensive expertise available for constructing a nuclear waste facility, but it was more concerned about society's ability to maintain enough societal infrastructures and services for the safe use of nuclear energy. The Finnish government granted a construction licence to Posiva for a used nuclear fuel encapsulation plant and final disposal facility at Olkiluoto on the 12th of November 2015.