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Socio-technical risk governance through dyadic risk dialogue:

Copper corrosion as a safety challenge in the geological disposal of spent nuclear fuel

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Socio-technical risk governance through dyadic risk dialogue:

Copper corrosion as a safety challenge in the geological disposal of spent nuclear fuel

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Contents

Glossary

CLA	Construction Licence Application (in accordance with the Nuclear Energy Act), which Posiva submitted in December 2012
DiP	Decision-in-Principle (in accordance with the Nuclear Energy Act)
Fennovoima	Power company established in 2007. It plans to build a new NPP unit at Pyhäjoki, Finland.
FPH	Fortum Power and Heat Fortum Power and Heat Ltd (formerly IVO), part of Fortum Consortium, the State of Finland is the biggest shareholder of Fortum with an over 50 per cent holding. Fortum Power and Heat operates the NPP at Loviisa and owns 25,8 per cent of TVO
GD	Government Decree
IAEA	International Atomic Energy Agency
IVO	Imatran Voima Ltd, 100 per cent state-owned power company established in 1932. Known as Fortum Power and Heat since 1998
KBS-3	Kärn bränsle säkerhet (nuclear fuel safety), Swedish concept for final disposal of spent nuclear fuel. Number 3 indicates that this is the third conceptual description of the repository system drawn up by SKB since 1976
KBS-3H	KBS-3H and KBS-3V are the two design alternatives of the KBS-3 spent fuel disposal method. KBS-3H is the horizontal deposition alternative for vertical reference design
KBS-3V	KBS-3H and KBS-3V are the two design alternatives of the KBS-3 spent fuel disposal method. KBS-3V is vertical deposition alternative, which is the reference design
MEE	Ministry of Employment and the Economy (formerly the Ministry of Trade and Industry)
MTI	Ministry of Trade and Industry
NEA	Nuclear Energy Agency
NH_4	Ammonium, chemical name
NWM	Nuclear Waste Management
NWM-2012	Nuclear Waste Management at Olkiluoto and Loviisa Power Plants: Review of Current Status and Future Plans for 2013-2015 (Posiva’s Nuclear waste management programme 2012. In Finnish: YJH-2012 – Olkiluodon ja Loviisan voimalaitosten ydinjätehuollon ohjelma vuosille 2013–2015

NPP	Nuclear Power Plant
OL1-4	Nuclear power plant units at Olkiluoto in Eurajoki, OL1-2 are in operation, OL3 is under construction and OL4 in planning
ONKALO	Posiva's underground rock characterisation facility
PASS	Project on Alternative System Studies
pH	Stand for "power of hydrogen", it is a measure of the molar concentration of hydrogen ions in the solution and a measure of the acidity
Posiva	Nuclear waste management company owned by Teollisuuden Voima (60 per cent) and Fortum Power and Heat (40 per cent), established in 1995
Pre-CLA	pre-construction licence application, which was required from Posiva in 2009 before the official CLA in 2012
R&A	Review and Assessment
R&D	Research and Development
RTD	Research, Development and Technical Design
SKB	Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Company
SKBF	Swedish Nuclear Fuel Supply Company
SNF	Spent Nuclear Fuel
STUK	Finnish Radiation and Nuclear Safety Authority
TVO	Teollisuuden Voima Ltd, operates the NPP at Olkiluoto site in Eurajoki
VLJ	Voimalaitosjäte, NPP's low and intermediate level waste
VTT	Technical Research Centre of Finland
Weichselian-R	Climate Evolution Scenario
YJH-2012	Olkiluodon ja Loviisan voimalaitosten ydinjätehuollon ohjelma vuosille 2013–2015 (Nuclear Waste Management at Olkiluoto and Loviisa Power Plants: Review of Current Status and Future Plans for 2013-2015; Posiva's NWM 2012 – Nuclear waste management programme 2012)
YJT	Nuclear Waste Commission of the Finnish Power Companies

Abstract

The risk of corrosion in oxygen-free water has become an issue of scientific controversy possibly even threatening the realisation of the final disposal of spent nuclear fuel in Finland and Sweden. In Sweden there has been extensive discussion about the issue since 2007, but only recently has this debate increased in Finland although the similar disposal concept (KBS-3) is applied in both countries. In this report, we analyse how the implementer, Posiva (a Finnish nuclear waste company), and the regulator, STUK (the Finnish Radiation and Nuclear Safety Authority), have been engaged in a dialogue on the risk of copper corrosion. For over thirty years the implementer and regulator have been engaged in a series of negotiations on the advancement of research, planning and technical design related to SNF disposal. The aim here is to determine 1) how the implementer, Posiva Oy, has presented the issue of copper corrosion and copper corrosion related research, 2) how the regulator, STUK, has assessed and reacted to what Posiva has presented and 3) what the long-standing risk dialogue tells about the transformation of the Finnish regulatory culture and relationship of the parties. Moreover, the study discusses the importance of risk dialogue at different stages of the risk governance processes and how the risk dialogue transforms the roles of the parties. The insight into the risk dialogue between Posiva and STUK was gained by examining core documents regarding this interaction, namely the Research, Development and Technical Design (RTD) review process and the construction licence application (CLA) review process. From Posiva's side RTD programmes published in 2003, 2006 and 2009 and their successor, the Nuclear Waste Management (NWM) programme published in 2012 were studied. When examining STUK, we analysed the statements by the regulator to the Ministry of Employment and Economy (MEE) on the basis of Posiva's reports. Posiva's pre-licence construction application (pre-CLA) in autumn 2009 and STUK's review of it were also included in the analysis. As the STUK's review of Posiva's construction licence application, submitted in 2012, is still under way, only Posiva's application has been examined.

Finnish nuclear waste risk governance is characterized by a strong role of central actors, STUK and Posiva with little or no opportunity for public participation. The Finnish regulatory culture is deemed flexible, development oriented and, as such, oriented towards gradual learning and refinement. The results of the risk dialogue study suggest that Posiva's reporting evolved from merely presenting a situation, to more focused and extensive discussions. The investigation of the dialogue showed that STUK exercised its right to demand further information, while the implementer, Posiva, was compelled to comply with the requirements. Nevertheless, the organisations appeared to operate consensually, meaning that they both pursue the successful development of a safe repository for SNF, indicating rapprochement and transformation of clear-cut roles. However, the results show that under the normal steady flow of interaction, risk governance process is oriented towards mutual learning and improvement, but at the time of crucial decision-making extra tensions come into relationship. In the ideal cases the roles of implementer and regulator should be clear-cut, but the study of long-standing interaction indicates that the engagement in dialogue has transformed STUK's role in the direction of development-orientation. Thus shifting STUK's input to the advancement of the project gives it a sort of consultative role, while at the time of crucial decision-making the role of regulator is strengthened.

Keywords: Risk governance, regulation, nuclear waste disposal, copper corrosion

1 Introduction

The risk of corrosion in oxygen-free water has become an issue of scientific controversy possibly threatening even the realisation of the final disposal of spent nuclear fuel (SNF) (Andersson 2014, 2; Wallace 2010). In Sweden there has been extensive discussion about the issue since 2007 (Andersson 2014; SNCNW 2013), but only recently has this debate increased 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 are also more discussions regarding other types of corrosion related to these canisters. The theme of copper corrosion has a long scientific history in the Swedish KBS-3 method (King et al., 2002: 137). These canisters, containing SNF, will be surrounded by bentonite clay at a depth of approximately 500 metres in the bedrock. The current scientific assumption is that that copper corrodes at an extremely slow rate in such an environment and oxygen free corrosion does not happen (see e.g. King 2010; Posiva 2013, 434-436). However, as Andersson (2014) has indicated, this assumption has been challenged by experimental results of researchers working at the Royal Institute of Technology in Sweden. The researchers are suggesting that copper could corrode in an oxygen-free environment by taking oxygen from water molecules. This continuation of general corrosion could mean that the canister would not withstand the final disposal conditions for a 100,000-year lifetime, if the thickness of copper were five centimetres as planned (Hultquist, 1986; Szakálos et al. 2007).

In this report, we analyse how the implementer, Posiva (a Finnish nuclear waste company), and the regulator, STUK (the Finnish Radiation and Nuclear Safety Authority), have dealt with the issue of copper corrosion in general. We look at the dyadic risk communication between these two organisations regarding copper corrosion related issues as they negotiate risks. The study design resembles Wärnbäck's (2012) extensive analysis of expert dialogue between the Swedish Nuclear Waste company, SKB, regulatory authorities and the Government. She studied the long lasting interaction and engagement between the parties with special focus on the production of the industry's research programmes and the authorities' official statements of opinions on these programmes. As in Sweden (Wärnbäck 2012; Wärnbäck et al. 2013), in Finland, too, the implementer and regulators have been engaged in a series of conversations on the advancement of research, planning and technical design related to SNF disposal. Even though the Ministry of Employment and the Economy (MEE) has the general regulatory power in the disposal of SNF waste[1], the study of dyadic interaction between STUK and Posiva is important, because these two organisations negotiate SNF disposal risks and are tied together by legislation (see section 3).

The structure of the report is as follows: first we discuss risk dialogue as a part of risk-related decision-making, then we move to describe the Finnish regulatory culture in its institutional settings before reporting on methodological choices and formulating the research questions. The main empirical findings are presented in four sections covering each of the phases of risk dialogue studied. The final section of the paper discusses the findings and draws conclusions.

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[1] MEE decides on the principles and creates timetables which must be followed by the power companies. 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, 50)

2 Risk dialogue as part of risk-related decision-making

In this study we are interested in risk dialogue as a fundamental part of risk-related decision-making. Risk-related decision-making can be characterized as a question of addressing complex cause-effect relationships and trade-offs in trying to reach commonly acceptable agreement together with different involved parties (Renn 2008: 275-284; Gregory et al., 1995; Amendola, 2001; OECD, 2002; Fahlbruch et al., 2006). While the mainstream risk communication literature focuses on how expert organisations communicate risks to stakeholders (Irwin 2008; Bucchi & Trench 2008), the aim of the study is to enhance the understanding regarding the socio-technical nature of risk governance and how the definition of risk and safety takes place in dialogue structured by risk regulation. Therefore the exchange of information between experts and expert organisations is central to risk assessment and management. Previously the role of cooperation among experts and policy-makers was underestimated, but now it is clearly understood to be an important prerequisite for risk governance and being at the heart of regulatory cultures (Renn 2008: 202-203; Wärnbäck 2012). What makes risk related decision making particularly interesting socio-technical process is that it depends not only upon systematic scientific knowledge, but also upon legally prescribed procedures and social values. (Renn 2008: 358-361)

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 to reach governmental permission to implement the plans. (Dewulf et al., 2004; 2009; Fairman et al. 2012; Risley 2011)

In spite of the fact that the conceptualisation of the term 'risk' varies depending on the discipline and the approach (Slovic, 1999; Althaus, 2005; Breakwell, 2007; Renn, 2008; Zinn, 2008), the regulatory authorities in different countries have to manage and regulate nuclear waste risks irrespective of the difficulties (Sjöberg, 2000; 2002; Elam et al. 2010, 8-9; Vuorinen 2008, 678-679; OECD 2003, 9-10). Although there is a tendency to involve many stakeholders in risk-related decision-making, we share the view of some researchers who emphasize that the institutionalisation of risk governance has led to risk professionals and expert organisations being given a powerful role in risk regulation (Renn, 2008: 203-204; Beck, 1992; OECD, 2002). In many cases powerful expert organisations have significant power to frame issues and conceptualise debates (Dewulf et al., 2009: 166). However, one must see that risk communication is not free of constraints, because it takes place within certain institutional settings (Renn 2008, 215-217) and sociocultural contexts. (Kasperson et al. 1988; Kasperson et al. 2001)

For us risk communication is either a two-way or a multidimensional process, meaning that it can also be seen as an interactive risk dialogue between the parties involved (Golding, 1994; Breakwell, 2000; Palenchar, 2005; Breakwell, 2007; Palenchar and Heath, 2007; Venables et al., 2009; Sellnow and Sellnow, 2010). Thus risk definitions, regularly perceived as purely technical issues, are truly dynamic socio-technical processes, where information and knowledge are produced, communicated and processed among individuals, social groups and organisations regarding risks to health, safety and environment. (Breakwell, 2000: 110-111; Irwin 2008; OECD, 2002; Sellnow and Sellnow, 2010)

3 Development oriented regulatory culture in institutional settings

Four regulatory cultures have been distinguished in the literature: 1) the adversarial approach is characterized by an open forum for different actors to compete for social and political influence in the respective policy arena and stakeholder involvement is seen to be mandatory, 2) the fiduciary approach resembles the decision-making process, where a group of patrons are obliged to make the 'common good' the guiding principle in their action and public involvement is almost entirely excluded, e.g., in issues related to policy formulation or important negotiations, 3) the consensual approach is based more on a closed circle of influential actors negotiating behind closed doors and stakeholder participation is only required to the extent that the group needs further insights from the affected groups or that the composition of the group is challenged and 4) the corporatist approach comes close to a consensual approach, but is far more formalized in the sense of the representation of major forces of society. (Renn 2008, 358-361)

These regulatory styles are difficult to find in absolutely pure forms in the countries studied. For instance, the Finnish regulatory culture in the case of nuclear regulation is a mixture of fiduciary and consensual approaches, because of the prominent role of the central actors, STUK, the nuclear industry and the MEE, and little or no opportunity for public participation. Due to a stepwise decision-making and implementation process, the regulatory process is stepwise. In practice, this means that the Finnish regulatory culture is flexible, development oriented and, as such, oriented towards gradual learning and refinement. As NEA has described, this kind of process facilitates the development of regulations in a gradual way, starting from very general principles and ending with the guidance applicable to a licencing review. In this way the job of regulating is intrinsically one of gradual learning and refinement (NEA 2003, 12). This Finnish model of "informal" dialogue between implementer and regulators is seen to require 1) strong social trust in the regulatory authorities, 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 regulatory philosophy of gradual learning is characterised by saying that it provides more opportunity for a constructive dialogue between regulator and implementer, which can be beneficial for the development of technical procedures, but also leaves room for interpretations and control by the authorities (NEA 2003, 12-13; see also Laaksonen 2006, 59-60.) The example NEA gives is the reply STUK's former Director General Laaksonen gave when he was asked about the knowledge base of their review of the Decision-in-Principle (DiP). 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, 12-13). Laaksonen (2006) himself has described the interaction and communication with the licencees as being open and easy. The parties can make informal direct contacts any time in case of confusion, differences in views or urgent needs. If a regulatory decision is intended to be different from the one proposed by the licencee, the licencee is always contacted and granted an opportunity to present comments or further arguments before a formal decision is made. Laaksonen emphasises that in regular meetings, arranged several times a year, even small concerns can be raised and discussed in an informal manner with the licencees. (Laaksonen 2006, 59-60.) Laaksonen (2007, 4) has also emphasised the regulators' need for an independent safety assessment capability, i.e. research, to assure both themselves and the general public on the safety of the disposal concept. R&D for nuclear waste management in Finland is the responsibility of the licencees. As the regulator STUK has access to research and STUK is vested with some power to influence the preparation of public R&D. Therefore, according to Laaksonen "the need and importance of nationally coordinated research is not as big as in the area of nuclear power plant safety".

However, Posiva's and STUK's risk dialogue takes place in legally and institutionally defined settings. In accordance with the Finnish Nuclear Energy Act (990/1987)[2], 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[3], 4) STUK conducts the safety review in each of the licensing processes[4], 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 direct 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)

STUK's regulation is constrained by two powerful decisions. Firstly, the Nuclear Energy Act establishes the principle that all nuclear waste which has been generated in Finland must be handled, stored and finally disposed of in Finland. Secondly, the Government has made and Parliament ratified a decision-in-principle according to which the spent fuel produced by the NPP units shall be disposed of in Olkiluoto, Eurajoki. STUK's former director Tero Varjoranta has described the importance of DiP by saying that in the eyes of STUK Posiva's DiP in 2001 made the company also a construction organisation besides its earlier role as a research and development organisation. (Nikula et al, 2012, 73)

In addition to this, STUK and Posiva both interpreted that the political part of the licencing ended when the Finnish Parliament ratified the DiP in 2001 (Äikäs 2013; Isaksson 2007). The DiP is seen as Governments answer to the main political question: is the proposed build nuclear facility in line with the overall good of the society? According to Isaksson, Information Officer of STUK, (2007, 177) after ratification the processes directing towards construction permit and operating licence are more or less technical, i.e. not (so) political in nature. Posiva has also emphasized the importance of political consideration and decision in an early phase of the licensing process and thus indicating the

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[2] 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) (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, 15)

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

[4] For major nuclear facilities, including spent fuel storages and disposal facilities, the nuclear legislation defines a three-step authorization 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.

commitment of society (Äikäs and Sundell, 2014, 8–9). Therefore both STUK and Posiva seem to support a clear division between the ‘technical’ and the ‘political’. As a result the licencing procedure is framed as a forum for technical expertise and therefore it can be characterized by presenting Renn’s two approaches: fiduciary and consensual. (Renn 2008, 359)

This institutionally defined, decades long risk communication between the implementer and STUK has created a special relationship between the parties. Although this study traces dialogue from formal, legally regulated, interaction, informal interaction, which is difficult to trace and document, also deserves attention. This informal communication between the parties is significant as it creates interactional culture and some sense of togetherness. In general one can say that STUK has to balance between three sometimes conflicting roles in its regulatory tasks. STUK has a 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, 188)

Wärnbäck et al. (2013) shed light on the development of a regulatory culture and the conflicting roles of the regulatory authority in Swedish nuclear waste management. Investigators state that the long-term shared experience and learning among government bodies and implementer have led to a convergence of perspective, narrowing options and potentially reinforcing implementer’s influence and power over policy. As Wärnbäck et al. (2013, 2214) state, besides convergence of the actors’ perspective another important question is the changing of roles. In Sweden the competent authorities that had been an integral part of this planning process, in their roles as interlocutory partners and as the formal reviewers of SKB’s research, became formal reviewers of the application when it was submitted (Wärnbäck et al., 2013, 2213–14). The researchers note that the disposal project began in 1973 as a joint concern for the state and the industry. However, pressure on the industry to introduce the solution alone was increased in 1977 when the Stipulations Act (SFS, 1977) came into force. One aim of the Act was that “the state should maintain a position outside the nuclear fuel safety (KBS) project in order to be able to pass independent judgment upon it”. (Wärnbäck et al, 2013, 2213-14; see also Elam and Sundqvist, 2009, 973)

The Finnish regulatory framework and the relationship between the implementer and the safety authority are somewhat similar to those of Sweden. There are also differences – mostly of historical origin – between the countries in nuclear safety practices (Wahlström, 1999). In Finland the main actors have had close dialogue before the regulatory review of the CLA (Construction licence application) began (See Figure 1). Still, in the Finnish context responsibility and the nuclear waste management obligation of a licencee are perhaps more commonly used as an argument for the existing regulatory approach than the independence of the state in the review process. Wärnbäck et al. (2013, 2214) raise the question of clear roles and responsibilities for actors. They claim that a “clear separation of responsibilities between the implementer and the regulator is also a cornerstone of the Swedish legislation on nuclear waste management” (Wärnbäck et al., 2013, 2214). Clear roles and separation of responsibilities have also been deemed one key factor for success of the plan to dispose of SNF in Finland. For instance Äikäs and Sundell (2014, 8; see also Rasilainen, 2002, 9–10) note that *“Finland has managed to build a system with clear responsibilities for nuclear waste management”.* Furthermore they conclude that:

> *“The success of ONKALO was based on a systematic long-term programme in which site selection research received an emphasis. (…) During its course the programme has been guided by a “do and see” strategy which has made possible the flexibility in the consideration, based on science and technology, between the alternatives for SNF management.”*

This seems to indicate how the waste management company enjoyed its responsibility and flexibility as an implementer without any complaints about too strict regulation.

Another factor affecting the regulatory culture is interaction with each other. We share the notion of Wärnbäck et al. (2013) that close cooperation over a long period of time might thus 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 they have been claimed to be. For instance, Posiva's preliminary (draft) licence documentation (submitted in 2009) which was required by the MEE was perceived as an exercise for the actual licence application review by STUK (Heinonen et al. 2014, 3). In general, the aim of the exercise was to improve the actual performance, which refers to the idea of learning and reflection with the aim of potential transformation of regulatory approach or some aspects of it.

A similar aim of learning characterises the description of the dialogue process in general. According to Heinonen et al. (2014, 3–4):

> *"The aim of the step-wise review, close follow-up and regular meeting with Posiva has been to identify the safety relevant issues and especially key safety concerns already before Posiva finalizes and submits the construction licence application. During the licence application preparatory phase STUK had a process for collecting and updating the position of key safety concerns with regular dialogue between STUK and Posiva. However, after a while it was acknowledged that addressing single safety concerns did not in many cases lead to a better overall understanding and sometimes the linkage to safety was not very clear. From this experience [there was] a need for more structured R&A [review and assessment] process."*

The time of crucial decision-making is at hand. 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[5], at the end of 2012[6] (cf. Posiva 2010c; Posiva 2012a, 2012b; Posiva 2013). From the perspective of the licencing procedure of nuclear facilities, the nuclear waste management project has reached the second of its three milestones. The Finnish Nuclear Energy Act (990/1987, §) defines a three-step

[5] Theoretically Posiva applies IAEA's and NEA's definition of safety case. It says that "A safety case is a synthesis of evidence, analyses and arguments that quantify and substantiate the safety, and the level of expert confidence in the safety, of a geological disposal facility for radioactive waste" (Posiva, 2008: 3). In concrete terms, the safety case consists of several complementary reports, which cover topics related to long-term safety, such as developments at the final disposal site and in the repository as well as changes that could occurring in the biotic environment thousands of years into the future. According to Posiva (2008), the reference period for the safety analyses spans some 250,000 years, which means that it also includes at least one ice age cycle. However, in their safety case there are also investigations which cover the next million years. (e.g., Posiva 2013: 399)

[6] Posiva submitted the Decision in Principle (DiP) in May 1999. In May 2001, the Finnish Parliament ratified the DiP made by the government concerning a spent nuclear fuel disposal facility in Olkiluoto in the Eurajoki municipality. Two crucially important requirements for the acceptance were positive statements on the DiP application that had to be made by the Radiation and Nuclear Safety Authority (STUK) (Ruokola, 2000), and the municipality of Eurajoki. In ratifying the DiP, Parliament stated that the facility was "for the overall good of society" (Yhteiskunnan kokonaisetu todetaan PAPissa jonka tekee hallitus). Posiva emphasises that Finnish decision-makers, on both the local and national level, have approved, in general, not "only the site but also the technical disposal plan suggested in the application". (Rasilainen, 2004: 7)

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). At the present time, STUK is conducting a safety appraisal of Posiva's CLA's safety case, as part of the procedure related to the second milestone of the authorisation process, the construction licence. According to the Nuclear Energy Act (990/1987, §55) STUK is responsible for the supervision of safe use of nuclear energy, is to participate in the processing of licence applications and to provide expertise for other authorities.

RTD work has continued for over 30 years[7], but there are still some uncertainties regarding the KBS-3 concept[8]. As the KBS concept is originally Swedish, Posiva has been cooperating closely with its Swedish counterpart, the Swedish Nuclear Fuel and Waste Management Company (SKB) (Kojo and Oksa, 2014). Because of the similarities in the technical plans and safety cases they have had *"extensive research cooperation covering the whole disposal technology."* (Posiva, 2010a, 12-13)[9]

4 Research questions, data and method of the analysis

The purpose of this study is to investigate dyadic risk communication and the exchange of risk-related information among expert organisations. The case to be studied is the risk dialogue over copper corrosion between Posiva and STUK[10] and how they deal with the challenge presented by it to the geological disposal. The analysis is thus country-specific, highlighting interesting features of the regulatory system of SNF disposal in Finland.

Our aim is to determine 1) how the implementer, Posiva, has presented the issue of copper corrosion and copper corrosion related research in their RTD reports, 2) how the regulator, STUK, has assessed the challenge and reacted to what Posiva has presented, 3) how the risk of copper corrosion is co-

[7] 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: 9)

[8] 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 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.

[9] 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.

[10] STUK (the Radiation and Nuclear Safety Authority – an independent regulatory and research authority) issues its statements on the safety of nuclear facilities, e.g. licencing, to the Ministry of Employment and the Economy. Administratively (e.g. concerning budget matters), STUK is under the Ministry of Social Affairs and Health, which is the administrative authority for the use of radiation, but licence applications for nuclear facilities are handled by the Ministry of Employment and the Economy, which is the administrative authority for the use of nuclear energy. (IAEA, 2002: 37.)

constructed by Posiva and STUK and 4) what the long-standing risk dialogue reveals about the transformation of regulatory culture and relationship of the parties.

The insight into the risk dialogue between Posiva and STUK was gained by examining core documents regarding this interaction, namely the Research, Development and Technical Design (RTD) review process and the construction licence review process. The analysis was made in two stages. In the first stage our focus was on the RTD review process, but as it became obvious that the construction licence review process was an organic, inseparable, part of this dialogue, it was included in the analysis. We are aware that our data is still able to illuminate only a part of a more complex picture of risk dialogue between the actors because we concentrate solely on the official written exchanges of information, but even here we had plenty of material to examine, and any larger study would, this time, have been beyond our scope. We are also aware that both Posiva and STUK have a larger research network behind them as they commission research institutions and consulting companies to carry out the investigations. Therefore, in practice, risk dialogue in the case of copper corrosion is more multidimensional as Posiva and STUK have also risk dialogue with other experts, not just between themselves.

The RTD review process documents examined from Posiva's side are RTD programmes published in 2003[11], 2006 and 2009, and their successor, the Nuclear Waste Management (NWM) programme published in 2012[12]. The idea of the RTD programmes is to inform readers about the progress as well as the management of radioactive waste activities of Posiva for its owners, TVO and FPH. As the focus of the reports relies on the phase of development of the spent nuclear fuel disposal programme, the documents from 2003 to 2009 reflect the steps taken to prepare for the construction licence application and aim at showing the feasibility of the repository (Posiva, 2006: 11). 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. According to Posiva (2012c, Summary, 12):

> *"As the disposal programme for spent nuclear fuel advances to the construction licence phase and the focus of work aimed at final disposal changes from R&D to implementation, it has been deemed appropriate to change the name of the document into a nuclear waste management programme[…]" but it still "follows largely the same lines as its predecessors".*

The CLA review process documents examined are the pre-CLA, the actual CLA and essential parts of Posiva's 2012 Safety case for the disposal of spent nuclear fuel at Olkiluoto.

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[11] 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, 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 already 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 annual reporting.

[12] 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)

When examining STUK[13], we analyse the statements from the regulator to the MEE on the basis of Posiva's reports. Additional material used in the analysis includes the appendices of the statements[14] that give more detailed accounts regarding the issues raised in the statements. In these documents, STUK, together with its experts, evaluates the RTD efforts and preparedness of the company's application material, comments on the planned research, development and technical design of the spent fuel repository system and state of application material, making recommendations regarding the further development.

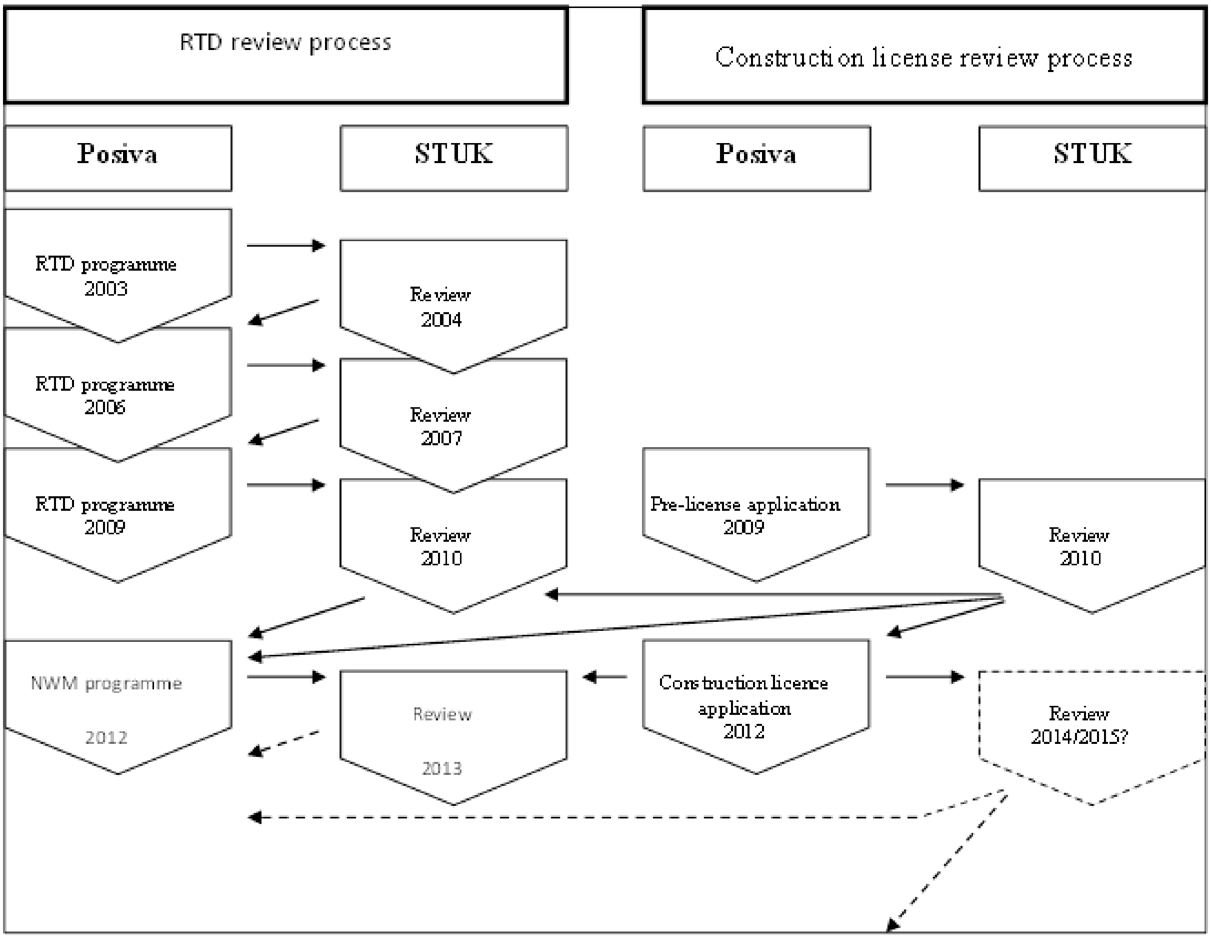
In the first stage, three RTD reports from Posiva and four statements with fifteen appendices on STUK were included in the analysis. In the second stage an NWM report, a pre-CLA with ten appendices, a CLA licence with eight appendices and seven safety case documents from Posiva and three statements with two appendices on STUK were included. The chosen documents were read focussing on the copper corrosion issue. In the data analysis, both copper corrosion and (if not specified) the corrosion issue in general, were taken into account. However, other forms of corrosion that do not relate 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. In order to present the results in a reader-friendly way, we decided to mention just a few examples to illustrate those issues that were discussed and have placed the rest of copper corrosion related information in a table summarising all the results in the timespan covered.

The design of our study rests on a fairly complex scheme (see Figure 1) that follows the sequence of the dialogue between Posiva and STUK. The risk dialogue we have investigated can be divided into two parts: 1) the RTD review process and 2) the CLA review process. The progress of Posiva's RTD on the possibility for an underground nuclear waste repository is influenced by continuous exchanges of information with STUK (illustrated with arrows) as well as the official statements of the authority (illustrated 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 started 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.

[13] 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.

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

Figure 1. The flow of risk dialogue between Posiva and STUK



5 Risk dialogue between Posiva and STUK

5.1 Years 2003 and 2004: Setting the stage

In 2003 and 2004 there were many uncertainties regarding the issue of copper corrosion. Nevertheless, Posiva seemed to stay 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: 2) considered Posiva's RTD report of 2003 as 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. A summary of all copper corrosion related issues that were covered in 2003 and 2004 is presented in Table 1.

Table 1 Summary of the copper corrosion related issues discussed by Posiva and STUK in 2003 and 2004.

Issues Discussed	
Posiva Oy	**STUK**
- Canister holding the spent nuclear fuel for more than 100,000 years - International collaboration while investigating copper corrosion (e.g. the behaviour of copper corrosion in sulphide containing compacted bentonite) - Conducted research on: - general corrosion in oxygen free and saline conditions - localised corrosion (pitting or stress corrosion cracking) - impact of redox conditions - effects of methane - effects of high-pH conditions - Other issues: - grain size of the copper - unlikely microbial impacts - thickness of the copper shell - participation in the international co-operation group "GAMBIT Club" - Aspects that need further research: - evolution of redox conditions - localised corrosion processes - chemical conditions - general corrosion in oxygen free and saline conditions	- Expected lifespan of the canister mitigates numerous concerns - Consideration needed on: - temperature in some designs may produce mineralogical alterations & changes in volume due to corrosion of canisters may exert pressures on buffer and rock - ability of a thinner copper shell to stand corrosion - possible manufacturing defects - groundwater conditions in the bedrock of Olkiluoto - copper corrosion model in sulphide containing compacted bentonite - Clarifications needed on: - formation and expansion of corrosion products and related processes - interactions with canister corrosion products and the possibility of adverse effects on repository safety or reliability - choice to focus on interface kinetic studies on copper corrosion - possibility of localised corrosion due to NH_4 in groundwater - references concerning the effects of pH on corrosion - possible presence of impurities in methane at the site - Aspects that need further research: - creep behaviour of the copper canister - welding equipment and parameters - local corrosion forms - residual stresses - long-term properties of the copper canisters produced by according to different methods - stress corrosion cracking - microbial copper corrosion

Starting from the first RTD report in a new series of these documents, Posiva endeavoured to pave the way for transparent dialogue with relevant parties. According to the organisation (Posiva, 2003: 1, 267), the programme aimed to enhance transparency and enable:

> *"External review and discussion of the objectives, the achievements and the future emphases of the programme to take place. In this way, dialogue should be promoted between the various stakeholders on issues related to the process of disposal system development."*

With respect to the specifications of the canister for the isolation of spent nuclear fuel, Posiva (2003: 36) argued that canister design rests in 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 for spent nuclear fuel isolation. 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 admits the need for further research. (Posiva, 2003: 119)

At the time of the emergence of RTD report 2003, Posiva and SKB together with Canadian partners were engaging in a joint three-year project (2002–2005) focusing on the development of the model enabling the prediction of *"the long-term corrosion behaviour of copper canisters in sulphide containing compacted bentonite".* In addition to this, the company and its Swedish counterpart were concentrating on such experimental and theoretical research as general corrosion in oxygen free and saline conditions, localised corrosion, the impact of redox conditions on corrosion as well as the effects of methane and of high-pH conditions on corrosion. (Posiva, 2003: 119-120)

Some research tackling the above mentioned issues is presented in Posiva's 2003 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 relevant chemical, electrochemical and microbiological processes, is recognised as one more area of uncertainty. (Posiva, 2003: 120-121)

Regarding the effects of methane on corrosion, Posiva argued that, according to the literature reviewed, methane has no negative effect on copper (Posiva, 2003: 121). Finally, with respect to the effects of high-pH conditions on corrosion, Posiva (2003: 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. Posiva (2003: 245-246) promised to address the uncertainties related to copper corrosion in a forthcoming period (and indicated that would be in 2004).

Although Posiva's RTD report in 2003 provided a detailed overview in which the main issues regarding copper corrosion were thoroughly and logically addressed (Read, 2004: 8), STUK and its reviewers made numerous comments, questions and requirements about the need for further research concerning the challenge. In relation to Posiva's estimated lifetime of the canister, Hänninen (2003: 2) highlighted that the isolation of the waste in the canisters for more than 100,000 years as a much longer timespan *"compared to the operation time of any other industrial product",* while Apted et al. (2004: 11) believed that Posiva belittled numerous concerns about the repository. 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 consider all forms of corrosion and other risks. (Hänninen, 2003: 2)

While commenting on copper corrosion, STUK, together with its reviewers, highlighted some aspects that Posiva must take into consideration. For example, Apted (2004: 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: 2) agreed with Posiva that a thinner copper shell would be advantageous, but he also pointed out the need for proof that the shell would withstand corrosion. STUK (2004: 5) pointed out that groundwater conditions were more demanding in the bedrock of Olkiluoto than in the VLJ cave, and this must be kept in mind when interpreting the results of copper corrosion research. Moreover, Read (2004: 9) expressed his full support for the joint Posiva and SKB project, focusing on the development of *"a corrosion model for copper in sulphide media containing compacted bentonite".*

STUK and its reviewers stated that they would require more research on various issues. For instance, Hänninen (2003: 8) and Apted et al. (2004: 11-12) demanded that the representative creep behaviour of the copper canister be tested to avoid canister corrosion. Posiva was also asked to investigate and develop the equipment and welding parameters of the high-energy method to be used for the welding of copper (Hänninen, 2003: 4-6). More precise information was called for regarding local corrosion forms, stress corrosion cracking and microbial copper corrosion (STUK, 2004: 3; Hänninen, 2003: 5-8). For more requirements see Table 1.

5.2 Years 2006 and 2007: Focus on future projections

The discussion of Posiva and STUK expanded during 2006 and 2007 to consider 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 issue of copper corrosion related issues in Posiva's 2006 RTD report naturally 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 conceded the advances in Posiva's knowledge but once again required more information about certain issues related to the corrosion processes. Table 2 summarizes the issues related to the copper corrosion that the target organisations mentioned in their documents during 2006 and 2007.

Table 2 Summary of the copper corrosion issues discussed by Posiva and STUK in 2006 and 2007

Issues discussed	
Posiva Oy	**STUK**

- General and local corrosion extensively studied
- Interrelationship between various forms of corrosion and oxygen-free, saline, chlorine and alkaline conditions as well as the effects of temperature and pH
- Unlikeliness of:
  - stress corrosion cracking
  - emergence of discontinuities in the welded joint that may induce local corrosion and stress corrosion cracking
  - occurrence of sulphate-reducing bacteria contributing to uniform corrosion
- Impacts of foreign materials
- Interactions between cement, its additives and the canister
- Corrosion processes in evolving conditions during repository construction and climate change
- Aspects that need further research:
  - long-term corrosion behaviour of copper in the repository environment
  - microbial induced corrosion
  - corrosion in anoxic and saline conditions as well as compacted sulphide-containing bentonite
  - welding and the potential occurrence of corrosion
  - effects of acetates on corrosion
	- Improvements with respect to reporting and technical development
	- Clarifications needed on:
	  - long-term properties of the canister
	  - risk of canister failure due to creep or stress corrosion
	  - interrelation of groundwater and copper corrosion
	  - copper corrosion caused by sulphate-reducing bacteria
	  - stress corrosion cracking under reducing and oxidising conditions
	- Aspects that need further research:
	  - long-term durability of technical barriers, in particular special attention needs to be paid to the interrelationship between the copper canister and bentonite
	  - processes affecting the corrosion behaviour of copper
	  - biogeochemical inputs of the engineered barrier system that affect copper corrosion
	  - effects of sulphate on redox stability

In the continuing dialogue between the parties, 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 construction licence application was approaching, the focus of this report shifted towards the *"operational and long-term safety of the system"* (Posiva, 2006: 11).

When writing the RTD report for 2006, Posiva collected a substantial amount of knowledge regarding the corrosion of copper. The company (Posiva, 2006: 49) argued that such potential forms of corrosion processes in repository conditions as general and local corrosion were an extensively studied phenomenon, but information was still lacking on microbial induced corrosion. Stress corrosion cracking was deemed an unlikely process because of the small concentration of elements that induce stress corrosion cracking and the remarkably low corrosion potential values (Posiva, 2006: 49, 197). In the report, Posiva (2006, 49-50, 71, 238) also described what it had learnt about the interaction between earlier mentioned forms of copper corrosion (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 foreign materials on copper corrosion were considered in the report (Posiva, 2006: 257). For more comments on copper corrosion see Table 2.

Besides the above mentioned issues, Posiva paid special attention to the changing repository conditions and expected corrosion processes during the planned lifespan of the repository. While dwelling upon possible changes, the organisation took into account both the repository construction phases (e.g. early post-closure, the post-closure saturated phase) and climate change periods relying on the Weichselian-R scenario e.g. permafrost, glacial melting. (Posiva, 2006: 196-201) Despite the lack of clear insight into upcoming changes, the document stated that the investigations carried out into long-term corrosion development support prior conclusions regarding the feasibility of the copper canister concept (Posiva, 2006: 208).

Predictions about the long-term corrosion behaviour of copper in the repository environment are surrounded by numerous uncertainties, thus Posiva (2006: 62) said it would continue to research the issue. In addition, the future RTD efforts of the company were to be directed towards the investigation, for instance, of corrosion in anoxic and saline conditions as well as compacted sulphide-containing bentonite (Posiva, 2006: 50). Also, the company planned to continue studies on welding and the potential for corrosion as well as the effects of acetates (Posiva, 2006: 57-58, 140).

According to STUK (2007a: 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. With reference to the progress of Posiva's nuclear waste disposal programme during the past three years, the authority gave positive feedback on the reporting and technical development but simultaneously identified weaknesses and areas for further investigation.

STUK (2007b: 2) criticised the report for failing to give a clear picture of the research and a lack of evidence concerning the long-term properties of the canister design and argued that the risk of the early failure of the canisters due to creep or stress corrosion had received too little attention in the document. Other uncertainties were related to the interrelation between groundwater and copper corrosion (STUK, 2007b: 4; Bath et al., 2007: 20). Moreover, further explanation was required regarding the worst case scenario for copper corrosion caused by sulphate-reducing bacteria (Read et al., 2007: 30). Finally, Hänninen et al. (2007: 27) noted that there was a lack of information about stress corrosion cracking under reducing and oxidising conditions.

STUK, together with 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 that special attention needed to be paid to the interaction between the copper canister and bentonite. They also stated that the processes affecting the corrosion behaviour of copper also had to be investigated. (STUK, 2007a: 2.) Finally, Bath et al. (2007: 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.

5.3 Years 2009 and 2010: Diffusion of two processes

In 2009 and 2010 Posiva and STUK focused on almost the same themes related to copper corrosion as in earlier documents. This may suggest 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 RTD documents was more extensive than before and paid considerably more attention to comments made by STUK. Moreover, overlapping the RTD programme Posiva, within the same year, produced the pre-CLA material required by the MEE. STUK, finding the pre-CLA material lacking in many ways in its statement, extended this criticism to the RTD programme, also looking at it in the light of its assessment of pre-CLA material. In its statements, STUK demanded a more holistic picture from Posiva and at the same time continued to demand answers to outstanding strictly corrosion related questions before the next milestone – putting together the CLA in 2012. A summary of the issues raised in connection with the risk of copper corrosion is presented in Table 3.

Regarding the strictly copper corrosion related issues being raised, as the pre-licence material[15] and RTD programme were submitted at roughly the same time, there were really no significant differences between the two – and these will be considered in connection with the latter. But what is interesting is that, from STUK's comments, it is 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 concentrating excessively on individual issues. STUK assessed that some 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. (Table 1; STUK, 2010a.)

In the last actual RTD report, Posiva (2010b: 13) dealt with the topic of the disposal of spent nuclear fuel generated by its owners and presented research as well as technical development and design work. For example, in the document, the company discussed the significance of the bentonite buffer that would surround the copper canister, and protect it from corrosion as well as other risks (Posiva, 2010b: 292, 297-298, 309). Moreover, in relation to the chemical composition of groundwater, Posiva (2010b: 302-304) considered the potential for chloride corrosion, the unfavourable impact of solutes and other corrosive agents on the copper canister. Corrosion processes due to the influx of oxygen into the repository together with glacial melt water were also taken into account in the research and formulation of safety scenarios (Posiva, 2010b: 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, microbial induced corrosion), and did so with reference to different phases of the disposal of the canister (Posiva, 2010b: 356-357). For other issues that Posiva mentions, see Table 3.

[15] 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 organization and assessment of preliminary safety case status. (Heinonen et al., 2014, 3)

Table 3 Summary of the copper corrosion issues discussed by Posiva and STUK in 2009 and 2010 (both RTD 2009 and Pre-CLA are included in the table).

<table>
<tr><th colspan="2">Issues discussed</th></tr>
<tr><th>Posiva Oy</th><th>STUK</th></tr>
<tr><td>
- Characterisation of the design and safety functions of the copper canister
- Significance of the bentonite buffer
- Chemical composition of groundwater and its impacts regarding chloride corrosion, solutes and other corrosive agents
- Influx of oxygen to the repository together with glacial melt water
- Stresses caused by welding and the possibility of stress corrosion cracking
- Various forms of copper corrosion during different phases of the disposal of the canister
- Unlikeliness of localised and uniform corrosion induced by salts and oxygen as well as interrelationships between material defects in the canister and corrosion and water
- Avoiding extra corrosion by ensuring that maximum temperature between capsule and bentonite does not rise above +100 °C
- Comparison of the KBS-3V and KBS-3H canister design models and the possibility of corrosion
- Studies on the possibility of using copper as the canister over pack material (supercontainer)
- Remaining uncertainties concern:
  - sulphate and methane interactions
  - foreign material, especially nitrogen compounds
  - evolution of sulphide concentration in groundwater
- Aspects that need further research:
  - stress corrosion cracking due to evolving changes in both the climate and repository conditions
  - permissible material defects in the copper canister shell and weld
  - impacts of residual stresses
  - stress corrosion cracking due to the presence of oxygen, certain redox potential values, sulphide ions, and sulphide impacts under anaerobic conditions
  - unlikely but possible scenarios related to uniform corrosion induced by sulphide ions
  - bentonite buffer
  - localised increases in stress on the copper canisters
  - sulphate reduction process and its kinetics
  - copper corrosion in pure water
</td><td>
Pre-licence application review:
- Report concerning capsule design and knowledge and conclusions regarding copper corrosion has been delayed
- Open safety issues regarding for example corrosion of the capsule
- Broader considerations
  - Posiva has knowledge regarding design and performance of barriers but information is in great part presented incoherently and hard to trace
  - Performance targets have not been thoroughly justified and conclusions regarding applicability have not been presented
  - Models regarding safety affecting conditions are needed
  - Conclusions and arguments regarding favourability of the site are incomplete
  - How capsule works in different stages of different development paths should be studied
  - Connections between barriers and combined effects in case of barrier failure should be studied
RTD review:
- Substantial progress in copper corrosion research during 2007 and 2009
- Taking into account the possibility that there may be some deficiently manufactured capsules
- Aspects that need further research:
  - stress corrosion
  - copper corrosion in pure oxygen-free water
  - possible changes in the repository due to environmental conditions (e.g. groundwater or glacial melt water penetration of the repository)
.
</td></tr>
</table>

In the report, Posiva identified some areas of concern that needed further RTD. Although the company deemed stress corrosion cracking to be an unlikely phenomenon under the expected conditions, it admitted to the remaining uncertainties with respect to evolving changes in climate as well as repository conditions (Posiva, 2010b: 358-359). Therefore, Posiva planned to continue research, for instance, on possible material defects in the copper canister shell and weld as well as on the adverse impacts of residual stresses that might increase the risk of stress corrosion cracking (Posiva, 2010b: 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: 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: 362, 411). Posiva's other research plans are mentioned in Table 3.

STUK acknowledged the substantial progress that Posiva had managed to make with respect to copper corrosion and other issues during 2007 and 2009 (STUK, 2010b; STUK, 2010a: 2). Nevertheless, the body still required some clarifications because the material provided was incomplete on numerous safety issues related to the canister's corrosion properties. STUK considered that Posiva had a lot of work to do regarding presenting issues coherently and drawing both conclusions and presenting justifications, and that the schedule for the CLA was going to be tight, as a sizeable part of the long term research would continue 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 its safety case review. (2010b, 1-2, index p.18)

Although Posiva's further analyses of copper corrosion indicated that spent nuclear fuel would be safely isolated for 10,000 years in the canister, STUK, once again, suggested taking into consideration the possibility, for instance, of some deficiently manufactured capsules that would not necessarily last for the required period (Hämäläinen, 2010: 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 in order to provide a clearer picture of the corrosion processes (Hämäläinen, 2010: 5; Heinonen 2010, 10, 14, 22; STUK, 2010b: 4). On broader considerations, STUK 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 set. (2010b, 2-4)

5.4 Years 2012 and 2013: Crisis in the relationship

In 2012 and 2013 issues remained pretty much the same but the tone of STUK's criticism changed as it considered that Posiva had not taken its earlier criticism seriously enough. Posiva's CLA was submitted but was expected to be supplemented while STUK was reviewing it. A summary of copper corrosion related issues covered in 2012 and 2013 is presented in Table 4 and Table 5.

Table 4. Summary of the copper corrosion related issues discussed in NWM review process by Posiva and STUK in 2012 and 2013.

Issues discussed	
Posiva Oy	**STUK**
- Posiva has updated its safety case plan - Conducted research on: - sulphide corrosion of copper - copper corrosion in pure water - oxygen carried to the disposal depth by glacial melting waters - stress corrosion cracking - dependence of stress corrosion on the redox potential - impacts of sulphide on stress corrosion cracking in anaerobic conditions potential - deformation caused by internal corrosion products - stress corrosion cracking in the insert - analyses for estimating the consequences of stress corrosion - Other issues: - estimating the consequences of stress corrosion - investigations into associated processes that may damage the canister - microbial activity in the buffer and backfill - Broader considerations - hydrogeological, hydro-geochemical and rock-mechanical conditions and scenarios - performance of the buffer, backfill and closure solution - effects of foreign materials to conditions - effects of KBS-3H to conditions - Aspects that need further research: - copper corrosion in an oxygen-free aquatic environment - stress corrosion - geochemical evolution of the buffer and the backfill - manufacturing, assembly and sealing of the canister - closure solution - hydrogeological and geochemical conditions - target properties of and future evolution in the bedrock	- Stated that NWM-2012 was insufficient, after response from Posiva supplementing timetables and references to documents submitted with construction licence application issued new statement finding that with the additions NWM-2012 fills the law's requirements. - Posiva has largely focused on characterisation, setting performance targets and defining target properties. Assessed with the construction licence application review - Regarding the canister NWM-2012 refers to construction licence application documents making progress hard to assess - research information regarding the welding methods and stress inadequate - new information regarding stress corrosion and corrosion in oxygen free water lacking - Information regarding long term safety is limited Assessed with the construction licence application review - Aspects that need further research: - copper corrosion in an oxygen-free water - stress corrosion - welding stress and alternative welding method - performance of the backfill and closure solution - hydrogeological and geochemical conditions

In the NWM report Posiva (2012) tried to respond to STUK's criticism by updating its safety plan with extra care, taking feedback from STUK into account in the update. In fact, according to Posiva, it compiled the comments into detailed lists with an appended plan for taking them into account. In the programme Posiva identified research work done, for example, regarding the suitability of the site, future evolution of the system, barriers and canister (Posiva 2012 34-35, 46-98, 120-170). Although the NWM programme was to include future plans from 2013 to 2015 Posiva had chosen to make an account of plans to year 2018. The list of aspects needing further research still appeared extensive and included many issues similar to those which had been under investigation already; however not many of them were strictly copper corrosion related issues (see Table 4).

STUK rejected the NWM programme. According to STUK although Posiva planned in many instances to continue its research on the basis of projects started earlier, in many of these cases Posiva had not made clear how these related to safety, their contribution to safety and the time line of these projects. Also, according to STUK, Posiva had overestimated the time it had for the research to append to the licence application after it had been submitted. STUK stated that the information of the report regarding the long term safety was scarce and that it had already criticised the RTDs of 2006 and 2009 for not presenting sufficient information in that regard. STUK stressed that although it had emphasised the significance of the analysis of how performance targets were met, Posiva had still not produced a plan to show how these performance targets would be reached. (STUK 2013, 1-5)

After STUK's statement Posiva appended more comprehensive plans to the NWM regarding the schedules for the intended R&D. Regarding the issues concerning the long term safety, in its response Posiva referred in many cases to material submitted with the CLA. STUK deemed the appended NWM acceptable, but stated that regarding the long term safety that state of the plans would have to be evaluated as a part of the CLA review.

5.5 Years 2012-2014: Posiva's construction licence application under review

Currently STUK is reviewing the CLA, which Posiva submitted at the end of 2012. The planned duration for STUK's R&A is around two years and it is expected to be ready at the end of 2014 (Heinonen et al., 2014; Rasilainen et al., 2014). After that STUK will continue to comprehensively monitor the subsequent detailed design, construction, manufacture and pre-operational testing, which will be followed by the R&A of the pending operation licence application (Heinonen et al., 2014, 2).

In the safety case of the CLA Posiva has assessed that there are no significant uncertainties concerning the general understanding of copper corrosion under aerobic and anaerobic conditions. They argue that the uncertainties in the general corrosion rate are relatively small and the rate can be expected to be less than 1 mm in 100,000 years. According to Posiva, the main uncertainties relate to the evolution of the near-field geochemical conditions. Nevertheless, the company announced that the possibility of pure water copper corrosion is being investigated to understand some of the results published in the literature. (Posiva 2012f, 129; Posiva 2012a, 154.)

In the safety case submitted as a part of the construction licence application material Posiva (2012a, 236) argues that:

> *"[…]the proposed repository design provides a safe solution for the disposal of spent nuclear fuel, and that the performance and safety assessments are fully consistent with all the legal and regulatory requirements […]. Moreover, Posiva considers that the level of confidence in the demonstration of safety is appropriate and sufficient to submit the construction licence application to the authorities."*

Posiva admits that there are some uncertainties, but asserts that these do not threaten the basic conclusions (Posiva 2012a, 236). The company state that their final disposal solution based on the

Swedish KBS-3 concept relies on a multi-barrier system. The view of the implementer is that copper in copper canisters provides corrosion resistance. Other barriers (buffer, backfill, plugs, closure and host rock), according to Posiva, contribute to predictable and favourable conditions for the canister, the buffer surrounding the canister protecting it directly from unwanted outside influences and other barriers contributing to the stability of the surroundings. (Posiva 2012d, Appendix 7, 12-13, Appendix 16, 113; Posiva 2012a, Executive Summary, 9-10; Posiva 2012e, 51-54.)

Performance targets and design requirements for the canister are set out in the design basis of the safety case (Posiva 2012e, 85-99). The report lists multiple corrosion mechanisms, such as localised, microbial and stress corrosion that need to be taken into account, naming oxygen and sulphide as the most important corrosive agents (see Table 5). Interestingly, however, it is claimed that the scientific evidence regarding copper corrosion in pure water is weak, and as the process moreover would be self-limiting, it is not taken into account in the design. Nevertheless, Posiva also explains that the process is under study. In addition, it is duly noted in the safety case that corrosion relates to the near-field chemistry and that all requirements related to it are, hence, also related to the corrosion resistance, and that these relations are explored in detail (Posiva 2012e, 88-89, 93, 98; Posiva 2012f, 105-110, 123-133, 137-141; Posiva 2012g, 104-105). For a comprehensive list of corrosion issues named in the application and the attached safety case see Table 5.

Posiva's performance assessment identifies uncertainties in the initial state of the barriers and in the evolution of the repository system, and goes through the most likely lines of evolution and some variant and disturbance scenarios. (Posiva 2012a, 234; Posiva 2012g, summary, 25). According to Posiva, the analysis shows that the barriers will fulfil set performance targets for up to 10,000 years, with some possibility of incidental deviations. Regarding the corrosion issue, corrosion from the atmospheric and initially trapped oxygen, and from sulphide, which are named as the main corrosive agents in this time frame, is considered to be negligible. (Posiva 2012a, Executive Summary 19, 21; Posiva 2012g, 183, 281, 289.) Eventually, major climatic changes that may affect the repository conditions are anticipated. However, according to Posiva, no canister failures are expected during the first glacial cycle if the buffer performs as expected, and even if changes in the groundwater lead to chemical erosion, canister failures are unlikely in a time frame of 100,000 years. (Posiva 2012a, executive summary 21-24; Posiva 2012g, 380-385) With repeated glacial cycles the chance for canister failures rises but, in all scenarios, the calculated radiation release rates remain clearly below the set limits.

Table 5 Summary of the copper corrosion related issues discussed in Posiva's construction licence application in 2012.

Issues discussed
Posiva Oy
- Posiva presents construction licence application including safety case - Conducted research on: - corrosion before emplacement ○ atmospheric corrosion ○ oxidation - corrosion due to handling and emplacement ○ galvanic corrosion due to iron particles ○ corrosion due to surface discontinuities ○ corrosion due to plastic deformation of copper - stress corrosion ○ stress corrosion cracking ○ residual stresses due to welding ○ aerobic conditions ○ oxidation ○ surface reactions ○ copper-water interface ○ corrosion in anoxic water - internal corrosion ○ radiolysis of residual water ○ ammonia ○ radiolytic acid production - external corrosion in unsaturated buffer ○ salt contaminants ○ local separation of anodic and cathodic sites ○ wetting process ○ radiolysis of moist air - aerobic corrosion in the deposition hole ○ aerobic corrosion due to residual air ○ pyrite oxidation - copper corrosion in highly saline ground waters ○ corrosion under anoxic conditions - corrosion during buffer saturation ○ pitting ○ under-deposit corrosion ○ alkaline pore waters ○ microbial activity - corrosion after buffer saturation ○ sulphide corrosion ○ electrochemical, mass transport, redox, precipitation, and sorption reactions ○ pyrite and sulphate as sulphide sources ○ microbial activity ◦ stress corrosion cracking under anaerobic conditions - external corrosion due to radiolysis of buffer pore water ○ temperature around the canister - corrosion in the case of an intact buffer ○ evolution of groundwater conditions - corrosion in the case of a partially eroded buffer ○ evolution of groundwater conditions ○ transport apertures of fractures ○ sulphide concentration in the groundwater ○ microbial induced sulphide production - corrosion in pure water - Additional considerations: - swelling pressure from the buffer - aggressive agents (e.g. nitrates, nitrites) - high pH leachates from cementitious materials - canister corrosion's effect on buffer - Broader considerations - heat transfer - performance of the buffer - issues affecting the buffer - different evolutionary scenarios - No significant uncertainties concerning copper corrosion under aerobic and anaerobic conditions - The main uncertainties relate to the evolution of the near-field geochemical conditions - Under research: - the time-dependent variable amounts of sulphide that can reach the copper - capacity of the rock and filling materials to buffer infiltration of acidic and oxygenated water from the surface - localised corrosion mechanism in the presence of dissolved groundwater species in compacted bentonite - different evolutionary scenarios - corrosion by pure water - microbial-produced sulphide

6 Overview of findings

The purpose of the present study was to investigate risk communication, namely a dialogue in the exchange of risk-related information among expert organisations in risk governance processes. In this case study we focused on the dialogue between the nuclear waste management company, Posiva Oy, and the nuclear safety authority, STUK, paying special attention to the copper corrosion issue, which is one of the key challenges in the geological disposal of spent nuclear fuel. The study aimed at finding out 1) how the implementer, Posiva, has presented research on the issue of copper corrosion and copper corrosion in their RTD programme, since 2003, and the subsequent NWM programme in 2012, 2) how the regulator, STUK, has assessed the challenge and reacted to what Posiva has presented, 3) how the risk of copper corrosion is co-constructed by Posiva and STUK and 4) what the long-standing risk dialogue reveals about the transformation of the regulatory culture and the relationship of the parties.

Our findings suggest that the need for a spent nuclear fuel repository tends to shape Posiva's conceptualisation of the debate, and thus, it is formulated in an optimistic light right from the first RTD report in 2003, but still conceding its lack of knowledge on many different aspects related to the copper corrosion issues. The results suggest that Posiva's programmes evolved from merely presenting a situation to more focused and extensive discussions. Meanwhile, the primacy of the ultimate safety of radioactive waste 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 the safe final disposal is seen as the goal, supporting Posiva in pushing ahead in its RTD work, giving credit to Posiva's advancements advances and identifying the areas needing 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 successful development of a safe repository for spent nuclear fuel. However, the results show that under the normal steady flow of interaction, the risk governance process is oriented towards mutual learning and improvement, but at the time of crucial decision-making extra tensions come into the relationship. In 2003, only two years after the first step of the authorisation process and after having its DiP ratified by Parliament, the dialogue between Posiva and STUK set the stage for the copper corrosion debate. In 2003 Posiva described their own and their co-operative research on corrosion, but also disclosed their thoughts about aspects needing further research. Besides its own expertise, STUK employed hired experts to review Posiva's RTD of 2003. On the grounds of the review STUK demanded further consideration, clarifications and research on several issues. In 2006 the second round of the dialogue, the risk dialogue became both broader and more profound considering the future prospects and possible concerns related to the long-term corrosion behaviour of copper in changing repository conditions. The increased coverage of the corrosion issues indicated both increasing knowledge about the issue, but also remaining uncertainties. STUK gave Posiva credit for enhancing its knowledge, but still pointed out areas in need of further research and identified weaknesses. STUK and its consultants deplored the lack of a coherent picture of the research, the lack of evidence on the long-term properties of the canister design and was of the opinion that early failure of the canister due to creep or stress corrosion had not been sufficiently addressed. Other clarifications and further consideration of other matters were also required.

The regulatory review process of 2009 confused the simple review process as indicated in Figure 1. At this stage the regulatory review process, i.e. the RTD review process, was affected by the authorisation process, i.e. construction licence review process. This diffusion of two processes seemed to raise the stakes and increased STUK's criticism. Posiva prepared its RTD 2009 report, but at the same time it was asked also to submit so-called pre-construction licence application (pre-CLA). When STUK found the pre-CLA material insufficient in many ways, it also looked at Posiva's RTD from this perspective. The criticism voiced by STUK was 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 be paid to questions of corrosion. Interestingly enough, different perceptions of the pre-CLA by Posiva and STUK affected both of STUK's reviews. STUK had expected a more holistic view in the pre-CLA, whereas Posiva had opted for something more like a compilation of research accomplished so far. Therefore STUK's criticism was harsh. It deplored the lack of coherence, justifications and conclusions, but also Posiva's ability to keep up with its timetables.

Earlier tensions between the parties increased during the last regulatory review round of interest in 2012-2013. The analysis of the documents indicated that STUK was intensifying its criticism, because Posiva had not taken earlier criticism seriously enough. Thus STUK first rejected Posiva's NWM, and accepted it only after Posiva submitted clarifications and amendments based on STUK's initial review. Here, too, the two processes, the regulatory review process and the authorisation process, intersected 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. One of the important criticisms by STUK was Posiva's need for more time for certain of its studies. It was estimated that some studies would be completed only after the CLA review by STUK. The outcome of STUK's review of the Posiva CLA will be known somewhere around the end of 2014.

7 Discussion

The results of the research supported the assumption that long lasting interaction between the implementer and regulator tended 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 role 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 deemed flexible, development oriented and, as such, oriented towards gradual learning and refinement. This regulatory philosophy provides more opportunity for a constructive dialogue between regulator and implementer, which can be beneficial for the development of technical procedures, but also leaves room for interpretations and control by the authorities. In the ideal case the roles of implementer and regulator should be clear-cut, but the study of long-standing interaction indicates that engagement in dialogue has transformed STUK's role in the direction of development orientation, thus shifting STUK's input to the advancement of the project, giving it a sort of consultative role. However, at the time of the pre-licence application and actual construction licence application STUK reviewed Posiva's RTD and pre-licence application more from the point of view of a regulator.

The present study demonstrates that in some cases it takes a long interactional process to determine the seriousness of a risk, and even then it is not entirely sure whether all aspects of that risk have been considered. In our case the parties appeared to construct the risk through negotiations about what is safe, how safe is safe enough, and what has to be studied in order to reach the certainty about safety. Also the aspects; when one knows enough to claim that something is safe, how much research is enough to eliminate uncertainty, how new research findings contribute to the enhancement of minimisation of risk and what does the countless investigations tell about the overall understanding of safety, were also covered. Moreover, our analysis clearly indicates that increasing the number of scientific studies and results produced by the implementer is simply not enough even to approximate the risk. The regulator must have enough regulatory power to demand further considerations, clarification and additional research, for instance, on different epistemological problems related to the risk. Thus, we emphasise the importance of the legislation and the institutionally secured position of the regulator.

Even though the regulator may have enough regulatory power and enjoy powerful institutional status, the longstanding interaction may create convergence. Wärnbäck et al. (2013) warn about 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 the values and priorities could be seen in 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 they 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 the Posiva NWM programme and only after Posiva provided a supplement was the NWM programme accepted, stressing that the new NWM 2012 programme was once again to 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.

Besides the regulatory culture, an interesting question is the regulatory object. The study indicated that from 2003 to 2006 STUK's regulatory object was more the R&D process or the studies related to the advancement of disposal project, whereas from 2009 to 2012, due to the approaching licencing procedure, STUK started to focus more on an overall understanding of safety. These two issues are understandably connected to each other, but during the regulation process the emphasis seems to change. Another interesting question is how the parties understood the regulation. Both Posiva and STUK have stated that the DiP ratified by Parliament in 2001 consolidated the dominance of the scientific-technical approach over the political evaluation. Both parties made the interpretation that the DiP closed the gates to political intervention and legitimated the 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, 358-361). This interpretation has persisted for over a decade, but after STUK's review report expected at the end of 2014 the political evaluation of the CLA will begin.

Further research on dyadic risk communication is still needed. Even after this study it is fair to state that the dialogue between Posiva and STUK provides excellent longitudinal data for researchers interested in investigating the exchange of risk-related information between these parties. Our study gave only a hint that the two parties are not monolithic entities, because there are many experts in both organisations whose interpretations of issues may differ. Further research could moreover focus on how both Posiva and STUK "use" their external consultants. This study was also partly concerned with regulatory cultures. One factor contributing to the interaction between Posiva and STUK is undoubtedly that the MEE has the highest tutelage in the field of nuclear energy. It has a central role in the official process and the statements are in fact requested by the Ministry. However, the role of the MEE has not been under investigation as its role here is seen mainly in gathering and conveying the information. Still, one has to remember, for instance, that it is the MEE, which prepare the CLA for the Government to decide. In addition, both Posiva and STUK have also expressed their readiness to dispense with the role of MEE in R&D review process (see STUK 2010b, 1-2). A fruitful research design could be to compare regulatory cultures and regulatory regimes in different countries.

An important finding was that debate on copper corrosion in pure, anoxic water was of only minor significance in the expert dialogue between Posiva and STUK, whereas in the Finnish and particularly in the Swedish public debate it has actually become an issue with the potential to cut short the fulfilment of the geological disposal of SNF. What does it tell about risk governance and regulatory culture? If some recommendation could be made on the grounds of the study, we would like to propose further consideration on the role of other stakeholders. The closed circle of interaction between the two expert organisations would benefit from the input of informed outsiders, who in some cases could provide valuable input for assessing related uncertainties and possible approaches to the risks identified. A professional risk debate between an implementer and a regulator in an institutionally regulated setting can be seen to improve safety, but it can also create and impose rigid methods of operation and inflexible ideas, especially if no intervention is forthcoming from civil society, politicians or the mass media.

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