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Swedish Radiation Safety Authority

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Evaluation of the Swedish participation in the Halden Reactor Project 2006–2014

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SSM perspective

Background

The Halden Reactor Project is an international research collaboration renewed in three year intervals since the 1950s. The purpose of the Halden Reactor Project is to contribute to safety and reliability in operational nuclear facilities through research and development. Some 20 countries finance the Halden Reactor Project and over a hundred organizations within the nuclear sector take part in the collaboration. Stakeholders include nuclear industries, research institutions, reactor and fuel industries, utility companies and licensing and regulatory agencies. Operations at the Halden Reactor Project are centered around large scale research infrastructure facilities: the Halden reactor, which is purely an experimental reactor, and facilities for experimental research on human subjects, information systems, and their interaction.

Objectives of the project

This is a report on the evaluation of the Swedish participation in the Halden Reactor Project 2006-2014. The study has consisted in evaluating the types and extent of added value from the Swedish participation in the Halden Reactor Project, and to determine what additional added value the participation could supply for the Swedish authority.

Results

It can be concluded from the study that the impacts from the Halden Reactor Project are extensive and wide ranging, reaching beyond the scope of what has been possible to cover in the evaluation. This limitation is mainly due to the long history and continuity of the collaboration, extending far beyond the scope of the study. The evaluation further concludes that the Halden Reactor Project has come to play a systemic role for the nuclear sector in Sweden, supplying significant portions of the data underlying safety oriented research and development within the areas concerned. These impacts have mainly been realized in industry, and are promoted in particular by voluntary, bottom-up coordination and engagement by industry stakeholders. Academia has seen little added value from the Swedish participation in the Halden Reactor Project, while the public sector has benefited somewhat, however, its engagement has been limited in comparison with peer countries Finland and Switzerland.

Conclusions

The evaluation team recommends that the Swedish stakeholders continue funding the participation in the Halden Reactor Project. Additionally, the Swedish authority's funding of research infrastructures in general should be safeguarded by acknowledging this type of investment in the research strategy. The distinct and fundamental role of research infrastructures in innovation systems is being increasingly recognized, and the participation in the Halden Reactor Project is a clear example of the value of such institutions for the continuous expansion of knowledge. Furthermore, the Swedish strategy for benefiting from the Halden Reactor Project should be further elaborated, taking into account the possible actions of strengthening coordination, increasing funding to supplementary domestic research, and reviewing the responsibilities of the officials administering the Swedish participation.

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Content

Abbreviations

Abbreviations used in the report are listed below in alphabetical order

EHPG - Enlarged Halden Programme Group
F&M - fuel and materials
IASCC - irradiation assisted stress corrosion cracking
IFE - Institutt for energiteknik, Eng. Institute for Energy Technology
HAMMLAB - Halden Man Machine Laboratory
HPG - Halden Programme Group
HRP - Halden Reactor Project
HWR - Halden Working Report
LOCA - loss of coolant accident
MTO - Man-Technology-Organisation
NPP - nuclear power plant
R&D - research and development
SSM - Strålsäkerhetsmyndigheten, Eng. Swedish Radiation Safety Authority
TSO - Technical Support Organisation
VR - virtual reality

1. Executive summary

This is a report on the evaluation of the Swedish participation in the Halden Reactor Project 2006-2014. The study, commissioned by the Swedish Radiation Safety Authority, has been completed by a team of evaluation consultants from Oxford Research with the support of Dr. habil. Olof Hallonsten. The assignment has consisted in evaluating the types and extent of added value from the Swedish participation in the Halden Reactor Project, and to determine what additional added value the participation could supply for the Swedish authority. The work has been performed using document studies, interviews, a workshop and a minor international comparison. Theoretically, the study builds on an innovations systems and sociology of science approach, which has been realised in a somewhat exploratory process allowing for a measure of analytical flexibility.

The Halden Reactor Project is an international research collaboration renewed in three year intervals since the 1950s. The purpose of the Halden Reactor Project is to contribute to safety and reliability in operational nuclear facilities through research and development. Some 20 countries finance the Halden Reactor Project and over a hundred organisations within the nuclear sector take part in the collaboration. Stakeholders include nuclear industries, research institutions, reactor and fuel industries, utility companies and licensing and regulatory agencies. Operations at the Halden Reactor Project are centred around large scale research infrastructure facilities: the Halden reactor, which is purely an experimental reactor, and facilities for experimental research on human subjects, information systems, and their interaction.

It can be concluded from the study that the impacts from the Halden Reactor Project are extensive and wide ranging, reaching beyond the scope of what has been possible to cover in the evaluation. This limitation is mainly due to the long history and continuity of the collaboration, extending far beyond the scope of the study. The evaluation further concludes that the Halden Reactor Project has come to play a systemic role for the nuclear sector in Sweden, supplying significant portions of the data underlying safety oriented research and development within the areas concerned. These impacts have mainly been realised in industry, and are promoted in particular by voluntary, bottom-up coordination and engagement by industry stakeholders. Academia has seen little added value from the Swedish participation in the Halden Reactor Project, while the public sector has benefited somewhat, however, its engagement has been limited in comparison with peer countries Finland and Switzerland.

The evaluation team recommends that the Swedish stakeholders continue funding the participation in the Halden Reactor Project. Additionally, the Swedish authority's funding of research infrastructures in general should be safeguarded by acknowledging this type of investment in the research strategy. The distinct and fundamental role of research infrastructures in innovation systems is being increasingly recognised, and the participation in the Halden Reactor Project is a clear example of the value of such institutions for the continuous expansion of knowledge. Furthermore, the Swedish strategy for benefiting from the Halden Reactor Project should be further elaborated, taking into account the possible actions of strengthening coordination, increasing funding to supplementary domestic research, and reviewing the responsibilities of the officials administering the Swedish participation.

2. Introduction

This report documents the results of an evaluation of the Swedish participation in the Halden Reactor Project (HRP). The evaluation was commissioned by the Swedish Radiation Safety Authority to be conducted during the first half of 2016. The study has been completed by a team of evaluation consultants from Oxford Research with the support of Dr. habil. Olof Hallonsten. The evaluation team is grateful to all informants for their willing participation in the study. We especially acknowledge the HRP management for compiling basic data on the HRP operations.

2.1. What is the HRP?

The HRP is an international research collaboration renewed in three year intervals. HRP is situated at the Norwegian research institute Institutt for energiteknik (IFE) in Halden, Norway. IFE owns the reactor that has given the collaboration its name. The decision to build the reactor predates the research collaboration, it was conceived as a national Norwegian effort in the mid-1950s. However, the collaboration was established even before the reactor became operational, in the form of an agreement for a joint research project within the OECD (then OEEC). The initial agreement has been succeeded by continuing three-year agreements for collaborative research programmes. The purpose of the HRP is to contribute to safety and reliability in operational nuclear facilities through research and development. Some 20 countries finance HRP and over a hundred organisations within the nuclear sector take part in the collaboration. Stakeholders include nuclear industries, research institutions, reactor and fuel industries, utility companies and licensing and regulatory agencies.

Operations at HRP are based around large scale research infrastructure facilities, the Halden reactor, which is purely an experimental reactor, and the Halden Man-Machine Laboratory HAMMLAB, which is a test bed for Man-Technology-Organisation (MTO) research, in the form of a physical control room environment. A Virtual Reality (VR) centre is also included in the MTO research infrastructure. Close to 300 employees work at HRP. Activities are organised in two types of research programmes, one being joint programmes, the results of which are made available for all members of the HRP, the other being bi- or multilateral (commercial) programmes, the results of which are owned by the specific participants.

Since many years, joint programmes are conducted in parallel in three year periods. The different programmes focus on fuel (denoting whole nuclear fuel assemblies) and (reactor core structural) materials tests on the one hand, and MTO research on the other hand. The fuel and materials research programme comprises experiments on samples placed in the Halden reactor, and draws from natural science disciplines. The MTO research programme includes human subject research and research on software, drawing from diverse disciplines within behavioural sciences and information technology. The research results from each three year programme period is collected in one main Achievement report and is made available for all members. After some additional time, usually five years, results are declassified and open for the public. HRP/IFE also conducts other research not related to the nuclear sector on commission, especially within MTO and on behalf of Norwegian industry.

In addition to the main three-year achievement report, HRP produces work and status reports and arranges project conferences, workshops, meetings and summer schools. The HRP conferences are called Enlarged Halden Programme Group (EHPG) meetings and are usually attended by some 300 participants, meeting for 5-6 days. Knowledge dissemination is also promoted through a secondee system offered to members who may send staff to participate in research and training.

2.2. Assignment, delimitations and evaluation questions

We view the HRP as an international research collaboration in the form of a research centre, the activities of which revolve around large scale infrastructure facilities, the Halden reactor and HAMMLAB. The assignment consists in evaluating the types and extent of added value from the Swedish participation in HRP, and to determine what additional added value the participation could supply for SSM. By added value, we refer to unique outcomes or cost savings that the participation in HRP offers, respectively enables, for Swedish stakeholders. In a wider context, the evaluation should show the way that added value manifests in sequences of impacts in Sweden, in successively wider spheres of influence.

The study focuses on stakeholders that contribute towards the Swedish participation fee. Main partner and contract holder is the SSM. The other Swedish consortium partners consist of the utilities, the Swedish branch of Westinghouse Electric, working with nuclear fuel and services, and the nuclear fuel company in the Vattenfall group: Vattenfall Nuclear Fuel. The Vattenfall group is a major actor, being the majority shareholder of two out of three (operational) Swedish utilities. The consortium partners contribute to the membership fee, in monetary terms exclusively, or in combination with in-kind contributions. In short the consortium partners are the following:

- SSM
- Utility companies
    - Forsmarks Kraftgrupp AB
    - Ringhals AB
    - Oskarshamnsverkens kraftgrupp (OKG) AB
- Vattenfall Nuclear Fuel AB
- Westinghouse electric Sweden AB

Within Swedish industry, Studsvik AB, offering technical services to the nuclear power industry, and nuclear power safety and education provider Kärnkraftsäkerhet och utbildning AB, also play important parts in the relations with HRP/IFE. In addition to these stakeholders, relevant research environments at Swedish universities have been considered as secondary stakeholders. Academy plays the role as partner for research and a user of HRP results, however academic impacts is not identified as a core strategic aim for the HRP.

We have focused the study on the flow of data, knowledge and expertise from HRP to the Swedish stakeholders, and the impacts these carry. Impacts of Swedish stakeholders on the HRP has not been treated as a research question but is considered as a strategic issue to be addressed in recommendations for the SSM. The data collection and analysis has focused on activities, results and impacts taking place during the years 2006-2014. At the same time, the long history of the collaboration and the specific conditions this has led to is taken account as a background for the evaluation. The delimitation in time to the last three evaluation periods was agreed upon with the Swedish Radiation Safety Authority in order to provide with knowledge on the contemporary conditions of the participation, to ensure usability of the results for the authority. The summary investigation of more long term and historical conditions and developments limits the possibility to draw conclusions about what has been identified as the systemic role of HRP in the Swedish nuclear sector. This can lead to underestimating the strategic role of the HRP for Sweden. Insight about the importance of the long history of HRP and what we describe as a systemic role has surfaced during the work with the evaluation, and has been allowed to influence the theoretical understanding and direction of the research, see specifics in section 2.4 below. This perhaps unconventional approach has offered rich results and a detailed understanding of HRP's role and function.

2.2.1. The Swedish Radiation Safety Authority (SSM) and regulation of the Swedish nuclear sector

SSM was formed in 2008 in a merger of the previous regulatory authority the Swedish Nuclear Power Inspectorate (Statens Kärnkraftsinspektion, SKI) and the Swedish Radiation Protection Institute (Statens Strålskyddsinstitut, SSI). SSM is tasked with a mandate encompassing all radiation safety concerns, including both ionising and non-ionising radiation.[1] Within the area of nuclear safety, the authority formulates regulations, awards licenses and supervises the nuclear power industry in Sweden. SSM's responsibilities for nuclear safety is ensuring that the laws and regulations are followed and that licensees take responsibility for nuclear safety. In Sweden, the utility companies are the ones who carry the licenses. The licensees are fully responsible for all safety aspects of the operations of the power plants, hence SSM's responsibilities are limited to examining the safety procedures of the licensees, while the licensees are responsible for executing any procedures.

SSM is also tasked with maintaining and expanding knowledge within the scope of its responsibilities. The authority has a budget allocation for research amounting to between around 70 and 80 MSEK per year. The SSM independently decides on what research to fund. There is a process of revising SSM's research strategy ongoing.[2] However, research funds are currently grouped in two overarching categories: competency support and supervision support. Competency support is funding that aims to sustain and extend competence within SSM's areas of responsibility, within but also outside the authority. It encompasses funding of research positions, open calls and international collaboration. Supervision support mainly consists of commissioned research which is directly related to the authority's operations. The funding of HRP is included in the competency support category. It is the only major research infrastructure with long term funding from the SSM; specifically, it is the only test reactor routinely used by Swedish stakeholders.

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[1] Ionising radiation has enough energy to directly break chemical bonds, making it more directly harmful than non-ionising radiation, and placing it under stricter regulations. However non-ionising radiation, such as e.g. light in the ultraviolet (UV) spectrum, may also cause harm.

[2] SSM (2010). *Forskning 2010:03. Forskningsstrategi 2010-2014.*

2.3. Theoretical framework

The study draws from previous investigations of similar large scale research infrastructure facilities.[3] We are indebted to Dr. habil. Olof Hallonsten, sociologist of science and research policy scholar, for advice and critique on theory and analysis. The theoretical framework builds on the understanding of impacts from large scale research facilities as appearing directly (as economic investments or labour market effects) or indirectly (as innovation or knowledge dissemination) on regional, national or global scales. Being that the infrastructure is located in another country and we focus on Sweden, impacts are mainly indirect and appear on the national scale, the main exception being significant business relations between HRP/IFE and Swedish industry. We employ five distinct insights into the qualities of research and innovation processes and systems to explain and interpret the qualities of these, mainly indirect, national impacts.

The theoretical framework has been supplemented by proximity benefits and counterfactual alternatives as analytical concepts. Impacts from HRP in Sweden cannot a priori be attributed to the Swedish participation in the HRP. Bi- or multilateral programmes, partnerships, commissioned research or procurement from Swedish companies may have developed independently of Swedish participation in the joint programmes. Hence, the study has analysed to what extent impacts may be attributed to Sweden's membership in HRP. Impacts that are enabled, or amplified, by the proximity between Sweden and Norway, have been critically assessed as to what degree they are proximity based relative to being partnership based. Along a similar line of reasoning, we have assessed the additionality of the impacts offered by Swedish participation in HRP, compared to counterfactual alternatives for the use of funding spent on HRP.

2.3.1. The object of study is technological innovation systems

In its original and broad meaning, the innovation system concept describes all those actors, organizations, institutions (including rules, regulations, norms, habits) that have roles to play in the process of innovation. The core feature of the systems approach to innovation is that the system as a whole, and all its constituent parts, has a supreme function of achieving innovation. Therefore attention should be paid less to the capabilities of specific actors to achieve innovation, and more to processes involving several actors and organizations, drawing on a wider institutional and cultural battery of resources in the system.[4] Innovation systems may be geographically delimited (national, regional) or defined according to sectors, fields or businesses. In this case we use the concept of *technological innovation system* to organise our understanding of the innovation activities within nuclear safety research on fuel and materials and on MTO. A technological system is the network of agents interacting in a specific technological domain. They generate, diffuse, and utilize the specific technology of concern.[5] Applied to this context, the concept begs the question which technological domains the systems that make use of the different research infrastructures within HRP belong to. This question is answered in the final section of chapter 3.

[3] See e.g. Science and Technology Facilities Council (2010). *New Light on Science The Social & Economic Impact of the Daresbury Synchrotron Radiation Source, (1981 - 2008).*
[4] Edquist (2004) *Systems of Innovation: Perspectives and Challenges*. In Fagerberg J, Mowery DC and RR Nelson (eds), The Oxford Handbook of Innovation. Oxford University Press.
[5] Carlsson and Stankiewicz (1991). *On the Nature, Function, and Composition of Technological systems.* Journal of Evolutionary Economics 1:93-118.

2.3.2. Indirect impacts appear in complex sequences

In the context of evaluation, effects are sometimes placed in a chain ranging from inputs over outputs and outcomes to impacts. We have used a similar understanding of impacts as being more or less indirect, impacts from direct contact with HRP causing further impacts in sequences of steps expanding in successively wider spheres of influence.[6] Such sequences of impacts must be carefully traced evaluating for each step the significance of the contribution from HRP.[7] The sequence of impacts concept has been both an analytical tool to characterise impacts and a guiding principle for the investigations. The study has started out looking at direct impacts and present conditions, successively and simultaneously expanding the scope of investigations backwards in time and outwards including wider spheres of influence, thus allowing to trace how impacts have evolved over time. In practice this has entailed reviewing documentation in reverse chronological order and performing interviews with informants successively more peripheral to the HRP. The time limits of the study sets boundaries for the tracing of sequences of impacts. Given the long history of the collaboration, it can be expected that the full scope of sequences of impacts will remain obscure, especially as regards unexpected impacts with their origin dating back to well before the first programme period that is studied in its entirety (i.e. before 2006).

2.3.3. Different institutional spheres experience different impacts

To differentiate impacts beyond the direct-indirect and geographical distinctions, we explore impacts based on their realisation in different institutional spheres. Primarily, we consider impacts as either socioeconomic or scientific. The socioeconomic impacts have been assumed to manifest in industry or in the public sector, mainly through SSM. Industrial use of HRP and its results, as taking place through the joint programmes but also bi- or multilateral programmes or commissioned research, has been investigated to the extent that it has been promoted by the official Swedish participation in HRP. We ultimately expect this use to result in economic impacts for the industrial stakeholders. Technology transfer and procurement of services from Swedish companies have been explored as mechanisms causing socioeconomic impacts. The public sector impacts in turn, we have mainly assumed to be institutional, that is, regulatory or as affecting licensing or supervision. We have considered the institutional impacts as notable in and of themselves, noting potential cost savings related to such impacts to the extent that they have been evident. As regards scientific impacts, these consist of discoveries and data repositories enabling further research. In impact evaluations, such scientific impacts are normally investigated using bibliometric methods (publication statistics and citation analysis) to identify significant contributions. As peer reviewed scientific publication of findings is not a central component of HRP strategy, scientific impacts within the field have been investigated using more qualitative, exploratory and narrative, methods. Finally there is a common thread in all institutional spheres consisting of the achievements of people embodying knowledge from the HRP, acquired through training or education or interactions with the HRP in general.

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[6] Cf. Perez Vico (2014). *An in-depth study of direct and indirect impacts from the research of a physics professor.* Science and Public Policy 41: 701–719.

[7] This framework for analysing impacts of scientific research has also been used in an analysis of the role of research infrastructures in the economy; Olof Hallonsten (2016), *Big Science Transformed. Science, Politics and Organization in Europe and the United States*, chapter 6. Palgrave Macmillan.

2.3.4. Stability and durability of infrastructures contribute to continuity

The most important feature of research infrastructures and their role and function in innovation systems is best described with reference to core principles from the sociology of science and organization. Science, whether fundamental, applied or strategic[8] needs a certain stability in its institutions and organizations to breed the creativity and ingenuity it lives on[9], and by extension, some structures need to be in place and be durable and reliable in order for innovation to occur (cf. also the concept of 'protective spaces'[10]). Clearly, research infrastructures embody such stability, not only by their physical and material durability (which is all the more evident in the case of a reactor facility whose decommissioning procedure sets clear limits to how fast it can theoretically be closed and abolished) but also because they are usually governed by very durable and resilient political agreements (sometimes intergovernmental and hence with ramifications for diplomacy and foreign policy). In those cases when research infrastructures also provide services of a high standard to a community where access to such services is essential for short- and long-term productivity and quality of results, which clearly is the case in the very technology-intensive nuclear safety research and related fields, it is highly likely that the infrastructure develops a niche and a 'protective space' and grows, over time, to be an inalienable part of the technological innovation system it serves.

2.3.5. Functional differentiation explains the function of infrastructures

Infrastructures are also essentially different from other organizations and entities in innovation systems because of functional differentiation. The innovation systems approach was once conceived and developed in order to fully grasp the different parts of the innovation process and to acknowledge in theory and empirical work the full range of potential actors and processes that are involved in innovation; in short, innovation is neither linear nor simple, neither truncated nor momentary, but in most cases complex and cumulative.[11] But the systems approach requires a deeper and more sensitive understanding of process and function; although the purpose of the system as a whole is to produce and diffuse innovations, there are certainly actors, organizations and institutions that fulfil distinct or distinguishable roles and functions. Functional differentiation has an ancient history in sociology but was cultivated and popularized by Luhmann[12] in his development of systems theory. To pay attention to functional differentiation within a system means not that one needs to acknowledge the role and function of all its actors and organizations, in order to understand the function of the system, but that it must be acknowledged that every actor and organization in a system has a distinct role, otherwise it would not be part of it, or would at least not take the shape it does. The function of the entity determines its place and role in the system. For example, research infrastructures have a role of supplying the scientific community and the wider innovation system (including corporate R&D performers) with rare or unique experimental opportunities. Other actors have other roles, such as cultivating the capacity to utilize the opportunities offered, and the symbiosis between them and between other actors in the system(s) builds on functional differentiation; that each actor has a distinct role.

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[8] Cf. Stokes (1997). *Pasteur's Quadrant: Basic Science and Technological Innovation*. Brookings.
[9] Cf. Kuhn (1959). *The Essential Tension: Tradition and Innovation in Scientific Research*. In Taylor C (ed) The Third University of Utah Research Conference on the Identification of Scientific Talent. University of Utah Press.
[10] Kemp, Schot and Hoogma (1998). *Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management*. Technology Analysis & Strategic Management 10: 175-195.
[11] Lundvall (ed) (1992). *National Systems of Innovation.* Anthem Press.
[12] Luhmann (1995/1984). *Social Systems*. Stanford University Press.

2.4. Research practices, methods and material

Below follows a presentation of the methods and the material which have been used in the evaluation. The methods used has been adjusted to the available material and interview subjects. Below is a list of the main methods employed:

- Desk document studies
- Interviews (explorative, semi-structured and group interviews)
- Workshop
- International outlook

The Halden project database has been reviewed and extensive supplementary data has been kindly provided by the HRP manager. The material investigated may be categorised into the follow categories:

- Reporting
- Budgets and accounts
- Staff and participants
- Programme plans

In practice, we have allowed the initial conclusions, as noted in the workshop with SSM, to influence the direction of final research and analysis. In particular, this refers to the understanding of the importance of the concepts of technological innovation systems and functional differentiation to characterise the significance of the HRP for Sweden. This stepwise interaction between preliminary analysis and supplementary research has enabled an exploratory flexibility which has proven to be valuable in terms of explaining the study's findings.

2.4.1. Desk document studies

The mapping of Swedish participation in HRP has been organised by type of source and results have been compiled by different measures of Swedish participation.

HRP finances
HRP budgets and abstract of accounts has been reviewed and presented to give a view of the projects finances over the relevant period of time. The finances have been compared to the Swedish membership contribution in order to relate the Swedish contribution to the overall economy of HRP.

Bi- and multilateral contracts
Bi- and multilateral contracts are only presented on an aggregate level, focusing on their total value, as based on a compilation by HRP, since their content is confidential. The topic and content of bi- and multilateral research has been investigated in qualitative interviews documenting the information that participants have been willing to disclose.

Procurement
The compilation of procurement activities is relevant in order to track proximity effects for Swedish actors within the relevant sectors. Data on the value of procurement for Swedish actors has been compiled for the evaluation by HRP.

Swedish staff and participants

The Halden Project management has provided Oxford Research a compiled list of representatives of Swedish organisations participating in HRP as guest researchers, PhD's or secondees. In addition participants in summer schools and workshops have been compiled based on attendance lists and is displayed in tables and diagrams, relating the numbers to total stocks of participants.

Knowledge production

The overall content and direction of research within HRP has been compiled reviewing the 3-year programme plans and achievement reports that are produced by HRP for each 3-year programme period. A complete list of reporting and documentation of individual studies per programme has been compiled and each report mentioning Swedish involvement has been annotated and documented. Relevant documentation which has be scanned for Swedish involvement is:

- Halden Working Reports (HWR): One report is produced for each project comprising a detailed description of participants, methodology, results and conclusions
- Workshop presentations

HWR reports have been screened for Swedish involvement. This screening has been conducted by searching the HWRs from the relevant time period for Swedish stakeholders who have been identified to relate to HRP. For a full presentation of search words used see the Annex of this report. For working reports, which exist in multiples due to revisions, only the most recently revised report has been used.

The Swedish participation, as identified through the HWRs, has been categorized according to the type of involvement. For this categorization workshop-HWRs which include studies and results based on Swedish data or in other ways display Swedish participation have not been counted towards Swedish involvement. Swedish involvement in specific studies is instead presented in the relevant project result HWR, and workshop documentation has not been counted as involvement in knowledge production as to avoid double-counting. However, when individuals from Sweden have presented material the workshop documentation has been counted as Swedish involvement in HRP. Hits on Swedish actors in attendance lists have not been counted as Swedish involvement. General participation in workshops is instead presented under 1.5 "Staff and participants in Halden activities" where a full review of conducted workshops is presented.

2.4.2. Interview study

An interview study has been conducted in order to add qualitative data on the impacts of the Swedish participation in HRP. Swedish participation uncovered in document studies was further investigated through the interview study. The interviews investigated the impacts of participation and the relevance of the HRP membership for public, private and academic organisations.

In order to go beyond the task of investigating impacts of Swedish participation in HRP to investigating possible impacts of Swedish participation in HRP we have interviewed SSM staff active within the fields of fuel, material and MTO research. In three group interviews with SSM personnel we have assessed how HRP could be used and how Swedish participation could contribute more to the specific fields.

A site visit to the Halden site has also been conducted. The site visit provided contextual information for the evaluation and enabled face to face interviews with multiple researchers and managers active within HRP. Seven interviews were conducted at Halden with individuals responsible for research being conducted both within the 3-year program and within bi- and multilateral contracts within both the fuel and materials area, and the MTO area.

Informants for the interview study are listed together with other sources in the last chapter of the report. Specific sequences of impacts have been traced in supplementary data collection by phone or email and/or in follow up document studies.

2.4.3. Workshop for analysis and interpretation

Tentative results were discussed, analysed and interpreted in a joint workshop with the Oxford Research evaluation team and the SSM research unit. The workshop addressed two main questions:

- What are the alternatives for SSM to promote increased added value from HRP?
- What is the additionality of the impacts in comparison with alternative use of the funds?

The workshop took place two thirds of the time into the study, allowing for the conclusions from the workshop to influence the shape of the final phase of research, mainly consisting of supplementary interviews, supplementary document studies, and the international outlook.

2.4.4. Comparative study with other members countries

In order to compare membership effects with proximity benefits four interviews were conducted with regulatory authorities in Finland and Switzerland. This was supplemented by a minor desk study. The international outlook provided a context to the Swedish activities within HRP and enabled a comparative analysis. Finland, just as Sweden, pays an increased membership fee because of anticipated proximity effects, including the benefit of HAMMLAB simulators being based on both Swedish and Finnish nuclear power plants and could therefore be suspected to gain the same benefits as Sweden. Switzerland’s nuclear sector is of similar extent as the Swedish and Finnish, and should only be affected by the membership and could therefore be expected to lack benefits from proximity seen in both Sweden and Finland.

2.5. Outline of the report

The first two chapters of the report are the executive summary and the present introductory chapter. After these, there is a chapter summarising the history, structure and content of the HRP, as a backdrop for the rest of the report. The third chapter closes with an analysis of the technological innovation systems under concern in relation to HRP’s operations. Chapters 4 and 5 contain the results of the research. The fourth chapter focuses on quantifying the Swedish participation in HRP in monetary terms and in terms of personal involvement in research and meetings. The fifth in turn summarises the qualitative results from interviews with a broad range of stakeholders. The content is a synthesis of what can be inferred from the aggregate of different informants' views. The sixth chapter is pure analysis and discussion, summing up the identified impacts and relating them to the theoretical framework. In the seventh chapter, we draw brief conclusions and give recommendations as regards the significance of the study for SSM. The report ends with a final chapter listing all sources.

Throughout the report, especially advanced technical information is collected in text boxes such as this, intended for the initiated readers.

3. Background and context

This chapter summarises the history of the HRP and gives an overview of its governance and organisations, research facilities and research programmes within the research collaboration. The chapter ends with section concluding that the HRP functionally consists of two separate technological systems of innovation, which is then fundamental for the description of the usage of HRP in chapter 5.

3.1. A brief history of the HRP

The main focus of this historical presentation will be the last 25-30 years of HRPs history. This synopsis will describe how the forms of cooperation and the HRP infrastructure have developed. Information on Swedish participation and connections to Sweden will be presented when evident from the secondary sources.[13]

3.1.1. Establishment and the early years

In 1955 The Institute for Atomic Energy (now IFE) initiated construction of a nuclear research reactor in Halden. Initially plans had been made to establish a bilateral research cooperation together with the Netherlands, but the Netherlands left the cooperation when research reactors became available in the USA. The reactor in Halden was therefore built as a national Norwegian research reactor. In 1958, one year before the reactor was fully operational, a collaborative agreement was signed with OEEC (present-day OECD). This agreement establish the Halden reactor as an international research reactor and the Halden Reactor Project (HRP) was born. HRP has since 1958 been endorsed through 3-year international agreements which have outlined the research to be conducted for each following 3-year period. Initially twelve countries, including Norway, were included in the research cooperation and HRP had approximately 40 employees.

During the early 70s Norway planned to establish a national nuclear industry and commercial nuclear power plants in the country, but public opinion quickly shifted after the discovery of oil in the North Sea. After the Three Mile Island accident in 1979 opposition increased and the plans for a commercial Norwegian nuclear industry were scrapped all together.

3.1.2. The 1980s

Following the Norwegian decision not to establish a commercial nuclear industry the Institute for Atomic Energy was renamed the Institute for Energy Technology (IFE) and the institute's focus shifted towards broader energy based research.

The international community showed continued high interest in the nuclear research at HRP though, and during the 80s the reactor infrastructure was further developed, for example by the construction of high pressure loops. These high pressure loops enabled

[13] This section is based on the following sources when not stated otherwise: IFE (2009). *50 years of safety-related research. The Halden project 1958-2008*. ; The Research Council of Norway (2000) *Evaluation of the OECD Halden Reactor Project.* ; Skjerve and Bye (eds.) (2010). *Simulator-based Human Factors Studies across 25 Years: The History of the Halden Man-Machine Laboratory.*

simulation of the conditions in commercial reactors and, according to HRP, anchored the projects position as a leading centre for fuel research. The new infrastructure also strengthened the possibilities of materials research of the properties of i.e. stainless steels and other alloys under irradiation.

After the accident on Three Mile Island in 1979 the international interest in control-room behaviour increased, an area which HRP was active within. The Halden Man-Machine Laboratory (HAMMLAB) was establish in 1983 as a consequence of the growing interest of MTO-research. Both the international nuclear sector and Norwegian industry in general were interested in research from HAMMLAB. Simulator projects were conducted for Norwegian petroleum industry and arms industry. The HAMMLAB simulator was constructed based on control rooms in Swedish and Finnish reactors, which has been used as motivation for increased membership fees for both Finland and Sweden. Moreover both Sweden and Finland are subject to increased membership fees due to their proximity to Halden. It is common for host nations to pay an increased membership fee (usually called a "site premium" or "host premium") in similar research collaborations around infrastructure facilities, to compensate for the expected benefits of hosting a large infrastructure.

Regarding Swedish participation in HRP in the 80s it should furthermore be noted that two meetings with the Enlarged Halden Programme Group (EHPG) were held in Sweden (Strömstad and Gothenburg) during the time period. HRP results are mainly disseminated through EHPG meetings.

3.1.3. The 1990s

During the 90s the future of HRP was debated in Norway. To secure the continuation of HRP, IFE tried to make the results and the infrastructure of HRP more accessible to the Norwegian industry in general and IFE tried to position HRP as a project which could contribute to increased nuclear safety in Russia and Eastern Europe. The strategy was successful and between 1991 and 1996 contracts between IFE and the Norwegian industry more than doubled in value. The international interest in HRP increased during the 90s and a number of new countries became project members. The Norwegian government shifted to a more positive stance towards HRP after a spin-off company, Hand-EL Skandinavia AS, was formed in 1996.

The MTO-research developed further with the construction of a Virtual reality (VR)-lab in 1996 and the development of computerised operation support systems COSS. This VR technology has mainly been used to develop and evaluate control-room design.
The total turnover of the Halden reactor and the MTO-labs more than doubled between the end of the 80s and the mid-90s, but has since the 90s remained on a stable level with minor increases each year.

3.1.4. Year 2000 - today

Since the beginning of the 21st century the MTO infrastructure at Halden has developed further with a new laboratory complex for MTO being completed in 2007. Moreover the reactor, which is used for the fuel and material research, has been updated continuously to enable continued research.

Regarding by whom the Halden reactor is used and how the cooperation is organised a shift can be seen during the last 10 years. There has been a major increase in bilateral research projects and during the last 10 years the volume (in form of total investments) of international bi- and multilateral research contracts has tripled. Today around half of the tests which are run in the reactor are part of the OECD 3-year research program (HRP) and the other half are connected to bi- and multilateral contracts.

HRP has increased its dissemination activities during the 21st century by establishing an annual summer school in 2000. The summer school lasts for four days and each summer school has a specific theme, within either MTO or fuel and materials. The main target group of the course is young researchers but individuals from regulatory authorities and staff connected to the nuclear industry are welcome as well. The cost for the summer school is around 5500 NOK per participating attendee.

On the 5th of December 2014 the 19th international research co-operation agreement for HRP was signed and the Halden board of management approved the proposed budget of 413 MNOK for the next 3 year period. On the same day the Norwegian government gave a six year license renewal for operation of the Halden reactor, which means that research can continue until at least 2020. Today 19 countries and more than 130 organisations are members of HRP and the project has approximately 270 employees.

From previous research, we know that the physical durability of the reactor infrastructure and institutional durability of organisations like the HRP contribute to the continuity of this type of collaborations. At this point, we would like to note that this is important both for the stakeholders, who have reason to expect that the HRP will be in place for some time to come, and also for the process described here: although the Norwegian government can in principle choose not to renew the support for HRP (naturally, notwithstanding any potential safety concerns), the established and international nature of the collaboration as well as the weight of already made investments in physical capital impels the Norwegian government to continue hosting and funding the infrastructures. That all participants are so highly invested offers reliability and predictability that is valuable for the planning of research for all stakeholders.

3.2. Organisation of the HRP

As stated, HRP is an international research collaboration which is governed jointly by the member countries. Below we describe the governance and organisation of HRP, internationally, in Sweden and at the Halden site.

3.2.1. Governance and organs of the HRP

The supreme organ of the HRP is the board of managers.[14] Each signatory member appoints one representative in the board, which makes the final decisions about the content of research programmes and the experiments run in the reactor. There is a technical expert committee called the Halden Programme Group (HPG) comprising three representatives appointed within each of the three thematic areas, fuel, materials, and MTO. The

[14] As regards the governance of HRP we refer to the latest contract OECD NEA (2014) *Agreement on the organisation for economic co-operation and development (OECD) Halden reactor project covering the period 1st january 2015 to 31st december 2017.*

committee supervises the technical aspects of the research. In addition, expert and reference groups may form ad-hoc, one such being the IASCC review group.[15]

In advance of each new three year joint programme period the HRP prepares suggested programmes that are distributed to the members. The draft programmes contain a long-list of suggested research projects that comes with a scoring table for prioritising between them. The HRP goes on a tour to all members to discuss the draft programme and use the scoring tables to compile a final programme for the coming programme period, which is then approved by the board of managers. The HPG is involved throughout this process. The Halden board of managers also decides on the conditions for commissioning bi- and multilateral programmes from HRP. It is expected that an organisation is a member of HRP before commissioning bi- or multilateral research. This is more strictly observed as regards the use of the reactor, for which IFE always informs the board of managers if they plant to grant access to a third party, to get clearance for this. As regards the MTO area it is more lax. Only if a test would utilise the MTO facilities significantly IFE would assure that the board of managers approves that it may impact some of the HRP research.[16]

3.2.2. Swedish participation in governance and organs of the HRP[17]

Nationally, the Swedish membership in HRP is organised as a consortium of partners that contribute towards the Swedish membership fee. However, the formal signatory member is SSM. Consequently SSM appoints the Swedish seats in the Halden board and the HPG representatives for fuel, for materials and MTO, as well as for other expert or reference groups. The Swedish representative in the board is currently the director of SSM's research unit and representatives in the HPG are operative staff with responsibilities within the corresponding areas. The individual staff members representing Sweden in the HPGs have a number of professional duties in their area of responsibility, including both supervision of the licensees and coordination of the research needs of their units. SSM also has a staff member representing Sweden in the IASCC review group. For ad hoc working, reference or expert groups, SSM's representatives have at times designated experts from partners or e.g. Studsvik to represent Sweden.

3.2.3. Organisation of the staff at the Halden site

The Halden site is organised in two major divisions, in line with the different infrastructures. The one division is centred on the Halden reactor and all surrounding operations, including the operation of the reactor. As research goes, there is a department for research and development with units for both fuel and materials tests and various other supporting units. In addition the division has departments for the facility's workshop, for the nuclear materials, and for the operation of the reactor. The MTO division is made up of three departments, all concerned with research and development. They are the software engineering department, the systems and interface design department and the industrial psychology department.[18]

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[15] The status of ad-hoc expert and reference groups such as the IASCC review group is not regulated in the agreements. Information on the IASCC review group has been provided by HRP staff and group member informants.
[16] This paragraph is informed by interviews with the HRP manager and HPG representatives.
[17] This paragraph is based on interviews with SSM's representatives in HRP and on information provided by the SSM's research unit.
[18] HRP (2015). *Staff Organisation as of August, 2015 at the OECD Halden Reactor Project.*

3.3. Research infrastructures

The HRP research programmes are based on access to research infrastructures, mainly at the Halden site in southern Norway. They include major infrastructures for research within both physical sciences – fuel and materials research – and behavioural sciences – MTO research.

3.3.1. Fuel and material research infrastructures

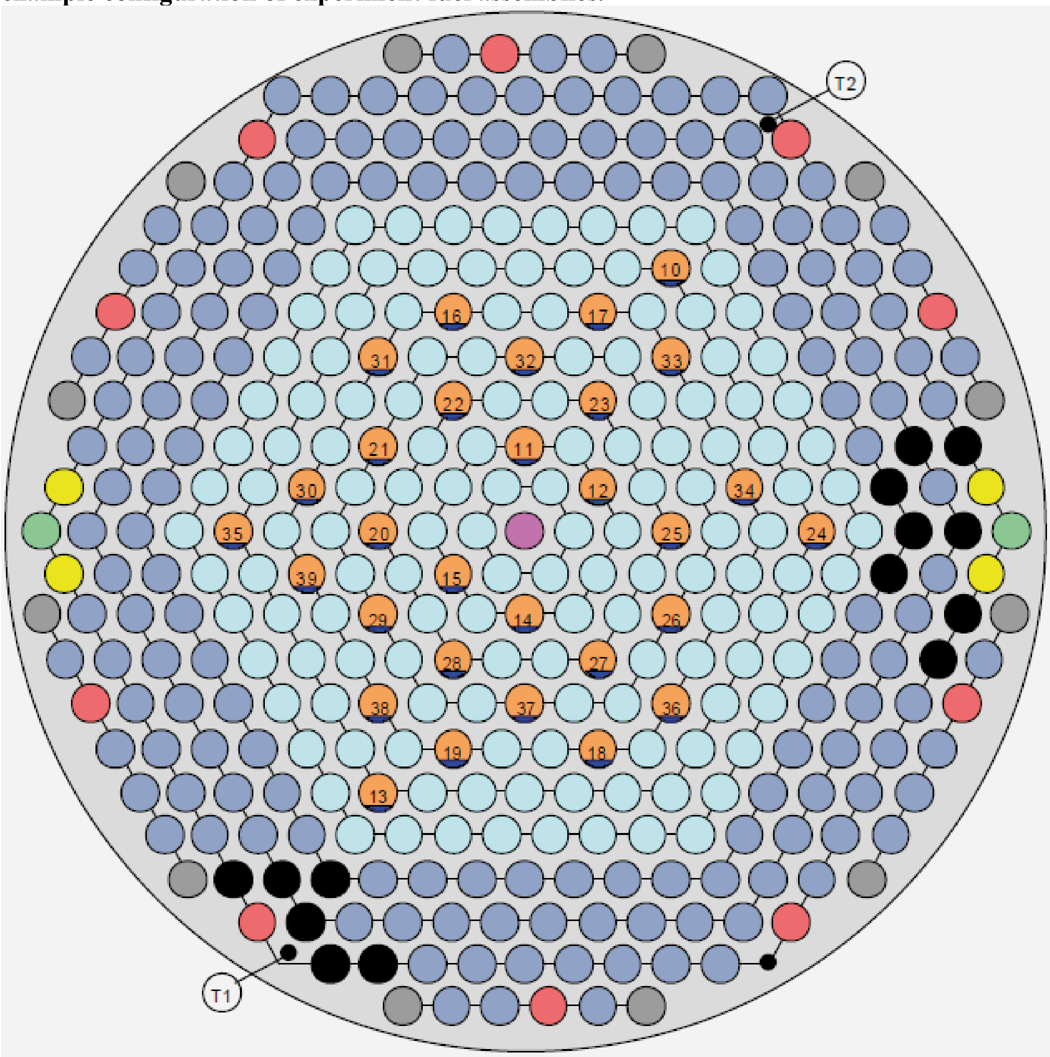
The main research infrastructure for fuel and materials research is the Halden Boiling Water Reactor (HBWR), generally referred to as the Halden reactor. The Halden reactor is a heavy water reactor, meaning that the nuclear fuel is cooled and moderated by heavy water. It is an uncommon design being that commercial designs for boiling water reactors use light water as coolant and moderator.

A nuclear reactor core is made up of a pattern of fuel assemblies, see the figure below for a schematic of the fuel assembly positions in the Halden reactor. Fuel assemblies are vertical bundles of fuel rods. The fuels rods in turn are made up of fuel pellets, the actual fissile material, stacked within metal tubes. The metal tube encasing the fuel is called cladding. The void between the stacked fuel pellets and the cladding is filled with helium gas.

The HRP fuel and materials testing infrastructure also include a 'hot lab' at the IFE site at Kjeller outside Oslo. A 'hot lab' is laboratory facilities equipped to enable examination of irradiated fuel and materials samples. After being irradiated in the core of the nuclear reactor during active operation, spent fuel and core material is highly radioactive and all handling is subject to strict procedures to ensure safety. In addition, design of experiments and instruments, and the operation of the reactor, as well as monitoring and analysis of reactor conditions is performed at the Halden site.

The Halden reactor is a dedicated experimental reactor, although a fraction of the power is delivered to a nearby saw mill as steam. The primary heavy water circuit is closed and separated from the external circuit by a secondary closed circuit with steam transformers between the different circuits. While some commercial concepts for pressurized water reactors operate with heavy water the Halden reactor operate at significantly lower reactor pressure and temperature. Given its unique conditions, the Halden reactor is a versatile experimental reactor.

Figure 1. A schematic from above of the Halden reactor core with fuel assembly positions. The light blue positions contain regular fuel assemblies, the darker blue positions are empty, as they are not needed to keep the reactor at criticality. The numbered positions show an example configuration of experiment fuel assemblies.



Tegn Hilary 26/6-97 M:Users/Hil/Melin/Hernes17.Drw (Safety 4). Taken from IFE (2003). *Halden boiling water reactor*. Used with permission from the HRP manager.

Fuel and materials experiments are conducted using special instrumented fuel assemblies occupying up to 30 of the 300 positions available for fuel assemblies in the Halden reactor core. An instrumented fuel assembly is an experimental test rig containing a smaller number of sample fuel rods, or a configuration of materials samples, and fitted with instruments recording experimental data within the fuel assembly during active operation of the nuclear reactor, so called in-pile measurements. The Halden reactor is fitted with separate cooling loops for simulating conditions in commercial reactors, both pressurised conditions and light water environments. Instrumented fuel assemblies may be placed in these separate cooling loop systems, enabling experiments to be run in conditions found in reactor types such as the following: BWR (boiling water reactor), PWR (pressurized water reactor), CANDU (pressurized heavy water reactor) and VVER (pressurized water reactor).

Table 1. Operating data for the Halden reactor.[19,20]

Maximum power	25 MW
Reactor pressure	33.3 bar
Heavy water saturation temperature	240°C
Maximum subcooling	3.0 MW
Primary steam flow (both circuits)	160 ton/h
Return condensate temperature	238°C
Subcooler flow	160 ton/h
Plenum inlet temperature	237°C

3.3.2. MTO research infrastructures

The MTO research laboratory consists of two major infrastructure facilities serving both experimental purposes and as test beds. One is the unique Halden Man-Machine Laboratory (HAMMLAB), which is a control room environment with corresponding simulators. The other is the Halden Virtual Reality Centre (HVRC) fitted with a variety of virtual, augmented, and mixed reality technologies. These two main infrastructures are located together in a joint research facility with additional infrastructure for monitoring and for test and integration laboratories, used to prepare implementation of new applications in the main control room environment laboratory. The premises also hold a collaboration laboratory for integrated operations (CIO-lab), to enable experiments on remote collaboration.[21]

HAMMLAB is an experimental control room environment complete with simulators of different nuclear power plants. Simulators in active use are the HAMBO operator based on BWR plants such as the Swedish Forsmark 3 plant, and the RIPS simulator based on the Swedish Ringhals 3 PWR plant. The control room and simulators are connected to an experiment management facility from which researchers may monitor and record experiments performed in the laboratory. The data collection capacities include eye-movement tracking and sound and video recording, logged in parallel with simulator events and operator actions.

Located in an adjacent room to HAMMLAB, separated by a fold-away wall, is the HVRC. The HVRC is fitted with a large simulated-3D projector display, a so called stereoscopic display. It enables life sized demonstration of virtual environments. In addition to other virtual, augmented, and mixed reality technologies such as head-mounted displays and pinch gloves for grabbing virtual objects, there are sensors for tracking various physical properties, including position, movement and tilt, lights and magnetism, and sound. Experiments may be monitored and recorded in a similar fashion as in HAMMLAB.

[19] IFE (2003). *Halden Boiling Water Reactor*.
[20] IFE (n.d.). *Halden Boiling Water Reactor (HBWR)*. IFE. Available at: https://www.ife.no/en/ife/laboratories/hbwr. Accessed on 2016-04-18.
[21] Skjerve and Bye (eds.) (2010). *Simulator-based Human Factors Studies Across 25 Years: The History of the Halden Man-Machine Laboratory.* Springer Science & Business Media.

3.4. Research performed within the joint programmes

Research performed within the joint programmes has expanded and become increasingly advanced during the course of the collaboration within the joint programmes. From the late 1990s and on the direction of research has consolidated, focusing on safety and reliability, while tests for development of new fuel and materials increasingly has been conducted within bi- or multilateral programmes other commissioned research or IFE's own development activities. The whole of this section is quite technical but is necessary to review to completely appreciate the content of especially chapter 5.

3.4.1. Brief overview of research conducted up to 2006[22]

The Halden reactor was constructed as a test facility to advance nuclear power as an energy source for the participating countries. Initial research was dedicated to fundamental reactor technology and physics, to provide basic knowledge for developing a nuclear power programme. As commercial nuclear power concept developed elsewhere became available during the 1960s the focus of research shifted to reactor performance. From 1967, the research programmes consisted of parallel programmes for fuel and materials testing and 'process supervision and control systems'.

During the following decade, the HRP research facility developed and expanded through increasing the number of instrumented fuel assemblies. Research was performed on the effects of power and temperature transients on fuel performance. Research on this topic continues to be relevant to this day. Computer based systems and TV screen displays were developed for process supervision and control. They constituted a basis for systems later installed in Swedish nuclear power plants.

By the end of the 1970s the Norwegian plans for a nuclear power industry were discontinued. HRP research however continued to attract interest and support from international partners. During the 1980s the Halden reactor was fitted with separate pressure loops enabling the simulation of conditions in commercial reactors. The research and testing of computer control systems also became topical as the Three Mile Island accident revealed operators exacerbated the accident through wrong decisions made in response to overwhelming information. The following programme development explicitly referred to the accident when setting out the plans for HAMMLAB, which was established in 1983. Operator support for monitoring, diagnostics and procedures were developed and validated in the new facilities.

Fuel and materials research continued to increase in extent during the 1990s. With increasing interest and many new partner countries, the joint programmes increasingly focused on issues of reliability and safety, while development and optimisation of new technologies and solutions was more often conducted within bi- or multilateral commercial programmes. The MTO research also extended its scope to studying new concepts and develop methods to evaluate human performance, and human error became a topic of investigation.

There is continuity in fuel and materials research from the 1990s and into the 2000s, focusing on reliability and safety in normal and transient operating conditions. The programmes are structured around the same research areas as the following periods, during

[22] When not stated otherwise, based on IFE (2009). *50 years of safety-related research. The Halden project 1958-2008.* and Skjerve and Bye (eds.) (2010). *Simulator-based Human Factors Studies Across 25 Years: The History of the Halden Man-Machine Laboratory.* Springer Science & Business Media.

the second half of the 2000s. The MTO research also continued along similar lines, dealing with human performance and human factors, and studies of new concepts and systems. The human error research expanded into a wider area of human reliability studies. Otherwise research areas and topics overlap with later programme periods.

3.4.2. Research programmes 2006-2014[23]

The HRP simultaneously conducts two separate joint programmes every three years, one on fuel and materials research, and one on MTO research. The different programmes are planned and reported separately. The fuel and materials research programme is in turn prepared by two different sections of the programme group.

The content of the programmes are structured into research areas, further specified into research topics. Studies are performed, mainly in the form of experiments, to produce data which can allow answering questions within the different topics. Most studies address issues within one topic. The table below displays the programme structure during the evaluation period.

Table 2. Programme structure of HRP research programmes on the level of research areas during the three programme periods 2006-2014. Source: HRP 3-year programmes and 3-year achievement reports, compiled by Oxford Research.

<table>
<tr><th>PROGRAMME STRUCUTRE 2006-2008/2009-2011</th><th>PROGRAMME STRUCTURE 2012-2014</th></tr>
<tr><td colspan="2">Fuel and materials</td></tr>
<tr><td>Fuel high burnup capabilities in normal operating conditions</td><td rowspan="3">Fuel safety and operational margins</td></tr>
<tr><td>Fuel response to transients</td></tr>
<tr><td>Cladding corrosion and water chemistry issues/Cladding creep, corrosion and water chemistry issues</td></tr>
<tr><td>Plant lifetime assessments</td><td>Plant ageing and degradation</td></tr>
<tr><td>Instrumentation for use in materials studies</td><td>Contribution to international gen-IV research</td></tr>
<tr><td>Programme basis, fuels and materials</td><td>Programme basis, fuel and materials</td></tr>
<tr><td colspan="2">MTO</td></tr>
<tr><td>Human performance</td><td rowspan="2">Human factors research for existing and new reactors</td></tr>
<tr><td>Design, evaluation and review of human system interfaces and control centres</td></tr>
<tr><td>Visualisation technologies supporting design, planning, operation and training/Mixed reality technologies</td><td></td></tr>
<tr><td>Surveillance and control systems in operation and maintenance/Computerised operations and maintenance support</td><td rowspan="2">Digital systems research for existing and new reactors</td></tr>
<tr><td>Software systems dependability</td></tr>
<tr><td>Programme basis, MTO-research</td><td>Programme basis, MTO-research</td></tr>
</table>

[23] Based on 3-year programme plans and achievement reports, supplemented with information from the interviews with HRP staff.

There is significant continuity between the different programme periods within the time frame for the evaluation, and with the preceding programme periods. This suggests HRP is a consolidated research collaboration providing data within areas that are relevant long-term for partner countries and organisations. The difference in structure of the programmes between the periods 2006-2011 in comparison with the period 2012-2014 is due to organising the research in broader research areas, rather than a major shift of scope, as explained below. This continuity should be interpreted as a manifestation of the reliability and predictability of the research collaboration, encouraging commitment from the participating stakeholders.

Fuel and materials research

The fuel and materials research programmes have focused on similar topics throughout the time frame for the evaluation, and even before. One important development that has taken place during the evaluation period is investigations of novel phenomena of fuel disintegration and dispersal under LOCA conditions. This has been a significant theme for the tests of fuel in transient conditions. The approximate range of simultaneously irradiated test rigs have been 9–15 during the three programme periods under consideration. That is, at any one time, between 9 and 15 different test rigs have been in place in the core of the Halden reactor to accumulate data and conditions for further testing and analysis. Each test rig may be used for several different experiments.

Apart from the increasing attention to LOCA tests on fuel disintegration and dispersal during the period 2008-2014, the research area defined as ‘Fuel safety and operational margins’ in the programme for 2012-2014 contains similar topics as the preceding corresponding research areas. These topics include fuel performance, gas release and rod overpressure, transient conditions, and cladding creep, corrosion and hydriding.

Earlier ‘Plant lifetime assessment’ research areas have covered similar topics as the studies within ‘Plant ageing and degradation’, namely cracking of core materials, stress relaxation and pressure vessel integrity. Similarly, the topics within the research area termed ‘Instrumentation for use in materials studies’ is covered in the gen-IV research contributions of the period 2012-2014, the topics of research being just instrument development and material testing. In addition to programme research, the HRP team continuously works on developing the infrastructure, experimental designs and tools forming the basis of the programme activities.

In addition to the programmes’ similar structures, fuel and materials tests may last for time periods extending beyond one, and even several programme periods, which is sometimes necessary to accumulate sufficient exposure and operation time of fuel and materials to answer the specific research questions. This means the horizon for planning experiments is sometimes longer than one programme period. This is yet another condition demonstrating the importance of the continuity of the HRP for the advancement of knowledge within the concerned fields.

MTO research

The MTO facilities were installed in a new research complex in 2007, the new RIPS simulator being installed and taken into operation in 2008. Just as for fuel and materials, the areas of research have largely remained the same during the evaluation period. Compared with earlier periods during the 1980s and 1990s the focus of research has shifted from developing whole systems to prototyping and developing individual applications.

The research is also increasingly including computational methods for analysing e.g. radiation protection aspects. Within the research on human subject the focus towards the interaction between control room operators and other nuclear power plant staff has increased.

The earlier studies within 'Human factors' and on human system interfaces and control rooms are succeeded by research on similar topics under the headline 'Human factors research for existing and new reactors'. Topics include human reliability, and human and organisational factors research. It also encompasses research on human system interfaces and control rooms, including design and validation or evaluation, and future control rooms. The research area consolidated as 'Digital systems research for existing and new reactors' in the 2012-2014 programme period is an umbrella for research topics previously covered as 'Software systems dependability' and research on technology to support operations and maintenance. It encompasses research on assessment of different safety aspects of software systems and their interactions as well as on technology, tools and methods to improve monitoring, maintenance and advanced control of nuclear power plants.

3.5. Fuel and materials respectively MTO are disjoint innovation systems

The concept of a technological innovation system helps us understand the dynamics of how HRP interacts with and impacts on the Swedish nuclear safety sector. Taking the perspective of which technologies and knowledge domains that are involved in the different research areas shifts the focus from formal collaborative structures between organisations, seen as monolithic units, to the dynamic exchange of knowledge and insight between experts in different institutional spheres and in different organisations. This is to say, an expert in a Swedish utility company, may have much closer interaction and more extensive exchange with their counterparts at HRP or at the regulator, than with colleagues in their own organisation but working in another research area. Setting forth from this basic understanding, we organise the presentation of how HRP is used in separate sections for the fuels and materials respectively MTO areas.

The differences between the research areas are manifested in the infrastructures and organisation of the HRP, separate infrastructures being operated by and servicing research and development within different parts of the organisation. This division may be summarised as in the table below

Table 3. Summary of organisational structure, infrastructures and scientific disciplines categorized by research area.

Area	Fuel and materials	MTO
Organisational structure	Fuel and materials division HPG Fuel HPG Materials	Safety MTO division HPG MTO
Infrastructures	HBWR	HAMMLAB VR-centre
Scientific disciplines	Physics Chemistry Technology	Psychology Cognitive science Human factors Information technology

This division between fuel and materials and MTO is an analytical tool which in part is based on convenience. Both of HRP's research areas are highly interdisciplinary, incorporating knowledge from several scientific disciplines. Within this division are also quite diverse subdivisions, one example is that structural materials and research on IASCC is quite separate from research on fuel, that is, on nuclear and cladding materials; another is that studies of human to human interactions are quite separate from research on digital instrumentation and control. In addition, while networks within the two major areas are largely disjoint, there are exceptions with agents being active in both areas, especially at the level of governance of HRP, as there is one board of managers for the whole of the collaboration. With these caveats in mind, the following chapters should be read taking the concepts 'fuel and materials area' and 'MTO area' to be understood as delimiting the corresponding technological innovation systems under investigation.

4. Swedish participation in HRP 2006–2014

In this chapter we present the results on the Swedish participation in HRP, both participation in HRP activities such as workshops, and participation in the knowledge production, through for example in-kind contribution of operators for experiments in HAMMLAB or of pre-irradiated fuel for testing. This chapter begins with a presentation of Sweden's financial contributions to HRP followed by a walk-through of Swedish participation in HRP activities such as workshops and summer schools. After this part Swedish involvement in the HRP knowledge production is presented.

4.1. Membership fees

The table below displays the Swedish contribution to the HRP budget in the form of the membership fee for participating in the collaboration. [24]

Table 4. Presentation of the total HRP budget and Sweden's contribution to it.

Period	HRP total budget (kNOK)	Swedish total contribution (kNOK)	In-kind part of Swedish contribution (kNOK)	Swedish proportion of the total budget
2006-2008	345 460	16 700	4 100	0.048
2009-2011	377 700	19 000	5 300	0.05
2012-2014	418 000	20 000	3 400[25]	0.048
Total	1 141 160	55 700	12 800	0.049

The membership fee is calculated based on the GDP, the size of the nuclear power sector (MW) and the GDP/capita of each country. The three factors are given different weights: 20 % for GDP 50 % for size of the nuclear power sector and 30 % for GDP/Capita. However, both Sweden and Finland pay increased membership fees due to anticipated proximity benefits as neighbouring countries. These proximity benefits are more thoroughly discussed elsewhere in the report. Sweden's membership fee excluding the increased fee for proximity effects would be approximately 12 MNOK for the period 2012-2014.[26]

The membership fee is typically split between SSM and the industry 60/40 %, SSM contributing the larger amount. The table below describes how the Swedish membership costs has been split between SSM and industry during the relevant time period. (Note that the convenience of in-kind contributions, sending samples and staff, depend on the proximity of HRP to Sweden.) The consortium partners are listed in the introductory chapter. The five industry partners share their portion of the cost for Sweden's participa-

[24] Data on the Swedish contribution to HRP is based on documentation from SSM. Data on the total budget of HRP is based on budget documentation from HRP.
[25] The total amount of in-kind contribution from SSM is unknown for the 2012-2014 period why the total Swedish in-kind contribution could be larger.
[26] See Figure 7 in Halden Board of Management (2015). *Determination of HRP contributions for new Member Countries*. HP-1426

tion almost equally. Regarding in-kind contributions, Vattenfall Nuclear Fuel and Westinghouse Electric Sweden contribute with fuel samples and the utilities contribute with operators for experiments in HAMMLAB.

Table 5. The division of HRP membership cost between SSM and industry partners.

	2006-2008		2009-2011		2012-2014	
	Total contribution (kNOK)	Of which in-kind (kNOK)	Total contribution (kNOK)	Of which in-kind (kNOK)	Total contribution (kNOK)	Of which in-kind (kNOK)
Industry	4 789	1 171	7 350	3 100	8 357	3 399
SKI/SSM	11 911	2 929	11 650	2 200	11 643	*[27]
Total	16 700	4100	19 000	5 300	20 000	3 399

Note the significant increase in in-kind contribution from the industry in the second period (2009-2011) in relation to the first period (2006-2008). During 2009-2011 the industry contributed with fuel samples in addition to operators for HAMMLAB experiments, which explains the increased in-kind contribution.

4.2. Bi-/multilateral contracts

Below we present the total value of bi-/multilateral contracts between Swedish actors and HRP where Swedish actors have bought goods and services from HRP. It is generally expected that an organisation is a member of the HRP prior to conducting testing on a bilateral basis within the fuel and materials area. Within the MTO-sector there are greater possibilities to utilize the MTO facilities for non-members.[28]

Table 6. Compilation of the value of bi and multilateral contracts within the fuel and material sector.

Year	Fuels and Materials		
	Contracts - Sweden	**All contracts**	**Swedish proportion**
	value in kNOK	value in kNOK	
2006-2008	na[29]	na[30]	
2009-2011	26 700	294 300	0.091
2012-2014	8 700	293 000	0.03
Total	35 400	587 300	0.06

Within the fuel area the following actors have bought goods and services from HRP during the relevant time period: Westinghouse, Studsvik (SCIP) and Chalmers (only 2014). Only Ringhals AB has bought goods and services within the materials area during the time period.

[27] Information on possible in-kind contributions from SSM for the 2012-2014 period is not available. The total value of Swedish in-kind contributions could therefore be higher and the cash contribution of SSM lower.
[28] Data on the value of bi- and multilateral contracts and the Swedish actors participating in bi- and multilateral contract work have been provided by HRP:
[29] Data only available for 2008, Swedish actors had bilateral contract of 6,619 MNOK in 2008
[30] Data only available for 2008, total contracts of 61,490 MNOK

Table 7. Compilation of the value of bi- and multilateral contracts within the MTO sector.

Year	MTO		
	Contracts - Sweden[31]	All contracts	Swedish Proportion
	value in kNOK	value in kNOK	
2006-2008	30 300	132 000	0.23
2009-2011	9 700	138 000	0.07
2012-2014	7 100	184 000	0.039
Total	47 100	454 000	0.104

A number of different Swedish organisations have bought services from IFE/HRP within the MTO area during the relevant time period for example Ringhals, OKG, Forsmark, KSU, Swedpower/Alstom, LKAB, Skellefteå Kraft, Siemens Industrial Turbomachinery AB. Notable bi-lateral projects are for example the work with large screen displays (LSD) performed within the HAMBO-group.

4.3. Procurement

As regards procurement by HRP from Swedish actors, the values in monetary terms are dominated by contracts within the fuel and materials area. Major items comprise fuel services procured from Studsvik and Westinghouse Electric Sweden. These contracts include fuel rods and material as well as hot lab services from Studsvik.[32]

Below we present the value of procurement by HRP from Swedish actors for the relevant time period. It should be noted that HRP provides further value for Studsvik by forwarding customers requesting for example hot cell services. When Studsvik's customers request services that require involvement by the HRP, Studsvik instead procures those services from Halden. The value of services procured by Halden from Studsvik is therefore underestimated when compared with the amount of services procured by Studsvik from Halden.

Table 8. Procurement by HRP from Swedish actors.

	Procurement from Sweden (kNOK)		
	MTO	**F&M**	**Total Procurement**
2007-2008[33]	2 444	6 790	9 234
2009-2011	1 338	13 552	14 890
2012-2014	169	16 417	16 586
Total	3 951	36 759	40 710

Within fuel and materials, HRP procures fuel for the reactor as well as fuel and cladding material for testing. Transportation of fuel and material is procured as well and hot cell lab work or work with mechanical properties in Studsvik. The following actors have sold goods and services to HRP within fuel and materials:

[31] MTO-contracts between NKS and Halden are included in this compilation.
[32] Data on the value of procurement have been provided by HRP. Furthermore information on the nature of procurement have been gathered from interviews with relevant actors and HRP staff.
[33] Note that data for procurement data for 2006 is missing why the total value of procurement for the 2006-2008 period is higher than the presented amount.

- Westinghouse
- Studsvik Nuclear AB
- SSM

Within MTO, HRP procures for example process expertise for the HAMMLAB simulator and training for the operators who work in the Halden reactor control room. Within MTO the following actors have sold goods and services to Halden:

- Alstom
- Forsmark Kraftgrupp
- LKAB
- Ringhals AB
- OKG AB
- SSM
- KSU
- Lund University
- Skellefteå Kraft AB
- Vattenfall
- Siemens Industrial
- Chalmers tekniska högskola

4.4. Staff and participants in HRP activities

Individuals from member countries may participate in shorter activities such as workshops or summer schools, or for longer periods of time through the secondee program, during which an individual spends two years in Halden. Below we present a compilation of the individuals who have participated in HRP for a longer period of time, as identified in HRP staff registries. Numbers in brackets display Swedish researchers and secondees primarily hosted by HRP. Fewer and fewer member states are sending secondees to HRP and HRP has requested that more countries send secondees. Other Swedish researchers have used HRP infrastructure or information from HRP during the period, but only PhD students and postdocs primarily hosted by HRP have been identified through HRP staff-registries. No postdocs from any country have been identified in this way during the evaluation period.[34]

[34] The compilation of participation in HRP activities is based on participation lists provided by HRP and through the internal HRP data base. Information of staff has been provided and compiled by HRP.

Table 9. Overview of HRP secondees, guest scientists, PhD-students and staff. Numbers in brackets indicate Swedish researchers and secondees primarily hosted by HRP.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
Secondees	10	12	7	5	7 (1)	7 (1)	7 (1)	8 (1)	5 (1)
Guest scientists	2	3	2	3	6	5	1	2	3
PhD				1	1		1	1	
In total:	12	15	9	8	13 (1)	12 (1)	8 (1)	10 (1)	8 (1)
All staff	268	270	269	259	259	260	257	261	233

In addition to the individuals presented in the table, several masters' students have cooperated with HRP. For example, one student from Linköping University writing a master thesis within the MTO area and one other master student from Chalmers University of Technology. Additionally, at least three PhD-students from Chalmers University of Technology have cooperated with HRP within the MTO area (by using HWRs or through having HRP staff represented in their reference group) during the evaluation period.

The two Swedes identified through the HRP staff registries are both active within the fuel and materials sector and affiliated with Uppsala University. The secondee, Scott Holcombe, was conducting PhD work at Uppsala University, and initially together with Westinghouse Electric Sweden, during his time at HRP. There is currently a Swedish post-doc, as well affiliated with Uppsala University, active at HRP, who has established contact with HRP building on the Holcombe collaboration. Holcombe is currently employed by HRP.

Three types of shorter activities are hosted by HRP: summer schools, workshops and EHPG meetings. Various workshops are organised each year. Every summer a four day summer school is conducted. Once every 18 months an enlarged Halden programme group meeting (EHPG meeting) is organised. This meeting generally lasts for two days. Below we display the Swedish participation in these activities in three tables. HRP staff are not accounted for in the total participation column of the EHPG meetings. Numbers in brackets indicate the number of the Swedish participants who are affiliated with industry actors. The remaining Swedish participants are either affiliated with SSM (previously SKI) or with a university or college. It can be noted that individuals affiliated with industry make up a significant majority of Swedish participation in all HRP activities.

Table 10. Compilation of summer school participation.

Year	Summer Schools (F&M)			Summer Schools (MTO)		
	Total partici-pation	Swedish partici-pation	Proportion Swedish participation	Total partici-pation	Swedish partici-pation	Proportion Swedish participation
2006-2008	35	7 (5)	0.2	22	2 (1)	0.091
2009-2011	92[35]	15 (9)	0.163	36	7 (7)	0.194
2012-2014	56	4 (4)	0.071	23	1 (1)	0.043
Total	183	26 (18)	0.142	81	10 (9)	0.123

Table 11. Compilation of F&M and MTO workshop participation

Year	Workshops (F&M)			Workshops (MTO)		
	Total partici-pation	Swedish partici-pation	Proportion Swedish participation	Total partici-pation	Swedish partici-pation	Proportion Swedish participation
2006-2008	248	14 (10)	0.056	381	39 (34)	0.102
2009-2011	239	16 (11)	0.067	288	14 (13)	0.049
2012-2014	292	26 (19)	0.089	246	33 (29)	0.134
Total	779	56 (40)	0.072	915	86 (76)	0.094

Table 12. Compilation of participation in EHPG-meetings

Year	EHPG-meetings (F&M)[36]			EHPG-meetings (MTO)[37]		
	Total partici-pation	Swedish partici-pation	Proportion Swedish participation	Total partici-pation	Swedish partici-pation	Proportion Swedish participation
2006-2008	173	8 (6)	0.046	154	17 (10)	0.11
2009-2011	178	9 (6)	0.051	167	26 (19)	0.156
2012-2014	206	24 (18)	0.117	177	37 (28)	0.209
Total	557	41 (30)	0.074	498	80 (57)	0.161

Note that that the same individuals may take part in both the fuel and materials EHPG and the MTO EHPG.

[35] During 2009-2011 there were two summer schools focused on F&M. For all other time periods there has been one school within F&M and one within MTO.
[36] Note that the same person can attend both the F&M and the MTO EHPG-meeting
[37] Note that the same person can attend both the F&M and the MTO EHPG-meeting

4.5. Involvement in knowledge production at HRP

HRP studies are documented in Halden Working Reports (HWR). Three different types of HWRs have been identified. The most numerous type of report is the project result report where results from a specific study is presented. The second most common type of HWR is workshop documentation where presentations and background material for a specific workshop is put together as a HWR. Finally, a few HWRs are literature reviews of research being conducted within a specific field for an extended period of time.[38]

The table presents a rough overview of Swedish involvement in the knowledge production at HRP, although the involvement can take various forms and therefore provide different levels and types of impacts. It should also be noted that some bi-lateral MTO projects have also resulted in HWR-reports why the number of HWRs within MTO reflect both work done within the programme and also, partly, participation in bi-lateral MTO projects.

Table 13. Compilation of HWRs and Swedish involvement in HWRs.

Year	F&M Total	F&M Sweden	Proportion Sweden	MTO Total	MTO Sweden	Proportion Sweden
2006-2008	33	10	0.303	52	10[39]	0.192
2009-2011	39	14	0.359	66	23	0.348
2012-2014	29	8[40]	0.310	40	6	0.15
Total	101	32	0.317	158	39	0.247

[38] The tables below have been compiled by searching HWR:s for key-words accociated with Swedish actors. Furthermore a qualitative analysis has been conducted. For a further description see 2.4.1 “Desk document studies”

[39] In addition results from studies using Swedish operators or being conducted in cooperation with Swedish researches have been discussed at two workshops. These workshops have not been included as Swedish participation in the HWR data, since Swedish actors did not participate in the presentation. The results discussed can also be found in the project report HWRs.

[40] In addition results from studies on fuel, cladding material and material has been discussed at two workshop without being presented by a Swede. These instances of Swedish participation have not been included since the results discussed can also be found in the project report HWR.

4.5.1. Swedish involvement in fuel and materials knowledge production

Swedish participation in knowledge production within the fuel and materials sector can be categorized as described in the table below. The numbers in parenthesis indicate a special acknowledgement to a Swedish actor.

Table 14. Categorisation of Swedish involvement in F&M HWRs

Year	Cooperation with Swedish University	Fuel and/or cladding material from Swedish vendors	Fuel rods and/or cladding material irradiated in Swedish NPPs	Structural material irradiated in Swedish NPPs	Presentation given by Swedish actor[41]	Swedish author
2006-2008	1	5		2 (2)	2	
2009-2011	1	7	2	3 (2)	1	
2012-2014		4	1	1 (1)	1	1[42]
Total	2	16	3	6 (5)	4	1

The table above shows that the industry actors are responsible for most of the Swedish involvement in the knowledge production at HRP. A clear exception is the close cooperation between Karen Gott and HRP when Karen worked at SKI/SSM. After Karen left SSM, no acknowledgement to SSM employees has been identified in the material.[43] Swedish participation within the fuel and materials area mainly takes the form of testing being done on Swedish fuel samples, cladding material and structural material. The category ‘Fuel and/or cladding material from Swedish vendors’ includes both fuel and materials provided HRP as part of the in-kind payments from Westinghouse Electric Sweden and Vattenfall Nuclear Fuels to HRP, and fuel bought from Swedish actors by IFE/HRP. The category ‘Structural material irradiated in Swedish NPPs’ only consists of IASCC studies. The categorisation of involvement through pre-irradiation in Swedish nuclear power plants is conservative and only articles where it is clearly stated that the fuel or cladding material has been irradiated within a Swedish nuclear power plant have been put into this category. Oftentimes, experiments within a study is done on different types of fuel and material, some of which comes from Sweden.

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[41] In all instances of a Swedish presenter at a workshop the presentation has mentioned the use of Swedish fuel & material and/or the participation of Swedish actors in the experiment. The workshop-reports are only categorized as “Swedish presentation” though as to avoid double-counting.

[42] In addition also fuel from Swedish vendor

[43] In addition to the participation categorized in the table above an acknowledgement for helpful discussions has been given to Karen Gott in five of the six reports where Swedish pre-irradiated structural material has been used.

4.5.2. Swedish involvement in MTO knowledge production

Swedish participation in knowledge production with the MTO sector may be categorized as in the table below.

Table 15. Categorisation of Swedish involvement in MTO HWRs

Year	Coop-eration with Swe-dish Univer-sity	Swe-dish partici-pation (opera-tors)	Swe-dish partici-pation (analy-sis)	Study on Swedish data and/or cases	Presen-tation given by Swe-dish actor[44]	Prototype develop-ment or other work for Swedish actors	Swe-dish author	Other
2006 - 2008	1	3		3	3			
2009 - 2011		6	3	5	1	4	1	3
2012 - 2014		1 (1)[45]		2	2			1
Total	1	10 (1)	3	10	6	4	1	4

As noted earlier, MTO HWRs include reports written based on bilateral work as well.

Cooperation is mainly seen between the industry and HRP. SSM is included in one HWR where the authority has taken part in a survey study. The category ‘Swedish participation (operators)’ includes the utilities’ in-kind contribution of operators to take part in HAMMLAB experiments. Involvement through analysis entails human reliability analysis teams from Ringhals who have taken part in a wider study where different Human Error Assessment and Reduction Techniques (HEART) have been compared. The study on Swedish data and/or cases include studies conducted on signal data from Swedish nuclear power plant control rooms, and the studies of Swedish cases are mainly studies on incidents at Swedish plants and comparisons made between Swedish incident cases and cases in other countries. The category ‘Prototype development or other work for Swedish actors’ contains the three HWRs written on Large Screen Display prototype development for the Swedish utilities.

[44] Just as within fuel and materials, when a Swedish actor has presented a study or a case at a workshop the presentation has mentioned the use of Swedish data and/or the participation of Swedish actors in the experiment. The workshop-reports are only categorized as “Swedish presentation” though, as to avoid double-counting.
[45] One of the studies on Swedish data also includes the participation of Swedish operators.

5. Usage of the HRP

In this chapter we present the results on the interplay between HRP and Swedish stakeholders in the different research areas. The focus is on the relation between HRP and Sweden, but we also present a short overview of how the usage of HRP is organised in two peer countries. The presentation is divided in two parts for the two different technological innovation systems.

5.1. Swedish usage of HRP within the fuels and materials area

This section details the results of interview studies as regards how the Swedish stakeholders within fuel and materials relate to and make use of HRP.

5.1.1. Swedish stakeholders and networks within the fuel and materials area

The main industry stakeholders in the fuel and materials area in Sweden are quite well defined and tightly connected. They consist of the consortium partners and global research and development service consultancy group Studsvik, headquartered in Sweden. Studsvik has taken a central position as a partner for HRP/IFE and Swedish industry owing to the fact that the company handles waste, including irradiated fuel and materials samples, for the utilities. Studsvik also carries out the transport of such samples to Halden – Swedish in-kind contributions to HRP – as well as receiving samples for further examination after a test has concluded. The partnership relation has evolved during the last ten years, that is, during the evaluation period, after the last of Studsvik's own experiment reactors was shut down for decommissioning in 2005. Finally, there is one small analysis consultancy – JMM Quantum Technologies AB – that performs fuel calculations and modelling for SSM on a regular basis, in practice functioning as a minor TSO in the fuels area.

The number of concerned individuals at SSM are in turn fewer. The authority has one representative in the programme group for the two areas of the programme, fuel respectively materials. There is also one SSM representative in the IASCC review group. While results from Halden may be relevant for other SSM staff members, the formal representatives are the ones who mainly have communicated such results within the organisation.

The academic institutions invested in research into the physical aspects of nuclear power generation also consist of a few major research environments at Chalmers University of Technology, the Royal Institute of Technology, and Uppsala University. They also participate in the joint Swedish Centre for Nuclear Technology (SKC), financed by the Swedish utilities and Westinghouse Electric Sweden and based at the Royal Institute of Technology. However, only a few individuals from academy have had any interaction with HRP and until recently there have been no formal agreements between academic institutions and HRP. An attempt was made by Uppsala University and HRP jointly to include Uppsala University as a trial university member in the HRP. The suggestion was not realised by the SSM, and Uppsala University and HRP has moved on to sign a Memorandum of Understanding, with the intention to increase academic participation in HRP.

In summary the main stakeholder organisations within the fuel and materials area are the following (HRP member organisations contributing to the membership fee in bold):

- Industry
  - Utility companies
    - **Forsmarks kraftgrupp AB**[46]
    - **Ringhals AB**[47]
    - **Oskarshamnsverkens kraftgrupp (OKG) AB**[48]
  - **Vattenfall Nuclear Fuel AB**
  - **Westinghouse Electric Sweden AB**
  - Studsvik AB
- Public sector
  - **SSM**
    - Department of Nuclear Power Plant Safety
      - Reactor technology and analysis unit
      - Structural integrity and event analysis unit
- Academy
  - Chalmers University of Technology
    - Sustainable Nuclear Energy Centre (SNEC)
  - Royal Institute of Technology
    - Swedish Centre for Nuclear Technology (SKC)
    - Centre for Nuclear Energy Technology (CEKERT)
  - Uppsala University
    - Division for applied nuclear physics

Governance and coordination of participation in HRP within fuel and materials

Swedish stakeholders within fuel and materials have composed and supplied input to the HRP mostly ad-hoc. This has been the case for the formal Swedish standpoints in preparation of new joint programme periods as well as for informal feedback to the present programme activities or for ongoing advocacy of Swedish interests. The formal Swedish standpoints on the joint programmes have been prepared in advance of a new three year period when the suggested programme has been made available by HRP. This is a concern exclusively for the consortium partners and other stakeholders are not consulted; hence, e.g. no academic institutions have participated in this process. The programme documents have been distributed to the consortium partners by the Swedish HPG representatives. All consortium partners are stakeholders within the fuel and materials area. The Swedish consortium partners have used scoring tables from HRP to compile the Swedish standpoints ever since such have been employed by the HRP for compiling the standpoints of the different member countries. Previously, a similar process of prioritising between suggestions was conducted through voting. The informants have reported that the different partners' standpoints on the programme have usually been similar and that the process of tallying the results has therefore been without complications. As a general practice the process has been concluded at a meeting organised by the Swedish HPG representatives, although this has not necessarily always been the case.

[46] Vattenfall majority shareholder.
[47] Vattenfall majority shareholder.
[48] Uniper majority shareholder.

The relative ease with which the formal standpoints of the Swedish partners are compiled may be related to strong informal coordination of research needs and interests. The management level R&D staff within industry and SSM's representatives have close professional relations. Such relations take place both in the context of general research and development issues as well as concerning technical matters within the context of supervision of the licensees, as both activities are part of the duties of the SSM representatives in the HPG. Additionally, the Swedish utilities have institutionalised research coordination groups that meet regularly, several times each year, to discuss fuel and materials research: 'Programgruppen för bränsle' (PGB, Eng. The Programme Group for Fuel,) including Studsvik as a participant, respectively 'Materialgruppen' (Eng. The Materials Group), in which only the utilities are permanent members. These coordination groups are organised by the utilities and SSM does not participate. The groups coordinate the general research needs of the nuclear sector, hence discussions are not mainly related to HRP. However, participants report that HRP activities are sometimes discussed at or in connection with meetings. Such a forum will clearly contribute to the coordination of Swedish industry as relates interests in HRP.

Informal networks related to HRP, and their formation, within fuel and materials
Informal networking between individuals in the Swedish fuel and materials area and HRP staff has mainly been established within the industrial sphere, through commercial relations or employees moving between HRP and Swedish employers. Since the coordination of Swedish input to HRP has been characterised by a low degree of formalisation and institutionalisation, deeply embedded individual experts have played an especially central part in exchanges between Sweden and HRP within fuel and materials. Informal networks and personal relations are important for the flow of information and opinions between Swedish stakeholders and HRP, more so being that much of the formal input to HRP is organised ad-hoc and sourced bottom-up, from the needs of the consortium partners, as established through interaction within their own discussion groups. The stakeholders who have interacted with HRP regularly have done so through individual contacts between experts in Sweden and at HRP, who share a personal connection. Questions and comments have generally been supplied by phone or email directly to operative HRP experts. That is to say, formal representatives, such as the Swedish HPG members, to a low degree have functioned as intermediaries passing on information between HRP and Swedish stakeholders, in between the planning of joint programme periods. Rather, there have been a few handfuls of informal brokers based in Swedish industry that have generated most exchange between HRP and Sweden. Notably, this also appear to be true for most of the enduring relations between academic institutions and HRP[49], although SSM has also, ad-hoc, mediated individual requests and projects directed to HRP, e.g. requests to view a specific report or facilitating the setup of a student thesis projects and the like.

A small number of key individuals have been identified and have contributed to the evaluation as informants. They also appear in contexts when a stakeholder has made repeated use of HRP, giving the impression that one instance of close collaboration or familiarity with HRP facilitates the exploitation of opportunities to regularly benefit from the HRP

[49] A few examples of the industrial basis of academic relations with HRP are the following: Westinghouse Electric Sweden has been deeply involved in Uppsala University's relations with HRP, for example collaborating around PhD students Ingvar Matsson (PhD 2006) and Scott Holcombe (PhD 2014, was also a secondee to HRP); utility company Ringhals AB is the long-time employer of Pål Efsing, also adjunct professor at the department for Solid Mechanics at the Royal Institute for Technology, having administered bi-lateral contracts with HRP worth on the order of several 10s of MSEK since 2005 on behalf of Ringhals and also providing the impetus to recent materials research on Halden samples at Chalmers University of Technology and at the Royal Institute of Technology; Norwegian company Thor Energy developing nuclear fuel technology based on thorium was the employer for industry-employed PhD student Klara Insulander, affiliated with Chalmers University of Technology (PhD 2015), who is now coordinator for the SNEC initiative (Sustainable Nuclear Energy Centre) at Chalmers.

collaboration. In addition to the examples given in the footnote to the above paragraph, there are two more notable key brokers. One is Jonathan Wright, former secondee from the UK to HRP but now a long-time employee of Westinghouse Electric Sweden. Wright coordinates the company's relations to HRP, which are extensive, incorporating needs of the utility companies, as customers of Westinghouse Electric, as well. Another example is Studsvik employee Francesco Corleoni, manager of the SCIP research programme and key account manager for Studsvik's customer relations with HRP. Francesco performed work for his PhD at HRP during the 1990s and still has close professional relations with HRP. His role is doubly significant since Studsvik not only is a significant stakeholder in the Swedish nuclear sector, but also because Studsvik administers much of the Swedish in-kind contributions to HRP. As mentioned, Studsvik stores samples from Swedish utilities and arranges for the transport of these samples to the Halden site. But being that they possess an overview picture of the available samples, they also support the consortium partners with suggestions and opinions about which in-kind contributions to offer and/or advocate. On the materials side, former SSM and earlier Studsvik employee Karen Gott was highly active in research and involved with a large network of expert within and outside of HRP.

5.1.2. The role and functions of HRP within the fuel and materials area in Sweden

Since Studsvik's last test reactor was shut down for decommissioning in 2005, the Halden reactor has been the closest and most readily accessible test reactor as regards the Swedish fuel and materials area. HRP has been the natural choice for irradiating samples for experimental purposes as far as Swedish nuclear industry has been concerned. In general, informants from R&D staff in Swedish industry have not demonstrated that they maintain an overview of alternative infrastructures offering similar services. Some have given examples of comparable service providers, however, several informants have also pointed out that finding information on a new facility and assuring its quality would be time consuming and costly. The same would go for transporting samples longer distances. Add on top of that, that HRP enjoys a reputation for high quality data, and the possibility to gain synergy from, or even replacing the need to buy services with, a test performed within the joint programme, and the access to HRP emerges as highly advantageous. Use of the Halden reactor for testing by Swedish academic institutions, either using results from joint programmes or agreeing on an experiment on a bi- or multilateral basis, is very limited, so HRP has played a very minor role for Swedish academy within fuel and materials. From the regulator's point of view, HRP has been one of several, if one of the major and more significant, sources of information to use to build knowledge and in some cases refer to, mainly in supervision. SSM's contribution to HRP is categorised as 'competency support' in the research budget, reflecting that the role of HRP results for SSM is of a basic nature. Although there are examples of direct use in supervision, operative work is usually supported by more customised research commissioned directly from other suppliers.

In addition to the fact that Sweden, since 2005, lacks capabilities to perform irradiation experiments domestically, HRP possesses some highly specialised capabilities when it comes to instrumentation and experiment design. Views on the level of specialisation differ between informants; some have asserted that the capabilities to record real-time data from within a test rig in the reactor during operation are unique to the world. Others have questioned such a statement or suggested that similar tests may be performed at other sites, it is however unclear if they have referred to the same quality of data or more generally to irradiation experiments. Additionally, these capabilities to produce real-time in-pile data appear to be more uniquely useful for fuel tests than for materials tests, as fuel lifetime and dynamics take place at shorter time scales than damages to and the lifetime of structural materials. We have not done a technical evaluation of HRP's infrastructures and hence cannot validate any of these claims. Several informants have stressed that participation in HRP has served to ensure access to this rare and conveniently accessible infrastructure. This access has also been argued to play a role as an insurance for industry, with capabilities for testing in case of unexpected irregularities, and an asset for the academy, for taking into account when planning research projects.

Functions of HRP in research and development within fuels and material
There are a few different ways in which HRP functions as an integrated component in research and development in the Swedish fuel and materials area. These range from direct operative use of research results to indirect, and more contextual functions.

The most direct use is found in the process of determining which fuel to load into nuclear power plants in Sweden. In Sweden, the utilities are fully responsible for all aspects of safety of the plants. Hence they are required to verify and demonstrate the safety of new fuels they wish to use in a plant, or of existing configurations based on new or updated regulations or guidelines. On the one hand, the utilities themselves have used HRP results when choosing vendor and make-up of fuel. On the other hand, when it comes to licensing and supervision of fuel, the fuel vendors take a central role, providing the utilities with documentation detailing the behaviour of the fuel, based on tests and calculations. A range of supporting knowledge is used in such documentation, and may include results from HRP joint programmes as well as tests performed on a commercial basis at HRP or elsewhere. HRP however reportedly has offered some advantages, for utilities/Westinghouse Electric Sweden and the regulator in Sweden alike. Results from the joint programmes have been available beforehand for both licensees and the SSM, which has led to familiarity with the data, and opportunities for both parties to analyse and draw conclusions. Such a common knowledge base, processed independently, has contributed to safe and secure licensing and supervision, according to the informants. In addition, many HRP tests are made on samples from Sweden, from the utilities or from Westinghouse Electric Sweden, ensuring next to direct applicability of the test data to Swedish conditions and fuel.

Utilities have also found direct use for HRP in demonstrating the safety of reactor materials for SSM in the context of supervision of a plant. One informant has explained that he has used HRP data to inform models for ageing and degradation. Such models provide support to verify the safety of materials and motivate practices for sampling of materials from a reactor core, for the purpose of demonstrating safety. According to the informants, data from Halden has in general been a crucial source for computational codes modelling of both fuel behaviour and of plant degradation. Westinghouse Electric Sweden has used HRP results to inform their fuel codes, but SSM has also commissioned analysis and modelling of fuel behaviour, mainly from JMM Quantum Technologies. HRP results have reportedly also been integral to many internationally available computational codes. One special area which has been highlighted as a significant contribution made by HRP during the evaluation period is the LOCA test series relating to fuel disintegration and dispersal. Results from these tests have been said to have provided novel understanding and contributed to revised acceptance criteria for the operational limits of nuclear power plants. It is also one concrete example when SSM has used HRP results as support when requesting that Swedish licensees demonstrate the safety of their operations in light of new knowledge.

On a more indirect level, HRP has contributed to sustaining a basic level of fundamental research and development for the Swedish fuel and materials area. The ongoing testing continuously contributes to the knowledge base of the Swedish consortium partners and pushes development. Both the industry partners and SSM's representatives have stressed this function as essential, although difficult to specify in detail, being that most of the HRP results have been reported as raw data and need to be analysed further. Hence, it is only in the context of the international collaboration and other research and development activities that they come to their full use. This function of contributing to fundamental research and development needs, has to a significant extent been accommodated within the joint programmes. Related to this is the fact that much testing is done on samples from Swedish industry, which has removed many uncertainties and therefore contributed to very high validity of the HRP results for Sweden especially. This is an added value for the industry partners as well as for SSM, who are invested in ensuring highest possible certainty in the demonstration of safety aspects. Tests on Swedish samples have also increased the probability of results incidentally becoming relevant for a concrete operative need, if an issue appears in a Swedish plant on a component with common, or even identical, properties as one tested by HRP. In addition to the function of the joint programmes, some of the consortium partners has made significant use of commissioning HRP to perform certain tests, notably Westinghouse and Ringhals. They then enjoy the benefits described above when choosing HRP as one of a selection of service providers.

HRP has not fulfilled significant functions for academic research in Sweden. HRP may have been known to researchers within the field of nuclear or reactor technology. However, being that academic institutions have not been included in the collaboration, even those academic researchers who have known of HRP have lacked a window into and overview over HRP's activities and tests. A few informants from academia who have indeed acquired such an overview assess that access to the HRP documentation database could stimulate curiosity driven explorative research and contribute significantly to education and thesis projects on both pre and post graduate levels, within the niche segment of nuclear fuel and materials.

Specific examples of sequences of impacts of fuel and materials results in Sweden

Supervision of declaration of use of TVEL TVS-K fuel at Ringhals 3
In 2013 the utility company Ringhals made a declaration to SSM regarding the introduction of vendor TVEL's fuel TVS-K as demonstration fuel in the plant Ringhals 3. SSM examined the declaration and requested a number of measures to be taken to supplement the declaration. One of these measures related to the documentation surrounding the behaviour of the fuel under LOCA conditions. The documentation supplied over verifications of the safety under these conditions related to hollow fuel pellets and not massive, as in the case of the fuel to be used in Ringhals 3.

In their response, Ringhals referred to tests performed within HRP joint programmes and at the Russian research reactor MIR. The tests had demonstrated that hollow and massive fuel pellets are comparable at LOCA conditions. Fuel disintegration and dispersal was similar as well as behaviour as regards ballooning and rupture of fuel rods. SSM could conclude, based on the documentation, that Ringhals and Vattenfall Nuclear Fuel had sufficient detailed information on material properties and fission gas release to evaluate the difference between hollow and massive fuel pellets. The resolution of the issue contributes to the potential introduction of the TVS-K fuel on the Swedish market, as the safety of the fuel has been demonstrated, which can be assumed to lead to increased diversity and competition in the market for nuclear fuel.

Informant: Anna Alvestav, SSM

Documentation: SSM (2015). *Ringhals 3 - Verksamhetsbevakning angående åtgärdspunkterna från TVS-K granskningen.* SSM2015-3902-1. ; SSM (2013). *Ringhals 3 - Anmälan om införande av TVS-K från TVEL som demonstrationsbränsle RA14 enligt SSMFS 2008:1 4 kap 5§.* SSM2013-5889. ; Wiesenack (2013). *Summary of HRP LOCA test series IFA-650.* Presentation given at the 2013 EHPG meeting in Storefjell.

Impacts of HRP IASCC materials testing on planned maintenance
An early development which has laid a foundation for further materials testing conducted on behalf of the utility company Ringhals, during the evaluation period, traces back to IASCC testing of material from control rods in the early 2000s. The samples were offered from Swedish plants Barsebäck and Oskarshamn to test material degradation with a view towards learning about the long-term integrity of standpipes, scheduled for removal and replacement in several Swedish nuclear power plants. The samples from the control rods matched the material and conditions in the standpipes.

Tests soon demonstrated limited degradation and sustained integrity of the materials. The maintenance programme for removal and replacement of standpipes was discontinued and the components could be left in the plants for long-term operation. This reduced waste and resulted in cost savings on the order of several MSEK per plant. The test results demonstrating the integrity of the material was obtained within the joint programme.

Since the initial materials tests early 2000s, Ringhals has repeatedly commissioned HRP to perform tests to contribute to the long-term operations programme of the utility, as noted in the chapter above. The common denominator being previous Barsebäck employee Pål Efsing joining Ringhals from 1999.

Informant: Pål Efsing, Ringhals AB

Documentation: HRP (2001). *In-pile crack growth behaviour of irradiated compact tension specimens in IFA-639 (second interim report).* HWR-675.

HRP's function for knowledge dissemination within fuel and materials
HRP organises conferences, workshops and summer schools which Swedish participants frequent. These different platforms contribute to the dissemination of HRP results but also of more general knowledge of the fundamentals and developments within the fuels and materials area. The EHPG meetings have been regarded as a valuable platform which fulfils several functions for the participants, however more so for fuel experts than for materials experts, in line with HRP's exclusive standing within fuel testing. Firstly, the EHPG meetings have offered an efficient and first hand summary of the results of the joint research programmes. This has facilitated the process of understanding and absorbing the conclusions and knowledge from the tests. Secondly, they have been a meeting place for a major part of the global fuel and materials community, and have hence been prime opportunities for building relations and networks, although not only with international peers, but also with domestic collaborators and business partners. Finally, the informants have reported that the EHPG meetings, and other HRP events and meetings for that matter, have offered a rare opportunity to get insight into what is on the agenda in

other countries around the world. Hence, the participation in HRP has filled a function of monitoring the developments in the fuel and materials area, globally. These functions have been described in common terms for the consortium partners and associated industry partners, such as Studsvik, alike. HRP's events have also served the purpose of training and introducing new staff to the fuel and materials area. Industry partners have confirmed that they have willingly sent new employees to participate in summer schools and to visit Halden. A few respondents have also described a strategy of sending one senior and one junior staff member to EHPG meetings, to allow for the senior employee to introduce their junior to the context.

Academic researchers have reported that the EHPG meetings have not offered the same academic merit that other conference contributions do, and that they are very niche events, limiting their relevance from an academic perspective. Another circumstance that distances academia from HRP is the publication practices employed. Few HRP results have been published openly, even after the five years of confidentiality have passed, and even fewer in academic journals. This has been assessed by the informants to significantly limit potential scientific impacts from HRP results.

5.2. Swedish usage of HRP within the MTO area

This section details the results of interview studies as regards how the Swedish stakeholders within MTO relate to and make use of HRP.

5.2.1. Swedish stakeholders and networks within the MTO area

Not all consortium partners are deeply invested in the MTO area, making the group of core industry stakeholders even more limited in the MTO area than within fuels and materials. Out of the partners, the utilities and SSM are the main stakeholders, since MTO is not a significant area of concern for the nuclear fuel companies. In addition to the consortium partners, another important industry stakeholder is the nuclear power safety and education provider 'Kärnkraftsäkerhet och utbildning' (KSU). KSU is an independent company that is owned jointly by the Swedish utilities. They are not a formal partner in the joint programmes, but have a separate agreement with IFE. Furthermore, other Swedish industry actors and high tech facilities have contracted Halden for work in relation to control rooms, e.g. mining and minerals group LKAB and the ESS (European Spallation Source) research facility.

At SSM there has been one research coordinator responsible for the participation in HRP, representing Sweden in the HPG for MTO. Within the same unit, there is a handful of SSM employees working with supervision in the MTO area. In addition, some of the work within the HRP MTO programme has been relevant for staff in the radiation protection department. As for the fuels and materials area, it has been the responsibility of the HPG representative to disseminate results from HRP to the relevant recipients.

There are many academic institutions in Sweden where research is conducted on human factors, design and digital and cognitive systems. As far as we have been able to determine, only two of these have been significantly involved with HRP over an extended time period: Chalmers University of Technology and Linköping University. In addition, the Swedish Defence Research Agency, (Totalförsvarets Forskningsinstitut, FOI), has performed some commissioned research for SSM in the MTO area, at the institute's Linköping site.

In summary the main stakeholder organisations in the MTO area are the following (consortium member contributing to the membership fee in bold):

- Industry
  - Utility companies
    - **Forsmarks kraftgrupp AB**[50]
    - **Ringhals AB**[51]
    - **Oskarshamnsverkens kraftgrupp (OKG) AB**[52]
  - Kärnkraftsäkerhet och utbildning (KSU)[53]
- Public sector
  - **SSM**
    - Department of Nuclear Power Plant Safety
      - Man-Technology-Organisation unit
- Academy
  - Chalmers University of Technology
    - Product and Production Development Department
      - Design & Human Factors Division
  - Linköping University
    - Department of Computer and Information Science
      - Human-Centered Systems Division

Governance and coordination of participation in HRP within MTO

HRP has been governed and coordinated in a similar way in the MTO area in Sweden as in the fuel and materials area, with the exception of significantly more systematic coordination of the commercial relations. Hence, there is likely to also have been more systematic informal feedback from industry to ongoing joint programmes. Formal Swedish standpoints on new programme periods have been prepared ad-hoc, as HRP has made available the suggestion for a new programme. SSM's representative for MTO in the HPG has compiled the views on the new programme. Out of the consortium partners, only the utilities have taken part in this process, and no outside stakeholders. Hence, the circle of decision makers has been even smaller within MTO than in fuel and materials. The process has usually concluded with a physical meeting.

The systematic coordination of industry stakeholders within MTO in relation to HRP has taken place in the HAMBO group. It is similar to coordination groups in fuel and in materials, but with significant differences. HAMBO is dedicated to coordinating bi- and multilateral programmes between HRP and utilities, and is in fact in itself a multilateral programme financed by the participating utilities. HAMBO formed in conjunction with the establishment of the simulator HAMBO based on Swedish nuclear power plant Forsmark 3. Furthermore, HAMBO is a joint group for utilities in Sweden and in Finland. The fact that there has been a parallel ongoing multilateral programme for Swedish utilities within MTO has ensured that needs and interests of Swedish utilities have been well

[50] Vattenfall majority shareholder.
[51] Vattenfall majority shareholder.
[52] Uniper majority shareholder.
[53] Owned jointly by the utilities.

established. The HAMBO group and its significance for the Swedish participation in HRP is detailed further below.

Informal networks related to HRP, and their formation, within MTO
In comparison with the counterparts in the fuel and materials area, the HAMBO group has been a more significant interface between Swedish utilities and HRP. In a sense, it has been *the* forum for exchange, being that HRP representatives participate actively in the meetings that have taken place regularly, several times a year. The utilities' informal networks appear to have been strongly related to this group, and several informants have referred to the collaborations related to HAMBO as the main context in which they interact with HRP. In addition to the HAMBO group, there has been significant interaction between operators at the utilities and HRP, being that they have participated as subjects in experiments conducted at HAMMLAB. Such interactions have contributed indirectly to building strong informal networks between Swedish utilities and HRP, since Swedish operators have been employed by HRP as process experts. A few of these ex-plant-operators have also been standing participants in the HAMBO meetings, offering in-depth insight into the design and functionality of processes and systems in Swedish plants.

Outside the participants in the HAMBO group, informal networking between the MTO area in Sweden and HRP staff has followed similar patterns as within fuel and materials. There has been a low degree of formalisation and institutionalisation of SSM's internal governance of the participation in HRP and of relations with additional stakeholders in industry and academia. Individuals with personal relations built on instances of extensive professional involvement in HRP activities have functioned as intermediaries for establishing several of the lasting collaborations. One example is the auxiliary industry stakeholder KSU, for which the currently most active collaboration was initiated through a contact supplied by Helena Broberg, previous employee of KSU and of HRP. KSU has a formal agreement with IFE as a service provider through which they also gain insight into the MTO testing within HRP. A long-standing relationship between Linköping University and HRP goes back to Erik Hollnagel, leading international safety researcher, for a time employed at HRP and later at Linköping University. Hollnagel's network with HRP and s series of joint workshops have been sustained by a colleague as Hollnagel has left Linköping. SSM has also contributed to lasting academic collaboration between Chalmers University of Technology and HRP through financing special PhD projects, one ten years back and one recent. SSM's representatives in the HPG for MTO have also noted the role that in-depth professional exchange plays to establish networks and have therefore shifted the responsibility for participating in the HPG as a strategy for distributing the networking among the staff.

5.2.2. The role and functions of HRP within the MTO area in Sweden

HRP has not been as unique in the MTO area as within fuel and materials. The informants have pointed out that the Finnish research institute VTT has possessed similar capabilities. However, there has certainly been no corresponding infrastructure available in Sweden, and hence HRP has been a valuable partner for the Swedish nuclear sector. In addition to the infrastructure, HRP has also amassed a concentration of expertise not matched by many, certainly not domestically in Sweden. HRP has mainly been used as a resource by Swedish industry, the utilities, KSU, and to some extent other advanced technology or production facilities. For SSM the role has been similar as in the fuel and materials area, as HRP has been one of the main knowledge sources to draw from for verifying claims and increasing understanding. The views of the informants was that HRP has not been generally known among academic researchers within human factors or cognitive science, and hence has played a very minor role for the academic sector in Sweden. The scope of research has also been also narrow, limiting its relevance mainly to researchers with a specific interest in the nuclear sector.

The question of the uniqueness of the infrastructure is not as easily discussed as is the case for the Halden reactor, perhaps owing to the different nature of the underlying scientific disciplines. However Halden has been openly available for commissions within the collaboration, and a few of the informants have claimed that they have not been aware of any alternatives to HRP.

Functions of HRP in research and development within MTO

Results from the HRP in MTO have been used in the Swedish nuclear sector, mainly in industry, although not as directly as in fuel and materials. The informants have reported that most of the research in the joint programmes has been difficult to implement due to different factors. One reason has been that research has been perceived as quite abstract and academic. Results obtained on a principle level have been difficult to translate to concrete practices. Another circumstance that has limited the implementation of HRP results has been that upgrades of the control rooms and systems are generally quite rare, so there have been limited opportunities for changing and updating them. Finally, several informants have explained that technical solutions for separate digital instrumentation and control system issues, although desirable, may be difficult to incorporate in a system, even if a complete upgrade is made, as the vendors have generally offered products in the form of already developed complete systems. They report that it has proven to be difficult to convince vendors to put additional time into developing custom products.

The HAMBO group has been one major context where the HRP results within MTO have found use. As mentioned, it has in effect been a multilateral supplementary programme to the joint programme, comprising the Swedish and Finnish utilities. The HAMBO group has served as a platform to coordinate efforts to draw from the results of joint programmes to develop prototypes and specifications to be used when placing orders for vendors of control system solutions. Thematic areas that have been investigated within the context of the HAMBO group are for instance large screen displays, and alarm systems. The HAMBO group and its significance for the Swedish participation in HRP is detailed further below. Other than in the HAMBO group, Swedish utilities have used the HRP results and expertise in the context of validation. HRP has developed methods for integrated system validations, which Swedish utilities have learned from, but they have mainly found use in direct commissions for validating upgrades in Swedish plants. Such commissions have been performed on several Swedish plants for the different utilities. This has been one context in which the collaborative nature of the HRP have contributed to the validity and reliability of supervision of the nuclear sector, as the fact that SSM has access to and follows HRP results has reportedly facilitated their ability to interpret and asses documentation from the licensee.

HRP MTO results have found more direct use in a limited niche of the nuclear sector, namely within operator training and education. The operator training and education provider KSU has assimilated several concepts, tools and even exercises, in addition to gaining insight and new perspectives on assumptions and general principles. One specific example is detailed below, but the informants have supplied more. KSU have found use and made conclusions from different evaluation tools developed by HRP. HRP research has also been important by having provided concepts – e.g. regarding the fundamentals of teamwork – that have been used for developing education for teams of operators and team leaders. More examples have included lessons learned by observing that simulator likeness to actual systems does not necessarily promote the learning of operators in training. Rather, the understanding of the process may improve more by a more efficient representation of process details in a simulator interface. Finally, the HAMMLAB infrastructure capabilities for recording data on experiments for analysis, have provided inspiration as to how training sessions may be documented for evaluation purposes. A related but indirect auxiliary result of the HRP activities have been the effects on Swedish operators that come to participate as subjects in experiments. The training effects on these operators has reportedly been marginal. However, participating in these experiments have been reported to have opened the eyes of operators for alternative possibilities for control rooms and systems, which has influenced them to contribute actively to various development projects.

As for academia, circumstances have almost been opposite as for industry, as HRP has been described as a highly niched facility, which has limited the opportunities for collaboration for academic researchers. The informants have explained that collaboration and joint projects have been initiated ad-hoc, based on specific projects or instances when common interests have been identified. Most examples of collaboration have consisted of thesis projects, on different levels. However, as for the fuel and materials area, academic institutions have not had access to the HRP results other than through SSM or personal contacts within HRP, which likely has meant that this assessment has been based on limited insight into the scope and extent of HRP's activities.

Specific examples of sequences of impacts of MTO results in Sweden

Establishment of the HAMBO group and its use for prototyping and specifications
The HAMBO group was established in the early 2000s in connection with the decision by the Swedish utilities to allow HRP to build simulators based on Swedish plants. The utilities recognised an opportunity to increase the benefit from this development through collaborating on the Swedish and Nordic markets. The HAMBO group has functioned as a forum to concretise the results from research within the joint programmes by developing prototypes and specifications to be used when placing orders with vendors, as it has proven difficult to implement joint programme results.

The activities have included alarm reduction and alarm presentation prototypes, the latter of which has been used as a foundation for specifying details in the order for an actual upgrade at the Oskarshamn 2 plant. Activities have also included concepts for large screen displays, which have been applied in other upgrade projects. Both of the two upgrades that have been completed at Oskarshamn plants during the evaluation period have included elements of HAMBO results to specify various details. HAMBO results have reportedly been used in a similar way in upgrades at other utilities during the evaluation period.

The establishment of the HAMBO group has been a direct result of the participation in HRP, and would likely not have been feasible without the national membership. The HAMBO group in itself may be regarded as an impact, as it is a forum for coordinating developments within MTO in the Nordic nuclear sector, which is likely to lead to synergies between utilities for improved performance in upgrades. However, while HRP has been regarded as a unique provider of these services, this might also be problematic, as it means there is no competition on the specific niche market.

Informant: Thomas Gunnarsson, OKG AB

Documentation: HRP (2007). *Halden reactor project workshop on human system interfaces (HSI) design and evaluation.* HWR-865 ; HRP (2010). *Large screen display for the HAMBO simulator, based on information rich design.* HWR-934. ; HRP (2011). *An empirical qualitative study of the Information Rich Design BWR Hammlab Large Screen Display.* HWR-1023. ; HRP (2011). *Large Screen Displays – a Usability Study of Three Different Designs.* HWR-1025.

Direct use of an exercise and evaluation tool for operator training

During the last complete programme period HRP developed the evaluation tool SCORE, and accompanying exercises, as a new methodology for integrated system validation. The development of the tool included experiments with teams of operators performing exercises specifically designed for this purpose. In the present example, the concerned exercise included control room operators and the emergency preparedness organisation working together in a severe accident scenario.

The exercise and the evaluation tool were directly adopted by KSU for the training of 14 teams of operators at two Swedish plants during 2016. There are plans for training sessions at another two plants at the same power station, and, reportedly, the other power stations will likely identify a similar need. The evaluation of the exercises found that the level of difficulty was appropriate and that learning objectives were satisfied.

This is one concrete example when HRP results have been used for the training and evaluation of staff at Swedish nuclear power plants. This example shows clearly the direct impact of HRP as both the exercise and the evaluation tool could be implemented without prior adjustment. Other examples range to more indirect and sequential impacts.

Informant: Bjarne Widheden, Kärnkraftsäkerhet och utbildning AB

Documentation: HRP (2015). *Halden project programme achievements 2012-2014.*

HRP's function for knowledge dissemination within MTO

The EHPG meetings have filled a very similar functions within MTO as within fuel and materials. The informants have described the way in which an EHPG meeting have offered a good overview over the research results. In addition, it has also been a venue for networking with peers from Sweden and all over the world, and has offered insight into what topics and issues have been on their agenda. As for academic researchers, the informants' perceptions have also similar as within fuel and materials. While it may have been a good venue to network with people within this specific field, it has not been a very high profile event and it has been quite specific, making it less relevant than some other conferences. As regards the publishing practices, it seems they have been less restricting in MTO, and the informants report to have found use of HRP reports and conference papers. However, the lack of peer review of HRP results in MTO have been identified as a disadvantage, from a quality assurance perspective. The informants at SSM assumed that increased academic collaboration with HRP would benefit both the Swedish nuclear sector and HRP itself.

5.3. Peer country usage – Finland and Switzerland

We close this chapter with a short section presenting the findings from the international outlook on the participation in HRP in Finland and Switzerland.

5.3.1. HRP's role in an international perspective

An international perspective on HRP lends credibility to the collaboration's important role. A few of the characteristics has made HRP stand out, especially during the last decade or so. It has to do with the fact that as international collaborations in nuclear safety go, it has been one of a kind with respect to its longevity and scale. Much of the research performed within HRP has not been feasible to finance domestically for smaller countries such as Sweden, Finland and Switzerland. As such, the activities have supplemented research that has been conducted domestically. Reportedly, the uniqueness of the capabilities offered by the Halden reactor infrastructure will be challenged as the Jules Horowitz test reactor in Cadarache, France, becomes operational. The Jules Horowitz reactor will offer similar capabilities and is also open for international collaboration. However, the combination of research on both fuel and materials, and MTO, in one facility, appears to have been unmatched. In addition, HRP's expertise in instrumentation and experimental design has been well noted.

5.3.2. The organisation of Finnish usage of HRP

In Finland, the signatory member and financier of the collaboration has been the Ministry for Employment and the Economy. The Ministry has also financed and governed the national programme for nuclear power plant safety research, SAFIR, which is the context within which the participation in HRP takes place. The formal representation of Finland in HRP has then been distributed on the regulatory body, STUK, and the main TSO, the state owned research institute VTT, operating with a national mandate. STUK has represented Finland in the Halden board and has appointed VTT staff as representative in the HPG.

The Finnish strategy for international cooperation within nuclear reactor safety research has been recorded in the strategy for the SAFIR programme.[54] International collaboration has been regarded as an essential and indispensable supplement to domestic research, and one objective of the national programme has been to help prioritise between international projects. The national research has also served the purpose to increase the benefit from international collaboration, by conducting parallel and supplementary research domestically, which has been said to lead to multiplying the benefit from international collaboration. The Halden project has been assessed as one of the most important of these international cooperation programmes.

In practice, the coordination of Finnish input to HRP has been organised in national research coordination groups, matching the thematic areas of the HRP. These groups have met in the context of the national research programme, to follow up on HRP as one of their tasks. Experts from STUK, VTT, other public agencies, industry and academia have all participated. The process of influencing the HRP programmes has begun before the suggested programme has been prepared by HRP, as the participants of the technical coordination groups have begun to grasp what has been on the agenda for a new programme period. The groups have made inventories of the national needs and interests from HRP and have produced internal reports to document the Finnish standpoints. This has been used to communicate Finnish interests to HRP, and has formed a supporting material for the formal process of compiling Finnish standpoints, when the draft programme has been made available. This process has been concluded with an open meeting

[54] Finnish Ministry of employment and the economy (2010). *National Nuclear Power Plant Safety Research 2011-2014. SAFIR2014 Framework Plan.*

when the HRP goes on its world tour to present the programme and final discussions and amendments made following this meeting. The Finnish utilities seem to have had a similar relation to HRP as the Swedish utilities. They have had their own research coordination groups and programmes, and have made use of HRP bi-/multilaterally.

The amount of working time spent by employees at the regulator STUK and main TSO VTT depends on how working time in relation to HRP is defined. The minimum to sustain the collaboration is participating in meetings and preparatory and subsequent work in connection to these meetings. The informants have assessed that such activities take up around two week's per year for each employee involved. At STUK less than a handful of staff members have been involved, some of which have spent a little more time on writing reports on HRP research, in total amounting to some months' worth of working time spent on HRP yearly. Within VTT, there are a few researchers working on research directly related to HRP activities, whose working time subsequently amounts to several years' worth of working time per year, as a part of VTT's own research budget. The informants stressed that national research activities designed to exploit synergies with HRP research is essential for harnessing the full benefit of participating in the collaboration.

5.3.3. The organisation of Swiss usage of HRP

The Swiss system has been similar to the Finnish, however, the membership has been administered by the regulatory body ENSI, having payed the Swiss contribution as well as having represented Switzerland in the Halden board. The Swiss regulatory body has also appointed experts from the main TSO, the Paul Scherrer Institute, PSI, primarily financed by the Swiss Confederation, to represent Switzerland in the HPG, together with experts from ENSI.

The main aim of the Swiss research strategy has been to investigate open issues within nuclear safety, but also to receive support for supervision and promote expertise and knowledge within ENSI and among independent experts.[55] International collaboration has been regarded as one desirable component in the strategy, filling the function of providing research that could not be conducted domestically, which has been assessed to be the case with the research conducted at HRP, in both programme areas. Another aim has been promoting the integration of the Swiss experts into international networks, something which has also been fulfilled by the collaboration within HRP.

Coordination of the collaboration has taken place in the Swiss Halden Committee and two technical committees, for the respective research programmes. The committees have met every six month to discuss developments of HRP, timed with HPG and Halden board meetings. The technical committees have expanded their scope to become platforms for discussing research developments in general, as twice yearly has proven to be too often to discuss only HRP. The Swiss utilities have reportedly been less active within the joint programme, and bi-/multilaterally, although there was active participation due to one employee at one utility, who had a strong academic research background. This individual e.g. arranged for samples to be sent to HRP as an in-kind contribution, for testing. After that specific employee retired, the utilities have participated through the common organisation 'swissnuclear'.

[55] ENSI (2013). *ENSI's Research Strategy*.

The amount of working time spent by employees at the regulator ENSI and main TSO PSI has been estimated to compare closely with the Finnish participation. Covering the necessary meetings within HRP takes up some weeks per year for the handful of employees that participate. In addition to that, there is working time spent processing HRP results, making the total working time for employees at ENSI amount to some months per year. Just as Finnish TSO VTT does, PSI also conducts research for which HRP is directly relevant, occupying a few of the institute's researchers full time. However this is part of the institutes own research and not financed through an external budget. Also the Swiss informants stress the importance of coordinating HRP projects of national interest with supplementary research performed domestically to ensure that the Switzerland enjoys full benefit from the collaboration.

6. Analysis of the impacts of HRP in Sweden

This chapter contains the analysis of the empirical material from document studies and interviews within the theoretical framework for the study. We begin with describing the types of impacts that have been identified within different institutional spheres, also commenting on the extent to which they are realised, and also pointing out potential impacts that have not been exploited. Thereafter follows an analysis of the additionality of these results, and of Swedish proximity benefits from an international comparative perspective. The chapter closes with a general discussion referring to the remaining elements of the theoretical framework.

6.1. Types of impacts and their realisation in different institutional spheres

The presentation of impacts is organised based on the theoretical framework, dividing them into socioeconomic – industrial and institutional – and scientific impacts. However, we begin with describing the impacts that have been common to all involvement in HRP.

6.1.1. Impacts common to several institutional spheres

While the impacts of the participation in HRP have clearly been most extensive for industry stakeholders, there have been impacts that have been common also to the other institutional spheres. These impacts have on the one hand been related the main purpose of HRP, to produce research results, and on the other hand to a common thread of learning and increased knowledge embodied by individuals that have interacted with HRP. We have made the following categorisation of these impacts:

- Cumulative research and development
- Networking
- Monitoring of research and development in the nuclear sector
- Education and training

The first point relates to the main purpose of HRP, to produce research results. It appears that HRP has in fact served the purpose of replacing what would otherwise have been conducted as domestic research and development, in industry and within SSM. That is, HRP seems to have become an integral part of research and development in the Swedish nuclear sector, sustaining much of the ongoing strategic knowledge activities. This has been especially true for Sweden, and for industry, being that samples and operators from Swedish utilities have been involved in significant proportions of the HRP experiments. It has also been supported by statements from the informants that it would have been difficult to replace HRP, either for it being unique or alternatives being prohibitively expensive. The large sums payed for commissioned research in bi- or multilateral programmes, in fact greatly exceeding the Swedish membership fee, also give witness to this significance of HRP in Swedish nuclear safety research and development. The SSM has not had any research and development of its own, but the informants have described a similar impact from HRP, of having sustained an ongoing accumulation of knowledge and investigations of new issues and circumstances. Academia has not been impacted in the same way, as most HRP results have remained undisclosed to academic researchers.

The participation in HRP has also impacted the level of knowledge of individuals that have been involved. The more extensive the involvement, the more extensive the impacts that have been recorded, and most of all for the individuals that have spent time as employees at HRP, as they have managed to realise quite extensive and lasting results in the form of concrete development projects and lasting relations as they have moved on in their careers. The examples given in the preceding chapter indicates towards significant systemic impacts in accordance with the sequences of impacts framework. However, there are also clear indications, from the extensive participation in HRP events and meetings, especially by Swedish industry, that the impacts on contextual knowledge is significant. Informants who have participated in e.g. EHPG meetings have described their impact on networking with experts both internationally and domestically, as well as an important contribution in the form of an overview of topical issues in the international nuclear safety community. The educational impacts of the HRP have also been reported to have been competitive, not least the summer schools where Swedish participants have made up a significant proportion.

6.1.2. Industrial impacts

The impacts of Sweden's participation in HRP have mainly been realised in the industrial sector. In addition to the significant role that the collaboration has played as an integral part of the industry's ongoing research and development, we have identified impacts that may be categorised as follows:

- Direct knowledge productivity
- Technology (and methodology) transfer
- Business opportunities

Direct knowledge productivity refers to the fact that knowledge is in effect a productive factor in the advanced technology and highly regulated nuclear sector. To take a plant into operation with new fuel, after years of material exposure and degradation, or after an upgrade of control rooms or control systems, requires that knowledge be used to verify the safety of the operations. Without knowledge, there would be no production, and the results from HRP, in fuel and materials even results taken directly from the joint programmes, have been used for this purpose. This is an even more direct impact of the participation in HRP than the more long term ongoing research and development function that it fulfils. Oftentimes, for this impact to realise, the Halden results have needed to be supplemented by additional investments, for example in analysis and computational models within fuel and materials, or through commissioning validation services of control systems.

We have identified transfer of technology and methodology as an impact especially within the MTO area. The HRP instrumentation and reactor technology does not appear to have similar counterparts in the Swedish fuel and materials area and this type of impacts has therefore been limited, perhaps with the exception of techniques and evaluation methods to verify the safety of ageing materials, for which Ringhals has employed HRP. As for the MTO area, the HAMBO group has been a forum dedicated to promoting technology transfer from HRP to Swedish industry. This has proven to be difficult and should therefore be considered a minor impact, even if there have been successful examples. Transfer of validation techniques, and accompanying tools and theories, have also made a significant impact on the training of Swedish operators through KSU.

Finally, mainly Studsvik has been able to exploit business opportunities by shifting from competition to collaboration with HRP, after Studsvik's last own test reactor was shut down for decommissioning in 2005. Procurement from Sweden, used as a proxy for business opportunities, is not as extensive as the membership fee taken over the three programme periods investigated, but it is comparable.

6.1.3. Institutional impacts

As stated above, the HRP has contributed in a similar way to the accumulation of knowledge within the SSM as within industry. SSM's employees have also been strengthened in the same way through networking and learning. However, due to the character of the regulatory framework, the HRP results, technologies and methods have not been as directly applicable in SSM's operations, as within industry. It is the licensees who are responsible for demonstrating the safety of the nuclear power plants, hence SSM has neither conducted tests nor stipulated in regulations how this is to be done. Hence, the main impact on SSM has been the following:

- Supervision support

SSM has used HRP results as one of several sources when supervising the Swedish licensees. The collaborative nature of HRP has increased the impact that HRP results have had, through opportunities to analyse data beforehand and through getting multiple second opinions on the interpretation of results from peers in the international nuclear safety community. In short, HRP results have helped SSM ensure the safety of Swedish nuclear power plant operations. One concrete example is the additional verifications that were requested as the HRP LOCA test series showed unexpected results in the form of fuel disintegration and dispersal.

6.1.4. Scientific impacts

Scientific impacts have been significantly more limited than both industrial and institutional impacts, especially if regarded across all potential participants in academic institutions in Sweden. While most of the main industrial and public stakeholders have been directly involved with HRP, the academic stakeholders have only been involved as an exception. Such involvement has to some extent provided the common impacts detailed above, albeit to a lesser extent, since the field is narrow and the fact that the context is skewed towards authorities and industry. However, it has also supplied minor impacts in the following form (we mark the impacts with a star to denote that the impacts have not been generally distributed among relevant stakeholders):

- Thesis projects*
- Reference research*

The most extensive use of HRP in the academic sector appears to have been collaboration around thesis projects, for students or for PhD students. We have encountered more instances of such collaboration, than of joint projects resulting in academic publications. This might be due to the fact that publishing in academic journals has not been a general practice at HRP and thesis project have therefore been more fitting for the context. Similarly, HRP results have mainly been used as reference results to contextualise current research projects. Since HRP results have rarely been published in academic journals, it is our impression that they are rarely cited, and hence have not been used explicitly for supporting claims or arguments in the academic research. Both the organisation and the publication practices of HRP have clearly been detrimental as regards achieving scientific impacts.

Two types of impact one could expect, but which we assess not to be fulfilled to any significant extent, is on the one hand joint research and publication, and on the other hand, the use of data repositories and other documentation as an asset for research and education. On the first note, as was stated above, we have found few instances of collaborative research projects among the Swedish academic researchers who have been involved with HRP, apart from PhD thesis projects. Senior academic researchers appear not to collaborate or co-author journal articles with HRP staff on a regular basis. On the second note, none of our informants have had access to the HRP documentation, which has clearly hindered the use of this wealth of information for curiosity driven research or for educational purposes.

6.2. Additionality of the impacts of HRP in Sweden

Additionality refers to the extent to which the impacts of HRP in Sweden can be argued to have amounted to added value, as compared with an alternative use of the membership fee. This question depends on the possible alternative uses of the funds. As noted in chapter 2, SSM has divided its research budget into competency support and supervision support. In addition to international collaborations, such as HRP but also the SCIP programme, competency support has encompassed funding of researcher positions and open calls for research proposals. The supervision support has mainly consisted of commissioned research. As international collaborations go, there have been no comparable alternatives to HRP, and will not be until the Jules Horowitz reactor becomes operational. The main alternative has therefore been more domestic research funding, of different varieties, although it is doubtful whether the use of the funding for domestic research projects would have led to similar effects as participation in the HRP, given the latter's role as a research infrastructure with great importance for the concerned technological innovation system in the Nordic countries. The question of what impacts could have been achieved from domestic research funding of the same amount as the membership fee is unavoidable but somewhat wrongly put, given the differences in character of different types of research funding (cf. the discussion on functional differentiation in chapter 2).

The research conducted within HRP would not have been possible to repeat in Sweden. There have been no facilities which have offered the necessary capabilities. Hence, the impacts in terms of new knowledge have complete additionality, as the Swedish membership fee would not have gone far towards building a corresponding facility unilaterally. Speaking in the terms of functional differentiation, there is no corresponding institution within the Swedish system which fulfils the function that the HRP does. Hence, it is not surprising to discover this systemic role. Discussing this systemic role further, one should include the interplay between HRP and Studsvik during the time when Studsvik was still operating test reactors in Sweden. This however predates the limitations of the study and we leave it as an open question. Furthermore, there is a consortium of partners contributing towards the Swedish membership fee, which can be regarded as a multiplier effect from SSM's perspective. Industry does contribute to funding research directly, e.g.

through the Swedish Centre for Nuclear Technology (SKC). However, the willingness to pay for the membership in HRP is clearly related to the specific nature of the HRP capabilities and significant relevance for industry, i.e. its function in the technological innovation system. Hence, the actual amount that would have been available for alternative uses would have been lower, closer to the amounts that SSM contributes itself.

A domestic research programme amounting to 3 MSEK yearly would have produced some more research results domestically, adding on the margin to the existing national research, however we assess that the impact of such an addition would have been negligible in comparison with the impacts recorded in the evaluation. The HRP mainly produces data, the knowledge production from which is multiplied by analysis performed and additional research commissioned by the stakeholders, amounting to working time and monetary values more than doubling the investment made through the membership fee. This argument is especially strong since the bi- and multilateral programmes are highly dependent on the participation in HRP as they build on the results from the joint research. In addition, the participation in HRP has had significant impacts on the knowledge, skills, networks and international outlook of experts in both research areas. These impacts are auxiliary to the production of new knowledge, but are difficult to imagine how to reproduce using the domestic research funding, without financing a correspondingly high profile and established platform and content production for the necessary meetings to take place. The only potentially low additionality impact we can identify is the business opportunities for Swedish industry due to HRP's procurement of goods and services. They do not seem to be conditional upon the Swedish participation but are probably more related to the proximity of Swedish vendors.

6.3. Proximity benefits and an international perspective on the Swedish participation in HRP

Sweden has clearly enjoyed significant benefits from the proximity to HRP. Mainly, the proximity can be argued to have contributed to more extensive but similar benefit as other countries. The main mechanism for these benefits is that the proximity has facilitated the movement of both samples for testing and people between Swedish stakeholders and HRP. This has meant that much of what has been studied has been of Swedish origin, which has increased the benefit from the research results through a more direct reliability when applying them to Swedish conditions. A similarly increased benefit can be assumed to have been enjoyed due to increased participation in HRP's meetings and events, leading to increased learning, networking and a more widely distributed insight into the topical issues within the international nuclear safety community. These types of proximity benefits should be interpreted as multipliers increasing impacts and would not be enjoyed without participation in HRP. Other factors which have not been specifically investigated, but which likely contribute to this multiplier effect, and the integration of HRP within the Swedish innovation system, are the cultural proximity, referring to language and common work practices, and the common institutional basis in a close and long standing Nordic cooperation. One proximity benefit which is likely less related to the participation is the business opportunities for Swedish companies. They are notable, but not significant for the evaluation of the added value of Sweden's participation in HRP.

The international perspective offered by the cases from Finland and Switzerland points to a more elusive, systemic proximity benefit, also contingent on the participation in HRP. Comparing the Swedish participation in HRP with the Finnish and the Swiss gives weight to the description of the Swedish system as functioning with a low degree of formalisation and institutionalisation. The significant follow up investments and impacts in Sweden that we have documented are promoted by voluntary, bottom-up coordination and engagement with HRP from the industrial partners. This could be interpreted as a proximity benefit as industry involvement seems to have been significantly more limited in Switzerland. However, the case of Finland indicates that impacts could be further multiplied by increased coordination of domestic research, to amplify the benefits from HRP activities.

6.4. Discussion

It is quite clear from the analysis in this report that HRP has a crucial role in the technological innovation systems of Sweden in nuclear safety. There are several possible reasons for this; one is certainly that the facility has been in operation for several decades, which has meant that it has bred a reliable position for itself in the system: users, whether these are in industry, academia, or the public sector, regard the HRP as a durable and dependable partner. While such reliability clearly is not enough in itself but needs to be combined with a high and stable level of quality of operations, there are several observations to be made that relate to the state of the art of the knowledge about the role and function of research infrastructures in innovation systems, as discussed by Crow and Bozeman[56], Meusel[57], and Hallonsten[58], among others. Meanwhile, as will be returned to below, the structure of the interactions between HRP and the actors and organisations it is supposed to serve has some impact on its role and function, and how well it can fulfil its mission on overall.

Returning briefly to the concept of functional differentiation and how it applies to technological innovation systems, it can be reiterated that organizationally, innovation systems consist not only of academic research environments with some emphasis (but no exclusive focus) on fundamental or curiosity-driven research, companies and their research and development units where emphasis lies on applied research and product/process development, regulating actors such as the state and other authorities that set the framework, and so on. Functionally, innovation systems consist not only of research, product and process development, marketing and so on. There is a big and growing niche, both organizationally and functionally, for infrastructures and other durable resources that enable activities that are part of innovation processes to make use of state-of-the-art instrumentation and technology, human competence and skill, archive and data deposits, and so on, in a dynamic interplay where the functional differentiation of the system is driven further and creates a division of labour that enables specialization and the development of strategic niches, on basis of which, in the next step, interaction is deepened and synergistic relationships achieved.[59] It is also clear, both from analyses of research groups and their use of instruments and infrastructures[60], and from analyses of the organization of contemporary, multidisciplinary Big Science[61], that the complexity of

[56] Crow and Bozeman (1998). *Limited by Design: R&D Laboratories in the U.S. National Innovation System.* Columbia University Press.
[57] Meusel (1990). *Einrichtungen der Großforschung und Wissenstransfer*." In Schuster HJ (ed) Handbuch des Wissenschaftstransfer. Springer.
[58] Hallonsten (2016). *Big Science Transformed. Science, Politics and Organization in Europe and the United States.* Palgrave Macmillan.
[59] Cf. Ziman (1994). *Prometheus Bound. Science in a dynamic steady state.* Cambridge University Press.
[60] Shrum, Genuth and Chompalov (2007). *Structures of Scientific Collaboration.* MIT Press. ; Jeppesen, Andersen, Lauto and Valentin (2014). *Big Egos in Big Science.* Paper presented at the DRUID Academy conference in Rebild, Aalborg, Denmark on January 15-17, 2014.
[61] Hallonsten (2016). *Big Science Transformed. Science, Politics and Organization in Europe and the United States.* Palgrave Macmillan.

instrumentation and the specialization of research fields, as well as the areas of technological development that has direct relevance to scientific research, has given rise to a new type of intermediary or 'broker' role for individuals with deep knowledge and competence in specific instrumentation, who become highly valuable in the process of securing productive use of such instrumentation by other actors from academia and industry. These actors have so far mostly been seen as having roles as enablers or catalysers of existing relationships, but it is reasonable to suggest that their importance will grow as technical sophistication and scientific specialization is driven further, so that they become indispensable as mediators.[62] It is quite clear from the analysis in the preceding chapters of this report, that the HRP fulfils such roles in the technological innovation system of nuclear safety in the Nordics, also to the extent that it could be used directly as an instructive example of functional differentiation and the growingly important role of durable and reliable infrastructures, besides e.g. funding agencies and performers, in the overall innovation system.

On policy level, the role of research infrastructures in research and innovation systems has been increasingly highlighted in national and supranational contexts, and new initiatives have been launched within existing organizations (research councils, innovation agencies, ministries) as well as outside them, e.g. on EU level, to coordinate and promote research infrastructures and their role in research and innovation systems. Both on national and supranational (e.g. EU and OECD) level, infrastructures are being highlighted as increasingly important parts of national and transnational innovation systems, and as crucial resources in the pursuit of sustainability and a globalized knowledge economy. The results of this evaluation of the Swedish participation in HRP should be seen in light of these recent developments on the policy stage, as they indirectly point out and strengthen the implication that HRP indeed has a very strong, almost indispensable, role.

There are several, quite expectable, explanations for this. As this report has shown, HRP is a research infrastructure of high quality and even with globally unique properties, sustaining research and development efforts in academia and the private sector alike that are repeatedly lauded for their excellence and relevance. On long term, given that the reactor has been in operation since the mid-1950s, this has led to a situation where the HRP has come to occupy a clear and evident niche in the Swedish and Nordic technological innovation system in nuclear safety research, and this is in itself a valuable example of functional differentiation in innovation systems: The HRP has a facilitator role and occupies a niche in the system that has made it all but indispensable. This can clearly explain the findings that the participation in HRP offers high impacts of high additionality, which are not reproducible domestically without prohibitively large investments in corresponding infrastructure.

From the perspective of SSM, functional differentiation and the role of infrastructures thus has a very concrete policy implication: Since the Swedish support for the HRP is only one among several different activities financed through the research budget of SSM, and thus the potential of a conflict of interest or situation of competition between the HRP support and other research and development activities funded by SSM cannot be ruled out, it should be properly and duly acknowledged within the SSM, and in its external communication, that (1) research infrastructures generally have an important niche in innovation systems and that (2) support for research infrastructures is a natural and distinct part of research and development programs, and that the HRP appears to have an especially important role to play as a research infrastructure almost indispensable in the

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[62] Cf. Ziman (1994). *Prometheus Bound. Science in a dynamic steady state.* Cambridge University Press

current system. Any funder or performer of research and development needs to act strategically and with awareness of how functional differentiation on system level translates to its own activities and mission, so as to avoid one-sidedness while simultaneously keeping a sharp and relevant focus. Support to infrastructures may be very powerful activities that can complement project funding or long-term commitments of other types, such as the (partial) financing of research groups or university research positions over long time.

Nonetheless, it should also be mentioned that positive effects of functional differentiation and the dynamic interplay of actors in an innovation system does not come by itself but is usually the result of purposeful efforts to secure healthy interdependences and exchanges. In the case of HRP and SSM, some things should be critically examined before the brief analysis above is translated into conclusions and policy advice. It should be acknowledged that access to the infrastructure, in a formal sense, is not enough for actors and organizations to be able to use it and fulfil its potential. Also informal channels and a positive culture of interaction, reliability and trust are important, and these are typically built on long-term. There are signs, in the specific case of HRP and Sweden, that the precedence of industrial use of the infrastructure and its resources has created a suboptimal situation regarding the involvement of e.g. academia. The question is whether this should be viewed as harmful or wasteful, or merely as unfulfilled potential. In any case, it seems there is room for improvement but it is also difficult to devise a simple solution or action plan. Likewise, given the demonstrated role of intermediaries or brokers in the use of infrastructures and instrumentation (see above), it should be further studied and discussed whether limited availability of in-house expertise in relevant areas at SSM in any way has a hampering effect on fulfilling the potential of HRP for SSM and in the associated technological innovation systems in Sweden.

7. Conclusions and recommendations

In this concluding chapter, we draw conclusions and make recommendations reconnecting to the evaluation questions. Recall that the evaluation questions concern types and extent of added value offered from the participation in HRP, as well as potential for increased added value, and the ways in which added value has manifested.

7.1. Conclusions

Introducing the conclusions of the evaluation we affirm that the participation in HRP has offered highly significant added value to the nuclear sector in Sweden. The impacts are extensive and wide ranging, reaching beyond the scope of what has been possible to cover in this evaluation, mainly due to the long history and continuity of the collaboration, which has not been fully investigated. Further characterising the added values that have been observed, we conclude the following:

- The impacts of HRP in Sweden have gone above and beyond the concepts of added value and individual sequences of impacts. HRP is functionally different from any domestic institution, and in some respects even any globally available institution. This has given HRP a strategic and unique role, which is best described as systemic, in the innovation systems that it services. I.e. HRP has had an integral role underpinning and enabling significant portions of research and development conducted. Rather than separate sequences of impacts, the ongoing and cumulative research processes have continuously contributed complex flows of impacts more aptly described as a web, within which we have highlighted some individual strands.
- In addition to the main purpose of performing research, the added values of HRP for Sweden have also entailed significant contributions towards retaining and developing knowledge and skill among sectoral experts, as well as promoting the growth and connectivity of domestic and international networks of experts. These impacts range from marginal contributions to the level of knowledge of individuals to, in effect, the training of brokers with extensive knowledge of research capabilities and experimental design at HRP, who have moved on to become informal coordinators of the relations with Swedish stakeholders. Such brokers have generally been identified in conjunction with instances of significant and extended use of HRP by Swedish actors, embodying the concept of sequences of impacts.
- The impacts of the HRP have truly represented *added* value since the HRP has filled functions which have been uniquely available through this specific collaboration. The HRP has been next to irreplaceable for the innovation systems that it has served. This condition has been emphasised by the proximity benefits, allowing for a more complete integration of the HRP into the Swedish innovation system than for more distant countries. Having spent the same amounts of money on domestic research would have provided negligible impacts in comparison.
- The main portion of the added values has been realised within the industrial sphere. This is evident from the quantifiable indicators of participation presented in chapter 4 and the usage of HRP traced out in chapter 5. The HRP has contributed in different ways in the different technological innovation systems con-

cerned. However they share the common quality of an intimate interplay between joint programmes and commissions. Note that the fact that added value is mainly realised in industry, and that proximity benefits mainly work as multipliers increasing these added values, Swedish proximity benefits may be assumed to decrease in proportion with decreases in installed nuclear power, as expected during coming programme periods.

- While industry has benefited significantly from the Swedish participation in HRP, we can confirm that academic institutions in Sweden have gained little added value. Scientific impacts are hampered by the forms of the collaboration, in practice having limited the access to results of the research to signatory and other approved partners, and by the publication practices of the HRP. We concur with the assessments that there is significant potential for increasing scientific impacts by inviting academia to take part of the results from HRP.
- Swedish coordination of input to HRP has been markedly more ad hoc based than comparable member countries. We have not recorded any indications that this has been detrimental, but given the testimonies of peer country representatives, one can assume that carefully organised strengthened coordination would ensure more attention to Swedish interests and a stronger stance for negotiations. Strengthening coordination of national research to supplement operations at HRP would also likely contribute to increased synergies.
- Swedish coordination and ongoing governance of HRP is dominated by voluntary and self-organised engagement from industry stakeholders. At the same time as the ad hoc coordination of the Swedish views on HRP may lead to suboptimal attention to Swedish needs, the voluntary, self-organised engagement from industry stakeholders is likely an important factor for the extensive use of HRP by Swedish industry.
- Additional public investments to multiply the benefits from the participation in HRP are significantly lower than in comparable member countries. Both Finnish and Swiss representatives have stressed the importance of supplementing research of national interest performed within the HRP with domestic research aimed to fully exploit its potential impacts. One may interpret this as promoting favourable preconditions for the generation of sequences of impacts based on the expectation of added value that cannot be properly estimated in advance.

7.2. Recommendations

Based on the conclusions, we make a number of recommendations, directed primarily at the SSM. The main recommendation is to, for the time being, continue funding and increasingly promote the use of HRP. More specifically, we recommend the following:

- Strengthen coordination of Swedish interests and research, and promote participation in HRP. Strengthened coordination of the national research agenda should multiply added value by increased attention to Swedish needs and interests and increased engagement by Swedish actors, and hence the absorption of results. Note that strengthened coordination does not necessarily mean more formal or hierarchal practices. Rather, the potential gains seem to relate to more inclusive and systematic practices, and improved predictability and transparency. Inspiration for the specific forms of such practices can be taken from the international outlook.
- Safeguard the financing of research infrastructures within the nuclear sector, and radiation safety in general, by highlighting the particular function that infrastruc-

tures fulfil in innovation systems. A research strategy that takes into account the concept of functional differentiation should acknowledge the specific nature of research and innovation infrastructures, e.g. by supplementing the current categorisation of research funding with a third category comprising infrastructure support.

- Develop strategy and corresponding coordination of domestic funding of research to increase added value by exploiting synergies between international and domestic research activities. Finnish and Swiss representatives alike stress the importance of supplementing the research at HRP with domestic research projects to fully exploit potential synergies.
- Exploit the opportunity to spearhead inclusion and promotion of academic institutions within the collaboration as this would likely contribute with significant scientific impacts as well as increased levels of expertise within the Swedish nuclear sector. In such an effort, attention must be given to developing practices for resolving intellectual property and confidentiality issues for open publication in academic journals. Examples of such practices exist from other private-academic research partnerships.
- Review the time allotted for SSM staff for absorbing and disseminating the results from HRP, and the allocation of research funding for domestic research, taking into account the role and time spent by experts in TSOs in Finland and Switzerland. Significantly more resources are allocated by the public sector for promoting uptake and synergies from HRP results in the peer countries. How this may be accommodated in the Swedish institutional context is open for investigation.
- Review the responsibilities of staff representing Sweden in the HPG with specific attention to their role in performing supervision of the consortium partners. We stress that we have recorded no indications that the independence of SSM's representatives has been compromised by this dual role. Rather, the recommendation aims towards offering strategic support in their work, with a view towards arranging the responsibilities in such a way as to optimise absorption and dissemination of results from HRP.

8. Sources

8.1. Written sources

8.1.1. Public documents

Bignan, Bravo, Lemoine & Maugard (n.d.). *The Jules Horowitz Reactor: A New European MTR (Material Testing Reactor) Open To International Collaboration: Update Description And Focus On The Modern Safety Approach*. French Atomic Energy Commission.

Carlsson and Stankiewicz (1991). *On the Nature, Function, and Composition of Technological systems.* Journal of Evolutionary Economics 1:93-118.

Crow and Bozeman (1998). *Limited by Design: R&D Laboratories in the U.S. National Innovation System.* Columbia University Press.

Edquist (2004) *Systems of Innovation: Perspectives and Challenges*. In Fagerberg J, Mowery DC and RR Nelson (eds), The Oxford Handbook of Innovation. Oxford University Press.

ENSI (2013). *ENSI's Research Strategy*.

Finnish Ministry of employment and the economy (2010). *National Nuclear Power Plant Safety Research 2011-2014. SAFIR2014 Framework Plan*

Hallonsten (2016). *Big Science Transformed. Science, Politics and Organization in Europe and the United States*. Palgrave Macmillan.

IFE (2003). *Halden Boiling Water Reactor.*

IFE (2003) "*Tegn Hilary 26/6-97 M:Users/Hil/Melin/Hernes17.Drw (Safety 4)"* in IFE (2003) Halden boiling water reactor.

IFE (n.d.). *Halden Boiling Water Reactor (HBWR)*. IFE. Available at: https://www.ife.no/en/ife/laboratories/hbwr. Accessed on 2016-04-18.

IFE (2009). *50 years of safety-related research. The Halden project 1958-2008.*

Jeppesen, Andersen, Lauto and Valentin (2014). *Big Egos in Big Science. Paper presented* at the DRUID Academy conference in Rebild, Aalborg, Denmark on January 15-17, 2014.

Kemp, Schot and Hoogma (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management* 10: 175-195.

Kuhn (1959). *The Essential Tension: Tradition and Innovation in Scientific Research*. In Taylor (ed) The Third University of Utah Research Conference on the Identification of Scientific Talent. University of Utah Press.

Luhmann (1995/1984). *Social Systems*. Stanford University Press.

Lundvall (ed) (2010). *National Systems of Innovation*. Anthem Press.

Löwenhielm (2008). *Kort information om Haldenprojektet.*

Meusel (1990). "*Einrichtungen der Großforschung und Wissenstransfer*." In Schuster HJ (ed) Handbuch des Wissenschaftstransfer. Springer.

OECD NEA (2014) *Agreement on the OECD Halden reactor project covering the period 1st January 2015 to 31st December 2017.*

Parsons (1937). *The Structure of Social Action*. Free Press.

Perez Vico (2014). *An in-depth study of direct and indirect impacts from the research of a physics professor.* Science and Public Policy 41: 701–719.

Science and Technology Facilities Council (2010). *New Light on Science The Social & Economic Impact of the Daresbury Synchrotron Radiation Source, (1981 - 2008).* Swindon, United Kingdom.

Shrum, Genuth and Chompalov (2007). *Structures of Scientific Collaboration*. MIT Press.

SKI (2005). *Haldenprojektet 2006-2008; Kostnadsfördelning Sverige.* SKI2004/55

Skjerve and Bye (eds) (2010). *Simulator-based Human Factors Studies Across 25 Years: The History of the Halden Man-Machine Laboratory.* Springer Science & Business Media.

SSM (2015). *Ringhals 3 - Verksamhetsbevakning angående åtgärdspunkterna från TVS-K granskningen.* SSM2015-3902-1.

SSM (2013). *Ringhals 3 - Anmälan om införande av TVS-K från TVEL som demonstrationsbränsle RA14 enligt SSMFS 2008:1 4 kap 5§.* SSM2013-5889.

SSM (2011). *Kostnader för svenska deltagare i Haldenprojektet 2012-14*. SSM2010-4585.

SSM (2010). *Forskning 2010:03. Forskningsstrategi 2010-2014.*

SSM (2008). *Kostnader för svenska deltagare I Haldenprojektet 2009-11.* SSM2008/191
Stokes (1997). *Pasteur's Quadrant: Basic Science and Technological Innovation.* Brookings.

The Research Council of Norway (2000). *Evaluation of the OECD Halden Reactor Project.*

Ziman (1994). *Prometheus Bound. Science in a dynamic steady state.* Cambridge University Press.

8.1.2. Internal HRP documents

Braseth (2011). *An empirical qualitative study of the Information Rich Design BWR Hammlab Large Screen Display.* OECD Halden Reactor Project, HWR-1023.

Braseth, Karlsson and Jokstad (2010). *Large screen display for the HAMBO simulator, based on information rich design.* OECD Halden Reactor Project, HWR-934

Halden Board of Management (2015). *Determination of HRP contributions for new Member Countries*. HP-1426

HRP (2006-2014). *Abstract of accounts.* Yearly abstract of accounts for 2006-2014

HRP (2006-2015). *Achievement Reports.* Annual and summary reports every three years for F&M and MTO during 2006-2014.

HRP (2006-2014) *Halden Working Reports.* HWR 775 – HWR 1141

HRP (2007-2014). *Participation lists from EHPG-Meetings.*

HRP (2006-2014). *Participation lists from summer schools.*

HRP (2006-2014). *Participation lists from workshops.*

HRP (2005-2015). *Revised Project Budget*. Yearly budget 2006-2014

HRP (2006-2015). *Status Reports.* Half-year status reports for F&M and MTO during 2006-2014

HRP (2005). *Halden Reactor Project Programme - Proposal for the Three Year Period 2006-2008*. HP-1165

HRP (2008). *Halden Reactor Project Programme - Proposal for the Three Year Period 2009-2011*. HP-1233

HRP (2011). *Halden Reactor Project Programme - Proposal for the Three Year Period 2012-2014*. HP-1303

HRP (2015). *Staff Organisation as of August, 2015 at the OECD Halden Reactor Project.*

HRP (2016). *Compilation of HRP bi- and multilateral contracts*. Compiled for the evaluation

HRP (2016). *Compilation of HRP procurement from Swedish actors.* Compiled for the evaluation

HRP (2016). *Compilation of HRP staff.* Compiled for the evaluation

Kaarstad and Strand (2011). *Large Screen Displays – a Usability Study of Three Different Designs.* OECD Halden Reactor Project, HWR-1025.

Karlsen and Hauso (2001*). In-pile crack growth behaviour of irradiated compact tension specimens in IFA-639 (second interim report)*. OECD Halden Reactor Project, HWR-675.

Veland (2007). *Halden reactor project workshop on human system interfaces (HSI) design and evaluation.* OECD Halden Reactor Project, HWR-865

Wiesenack (2013). *Summary of HRP LOCA test series IFA-650.* Presentation given at the 2013 EHPG meeting in Storefjell

8.2. Informants

- Anna Alvestav, Halden Programme Group Fuel representative, Analyst, Swedish Radiation Safety Authority (SSM)
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- Andreas Bye – Department Head, Industrial Phycology, Halden Reactor Project
- Francesco Corleoni – SCIP, Studsvik
- Vinh N. Dang – Head of PSI group on Human Reliability Analysis. Paul Scherrer Institut
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Annex – Keywords

Below we present the keywords used for identifying HWRs involving Swedish actors.

Keywords	
ANT International	Quantum Technologies
Barsebäck	Ringhals
Chalmers	Saab Sensis
EBS	Sandvik
ES-Konsult	Scandpower
FOI	Solvina
Forsmark	Sweden
Forsmarks Kraftgrupp	Swedish
Global Nuclear Fuel-Americas	Swedish Defence Research Agency
GoalArt	Swedish Nuclear Power Inspectorate
Gott	Swedish Nuclear Inspectorate
KSU	Swedish Radiation Safety Authority
KTH	Studsvik
Kärnkraftsäkerhet och Utbildning	Sydkraft
Linköpings Universitet	University of Gothenburg
Linköping University	Uppsala Universitet
Lund University	Uppsala University
MATSAFE	Vattenfall
MTO Säkerhet	Westinghouse
OKG	ÅF-konsult
Oskarshamn	ÅF process

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

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

The Authority reports to the Ministry of the Environment and has around 300 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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