Emergency Preparedness Process Proposal for Radiological Incidents at Accelerator Driven Facilities

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EMERGENCY PREPAREDNESS PROCESS PROPOSAL FOR RADIOLOGICAL INCIDENTS AT ACCELERATOR DRIVEN FACILITIES

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Abstract
The European Spallation Source (ESS) is an accelerator driven research facility under construction. Once commissioned, a linear accelerator supplies protons to a target, whereupon neutrons are generated through a process called "spallation". Neutron beam time will be available for a variety of scientific experiments. Ionising radiation and the activation of material exposed to it is a consequence of this process. To prepare for undesired events emergency preparedness for radiological incidents is indispensable. Therefore, this thesis aims to investigate what considerations are crucial for emergency preparedness at accelerator facilities by investigating similar facilities through observations and interviews. To subsequently design, propose and implement an emergency preparedness process for radiological incidents at the ESS. The process is an iterative cycle with several activities. The key activities include the development of a concept of operation describing intervention procedures and mitigation actions in case of an emergency. The process was evaluated in a table top exercise and let to the conclusion that the design provides a good starting point and will gain more maturity in the upcoming improvement iterations. Based on the exercise results, the research suggests establishing an emergency task force at the ESS facility to enable sufficient and consistent risk communication and interoperability among different stakeholders. Further, it suggests to consider designing and facilitating progressive types of exercises to enhance preparedness. Overall, this thesis provides valuable first-hand insights on aspects to consider for designing emergency preparedness and common challenges planners at accelerator facilities have to overcome.

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SUMMARY

The European Spallation Source (ESS) is an accelerator driven facility presently constructed northeast of Lund, Sweden. Once the facility is being commissioned a linear accelerator will supply protons to a rotating tungsten target, whereupon neutrons are generated through a process called spallation. At the end of 2023, the ESS will offer neutron beam time to a broad variety of scientific experiments. Ionising radiation and the activation of material exposed to it is a consequence of the process. The radiological hazard in accelerators depends on the type of charged particle accelerated, its maximum energy and the beam current. A number of potential radiological incidents have been identified for the ESS facility. Unlike other accelerator construction projects, the first section of the accelerator, the Normal Conducting Linear Accelerator (NCL) will be commissioned in parallel to installation work along the rest of the tunnel. This demands already at this early stage special safety concepts and emergency preparedness in case of a radiological incident.

Emergency preparedness concepts for accelerator driven research facilities have neither been discussed nor presented in the literature. Standards or tailored guidelines for radiological emergencies at these facilities have not been published. Therefore, this thesis aims to investigate what considerations are crucial for emergency preparedness at accelerator facilities. To then formulate an informed proposal for an emergency preparedness process for radiological incidents at the ESS.

Since academic literature on the specific thesis topic could not be found secondary data in form of complementary literature and emergency preparedness and response plans from accelerator facilitates and nuclear power plants were reviewed. A range of potentially transferable information contributed to this thesis. To obtain a sufficient understanding and information on how to initiate the design of the ESS emergency preparedness process primary data was collected through observations and interviews. Semi-structured interviews were conducted both with accelerator and nuclear power plant personnel involved with radiation protection and emergency preparedness at their workplace.

First, based on the qualitative data, four underlying conditions, which need to be respected and considered prior to the design and implementation of an emergency preparedness process, have been identified. Namely, the *architecture* and *planned operations* determine the expected safety precautions and hazard profile. The *legislative framework* draws country specific requirements for radiological hazards a facility has to comply with. Furthermore, *available staffing* and *established procedures* do vary among investigated facilities and demand adaptability from the planner to specific circumstances. Established procedures do not necessarily imply effective emergency preparedness. Often, they are still revised after being implemented for a long time as proven insufficient or impractical. The alignment of several established procedures from different stakeholders both internal and external is essential to develop emergency preparedness and avoid gaps or mismatches.

Second, seven design criteria were established emphasising what properties the emergency process should achieve. The process should be *risk based* and *flexible* to also adapt to changing circumstances during an emergency. It also should be *interoperable* with other stakeholders' preparations, simultaneously being *clear in command* and responsibility distribution. The process should in addition be *training- and exercise-based* to guarantee learning. And lastly, it should be *continuous* with ongoing preparedness activities.

Third, the emergency preparedness process for ESS was designed based on the recommendations from the literature and simultaneously in respect of the underlying conditions and the design criteria. The process is an iterative cycle with several activities. The key activities include for example the development of a concept of operation describing intervention procedures and mitigation actions performed by the radiation protection personnel in case of an emergency. Further the performance and evaluation of a functional exercise could inform the developed design on adjustments and improvement opportunities. Until finally collecting all the pertinent information into a document serving as preparedness plan which was distributed to operational and strategic stakeholders.

Lastly, certain results of performed activities could be further evaluated in a table top exercise to determine whether the design is enabling a sufficient response. It has been concluded based on the exercise results that the design provides a good starting point and will gain more maturity in the upcoming improvement iterations. Especially the design criterion of clear command and responsibility distribution was identified to require close attention and actions for improvement. The identified gaps and improvement suggestions stipulate an ideal point of departure for future emergency preparedness activities at the ESS. Suggestions for the future implementation of the process are provided. These include the establishment of an emergency task force at the ESS facility to enable sufficient and consistent risk communication and interoperability among actors from different departments. Further, it is suggested to facilitate a variety of different types of exercises for the emergency response team, staff and visitors in the future.

The more general contribution of the thesis, outside of the ESS, is the provision of valuable first-hand insights on which aspects to consider for designing emergency preparedness at accelerator driven facilities and which common challenges planners have to overcome.

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ABBREVIATIONS

Abbreviation	Explanation
ALARA	As Low As Reasonable Achievable
Bq	Becquerel
BMBF	Bundes Ministerium für Bildung und Forschung Federal Ministry of Education and Research
BoT	Beam on Target
CCPS	Center for Chemical Process Safety
cm	Centimeter
DAtf	Deutsches Atomforum
EMPIR	Emergency Monitoring Plan for Ionising Radiation
ERT	Emergency Response Team
ESH	Environmental, Safety & Health
ESS	European Spallation Source
FR	First Responder
IAEA	International Atomic Energy Agency
IAEM	International Association of Emergency Managers
ICRP	International Commission on Radiation Protection
Kg	Kilogram
Linac	Linear Accelerator
MeV	Megaelectronvolt
mSv µSv	Millisievert Microsievert
NCL	Normal Conducting Linear Accelerator (Linac)
NCRP	National Council on Radiation Protection
NPP	Nuclear Power Plant
NFPA	National Fire Protection Association
OHS	Occupational Health and Safety
RF	Radio Frequency
RP	Radiation Protection
RPE	Radiation Protection Expert
RPO	Radiation Protection Officer
SCL	Super Conducting Linac
SEC	Skanska ESS Construction
SSM	Strålsäkerhetsmyndigheten Swedish Radiation Safety Authority
Sv	Sievert (Unit)
TTX	Table Top Exercise
WHO	World Health Organisation

GLOSSARY

Term	Description
Crisis	An event, or series of events with potential for strategic implications that severely impacts or has the potential to severely impact an entity's operations, brand, image, reputation, market share, ability to do business, or relationships with key stakeholders. A crisis might or might not be initiated or triggered by an incident, and requires sustained input at a strategic level to minimize its impact on the entity" (NFPA, 2019: 6).
Covid – 19	Coronavirus disease 2019
Decay	Process in which an atomic nucleus spontaneously emits one or more alpha (α-), beta(β-), gamma (γ-) or neutrons, thereby changing its identity (Grupen & Werthenbach, 2010: 288).
Dose Limit	According to the Swedish radiation protection regulation, a dose limit means the value of the effective dose or the equivalent dose in a specified period which shall not be exceeded for an individual.
Emergency	An emergency is characterised by an imminent or actual event threatening people, property or the environment and which requires a coordinated and rapid response by the local emergency and rescue teams. If managed in the wrong way, the situation could damage confidence and lead to a crisis (Alexander, 2012).
Functional Exercise	The functional exercise simulates an emergency in the most realistic manner possible, short of moving real people and equipment to an actual site. As the name suggests, its goal is to test or evaluate the capability of one or more functions in the context of an emergency event (IAEM, n.d.).
G area / G01	Number of the accelerator building at the ESS premises
Hazard	A source of potential harm or a situation with a potential to cause loss (BCI, 2008).
Incident	"An event that has the potential to cause interruption, disruption, loss, emergency, disaster, or catastrophe, and can escalate into a crisis" (NFPA, 2019: 6).
Likert scale	Likert scales result when survey participants are asked to rank their agreement with survey items on a scale that includes strongly disagree, disagree, neither agree nor disagree, agree and strongly agree (Robbins & Heiberger, 2011).

Max IV Laboratory	Swedish national laboratory providing scientists with X-rays for research.
Primary Data	Researchers first-hand collection or generation of new (primary) data
RAKEL	Radiokommunikation för effektiv ledning Swedish radio communication for security organisations and the rescue services
Risk	The chance of something happening, measured in terms of probability and consequences (BCI, 2008).
Secondary Data	Secondary data is data not directly collected by the researcher but is initially collected or produced for other purposes
Secondary Data Analysis	“Is any further analysis of an existing dataset which presents interpretations, conclusions or knowledge additional to, or different from, those produced in the first report on the inquiry as a whole and its main results” (Hakim, 1982: 1).
Source Term	Source term indicate the size and timing of a radioactive release (IAEA, 2007)
Table Top Exercise (TTX)	“An exercise that uses a progressive simulated scenario, together with scripted injects, to make participants consider the impact of an emergency on existing plans, procedures and capacities” (WHO, n.d.).

1 INTRODUCTION

At the northeast of Lund in Sweden the European Spallation Source (ESS), an accelerator driven research facility, is presently being constructed. Today the ESS is one of the largest science and technology infrastructure projects being built. Once the facility is commissioned a linear accelerator will supply protons to a rotating tungsten target, whereupon neutrons are generated. Neutrons are usually in the atom's nucleus. To gain neutrons, rapidly varying electromagnetic fields heat hydrogen gas in the ion source so that electrons evaporate from the hydrogen molecules. What remains are the bare hydrogen nuclei – the protons. Throughout an approximately 600-meter-long linear accelerator (linac) these protons are reaching 96% of the speed of light before they hit the rotating target wheel. The wheel is 2.6 meter in diameter and consists of hundreds of heavy metal Tungsten bricks encased in a disk of stainless-steel shielding. The high-speed protons kick out the neutrons in a process known as spallation. These neutrons are directed to the ESS instruments through a gauntlet of media, guides, optics and filters to be used for scientific research. The linear accelerator (linac) consisting of a normal conducting linac (NCL) proton beam will be accelerated in this section up to 74 MeV. The adjacent superconducting linac (SCL) is designed to accelerate the beam up to 2GeV onto the target creating neutrons via the spallation process (BMBF, 2018; ESS, 2017a).

The ESS's Environment, Safety & Health (ESH) Division supports, monitors and assures the implementation of ESS safety policies, rules, processes, objectives as well as best practices at all levels of the organisation. Within the ESH division the Radiation Protection (RP) group is responsible for management of emergency preparedness in case of radiological incidents. The RP group consists of a RP Expert Function that participates in operational RP team and in the RP services, e.g. radiation area monitoring, tracking of activated material, dosimetry and radioactive waste services. This master thesis project is supervised by the Radiation Protection Group Leader.

At the end of 2023, the ESS will offer neutron beam time to a broad variety of scientific experiments. Once in operation each year up to 3000 visiting scientists will perform their research using neutron beams at the ESS (Rabesandratana, 2014). Ionising radiation and the activation of material exposed to it is a consequence of the process to provide such a neutron beam. Today, ESS already prepares for possible incidents. The ESS, together with the relevant Swedish authorities and the local fire and rescue services, has identified a number of potential radiological incidents of varying severity. Any intervention related to radiological incidents shall be carried out according to ESS's emergency preparedness planning (ESS, 2019). During construction and the period of commissioning of beam on temporary dump for the accelerator, there will be an incremental handover of buildings from the principal construction contractor to ESS. Unlike other accelerator construction projects, the first section of the accelerator, the Normal Conducting Linac (NCL) will be commissioned in parallel to installation work along the rest of the tunnel. This demands special safety concepts also in case of a radiological event. The incremental building handover and the step-wise commissioning process are a challenge for the emergency preparedness planning which needs to be permanently developed alongside the process.

Emergency preparedness approaches for research and accelerator facilities have neither yet been discussed nor presented or compared in the literature. Due to varying architecture, experiments, radiation fields and respective expected dose rates each facility has different demands for emergency preparedness for radiological incidents. Standards, criteria or tailored guidelines have not been published to date.

1.1 Purpose and Research Questions

The purpose of this study is to develop an emergency preparedness process for radiological incidents at the ESS. It explores approaches from similar research facilities and Nuclear Power Plants (NPP). To identify suitable and applicable concepts for the ESS facility differences and similarities between the ESS facility and other facilities are assessed.

This thesis is conducted as a design science research project. According to Wieringa (2014), design science projects need to fulfil three iterative tasks**: investigating the problem**, **designing the solution** and **evaluating the solution**. These three tasks guide this thesis and are reflected in the research questions.

(I) Investigating the problem:

1. *What are the underlying conditions for developing an emergency preparedness process for accelerator facilities?*

2. *What design criteria have to be established for the development of an accelerator emergency preparedness plan at the ESS facility?*

The first question investigates concepts that similar or comparable facilities have implemented to ensure preparedness for emergencies. It analyses the underlying conditions that need to be considered in the process. It also identifies best practice examples from other similar accelerator facilities. The second question derives specific criteria from the analysis to inform the subsequent design process. These design criteria are explicit goals that must be achieved for successful planning.

(II) Designing the solution:

3. *How can an emergency preparedness process be formulated at the ESS facility to fulfil the proposed design criteria?*

The designed solution process is an iterative cycle which consists of several activities including the development of an emergency preparedness plan for radiological incidents at the facility, the design of operational procedures, and emergency preparedness exercises.

(III) Evaluating the solution:

4. *Is the emergency preparedness process enabling a sufficient response?*

The developed emergency preparedness process was tested in a table top exercise. The evaluation shows if the designed process is meeting the design criteria and the established response procedures at the facility. This research question analyses opportunities for improvement and needs for future training and exercises which were identified during the exercise.

1.2 Thesis Outline

Figure 1 presents the outline of this thesis by providing information on each chapter and its key content.

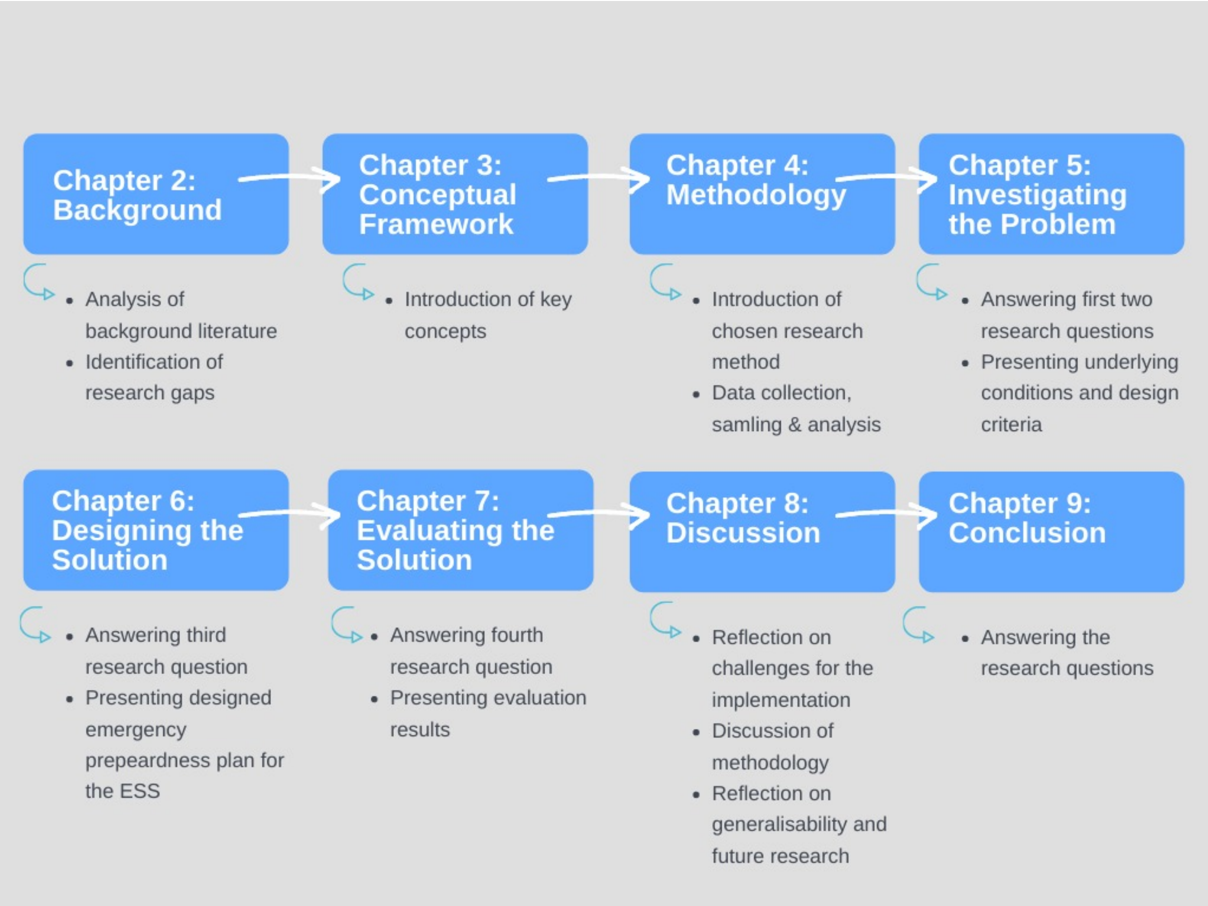

Figure 1 Thesis Outline

2 BACKGROUND

This research area is narrowly defined and existing research on this particular topic is limited. A range of potentially transferable information from emergency management, emergency preparedness, contingency planning, radiation protection at accelerator facilities and NPPs as well as other fields of study, contributed to this thesis. The rationale was to identify first which types of radiation exist and what kind of effects they can have, to then assess radiological hazards that could occur at accelerator facilities: How are these risks handled through safety mechanisms and what information is available to design emergency preparedness plans for radiological incidents?

2.1 Type of Radiation

Unstable types of atoms are called radionuclides and are radioactive. They decay hereby emitting one or more kinds of ionising radiation (particles or electromagnetic radiation) (Grupen & Werthenbach, 2010). The most important types of ionising radiation are coming from alpha (α-), beta (β-) and gamma (γ-) decay hereby emitting particles or photons. In addition, free neutrons are generated either by decay of a radionuclide or artificially induced, e.g. during nuclear fission or the spallation process. Since neutrons are electrically neutral, neutron radiation has a high penetrating power, similar to γ-radiation (Connor, 2019; Miska, 2008).

The number of transformations of a radioactive substance per unit of time, its decay rate, is called activity and is expressed in the unit of measurement Becquerel (Bq). For radiation protection decisions, the absolute level of activity is often not important. For this reason, the activity is related to another quantity; e.g. to an area (Bq/cm^2) to assess the contamination (impurity) of surfaces or to the mass (Bq/kg) to indicate the activity in food items. The activity of a radioactive substance, i.e. its decay rate, says nothing about a possible hazard. Here, the term radiation dose is used. The radiation emitted when a radioactive substance decays contains energy. When radiation strikes a human body, all or part of this radiation energy is absorbed by the body (DAtf, 2016). Depending on whether the whole body or individual organs are irradiated, one speaks of equivalent or organ dose. In the case of uneven irradiation, the dose is weighted over the various organs to obtain the effective dose, which describes the overall risk. People are exposed to natural radiation in everyday life. It comes from outer space (cosmic radiation) or from the natural radioactive substances in the soil, water and vegetation (terrestrial radiation) (DAtf, 2016). People are also exposed to radioactive substances through their use in research, technology and medicine (Miska, 2008).

The extent of biological radiation effects depends on various factors: the type of radiation, the radiation intensity, the duration of exposure, and the radiation sensitivity of the irradiated tissue and or organs. For the evaluation of all biological effects, the type of radiation and in which organ or tissue the radiation was absorbed must also be considered, as radiation sensitivity varies, especially with regard to delayed damages. The dose unit is called Sievert (Sv). Since 1 Sv is already a fairly high radiation dose, radiation dose values are usually given in millisievert (mSv) or microsievert (µSv). The radiation dose received in a given period of time is called dose rate (DAtf, 2016; Koelzer, 2017). For example, the average radiation dose received by the Swedish population is about four mSv per year. Figure 2 provides an overview of doses from sources of exposure and includes the dose limits for workers at ESS.

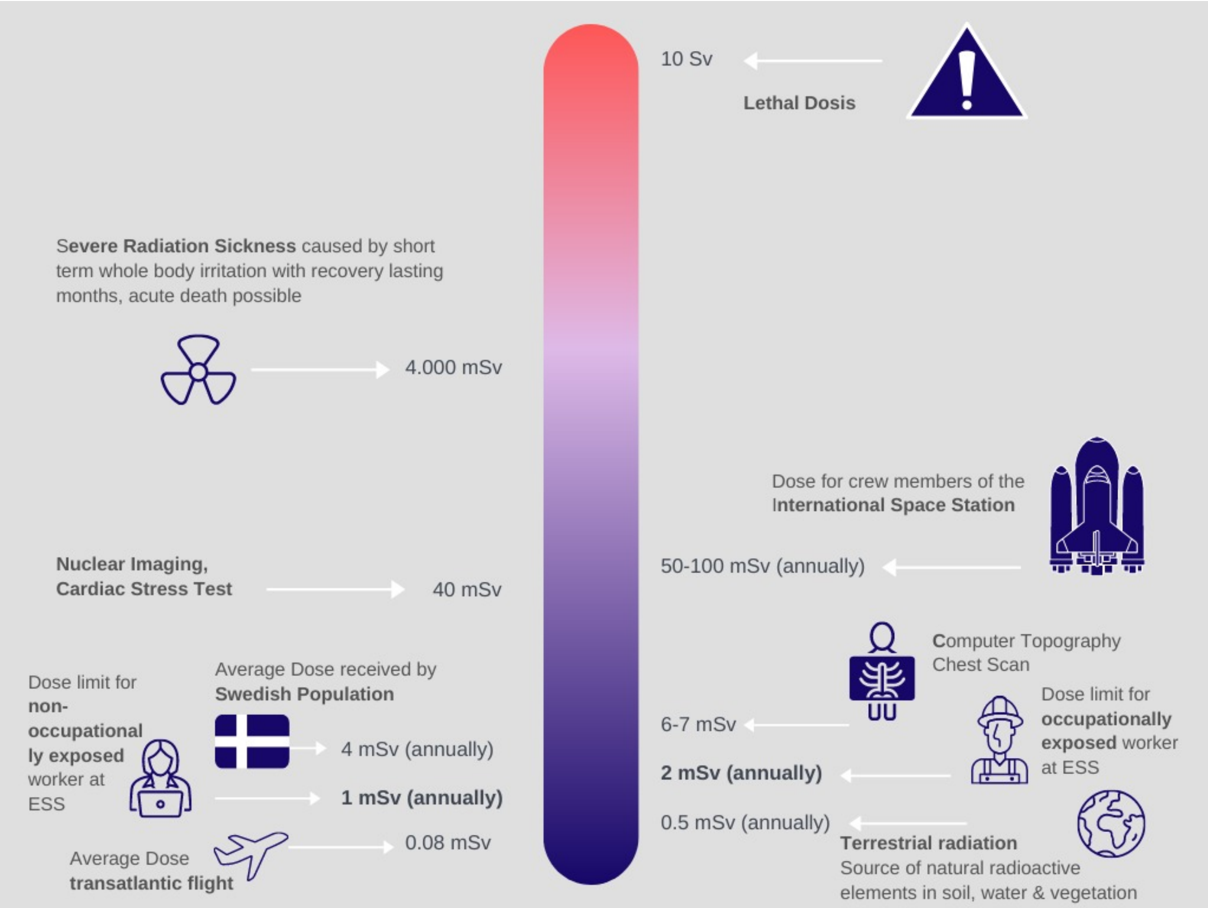

Figure 2 Overview of doses from sources of exposure

2.2 Radiological Health Effects

Exposure to ionising radiation can cause deterministic and stochastic health effects (Veenema, 2008). Deterministic health effects are immediate symptoms and damages such as, reddening of the skin, loss of hair, nausea, vomiting and damage to an unborn child, such as physical deformities. A deterministic health effect is one for which generally (1) a threshold level of dose exists, below which there is no effect observable, (2) above this threshold the severity of the effect increases with the dose received and (3) the effect can be clearly associated with the preceded radiation exposure (IAEA, 2007; Stabin, 2007).

Stochastic health effects are probabilistic (Stabin, 2007). These health effects are delayed and the probability of a possible damage depends on the dose. It remains uncertain whether serious sickness, such as thyroid cancer or leukaemia, will occur or not. Exposure to ionising radiation can also cause genetic damage, where the radiation absorption in germ cells can lead to mutations. They do not manifest to the irritated person but can impact the following generation (Grupen & Werthenbach, 2010). With stochastic health effects (1) a threshold may not be observable, (2) the probability of the damage increases with the received dose and (3) the damage may not be directly traced back to a distinctive event (Stabin, 2007).

To estimate the risk, both the type of ionising radiation (α, β, γ) and how someone is exposed have to be considered. Four different exposure pathways exist. (1) External exposure occurs from contact with or in proximity to a source of radiation (e.g. a source, a plume containing radioactive material or ground contamination). (2) The body can also take up radioactive substances over the ingestion of contaminated food or water, but also over the inadvertent ingestion of contamination on hands. (3) Inhalation from a plume or due to the resuspension of deposited radioactive material and (4) contamination of skin and clothes (IAEA, 2007: 8) can also lead to radioactive uptake.

2.3 Radiological Hazards at Accelerator Facilities

The radiological hazard in accelerators depends on the type of charged particle (e.g. electrons, protons), its maximum energy and the beam current. Depending on the charged particles that are accelerated the energy varies, which causes different kind of interaction with matter and entails varying radiation hazards (AERB, 2005). These interactions produce prompt radiation, which will immediately stop as soon as the beam is shut off. It also induces radioactivity of the components in the accelerator tunnel, which continue to emit after shut off (AERB, 2005; Stevenson & Vylet, 2001).

Another radiation hazard is the possibility of other types of particles being accelerated and arriving at other locations with other energies. These stray particles may also generate secondary radiations by collisions with the materials that make up the accelerator hardware and its surroundings. This might make these materials radioactive (NCRP, 2005). The principal problems will be associated with accelerator components irradiated by the primary beam. This includes the beam stop for the primary beam of the accelerator required during commissioning of the facility (Fieldnotes ESS). In general, the accelerator parts themselves and nearby auxiliary items that are subject to irradiation by the scattered beam or secondary particles will have lower concentration of induced activity (IAEA, 1988: 118). The issue of surface contamination is not as serious as induced activity within solid material. The latter requires careful surveillance and control during maintenance activities. Cooling water systems and the air surrounding the beam stops are subject to induced activity (ibid: 188).

Ionising radiation may cause damage to safety installations in the accelerator tunnel, such as warning lights or emergency off switches. It is important to shield them where required and possible to ensure that conventional hazards, such as electricity, fire or gas and mechanical or personnel failure are considered as well. Therefore, it is mandatory that the preparedness for undesirable events is carried out in collaboration among occupational health and safety (OHS) and radiation protection units in these facilities (Hall, 1969).

2.4 Radiation Safety and Radiation Protection

To guarantee the radiation safety at accelerator facilities the following two objectives are essential:

1. During normal operation, maintenance, decommissioning and in emergency situations, the radiation dose to workers as well as members of the public is kept below the legal dose limits.
2. All exposures are kept as low as reasonably achievable (ALARA) and in compliance with National and European regulations (AERB, 2005).

These objectives can be achieved, by implementing radiation safety systems engineered to monitor, control and mitigate prompt radiation hazards, such as adequate shielding, safety interlocks, radiation monitoring, access and administrative controls and emergency preparedness plans (AERB, 2005). In addition, specific services underlie the responsibility of the radiation protection personnel, including training of staff and externals, review of hazards of ionising radiation and radioactivity from installations, monitoring of the effectiveness of protective measures including radiation monitoring and personal dosimetry, as well as source term assessment and dose calculation in an emergency situation (ESS, 2020a). The classical definition of an accident is understood as a sudden event that causes injury. In radiation protection an accident includes already a possible increased radiation incident (Nünighoff, 2009) possibly causing later stochastic health effects (s. chapter 2.2).

2.5 Emergency Preparedness for Radiological Incidents

Nuclear or radiation related emergencies are categorised in threat categories (I-IV) (IAEA, 2007). Postulated events in category I can give rise to severe deterministic health effects in areas outside the facility boundary. In category II events on-site are postulated to give rise to doses to the public outside the facility that require urgent protective actions. In category III events on-site are postulated to give rise to doses or contamination that require urgent protective actions on the site of the facility. These emergencies of different threat categories are applied for nuclear reactors, industrial or research and medical facilities. Category IV comprises malicious acts or emergencies during transport which can occur at all times anywhere and are not related to a specific location (ibid). The Swedish Radiation Safety Authority (SSM) has classified the ESS in category II (Buhr et al., 2019).

In the past, disastrous events at NPPs - which were considered category I by the IAEA - have affected the public and challenged municipal or even national emergency management (IAEA, 2015; Purpura, 2008; Sylves, 1984). They also led to increased emergency preparedness on-site of NPPs (Elkmann, 2017).

Due to prominent past events, high radiation risk and resulting rigid requirements NPPs' experience in emergency preparedness efforts is scientifically documented. Elkmann (2017) and Kyne (2017) provide an overview of the history and evolution of emergency preparedness for radiological incidents. Their research informs on the evaluation of accidents and their influence on preparedness efforts. Repeatedly, the changes resulted in the more standardised and mandatory arrangements, like adapting emergency actions levels or minimum criteria for emergency plans as it was the case after the Three Mill Island emergency in 1979. The IAEA[1] (2003) published a method for developing arrangements for response to a nuclear or radiological emergency. The step-by-step approach provides detailed information on aspects to consider during planning, implementing and updating. Mainly the performance of risk assessments, the development of concept a of operations and the allocation of responsibilities. The last step is the implementation of the plan and testing of its capability. This method is intended for the development of national plans but its steps can also be transferred to facilities' on-site needs.

The literature review shows that the guidelines and safety standards for NPP are ample. The approaches for NPP are detailed, conservative and informative. Due to different risk levels and resulting preparedness demands they can however not be applied identically at accelerator facilities. Information on the emergency preparedness procedures at accelerator driven facilities is extremely scarce. So far, no frameworks or step-wise approaches could be found. Therefore, this thesis aims to investigate how an emergency preparedness process for radiological incidents could be formulated for an accelerator driven facility.

[1] IAEA as well as the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection Measurements (NCRP), are scientific advisory bodies. They "do not have the authority to issue or enforce regulations" (Stabin, 2007: 116) but their recommendations are often adopted by the regulatory bodies in America, Europe and other nations (ibid).

3 CONCEPTUAL FRAMEWORK

This chapter presents the **relevant concepts** of this thesis and also draws some relations among them. Brief definitions of the introduced terminology can be found additionally in the glossary.

Emergency preparedness planning is an important task that needs to be addressed because of the wide range of hazards that exist at unique research facilities. **Hazard**, is often confounded or equated with the term **risk**, the two terms however are not interchangeable. The term risk refers to the consequences and likelihood of occurrence of undesirable events. A hazard can relate to any source of risk (Health and Safety Professionals Alliance, 2012). Especially in industrial environments, a variety of different hazards can be found (Alexander, 2016). Only if hazards impact something humans value they can have a destructive impact (Becker, 2014).

When this kind of event happens, it is defined as an **incident**. The title of this thesis uses the term and the following definition is adopted for the purpose of this study: An incident is "an event that has the potential to cause interruption, disruption, loss, emergency, disaster, or catastrophe, and can escalate into a crisis" (NFPA, 2019: 6). For the purpose of this thesis a common and clear understanding of the terminology used is crucial. Therefore, it is also important to distinguish between **emergency** and **crisis**. Definitions for both terms can be found in the glossary.

Emergency and crisis management are two different however closely connected mechanisms within organisations (Alexander, 2012). Emergency management responds with short-term measures to particular accidents or emergencies while the crisis management team steps in to overtake the long-term strategic management. Crisis management usually aims to reach normal conditions or an acceptable "new normal". McConnell & Drennan (2006) state, that "serious consideration to strong, well-resourced and forward-thinking contingency planning" needs to be applied, to "gain control over a crisis when it hits". (p. 59).

The concept of **preparedness** has multiple meanings across the literature and is measured differently. Its conceptual ambiguity is preserved by the use of overlapping terminology (readiness, contingency planning, business continuity etc.) (Staupe-Delgado & Kruke, 2018). The literature provides several definitions of *preparedness* but "[…] practitioners have to face a critical issue of choosing what represents preparedness, as each choice has its own organizational and behavioural consequences" (Kirschenbaum, 2002: 8).

Keeping this in mind, the general construct of preparedness is subdivided into specific components, which are relevant for the approach in this thesis. The core of any type of preparedness effort contains the characteristics of an *active, continuous* and *anticipatory* process (Staupe-Delgado & Kruke, 2018). Especially the active character is crucial, since the preparedness efforts usually demand active steps from the personnel to prevent or lessen the impact of a hazardous event. To carry out these actions the readiness to respond has to be trained and drilled in an anticipatory planning process (Gillespie & Streeter, 1987). In addition, the concept of preparedness involves the access to knowledge, to determine appropriate behaviour to improve the safety or effectiveness of the response continuously based on new findings and lessons learned (Kirschenbaum, 2002).

For this thesis, two other attributes of preparedness are relevant: *planned* and *enabling*. Apart from a written emergency preparedness plan, Perry and Lindell (2003) emphasise the importance of the planning process itself for effective preparedness. Planning should take place in a pre-crisis phase and enable coping and adapting capacities so that a potential impact of an event can be absorbed and a crisis can be prevented (Staupe-Delgado & Kruke, 2018). The developed preparedness efforts should ideally enable the personnel to be aware of potential hazardous events and to be prepared and trained with procedures in place.

4 METHODOLOGY

The thesis is conducted in line with design science research. Wieringa (2014) states “design science is the design and investigation of artefacts in context” (p.4). The purpose of design science is to develop a yet non-existing artefact with the aim of solving a problem (Dresch et al., 2015). According to Wieringa (2014), design science problems are “problems hav[ing] a context in which some improvement is aimed for” (p. 4). For this thesis, the so-called artefact is the emergency preparedness process for radiological incidents. The design process aims at improving the overall preparedness within the ESS facility. Wieringa (2014) further stresses that an artefact itself does not solve any problem on its own. It is the interaction of the artefact with its context that will contribute to the solution of the problem. Therefore, the facility’s personnel needs to be involved through communication, training and exercising the developed process to guarantee interaction of the artefact with the environment.

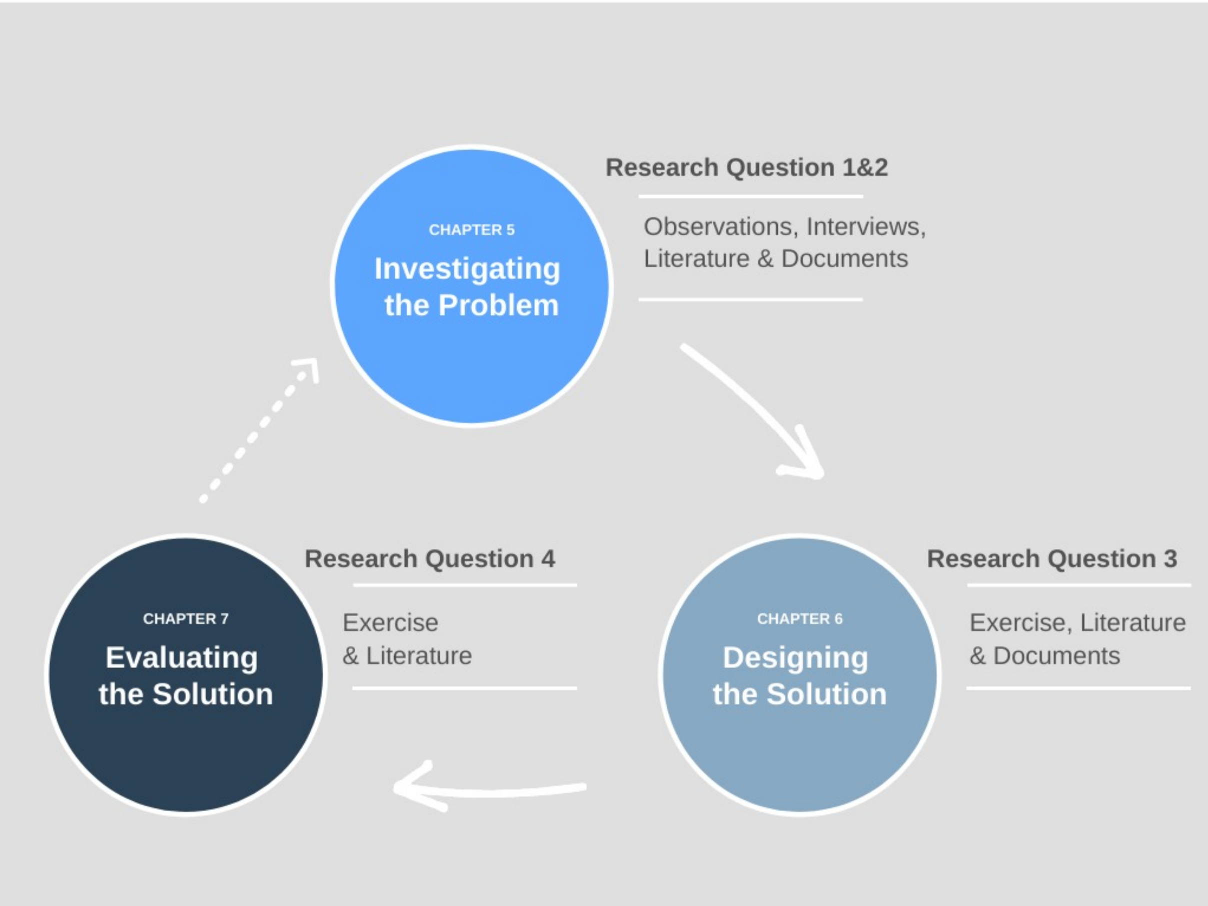

Figure 3 Visual outline of the methodology

Three iterative tasks provide the outline of this thesis and are displayed in Figure 3. The cycle starts with the **investigation of the problem**. Including the identification of underlying conditions and the development of design criteria. It continues with the **design of the solution** by performing design activities to formulate an emergency preparedness process, which then finally can be tested and evaluated in the last section. The research questions (chapter 1.1) reflect the three steps of the design cycle. Ideally the process is a continuous cycle as presented in Figure 3 with a dashed arrow. The proposed design will continuously be refined through evaluation and adjustments. However, due to time and resource constraints only one iteration was performed in this case and can be considered as a preparatory process for future refinements. The respective types of data collected, sampled and analysed for each research question are indicated in the boxes next to the tasks in the cycle. They are explained in more detail per task in the following section.

4.1 Investigating the Problem

4.1.1 Type of Data, Collection, Sampling & Analysis

4.1.1.1 Literature – Collection & Sampling

Emergency preparedness for radiological incidents in accelerator facilities is not a new concept but the search in literature showed that researchers have not specifically investigated it so far. Since academic literature on the specific thesis topic could not be found secondary data in form of complementary literature and emergency preparedness and response plans from accelerator facilities and NPP were reviewed.

Secondary data was collected by using the advanced search on LUBsearch and Google Scholar and searching with combinations of keywords, for example "emergency preparedness AND radiological", "emergency management", "industrial emergency preparedness". The title of the results was the first selection criteria. Then abstract and the table of content were combed through and chapters with relevant content were studied.

The sampling of the document study at the ESS was conducted by applying a snowball technique inspired by Wohlin (2014). Therefore, a starting set of documents provided by the ESS was reviewed and cross references to other internal or legislative documents were followed to identify relevant documents to be included in the study (Wohlin, 2014). Due to constant review update and new release of documents at ESS the document study can be understood as a continuous process throughout the thesis time. The relevant legal documents in relation to radiation protection and emergency preparedness for radiological incidents were also identified during the document review. A similar approach was applied to documents used in other facilities which could not be accessed in most cases due to confidentiality reasons.

4.1.1.2 Literature Analysis

For the preparation of secondary data, the programme Zotero was used to group documents and literature according to overarching themes (e.g. radiological hazards, emergency preparedness). A secondary data analysis of the reviewed documents and literature was conducted. Secondary data analysis is understood as the "further analysis of an existing dataset which presents interpretations, conclusions or knowledge additional to, or different from, those presented in the first report […]" (Hakim, 1982). The analysis followed the guidance of Johnston (2014). As a first step the overall purpose of each study and the responsible researchers were assessed. Simultaneously, the background of the researchers and owners of the document was considered. The retrieved information must be seen within the context of its publication and influential events of that time. To strengthen the arguments, it was assessed whether information is consistent from various sources.

4.1.1.3 Sampling of Observation and Interview Cases

Conducting only literature/document reviews and relying solely on data generated by other researchers could not gather sufficient understanding and information to start an individual design (Blaikie, 2010). Furthermore, the quality of the collected data remains uncertain (ibid) and recent articles were lacking.

To deepen the understanding of present emergency preparedness in unique environments the sources were diversified (Blaikie, 2010; Creswell, 2013). Primary data was collected through three observations of accelerator facilities and four semi-structured interviews with radiation protection and emergency preparedness staff from different facilities. The sampling method for the primary data collection is a combination of a non-probability-based selection of particular cases, introduced by Blaikie (2010) and critical cases. Critical cases "provide specific information about a problem" (Creswell 2013: 157). Four accelerator-based research facilities were contacted to conduct both observations and interviews. The chosen research facilities are of a similar structure to the ESS. The assumption is that the ESS will face similar problems once operational. However, their approaches to emergency preparedness efforts vary as they may have encountered different successes or challenges in relation to their preparedness efforts.

All four research facilities responded and indicated the possibility of a visit. In addition, the ESH division at ESS visited another similar facility where I joined. Due to the Covid-19 pandemic the responses from interview partners were impeded or delayed and travel restrictions inhibited the planned visit of two other facilities. Moreover, two of the four observed facilities were severely affected by the Covid-19 situation after visiting which led to a discontinuation of contact and foreseen interviews could not be conducted. Besides the two interviews at research facilities, two NPPs were included at a certain stage during the research due to their long experience with radiation protection in combination with emergency preparedness. Appendix 1 provides an overview of the contacted facilities, keywords of the main aspects studied and under which abbreviations the informants are referred to in this thesis.

4.1.1.4 Observations – Collection and Analysis

Observations were conducted during field visits at four accelerator facilities. This type of data collection enabled me to perceive a "phenomenon in the field setting through the five senses" (Creswell, 2013: 166). Notes and pictures were taken during meetings, presentations and tours. Daily observations at the ESS workplace as well as frequent site visits were performed between September 2019 and August 2020.

Creswell (2013) argues a good qualitative observer may change his role during an intervention. Therefore, insider views and subjective data were collected mainly under the role of an observing participant during the field visits, in conversations, presentations and meetings with personnel and by raising questions. The second role, the non-participant, allowed to collect data without direct involvement with the people's activities or environment. For both roles the approach for the data collection during observation was to start broadly by watching the physical setting and listening to guided tours, conversations and asking questions to inform the first research question.

The obtained fieldnotes and pictures were first read and viewed-to reflect upon the experiences. Subsequently, formulating a coherent text out of fieldnotes and complementing pictures with captions described the data. A short list of tentative codes was established to match segments of the collected data. Throughout the review process new codes were added to the list. The list of codes was then transformed into a list of categories emerging among the codes in order to formulate the results and refer back to specific categories.

4.1.1.5 Interviews – Collection and Analysis

Four semi-structured interviews were conducted. Two interviews with personnel of accelerator research facilities and two at NPPs. Preference was given to semi-structured interviews as its "questions are pre-planned prior to the interview but the interviewer gives the interviewee the chance to elaborate and explain particular issues through the use of open-ended questions" (Alsaawi, 2014: 151). This allows following the thoughts and direction of the interviewee. The main questions were sent out prior to the interview session. Semi-structured interviews also provided the option to ask follow up questions, flexibility and the room for spontaneous in-depth answers.

The selection of interviewees followed a purposeful sampling approach inspired by Creswell (2013) who states that she „select[ed] individuals and sites for [her] study because they can purposefully inform an understanding of the research problem and central phenomenon in the study“ (p. 156). The semi-structured interviews were targeting radiation protection and emergency preparedness employees in different facilities. Before the interview the thesis scope was presented and permission to record was obtained. All interviews were recorded with the laptop's built-in voice recording application "Voice Memo". The interviewees were informed that they and their workplace would remain anonymous. Every interview followed the same structure. The interview guide can be found in Appendix 2.

After transcription, the interview data was interpreted through a content analysis. During the coding process different categories arouse selecting passages that appeared to be interesting, important, challenging, consistent or simply different. As Seidman (2006) suggests applicable connective threats were drawn among the data but also individual informants' expertise and experience in the field were acknowledged individually.

4.2 Designing the Solution

The design of the solution was based on literature (s. method in section 4.1.1.1). The proposed solution is an iterative emergency preparedness process composed of several activities. In a first attempt to implement the proposed design one iteration of the process with its activities was performed. One activity was dedicated to the development of a procedure for intervention called concept of operation. In order to test the results of the activity a functional exercise with a subsequent participant survey (including quantitative and qualitative answers) was evaluated.

4.2.1 Functional Exercise and Participant Survey

4.2.1.1 Organisation

If the first attempts of the design activities were adequate or adjustments were necessary an intermediate evaluation was identified to be useful. Therefore, a functional exercise was conducted during the design phase on the 5th of May 2020 with the purpose to test the first drafted emergency procedure and refine further revision and design attempts. Thus, the design was challenged by the context it is interacting with. In addition, training and initial familiarisation of responding actors during an emergency were key objectives. Two training rounds with subsequent briefings were conducted. This allowed participants to raise questions, reflect on their actions and directly apply lessons learned. Notes were taken during the exercise and debriefings conducted to capture subjective observations and immediately shared narratives. The developed scenarios for each training round were not identical as the objective was to train participants on different injuries during the two rounds and foster response flexibility. A risk assessment was conducted before the exercise. Risk mitigation actions were implemented to ensure a safe exercise. Due to the Covid-19 pandemic ESS demanded to keep the number of participants to a minimum of ten people. The sampling of participants was based on the people's roles during a response to the developed scenario and their availability on site for the planned date. I developed the objectives and scenarios, invited participants, conducted the risk assessment and prepared the exercise scene. The facilitation was realised by the emergency team leader and I took over the role as an observer during the exercise.

4.2.1.2 Participant Survey

An online survey was sent out the day after the functional exercise to the participants composed of both closed questions (Likert scale and multiple choice (Robbins & Heiberger, 2011)) and open-ended questions. The participation was voluntary and no answers were mandatory. Collecting feedback anonymously was believed to increase the response rate. The questions soliciting input in text format were collected as narratives and written

feedback of the participants' individual experience. The online survey was created with Google docs forms and was in line with data protection regulations.
The analysis of the data obtained from the exercise consisted of several steps:

- reading the notes taken during the exercise
- reviewing the pictures and
- writing down the experience and evaluating the obtained survey data afterwards

A comprehensive evaluation report was conducted collecting all information relevant for interpreting the data. The functional exercise data actively informed and refined the design process (chapter 6).

4.3 Evaluating the Solution

"The goal of evaluation research […] is to investigate how implemented artefacts interact with their real-world context. Evaluation research is field research of the properties of implemented artefacts" (Wieringa, 2014: 31), but due to time and resource limitations the entire proposed process (the artefact) could not be evaluated. Therefore, the results of two activities in the process were chosen to inform the evaluation. For that purpose, the method of a table top exercise (TTX) was chosen to gather information of the interaction of the design and its entailing response capability, plans and procedures. A TTX provides a setting where challenges can be identified and resolved and even existing operational procedures can be refined through a constructive participant discussion (WHO, n.d.). A subsequent online participant survey was sent to the attendees (Appendix 3).

4.3.1 TTX and Participant Survey

4.3.1.1 Organisation

The TTX was conducted on the 11th of August 2020. Due to the Covid-19 pandemic the exercise was carried out virtually. In this exercise the participants were supposed to rehearse their roles, discuss, ask questions and identify gaps and training needs. The exercise was used to identify whether the proposed design meets the established design criteria and which improvement actions need to be followed in the future. A colleague from ESS and I were responsible for the design, scenario development and facilitation of the exercise. The invited participants were selected in consolidation with my supervisor at ESS. The aim was to gather relevant stakeholders from operational and strategic positions involved in the response to the fictional scenario. Four observers from the crisis management team at the facility were invited that should provide feedback after the exercise. The exercise was held via an ESS internal video chat application. Myself, as facilitator, and the co-facilitator were present together in the ESS premises to simplify the facilitation process. The exercise started with an introductory presentation by the facilitators, entailing

- Definition of a TTX
- Background information, purpose and scenario
- Specific objectives of the session
- Rules to play

- Foreseen time schedule (Appendix 4).

4.3.1.2 Participant Survey

The participant survey (Appendix 3) of the TTX had a similar structure as the one described in 4.2.1.2 and was filled out by the participants and observers in a designated time slot right after the exercise and initial feedback. This approach was chosen to benefit from the very recent experience and guarantee immediate responses due to time constraints in the thesis process. The obtained data from the TTX was compared with the established design criteria. The analysis leads to evaluate the design and identify gaps and opportunities and provided input for the process cycle to continue in the future (chapter 7).

5 INVESTIGATING THE PROBLEM

5.1 Underlying Conditions

The following section discusses the first research question. Through the analysis of relevant qualitative data four underlying conditions for developing an emergency preparedness concept have been identified. These are architecture and planned operations, legislative framework, available staffing and established procedures. In this section each condition is presented together with resulting implications for the ESS. This provides a deeper understanding of what distinguishes this facility from others.

5.1.1 Architecture and Planned Operation

Each accelerator driven accelerator facility has a unique layout depending on the scope of fundamental research to be carried out. The complex layout of the research facilities demands that personnel, contractors as well as scientist from all over the world are well trained regarding the site, hazards and emergency procedures (Fieldnotes A1, A2, A5). Orientation difficulties on the facility premises often originate from complex and sometimes underground structures of great dimension going far beyond the fenced premises (Fieldnotes A1). Underground tunnel constructions impose difficulties as they are considered as structures that underlie special safety regulations for underground areas. The design and architecture are similar to conventional tunnels but their use and purpose is different due to the ionising hazard. Individuals are not allowed in the accelerator tunnel when the beam is operating. Access to the tunnel is only allowed when the accelerator is not operating for example in case of maintenance or repair. Access is granted only after a radiological survey. According to safety legislation and requirements from the local fire and rescue services adequate rescue and escape routes need to be established (Fieldnotes A1, ESS). Common evacuation lists of personnel on the premises might not be sufficient for safety assurance in a kilometre-long underground vault and special access and personnel tracking systems have to be implemented (Interviewee A1). Accelerator driven systems can also be one part of a big research campus where buildings and departments are scattered across the premises and hazard profiles can vary significantly (Fieldnotes A1, A2). Observations (Fieldnotes A1, A5, ESS) have confirmed that there is still an “unmet need for emergency planning and management tools which provide emergency responders with means to become familiar with a facility from an expert point of view […] without requiring the responders to have ever visited the facility” (Davenport & Flacks, 2004: 1). Therefore, the approach remains to inform site personnel and external rescue services on hazard specific circumstances of planned operation, intervention and rescue routes beforehand or latest upon arrival (Fieldnotes, A1, A2, A5, ESS).

As introduced in chapter 2.3 electron accelerators are causing less activation within the tunnel vault during operation (A1, A2, A3) than proton accelerators (A5) due to the lighter mass of an electron than proton and the resulting different interaction with material (Forkel et al., n.d.; Fieldnotes A1, ESS). Proton beams “pose for comparable beam intensities a far higher radiological hazard; this calls for a much stricter control policy for the use of such beams” (Stevenson & Vylet, 2001: 320).

The main aspect regarding the planned operation of accelerator driven facilities for research is the usage of beam by users (scientists conducting experiments at experimental stations) once operational. The handling of an experiment entails risks. One informant mentioned the fact that in recent past there had been more applications for chemistry, material science and biology related than physics related experiments. Here, the handling and dispatching of probes demands different safety precautions and radioactive information. At facility A5 approximately a third of the users are newcomers to the site and more than 800 doctoral students are working on the premises. The degree of personnel fluctuation and lack of experience they bring to the site causes challenging safety training requirements (Fieldnotes, A5, ESS).

Architecture and planned operation are crucial underlying conditions to consider as they co-determine the hazard profile and necessary safety precautions.

5.1.1.1 Implications for the ESS

The ESS facility will be a research facility with the most powerful neutron source in the world and represents another exceptional architecture in the group of accelerator driven research facilities. The linear proton accelerator is built in a tunnel, the roof of which is at surface level with a berm on top of it. It is covered by 5 metres of soil to ensure sufficient shielding against the ionising radiation generated by the proton accelerator. The spallation target and the neutron instruments are at surface level (Garoby et al., 2018). Once in full operation the ESS facility will attract approximately 3000 researchers each year. Only 1.5 km down the road Lund University hosts the MAXIV synchrotron facility. It is operating since 2016 and provides X-rays for scientific experiments. In 2017 a Memorandum of Understanding was signed between ESS and MaxIV on close scientific cooperation, exploration of potential synergies and coordination of activities to ensure among others also user’s safety and training (ESS, 2017b). On the premises between the two facilities a project called “Science Village Scandinavia” is being developed that will provide common infrastructure and services (Figure 4) (Garoby et al., 2018). The first attempt to start or consider a collaboration between the facilities on emergency preparedness for radiological incidents remained unsuccessful due to different prioritisation and a significantly lower expected radiological risk at the synchrotron facility.

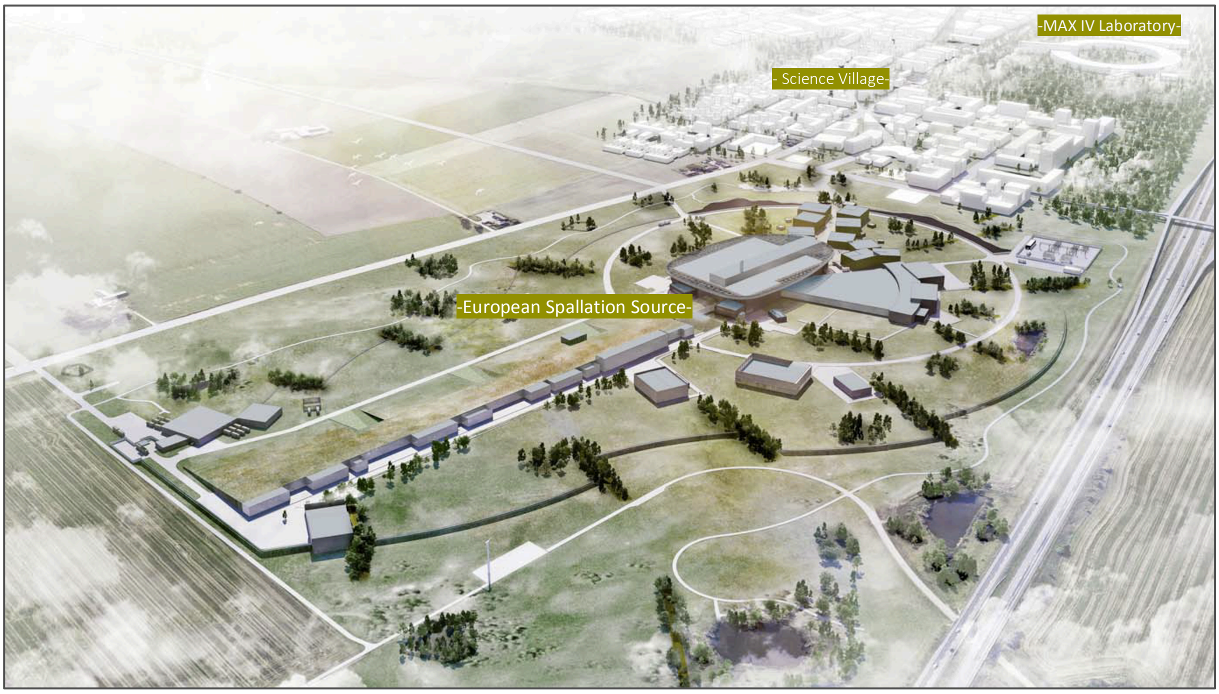

Figure 4 Conceptual illustration of the ESS, with the Science Village Scandinavia and MaxIV (circular shape) in the background (retrieved from Garoby et al. 2018)

The construction of the ESS facility is nearly finished and the installation of the accelerator has started. The first part of the accelerator, the normal conducting linac (NCL), will be commissioned in 2021 while the installation of the remaining accelerator, the superconducting part (SCL), will continue in parallel. This poses a challenge for radiation protection and emergency preparedness due to the ionising hazard of the NCL. To guarantee safe and simultaneous performance of commissioning of the NCL and the ongoing installation work in the remaining vault a temporary shielding wall is placed between the two sections. This shielding wall ensures that during commissioning of the NCL installation work can continue in the SCL part of the tunnel whilst protecting workers against ionising hazard from the NCL part. For the ESS accelerator, the identified radiological hazards are "prompt radiation from operational and accidental beam losses, prompt radiation (x-rays) from Radio Frequency (RF) fields, residual radiation from activated components and fluids in the tunnel, activated tunnel air and contamination due to release of inventory in activated components" (ESS, 2020b: 167). The hazards are present both during the NCL beam commissioning stage and at later stages including steady state operations. However, the level of hazard does vary. The NCL commissioning is posing less significant radiation hazard compared to the operation of the full accelerator. This is due to low beam intensities and low current resulting in less activation of materials than in the following stages with increased activation of material when the complete accelerator, NCL together with SCL, will be commissioned (ibid).

5.1.2 Legislative Framework

The European directive (latest version 2013/59/Euratom) introduces dose limits, exemption levels, emergency intervention levels and clearance levels for work with ionising radiation.

The relatively new directive demands a replacement of previous emergency management, which was based on intervention levels. Now "a more comprehensive system comprising an assessment of potential emergency exposure situations, an overall emergency management system, emergency response plans, and pre-planned strategies for the management of each postulated event" (p. 5) is required.

The proposed limits by the Directive are transposed into national regulations by all European countries and must be respected. The handling or production of radioactive material and the operation of equipment generating ionising radiation demands a license from the regulating authority. Depending on the facility's country, the respective national regulating authority is responsible to assess whether the facility applying for the license complies with the requirements imposed by the national Radiation Protection Act (Grupen & Werthenbach, 2010).

5.1.2.1 Implications for the ESS

Swedish national law and the transposed European Directive form the legal framework for ESS. The SSM and the Environmental Court issue the permits for construction and operation of the ESS. SSM issues the license to the ESS facility in stages (ESS, n.d.; Garoby et al., 2018) and controls whether the facility complies with the national legislation. Table 1 provides an overview of the legislative documents entailing aspects relevant for emergency preparedness. SSM has classified the ESS in threat category II (chapter 2.5), which implies that events may occur "involving a release of radioactive materials warranting urgent protective actions for the population outside this facility; however, the risk of severe deterministic effects posed to people off-site can be ruled out" (Buhr et al., 2019: 7).

Table 1 Overview of Legislative Framework

Legislation	Aspects relevant for Emergency Preparedness for radiological incidents
Radiation Protection Act Strålskyddslag (2018: 396)	Dose restrictions and monitoring of personal received doses during an accident
	Usage of protective devices and other measures
Radiation Protection Ordinance (SFS 2018:506)	Dose limits during practices with ionising radiation summarised in Appendix 5 Table 3 are not applicable in a radiological emergency, but should not be exceeded for workers assigned special tasks in a radiological emergency. ESS has established dose constraints on request by SSM presented in Appendix 5 Table 4.
	"The person responsible for the rescue work may determine reference levels to which workers are exposed, but these may not exceed an effective dose of 100 mSv or exceed an effective dose of 100 mSv but not 500 mSv, if needed to save lives, prevent serious radiation-health effects, or prevent catastrophic conditions from occurring" (chapter 3, §9).
Swedish Radiation Safety Authority Regulations on basic provisions for practice with ionising radiation	A written emergency preparedness plan, which specifies preparations and crisis management to deal with and limit the consequences of a radiological emergency, is requested.

subject to licence (SSMFS 2018-1)	
Special Conditions for the ESS facility in Lund (SSM, 2018)	The licensee shall prepare a comprehensive document, an emergency preparedness plan, basing the emergency preparedness management on developed scenarios, describing its main tasks, responsibilities, premises, resources and collaboration, as well as the foreseen activities in order to manage a radiological emergency at the facility and give references to the documentation that provides operational support.

5.1.3 Available Staffing

The analysis of the observations and interviews showed that available staffing is another crucial underlying condition for emergency preparedness. The available staffing for emergency preparedness and management efforts varies at each investigated facility. It is not precisely quantifiable, as emergency preparedness or management is often not a stand-alone job, but rather an add on responsibility to daily job routines. Moreover, one interviewee emphasised that management priorities often determine to what extent personnel can be involved in preparedness efforts (NPP 2). At all facilities, a radiation protection representative has to be reachable during operation for radiological emergencies. This person has to be on site within a set time or undefined short time period after alarm. Depending on the classification of areas at the respective facility, radiation protection staff can already provide advice via phone or has to be present on site before the intervention (Fieldnotes A1). In general, advice of experienced site staff is indispensable as rescue personnel should not enter without first identifying the potentially hidden hazard (Casavant, 2003: 122). At one facility with a low radiation risk profile, the issue is solved based on trust. "It is not possible to set up an on-call service with the available personnel. However, the personnel have telephones/mobile phones that can be used to reach them in an emergency" (Interviewee A1). At some facilities a fire brigade has been established. It is trained in radiological emergencies and can intervene independently. Radiation protection staff provides clearance after intervention and advice from safe distance (Fieldnotes A2, Interviewee A4). However, having a dedicated fire department on the premises is expensive. If the authorities do not require it, implementation is often omitted (Fieldnotes ESS). In that case the external fire and rescue services have to intervene and other first responder functions are established on site (e.g. alarm investigation teams trained in basic firefighting (Fieldnotes A5), technical support teams providing guidance to external rescue services (Interviewee A1)).

5.1.3.1 Implications for the ESS

The ESS is still in the construction and installation phase and not operating. Therefore, available staffing is limited. During construction and the period for commissioning of beam on temporary dump there will be an incremental handover of buildings from the principal contractor Skanska ESS Construction (SEC) to ESS. A "shared site" with two parties and stepwise changes in relation to responsibilities for different workplace areas requires collaboration (Fieldnotes ESS). The party's different emergency concepts need to be managed together. Site emergency response functions are planned but personnel are partially not appointed yet. The facility will not have a fire brigade on site. The current Emergency Response Team (ERT) is available weekdays during working hours and consists of the ESS and SEC appointed functions shown in Figure 5.

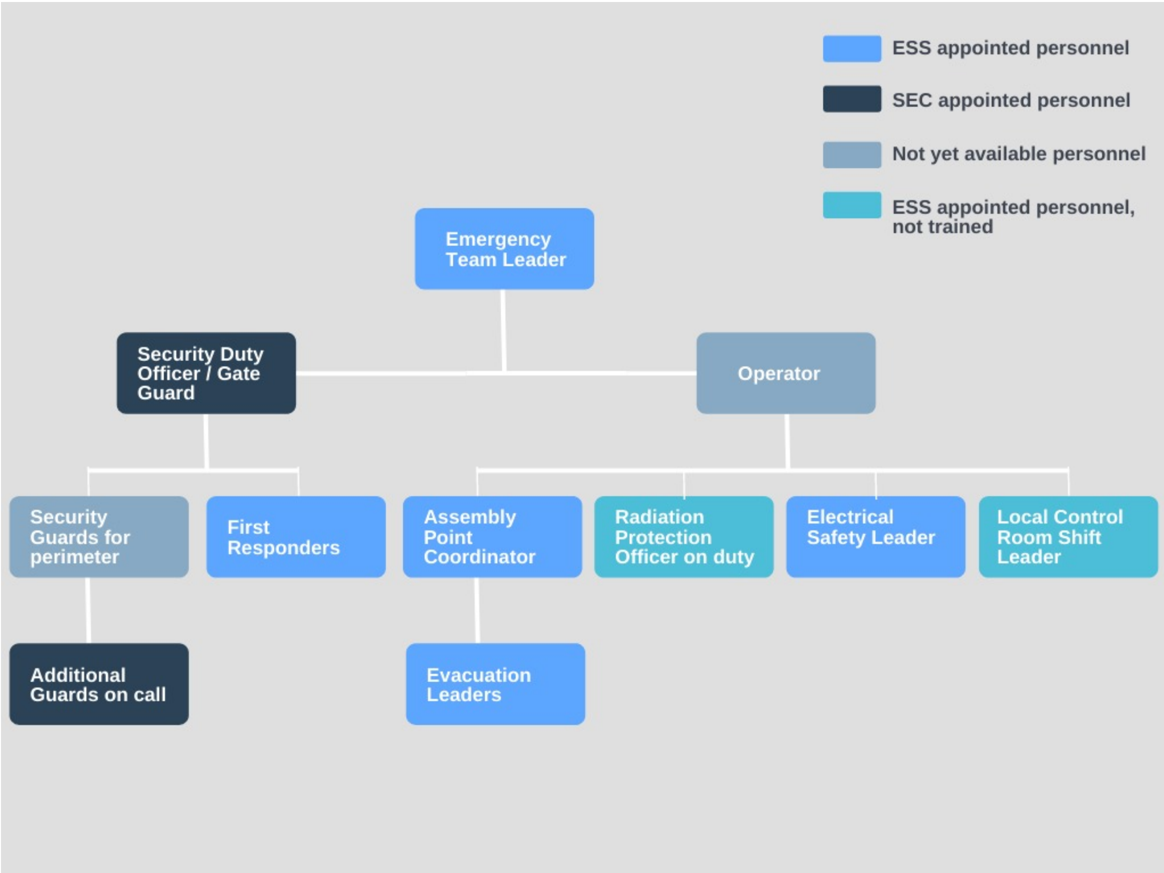

Figure 5 Emergency Response Team Organisation

The Emergency Team Leader leads and coordinates the accident and emergency interventions of all functions in Figure 5. As of August 2020, the First Responders (FR) are being trained in first aid and basic fire fighting, as well as site-specific hazards. Their knowledge and skill set gradually increases as the commissioning and construction process develops. The Emergency Team Leader can decide whom to alarm in addition to the FR depending on the situation and expertise needed (Fieldnotes ESS).

Staffing in the Radiation protection group for operational radiation protection currently allows for one Radiation Protection Officer (RPO) on duty that can respond to emergencies and the Radiation Protection Expert (RPE) who is available to be called in for advice or support the response on a strategic level. Currently at ESS the RPO on duty actions are also carried out by the RPEs who then also act as RPO on duty. RPO and RPE form the operational radiation protection team. Specific emergency response training or involvement has not been implemented prior to the suggested design (chapter 6). Similar, a Local Control Room Shift Leader managing a team of beam operators is appointed who oversees the operation of the ESS facility. Training on procedures in case of an emergency for this team is still pending.

5.1.4 Established Procedures

Each facility has plans and procedures in place to guarantee emergency preparedness. This does not necessarily imply their effectiveness or that these efforts have reached an optimal stage (Fieldnotes A2, A3, A5). One interviewee acknowledged that the established emergency preparedness procedures are currently reviewed. The reason is impracticality caused by too detailed documents (Interviewee A4). Another facility admitted that their plans don't have enough details and are useless (Fieldnotes A3). Also, it has been mentioned that plans are not used during exercises or real interventions and easily applicable procedures are absent (Fieldnotes A5, Interviewee A4). Both NPP interviewees mentioned the past Fukushima emergency in 2011 as a reason for challenged established procedures. A similar scenario to the Fukushima emergency had never been acknowledged or exercised but the emergency manifested the urgent need for innovation and complementary actions at the respective facilities (Interviewee NPP1, NPP2). Three out of four interviewees affirmed that they have encountered gaps or room for improvement. The following quote presents an example of a procedure change between the fire brigade and radiation protection personnel at one facility:

"Rules and regulations were put into place that hindered the fire brigade to use their knowledge because they were not allowed to enter. At that point, entrance without the formal go-ahead of the RP was strictly forbidden. This changed and if there is a real emergency now and life or property has to be saved the first responders can take measures and start to save lives. That was not possible in the previous procedure." (Interviewee A4).

5.1.4.1 Implications for the ESS

At the ESS, established procedures and emergency preparedness plans are already in place dealing with risks other than radiological. They are the foundation to build upon. Due to constant development, modifications can still occur. As the ESS accelerator is partly build at the time the emergency preparedness concept for radiological incidents only guarantees preparedness for the first NCL part. The concept gradually evolves in relation to the acquired knowledge about hazards of different commissioning stages and the progress of construction.

During the current period of construction and the start of commissioning by the end of 2020, the overall Emergency Preparedness Plan, developed by the OHS function within the ESH division is not applicable yet. Instead, a transitory Emergency Contingency Plan has been developed. At the time of commissioning of beam on target (2023), the overall Emergency Preparedness Plan will be implemented and automatically replace the Emergency Contingency Plan. A minimum of six months prior to operating the accelerator with the beam on target, all functions as defined in the Emergency Preparedness Plan will be trained in a large exercise. The SSM will evaluate this activity (Fieldnotes ESS). The emergency preparedness concept for radiological incidents is therefore subordinate to these high-level documents, hereby informing and providing knowledge, arrangements and procedures for radiological incidents only. The design of the emergency preparedness for radiological incidents had conclusively to be linked to the Emergency Contingency Plan bearing the potential to further develop until the final commissioning phase and even beyond (Fieldnotes ESS). These dynamic circumstances regarding current procedures and planned future arrangements need to be considered before the design.

5.2 Design Criteria

After an analysis of the underlying conditions and their implications for the ESS the next section aims to answer the second research question. The seven design criteria presented are obtained and compiled from literature, interviews and facilities internal documents.

Table 2 summarises the design criteria and their appearance in interviews, observation and literature.

Table 2 Overview of Design Criteria

Design criteria	Interview	Observation	Literature
Risk-based	A4, NPP1, NPP2	A3	(CCPS, 2010; NCRP, 2005; NFPA, 2019; Perry & Lindell, 2003)
Flexible	A4, NPP2		(Alexander, 2016; Perry & Lindell, 2003)
Interoperable	A4, NPP1, NPP2		(Alexander, 2016; Casavant, 2003; Grupen & Werthenbach, 2010)
Clear in command	A4, NPP2	A5	(Casavant, 2003; Erickson, 1999; Gow & Kay, 1988)

Training-based	A1, A4, NPP1, NPP2	A2, A5	(Casavant, 2003; CCPS, 2010; Ford & Schmidt, 2000; Perry & Lindell, 2003)
Exercise-based	A1, A4 NPP2	A2, A5	(Casavant, 2003; Erickson, 1999; Gow & Kay, 1988)
Continuous	A4, NPP1, NPP2,	A5	(Alexander, 2016; Gow & Kay, 1988, 1988; McConnell & Drennan, 2006; Perry & Lindell, 2003; Staupe-Delgado & Kruke, 2018)

Their origin, justification, informing quotes and motivation is described in more detail in Appendix 6. The following section provides brief summaries for each design criterion.

5.2.1 Risk-based

The emergency preparedness process should be based on the assessed risks and the planning of resources. Mitigating consequences should be proportionate to the risks.

The special conditions for the ESS issued by SSM (2018) demand to base the emergency preparedness on scenarios grounded on events and circumstances in different event classes of different likelihood. In order to achieve a degree of planning that is reasonable for the risk and expected consequences risk assessments can create knowledge about certain threats.

5.2.2 Flexible

The emergency preparedness process should be flexible to enable adaptation to changing circumstances.

Several commissioning stages with different risk levels and combinations of risks demand adaptive capacities. Procedures cannot capture every eventuality without getting too complex and impractical.

5.2.3 Interoperable

The emergency preparedness process should be interoperable and compatible with equipment and procedures between different stakeholders.

During an emergency, the successful coordination and compatibility between internal functions as well as external stakeholders, e.g. rescue services or the police is crucial. This enables an adequate respond and avoids misunderstandings or knowledge gaps.

5.2.4 Clear in Command

The emergency preparedness process should be clear in command and responsibility distribution.

Especially in work environments with rather informal hierarchies, a clear command structure has to take over and be accepted during emergencies. This can be difficult to communicate to users of the facility. Researchers emphasize the necessity for actors to know who is in charge of decision making and what actions can be expected from which function.

5.2.5 Training-based

Emergency preparedness process should be trained, by creating safe learning environments. Personnel needs to gain routine on tasks performed during an emergency.

Training is ideally an integral part of the preparedness process. It is tailored to the respective function. A frequency and conditions for execution of additional training should be agreed upon.

5.2.6 Exercise-based

The emergency preparedness process should be exercised based, by conducting a set of realistic exercises of varying size and execution.

To test emergency preparedness concept and process exercises are a suitable tool. Diverse setups, scenarios and ways of facilitation achieve different objectives. Realistic circumstances are important in order to prepare participants as best as possible for a real emergency.

5.2.7 Continuous

Emergency preparedness process should be continuous with ongoing activities.
Ongoing activities imply for example training, exercises, review and adjustment of plans and procedures, as well as equipment purchases. The emergency preparedness process does not reach a desired end state or terminates at a certain point. It continues infinitely.

6 DESIGNING THE SOLUTION

After the presentation of the underlying conditions and the design criteria the following section aims to answer the third research question. The core of this segment is the designed solution: the proposed emergency preparedness process displayed in Figure 6.

The design of this process was guided by both the underlying conditions (chapter 5.1) and the established design criteria (chapter 5.2). The ESS specific implications of the underlying conditions as well as the seven criteria form the foundation to tailor the design according to the ESS needs. Further, approaches at general industrial facilities (CCPS, 2010; Gow & Kay, 1988) as well as relevant literature presented in chapter 2 were considered. In addition, literature on general recommendations for emergency planning was reviewed (Alexander, 2016; Alexander, 2009; Casavant, 2003; Erickson, 1999; NFPA, 2019; Perry & Lindell, 2003). The review results lead to the conclusion that emergency preparedness has components, which are hardly hazard specific. The authors provide minimum aspects to include during the planning and advice how to plan for training and exercises. Hereby the researchers are not addressing any specific hazard. It is the obligation of the planner to tailor the process to their identified risks.

The process is designed as a continuous cycle with further smaller iteration possibilities. The boxes entail activities. These activities are components of each step in the emergency preparedness process. The overall structure of the process is influenced by general recommendations from the literature. The activities themselves are tailored to the focus of this thesis: the radiological hazard at accelerator facilities. To be noted, emergency preparedness at the ESS needs to adapt to the changing hazard characteristics in the future. Once fully operational in 2023 the facility will be hosting significantly more people on site. The emergency preparedness process will have to alter according to the circumstances. The dynamic circumstances at the ESS do influence also the revision demands of written plans and documents. If changes in cited documents, procedures or checklists occur the plan must be reviewed to maintain its validity. In accordance with McConnel & Drennon (2006) “active planning instead of symbolic readiness” (p. 62) is what the emergency preparedness process should aim for. Therefore, the training and exercise components are placed in between the activities for writing plans, procedures and checklists.

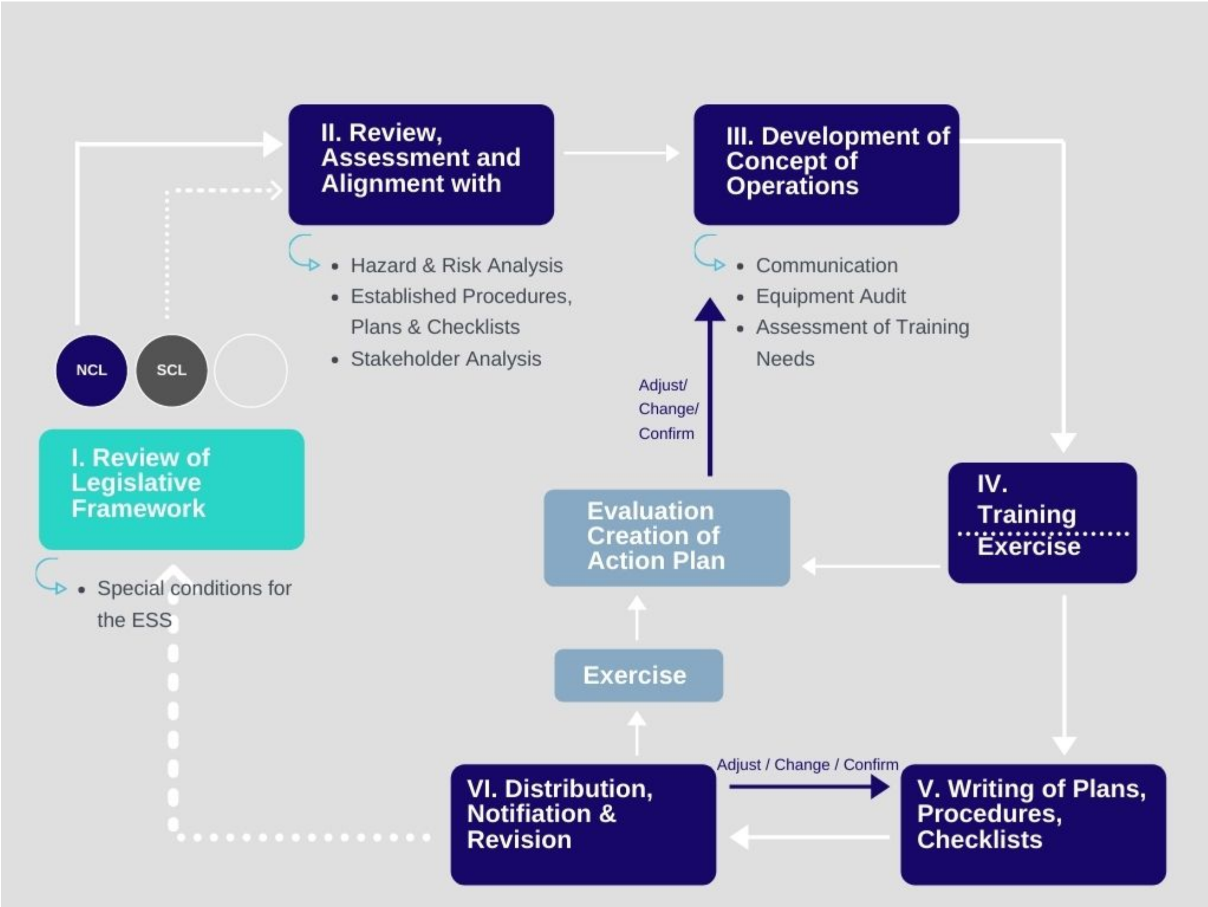

Figure 6 Emergency Preparedness Process

Figure 6 presents the proposed design of the emergency preparedness process at the ESS for the current commissioning stage which is the result of nine month of research and continuous observations at the ESS.

After the performance of each activity, the activity's results enable to move forward to the next box following the arrows in the process. The process and its activities are designed to be ideally continued after the first performed attempt for upcoming commissioning stages. In Figure 6 a dashed line marks the outlook for the next start of design cycle.

After the design a first attempt of implementing the process and its activities has been performed at the ESS from December 2019 to August 2020. This initiated the emergency preparedness process for radiological incidents at the ESS facility related to the upcoming NCL commissioning operations. The key results of the performed activities are presented in the next section. The two grey boxes in the Figure 6 symbolize the evaluation activities and are addressed at a later stage in chapter 7. The roman numerals (I-VI) in Figure 6 correspond with the activity's headings in the subsequent section.[2]

[2] Table 5 in Appendix 7 provides detailed information of the performed activity, its key methods and sources, which kind of underlying conditions were considered and which design criteria were targeted by the activity.

6.1 Key Results of the Activities

Activities I. and II. were performed to identify needs and resources. Activities III., IV., V. aim to design procedures, plans, training or exercises to close the gap between needs and resources. Lastly, activity VI. enables to share the arrangements.

6.1.1 Review of Legislative Framework (I.)

The first performed activity was the review of the legislative framework to obtain an overview of emergency preparedness and radiological specific requirements. The respective box is highlighted in green in Figure 6.

The review of the SSM special conditions for the ESS facility (SSM, 2018) showed that:

- 32 out of 79 conditions needed to already be addressed for NCL commissioning. Of these 28 were addressed by the end of August 2020
- An action plan was developed to indicate which conditions have to be addressed for which upcoming commissioning stages (Appendix 8)

6.1.2 Review of Risk and Hazard Analysis (II.)

The review of radiological hazard analysis and risk assessments for the NCL section resulted in the following findings:

- To achieve a sufficient planning base malfunction of safety systems or human failure and also incidents originating from other hazard sources occurring in radiation areas were included.
- The postulated event, determined by SSM demanding off-site emergency response planning, is not yet applicable for NCL commissioning. It is required with beam on target operations (Buhr et al., 2019). It will be considered as an outlook.

6.1.2.1 Assessment of Established Plans & Procedures & Checklists

The review of RP related documents, emergency and crisis management documents was conducted to guarantee alignment of the design and resulted in:

- Establishing plans and procedures to respect and entry points for the design
- Understanding of established command and emergency management structure for other hazards at the ESS
- Identification of 33 internal documents that are direct sources for emergency preparedness information

6.1.2.2 External Stakeholder Assessment

The assessment of relevant external stakeholder in case of a radiological incident revealed:

- Sufficient hospital preparedness in the Skåne region identified
- Joint exercises and collaboration meetings are worth considering
- Fire and Rescue services are already involved in the planning and exercises on site and are kept up to date on the facility’s hazard potential

- Ambulance personnel needs guidance and cannot enter radiation areas

6.1.3 Concept of Operation (III.)

Based on the achievements in the two first boxes of the process in Figure 6 a concept of operation for the radiation protection group has been developed. Following the IAEA (2003) and CastroSilva & Medeiros (2015) suggestions the RPO actions were clustered according to:

- Prompt assessment and projection of the likely evolution of the accident
- Urgent protective measures
- Rescue mechanisms and decontamination of persons in classified areas
- Long-term actions to be taken after the accident

Further, to guarantee the RPOs availability and alarm readiness, the decision was made to have the RPO on radio during presence on site. This is not necessarily common at other facilities, however, since the ERT operates on radio and the designated radiation areas are increasing gradually, rapid response can be enhanced. This new implementation has to be trained first.

6.1.4 Training & Exercise (IV.)

The recent introduction of the radio communication device and responsibility for the RPO on duty function demanded training. The facilitated training provided information on the functionality of the radio device and radio communication vocabulary. A subsequent testing on site was included in the session to familiarise the RPO with the device in practice. It is foreseen to implement training for all members of the operational RP team prior to NCL commissioning.

To test the design of the concept of operation a functional exercise was prepared and facilitated (methodology described in chapter 4.2.1). Main objectives were to identify adjustment potential and familiarise RPO on duty with the FR.

The following key results were obtained:

- More training is necessary for both functions
- Need to strengthen the interface, trust and understanding of responsibilities and capabilities among actors
- The concept of operation needs changes in the course of tasks of the RPO on duty

Based on the results of the exercise refinements were made in the concept of operation before moving on to the next activity box. This iteration within the overall process is also displayed in the top right corner in Figure 6.

6.1.5 Writing Plans, Procedures & Checklists (V.)

This activity includes the writing of a plan containing all pertinent information of preparedness arrangements for radiological incidents at the ESS. In addition, the plan itself is required by SSM and provides references to other addressed SSM special conditions (legislative framework) and documents (incl. procedures and checklists) at the ESS. During the collection of information, the following key aspects were identified:

- Many decisions are still pending and interdependencies are still to be clarified, therefore a colour-based system indicates sections "to be decided"
- Due to gradual design for commissioning written plan demands continuously update. Risk assessments will alter and demand new balance of resources. In case referenced documents are updated a review process has to ensure remaining compatibility
- No clear communication and updating structure regarding emergency preparedness efforts yet

6.1.6 Distribute, Notify & Review (VI.)

The first draft of the plan led to the next activity to share the progress. A wide range of reviewers for the plan was chosen based on the apprehension that "if the emergency management team consists of employees with similar backgrounds, education, responsibilities, and job titles, the plan will be written in a vacuum" (Casavant, 2003: 114). The plan was shared first among ESH staff to obtain input and comments. Their findings were either directly implemented or taken to operational meetings for discussion.

6.1.7 Conclusive Summary of the Activities

The first attempt to perform the emergency preparedness process at the ESS provided several findings. Very tangible results were obtained, such as an action plan to address the legislative conditions, the first draft of a plan for radiological emergencies and a concept of operation. At the same time more subtle achievements were acquired such as the familiarisation of different functions with each other during the functional exercise.

The smaller iterations in the overall process enabled prompt adjustments to findings along the process before moving forward to the next activity. This aspect was perceived as useful because the design is placed in a steady developing environment at the ESS. To address the dynamic changes the iterations can be performed more than once before continuing the process.

Further, the interface, trust and understanding of responsibilities and capabilities among functions of the ERT require further attention. For some functions this is a new working environment, new situation and possibly a new role. Many training sessions and exercises are ideal for getting to know each other. Joint exercises and collaboration meetings with external stakeholders are worth considering already at an early stage of the emergency preparedness process. Hereby, the interoperability with equipment and personnel can grow gradually with the increasing risk profile of the facility.

7 EVALUATING THE SOLUTION

The design criteria aimed to be addressed and respected during the design activities to obtain knowledge on how the design interacts with its context for the NCL commissioning stage. The subsequent section presents the evaluation of the design.

The scarce availability and absence of an agreed standard also implies that no agreed information on creating, evaluating and approving emergency preparedness processes is yet available (Alexander, 2005). Often, the aspect of evaluation and continuous efforts to improve the plans are highlighted among the literature, however, no frameworks or procedures are available (ibid). In order to evaluate the designed solution, the format of a TTX was chosen (chapter 4.3).

The exercise aimed to examine and strengthen the designed plan, established procedures and capabilities at the ESS through a facilitated group discussion. The entire process could not be evaluated in one exercise. Therefore, the results from the two activities marked in a red circle in Figure 7 were addressed. The blue boxes indicate the activities described in this chapter.

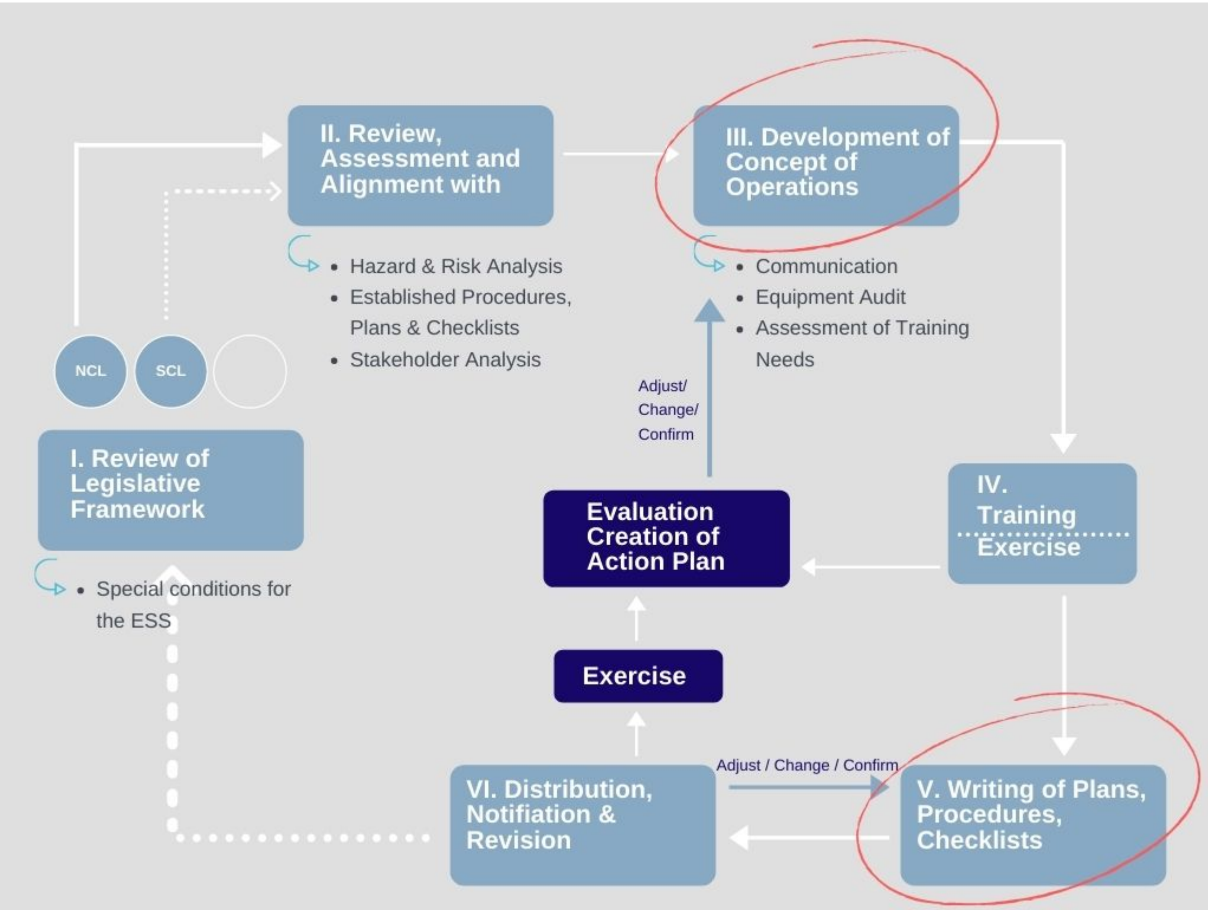

Figure 7 Components evaluated from the designed emergency preparedness process

In addition, it was evaluated whether the results are meeting a set of the design criteria. How the design criteria *risk based*, *flexible and clear in command* were achieved was assessed through the participant surveys statements. They are presented in (chapter 7.1., Figure 8). Attendees had to indicate their level of agreement with each statement. The design criterion *interoperable* was already addressed by the choice and variety of operational and strategic stakeholders invited to the exercise but also implicitly through survey questions soliciting written input. Asking the participants for potential identified training and exercise needs in the future (7.2 & 7.3) targeted the two criteria training- and exercise-based. By using the TTX as an evaluation method, it was possible to say that the current emergency process is exercised-based. However, if the process will be training- and exercise-based in the future cannot be evaluated. It depends only on the implementation and follow-up of the proposed design. Similarly, it could not be evaluated with the exercise if the emergency preparedness process is continuous, as this will manifest itself only in retrospective at a later stage if the proposed design has been driven forward.

7.1 Results of the Participant Survey

This chapter presents the results obtained from the participant survey send out at the end of the TTX to all attendees. Figure 8 presents the level of agreement with the statements on the design criteria stated in the participant survey.

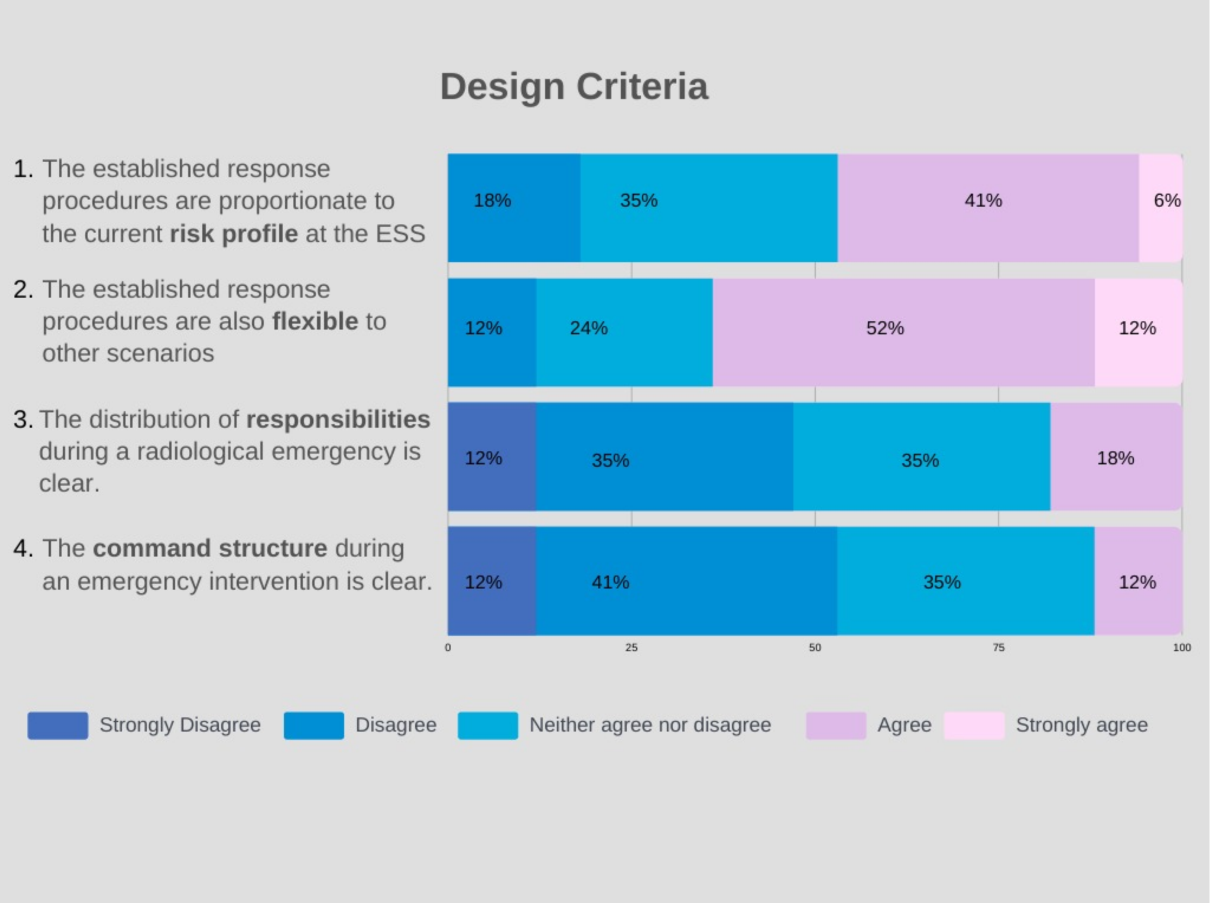

Figure 8 Participant Survey Results: Design Criteria

7.1.1 Risk Based

About half of the respondents (47%) agreed that the procedures reflected the current risk profile. Only 6% agreed strongly whereas 18% disagreed and the rest remained neutral. The following gaps and suggestions for improvement were identified:

A better understanding of when to move casualties out of the area related to assessed values needs to be achieved. Further, operating procedures for handling of contamination and personal protective equipment advice remained unclear. Observation during the exercise and survey answers indicated the need to re-assess which functions in the ERT are available. During the exercise a potential lack of knowledge, which personnel had to be alarmed, was identified. The present staffing of the FRs does not allow function coverage around the clock. During the debriefing session it was highlighted that there has been a misunderstanding on the actual severity of the event and imposed risk and consequences. One attendee emphasised the need to align and gain a common understanding of the risk to achieve an adequate balance between safety and operations. Especially the RPO function should get training on the radiological risks associated with the commissioning. Based on the aspect that only the RPE functions have been involved in the risk assessment processes at the facility. Therefore, the RPO functions were lacking knowledge on the potential risks.

7.1.2 Flexible

The majority of the respondents (64%) agree or even strongly agree with the second criterion statement of the flexibility of established procedures to other scenarios. In addition, to the survey question, flexibility aimed to be examined by having different stages within the scenario during the exercise. The following suggestions were identified to increase flexibility:

It was emphasised several times that checklists were the preferred tools to improve or complement the established procedures. Checklists could provide a coarse framework with important steps. They should not provide any detail to enable the adaptation to unique and changing circumstances during the emergency. Further, there is a lack of understanding on when to declare a confirmed emergency. Escalation of every operational deviation needs to be prevented but on the other hand implementing an alert for the ERT to get ready and inform the RP group as they must file a report on any occurred incident.

7.1.3 Clear in Command

Two statements asked whether the emergency preparedness process is providing a clear structure of command and responsibility distribution. The levels of agreement among the respondents are relatively similar. The command structure seems to be less clear than the responsibility distribution. None of the respondents strongly agreed on either of the two statements, but 12% strongly disagreed on both statements. The results show that in comparison to the other design criteria clarity in command and responsibility distribution achieves the lowest level of agreement. In the written input sections of the survey the necessity for more clearly distributed roles within the RP group, clarification of the role and responsibilities of the shift leaders, general chain of command and roles within the emergency response organisation were often indicated. Ambiguity about decision power for safe intervention was also mentioned. One attendee mentioned the need to clarify how normal operational roles deviate from the taken roles during emergencies. Further, a better understanding of the interface with the external emergency services with on-site functions is desired.

7.2 Training Needs

One question solicits written input from the participants on identified training needs during the exercise. All functions of the ERT and stakeholders involved in an emergency situation should be further trained on radiological hazards in off-normal and emergency conditions. The interface between shift leaders and RPO, the procedure on FRs entering a radiation area and the overall coordination among the functions were specifically mentioned.

The use of radio communication as well as evacuation procedures from the accelerator building needs to be trained by defining when and how to assemble the personnel effectively. One observer suggested training a “standard emergency scenario” on how to react and include events considering the contamination aspects.

7.3 Exercise Needs

The question solicits written input from the participants on identified exercise needs. Several attendees emphasised the need for having TTXs more often and with different scenarios, different people or for a different unit like the Crisis Management Team. It was identified as a useful tool to collect improvement opportunities, inconsistencies, test roles, chain of information, responsibilities and gaps in the emergency response procedures. It was also mentioned, that this exercise could be conducted again after correction and implementation of lessons learned and prior to the commissioning of NCL. One observer suggested having two workshops with the functions, by going through the necessary procedure, roles, communication lines and then conduct the exercise again.

7.4 Conclusive Summary of the Evaluation

The level of achievement of the design criteria statements answered in the survey provides a good overview of where the process is successful or in need of refinement. The process is considered by the majority of the attendees to provide flexible and risk-based procedures. A better understanding of the current risk profile and complementary checklist were mentioned to foster the criteria. The distribution of responsibilities and established command structure on the other hand was only perceived clear by less than a fifth of attendees. Therefore, the process should especially aim to clarify roles and responsibilities among the emergency response actors during upcoming refinement activities.

The chosen exercise scenario was realistic as it was based on the risk analysis for the NCL commissioning. The identified procedure gaps and improvement opportunities need to be addressed not only to refine the process but also to improve ESS capabilities to respond. It was the first time to conduct a TTX for radiological emergencies and the first time for actors to be engaged. This exercise enabled to identify interdependencies among actors but more importantly to start familiarising with each other. In order to transform the lessons of this experience through actions into lessons learned (Alexander, 2016) the evaluation report includes suggestions for improvement. After implementing the improvements another exercise could be conducted to assess their success. The designed solution is a preparatory process and provides a good starting point for the upcoming improvement cycles.

8 DISCUSSION

This section provides a discussion of challenges and suggestions for the future implementation of the proposed design. Further, a reflection of the thesis methodology and the generalizability of the results and future research possibilities are presented.

8.1 Challenges of Implementing the Proposed Design

The first performed iteration of the emergency preparedness process for radiological incidents at the ESS facility serves as a good start. The results obtained from the preparedness activities and TTX build a valuable foundation to continue working with.

In general, the proposed design has to gain more maturity and also address aspects such as post-intervention actions and recovery. Since it is a never-ending process the gaps and improvement opportunities from the evaluation (chapter 7) have to be implemented as soon as possible. The evaluation and preparation for future exercises is time consuming and should ideally be agreed upon early on the planning horizon.

Moreover, several revision and updates are still to come, as plans, procedures and resources will alter with the increasing risk profile of the facility. Throughout the exercises the information transfer of present risk profiles and understanding of the consequences of the respective risk have been identified as lacking. ESS will gradually develop over the next years. Due to the step-wise design for commissioning stages risk assessments will alter and demand new balance of resources. Plans and procedures need to be updated to reflect the altering arrangements. The adherence of continuity will be challenging. The increasing complexity of the facility, staffing and number of established procedures demands a clear common understanding among the members of the ERT, employees, visitors and users.

The presence of two different emergency preparedness concepts on one site demands special attention to foster the interoperability of SEC and ESS in case of an emergency. To gain a common understanding and agreement clear communication among several parties at ESS is crucial. This includes also the facilities crisis management team and external rescue services.
As identified during the exercises, difficulties are already present for functions or divisions internal information distribution. Increasing complexity of the risk profile and staff availability will challenge the communication among all levels even further.

8.2 Suggestions for Future Implementations

Throughout the development and design process, it might be identified, that procedures or aspects are not working. It is advised to consider established plans and procedures as continuously improvable and living documents instead of a final decision (Alexander, 2016). According to McConnell & Drennan (2006) openness and cognitive ability to change is a prerequisite for success (Appendix 6). Therefore, critical reflections during training and workshops, as well as different types of exercises are indispensable despite their time-consuming nature.

To support this effort, it is suggested to establish an Emergency Task Force. This would consist of representatives from each function of the ERT to create a shared mental model, which can be directly communicated by the representatives to the respective whole function. This way information on established plans and procedures could be agreed upon and shared. It is believed that this task force could avoid miscommunication, double work, lack of understanding among the involved actors and be the central communication point towards external stakeholder. Moreover, based on the observations during both exercises an early formation of trust and understanding among functions seems necessary. Primarily, among the functions intervening in hazardous areas on the ESS premises. Each response function seemed aware of the risks to their own function but these were not necessarily apparent to other functions. The current commissioning stage has lower risks than later stages which provides an opportunity to initiate efforts towards a close collaboration. Hereby, trust and knowledge can simultaneously increase with the facility's risk profile. With the variety of expertise represented in the task force exercises addressing these aspects could be designed.

Researchers often emphasise the importance of the exercise component of emergency preparedness. Alexander (2016), Casavant (2003), Erickson (1999) and Gow & Kay (1988) present different types of potential exercises ranging from internal classroom set ups to full-scale exercises. However, advice on what type of scenarios or exercises advantages for specific hazards are not addressed. The result of this study adds a valuable practical advice to this discussion. One interviewee suggested designing realistic and smart exercises. A realistic exercise has credible rather than worst-case scenarios. It should also include a simulation with software measurement tools or monitoring programs displaying expected values in an emergency instead of paper hand-outs. Exercise attendees appreciate these arrangements and live the scenario, as it would be a real emergency. An exercise can be smarter by acknowledging that on occasion smaller exercises have a bigger benefit than complicated big scale ones. Full scale and expensive exercises can be threatening and leave no time for reflections or questions. Creating environments where improvement and new approaches are encouraged is more beneficial for the preparedness process than normative evaluation of performance (Ford & Schmidt, 2000; Interviewee NPP2). Exercises for permanent staff on site and the staff holding ERT function are already time consuming. It would be therefore interesting to assess the possibility of implementing an online tool on emergency preparedness for temporary visitors or scientist prior to arrival on site. The tool could provide virtual small exercises, which could complement the mandatory safety induction, performed upon arrival.

8.3 Discussion of the Methodology

The wide scope and variety of data collection helped to approach the information available from different angles. At the same time, it limited in-depth research at the respective facilities. Initially, the aim was to limit the cases to three research facilities, but Covid-19 impeded the responses from interview partners drastically. In addition, the travel restriction inhibited the planned access to sites. The sampling of facilities and interview partners could partly be considered as convenience cases, in addition to judgemental and critical case sampling (chapter 4.1). The ESS's network and I established the connection to the respective contact persons.

Writing the thesis in collaboration with the ESS facility provided a large set of benefits. This includes, the potential to be involved and interact with employees of the facility on a daily basis, grasping the emerging challenges for radiation protection and safety aspects at a constant developing research facility and expanding the network as well as understanding work flows. The topic of the research becomes less abstract, as it strives to solve a real-world problem in a complex setting. Without interacting with the problem's environment, the research would not have been as tangible as it became now. During the research process the collaboration was mainly challenged because plans or procedures were frequently renewed, adjusted or newly developed. This caused the need to follow-up which could only be realised until August 2020.

8.4 Generalizability of the Results and Future Research

The proposed design is specifically tailored to the ESS and most probably not identically replicable for other facilities, as the architecture, planned operations, hazard profile and staffing vary. However, the overall process itself is believed to be rather generic. Provided that the activities contained therein are individually designed, the process can also be used in other companies, organisations and facilities. The process structure can guide preparedness planners through the iterations and is potentially flexible to be adjusted or updated. The absence of standards or criteria for emergency preparedness at accelerator driven facilities might stem from the facilities' unique demands on safety and operations. According to the interviewees and observations this is unfortunate because emergency preparedness planning often needs improvement. The underlying conditions presented in chapter 5 cannot be addressed specifically by applying only general recommendations, guidelines and considerations introduced by researchers like Alexander (2016), Casavant (2003), Erickson (1999) and Perry & Lindell (2003). The literature does provide very generic stepwise approaches and recommendations for the design of emergency preparedness and response. The combination of established procedures for other hazards with new preparedness approaches is not addressed. Neither could recommendations be found how to balance available staffing and specifically involve them in emergency preparedness except from training and exercises. Similarly, the architecture and planned operation do not play a primary role in the literature even though these aspects can pose constraints for the design as presented in chapter 5.

Further, evaluation is often highlighted among the literature but due to time constraints only two components of the designed process could be addressed. Rather tangible activities' results were chosen, as the literature provided some necessary support for exercise and plan evaluation. Alexander (2016) also states the absence of literature and given challenge of evaluating "intangible aspects of the creation, maintenance […], learning cultures and adaptability" of emergency preparedness planning (p. 120). Future research could address the development of appropriate tools or procedures to successfully evaluate the entire emergency preparedness process with all its activity outcomes.

Despite the varying underlying conditions this thesis has identified common challenges at accelerator driven facilities, which are not addressed in the literature and could inform future research. These challenges are not yet present at the ESS because the use of the beam for experiments has not yet started. Once operational the number of fluctuating and inexperienced people on site will increase. To shift from a low hierarchy during normal operation to a rigorous command during an emergency may cause complications for emergency preparedness. As one interviewee phrases it:

"… *on a daily basis there is quite a loose consensus on the way of working instead of taking the lead giving directions and making decisions. There are a lot of scientists and you don't tell them what to do but you convince them. You coordinate them. But that's not the correct way on dealing with incidents and that is, I think, one of the most challenging parts of having a framework here that could be effective" (Interviewee A4)*

In accordance with the interviewee's quote the involvement of different occupational groups challenges accelerator facilities and is not covered by reviewed recommendations. The encounter of a great amount of different cultures, languages and occupations poses very special circumstances for all research accelerator driven facilities. Especially ambiguous experience and perception levels regarding radiological hazards can be observed. Risk communication, introduction to behaviour in case of an emergency and training must be meticulously planned and executed to ensure the same level of information to everyone.

The general recommendations for emergency preparedness in the literature are a useful tool to initiate a not yet existent emergency preparedness concept. In combination with the proposed design in this thesis a type of hazard can be addressed even though other procedures are already in place. As soon as operation and the user programme start additional challenges arise which are not covered by the general recommendations nor the proposed design. Ideally, the design will continuously develop according to the altering circumstances and risk profiles in the future.

The NPP recommendations are often very strict and do not address specific circumstances but foster the planners to draw boundaries. This shows the need for tailored approaches for accelerator facilities. Future research should focus on developing an advisory guide to address challenges for implementation or maintenance of emergency preparedness at accelerator facilities.

9 CONCLUSION

The present research presents an emergency preparedness process proposal for radiological incidents for the accelerator driven ESS facility.

First, based on observations and interviews four underlying conditions have been identified providing important implications to consider before starting the design of the process. Namely, the *architecture* and *planned operations* determine the expected safety precautions and hazard profile to consider. The *legislative framework* draws country specific requirements for radiological hazards a facility has to comply with. Furthermore, *available staffing* and *established procedures* do vary among investigated facilities and demand adaptability from the planner. The work with emergency preparedness is not a fully-fledged profession. Rather performed as an additional responsibility to daily tasks. Established procedures do not necessarily imply effective emergency preparedness. Often, they are still revised after being implemented for a long time as proven insufficient or impractical. The alignment of several established procedures from different stakeholders both internal and external is crucial to develop emergency preparedness and avoid gaps or mismatches.

Second, seven design criteria were established analysing both interviews and literature. They emphasise what properties the emergency process should achieve. The process should be *risk based* and *flexible* to also adapt to changing circumstances during an emergency. It also should be *interoperable* with other stakeholders' preparations, simultaneously being *clear in command* and responsibility distribution. The process should in addition be *training- and exercise-based* to guarantee learning. And lastly, it should be *continuous* with ongoing preparedness activities.

Third, the design criteria and literature the emergency preparedness process for ESS was designed based on the underlying conditions. It is an iterative cycle with several activities. The key activities include for example the development of a concept of operation describing intervention procedures and mitigation actions performed by the radiation protection personnel in case of an emergency. Further a functional exercise and its evaluation could inform the developed design on adjustments and improvement opportunities. Until finally collecting all the pertinent information into a document serving as preparedness plan.

To conclude, certain results of performed activities could be evaluated in a TTX to determine whether the design is enabling a sufficient response. For this purpose, the exercise provided a sufficient tool. It has been concluded based on the exercise results that the design provides a good starting point and will gain more maturity in the upcoming improvement iterations. Especially the design criterion of clear command and responsibility distribution was identified to require close attention and actions for improvement. The identified gaps and improvement suggestions stipulate an ideal point of departure for future emergency preparedness activities at the ESS.

The more general contribution of the thesis, outside of the ESS, is the provision of valuable first-hand insights on which aspects to consider for designing emergency preparedness and which common challenges planners at accelerator facilities have to overcome. It is believed that in an environment where such excellent science is carried out there should also be sufficient time and space for a continuously improving and progressive emergency preparedness process.

10 REFERENCES

AERB. (2005). *Safety Guidelines on Accelerators*. Government of India.

Alexander, D. (2005). Towards the development of a standard in emergency planning. *Disaster Prevention and Management: An International Journal*, *14*(2), 158–175. https://doi.org/10.1108/09653560510595164

Alexander, D. (2012). *Principles of Emergency Planning and Management* (6th ed.). Dunedin Academin Press Ltd.

Alexander, D. (2016). *How to Write an Emergency Plan*. Dunedin Academic Press Ltd.

Alsaawi, A. (2016). A Critical Review of Qualitative Interviews. *European Journal of Business and Social Sciences*, *3*(4). https://doi.org/10.2139/ssrn.2819536

BCI. (2008). *Glossary of General Business Continuity Management Terms*. https://www.thebci.org/knowledge/business-continuity-glossary.html

Becker, P. (2014). Conceptual Frames for Risk, Resilience and Sustainable Development. In *Sustainability Science* (pp. 123–148). Elsevier. https://doi.org/10.1016/B978-0-444-62709-4.00005-1

Blaikie, N. (2010). *Designing Social Research* (2nd ed.). Polity Press.

BMBF. (2018). *ESS – Eine neue Ära für die Neutronenforschung*. https://fis-landschaft.de/materie/ess/

Buhr, A., Johansson, Kock, P., Boson, J., Karlsson, S., Lindgren, J., & Tengborn, E. (2019). *2018:22e ESS research facility Basis for emergency preparedness and response planning*. https://www.stralsakerhetsmyndigheten.se/en/publications/reports/radiation-protection/2018/201822e/

Casavant, D. A. (2003). *Emergency preparedness for facilities: A guide to safety planning and business continuity*. ABS Consulting.

CastroSilva, M. V., & Medeiros, J. A. C. C. (2015). Model of Performance Indicators in Nuclear Energy Emergency Plan Assessment applied to Emergency Exercises. *Procedia Computer Science*, *55*, 288–297. https://doi.org/10.1016/j.procs.2015.07.100

CCPS. (2010). *Guidelines for Technical Planning for On-Site Emergencies (CCPS guidelines series)*. John Wiley & Sons.

Connor, N. (2019, December 14). What is Neutron Decay—Neutron Emission—Definition. *Radiation Dosimetry*. https://www.radiation-dosimetry.org/what-is-neutron-decay-neutron-emission-definition/

Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches* (3rd ed). SAGE Publications.

DAtf. (2016). *Radioaktivität-Strahlenarten und Messgrößen*. Deutsches Atomforum e.V.

Davenport, H. E., & Flacks, A. (2004). *Method and system for emergency planning and management of a facility*.

Dresch, A., Lacerda, D. P., & Antunes, J. A. V. (2015). An overflight over research. In *Design Science Research* (pp. 11–45). Springer, Cham.

Elkmann, P. (2017). *Emergency planning for nuclear power plants*. CRC Press.

Erickson, P. A. (1999). *Emergency Response Planning: For Corporate and Municipal Managers*. 579.

ESS. (n.d.). *Radiation Protection & Safety | ESS*. Retrieved 6 August 2020, from https://europeanspallationsource.se/building-project/radiation-protection-safety

ESS. (2017a). *Description of the ESS accelerator systems and related infrastructure*.

ESS. (2017b). *ESS and MAX IV: Collaboration and Coordination for Better Science | ESS*. https://europeanspallationsource.se/article/ess-and-max-iv-collaboration-and-coordination-better-science

ESS. (2019). *Guideline for Radiological Hazard Analysis Dedicated To Workers Protection*.

ESS. (2020a). *Functional Description for the Radiation Protection Group*.

ESS. (2020b). *Preliminary Safety Analysis Report (PSAR)*.

Ford, J. K., & Schmidt, A. M. (2000). Emergency response training: Strategies for enhancing real-world performance. *Journal of Hazardous Materials*, *75*(2–3), 195–215. https://doi.org/10.1016/S0304-3894(00)00180-1

Forkel, D., Roesler, S., Silari, M., Streit-Bianchi, M., Theis, C., Vincke, H., & Vincke, H. (n.d.). *Radiation protection at CERN*. 22.

Garoby, R., Vergara, A., Danared, H., Alonso, I., Bargallo, E., Cheymol, B., Darve, C., Eshraqi, M., Hassanzadegan, H., Jansson, A., Kittelmann, I., Levinsen, Y., Lindroos, M., Martins, C., Midttun, Ø., Miyamoto, R., Molloy, S., Phan, D., Ponton, A., … Sordo, F. (2018). The European Spallation Source Design. *Physica Scripta*, *93*(1), 014001. https://doi.org/10.1088/1402-4896/aa9bff

Gillespie, D. F., & Streeter, C. L. (1987). Conceptualizing and measuring disaster preparedness. *International Journal of Mass Emergencies and Disasters*, *5*(2), 155–176.

Gow, H. B. F., & Kay, R. W. (1988). *Emergency Planning for Industrial Hazards*. Elsevier.

Grupen, C., & Werthenbach, U. (2010). *Introduction to radiation protection: Practical knowledge for handling radioactive sources*. Springer Berlin Heidelberg.

Hakim, C. (1982). *Secondary analysis in social research: A guide to data sources and methods with examples*. Allen and Unwin / Unwin Hyman. http://www.allenandunwin.com/

Hall, Wm. C. (1969). Primary Hazards of Particle Accelerators. *IEEE Transactions on Nuclear Science*, *16*(3), 577–578. https://doi.org/10.1109/TNS.1969.4325303

Health and Safety Professionals Alliance. (2012). *The core body of knowledge for generalist OHS professionals*. Safety Institute of Australia.

IAEA. (1988). *Radiological Safety Aspects of the Operationf of Proton Accelerators*. International Atomic Energy Agency.

IAEA. (2003). *Method for developing arrangements for response to a nuclear or radiological emergency*. International Atomic Energy Agency.

IAEA. (2007). *Arrangements for Preparedness for a Nuclear or Radiological Emergency*. International Atomic Energy Agency.

IAEA. (2015). *Preparedness and Response for a Nuclear or Radiological Emergency*. International Atomic Energy Agency.

IAEA. (2018). *Occupational Radiation Protection*. International Atomic Energy Agency.

IAEM. (n.d.). *Unit 6: Exercise Design*. International Association of Emergency Managers.

Johnston, M. P. (2014). Secondary Data Analysis: A Method of which the Time Has Come. *Qualitative and Quantitative Methods in Libraries*, *3*, 8.

Kirschenbaum, A. (2002). Disaster Preparedness: A Conceptual and Empirical Reevaluation. *International Journal of Mass Emergencies and Disasters*, *20*(1), 5–28.

Koelzer, W. (2017). *Lexikon zur Kernenergie*. KIT Scientific Publishing.

Kyne, D. (2017). *Nuclear Power Plant Emergencies in the USA*. Springer International Publishing. https://doi.org/10.1007/978-3-319-50343-1

McConnell, A., & Drennan, L. (2006). Mission Impossible? Planning and Preparing for Crisis. *Journal of Contingencies and Crisis Management*, *14*(2), 59–70. https://doi.org/10.1111/j.1468-5973.2006.00482.x

Miska, H. (2008). Die Johanniter—Radiologische Gefahrenlagen. *Deutsches Institut für Katastrophenmedizin*, 60.

NCRP. (2005). *Radiation Protection for Particle Accelerator Facilities:* (No. 144; p. 175). http://journals.lww.com/00004032-200502000-00009

NFPA. (2019). *NFPA-1600 Standard on Continuity, Emergency, and Crisis Management*.

Nünighoff, K. (2009). *Sicherheitstechnik im Wandel nuklearer Systeme: Strahlenschutz bei Spallationsneutronenquellen und Transmutationsanlagen*. Forschungszentrum Jülich.

Perry, R. W., & Lindell, M. K. (2003). Preparedness for Emergency Response: Guidelines for the Emergency Planning Process. *Disasters*, *27*(4), 336–350. https://doi.org/10.1111/j.0361-3666.2003.00237.x

Purpura, P. P. (2008). Risk Management, Business Continuity, and Emergency Management. In *Security and Loss Prevention* (pp. 263–293). Elsevier. https://doi.org/10.1016/B978-0-08-055400-6.50018-2

Rabesandratana, T. (2014). *European Spallation Source ready to start construction*. Sciencemag. https://www.sciencemag.org/news/2014/07/european-spallation-source-ready-start-construction

Robbins, N. B., & Heiberger, R. M. (2011). Plotting Likert and Other Rating Scales. *Proceedings of the 2011 Joint Statistical Meeting*, 1058–1066.

Seidman, I. (2006). *Interviewing as qualitative research: A guide for researchers in education and the social sciences* (3rd ed). Teachers College Press.

SSM. (2018). *Appendix 1—Special conditions for the ESS facility in Lund*.

Stabin, M. G. (2007). *Radiation protection and dosimetry: An introduction to health physics*. Springer.

Staupe-Delgado, R., & Kruke, B. I. (2018). Preparedness: Unpacking and clarifying the concept. *Journal of Contingencies and Crisis Management*, *26*(2), 212–224. https://doi.org/10.1111/1468-5973.12175

Stevenson, G. R., & Vylet, V. (2001). *Accelerator radiation protection* (Fysik- och astronomibiblioteket 6.2). Nuclear Technology Publishing.

Sylves, R. T. (1984). Nuclear power plants and emergency planning: An intergovernmental nightmare. *Public Administration Review*, 393–401.

Veenema, T. G. (Ed.). (2008). *Disaster nursing and emergency preparedness for chemical, biological, and radiological terrorism and other hazards* (2nd ed.). Springer Publ.

WHO. (n.d.). *WHO Simulation Exercise Toolbox*. WHO; World Health Organization. Retrieved 19 July 2020, from http://www.who.int/ihr/publications/exercise-toolbox/en/

Wieringa, R. J. (2014). *Design Science Methodology for Information Systems and Software Engineering*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-43839-8

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering - EASE '14*, 1–10. https://doi.org/10.1145/2601248.2601268

1 APPENDIX OVERVIEW OF DATA COLLECTION

No.	Interview	Observation	Reason for selection	Aspects studied
Independently organised Accelerator facilities				
A 1	Head of Radiation Protection	Deputy Head of Safety	Recent finalised construction project of a linear accelerator Possibility to obtain information from development and commissioning phase Lower radiation levels expected	Facility design Organisational set up Expected hazards Radiation safety concept Training
A 2	Not indicated	Head of Radiation Protection	Different facility design and organisational set up	Facility design Organisational set up Risk assessment method and accident history
A 3	Not suggested	Radiation Protection Officer Occupation al Health and Safety Consultant	Same legislative circumstances for design case and potential for cooperation Lower radiation levels	Facility design Emergency Preparedness procedures
A 4	Senior Fire Officer / Operational Lead	Indicated but not conducted due to Covid-19	Different facility design and organisational set up High radiation levels expected	Organisational set up Responsibilities Emergency Preparedness procedures and criteria
Organised by ESS				

A 5	Indicated but not conducted due to Covid 19	Members of the Radiation Protection Group Head of Experimental Operations Division and Emergency Management Head of Safety Health and Environment	Similar facility design and hazard profile	Tour of the facility Radiation risk assessment atrategy Emergency Preparedness and Business Continuity Strategy and Organisational Set Up
Independently contacted Nuclear Power Plants (NPP)				
NPP 1	Specialist Radiology	Not suggested due to Covid-19	Long experience with Emergency Preparedness Planning and high risks with severe impact Same legislative circumstances for design case	Organisational set up, responsibilities, tasks, emergency preparedness procedures and training
NPP 2	Deputy Radiation Protection Manager	Not suggested due to Covid-19	Long experience with Emergency Preparedness Planning and high risks with severe impact Same legislative circumstances for design case	Organisational set up, responsibilities, tasks, Emergency preparedness procedures and training

2 APPENDIX – INTERVIEW GUIDE

Topic	Question
Introduction	Could you give a brief introduction of your position at your facility and your involvement in emergency preparedness and management?
Radiological risks	What radiological incident scenarios are considered and create the design basis for the emergency preparedness plan at your facility? (worst case-accident, expected dose rate etc.)
Responsibilities	How are the responsibilities in case of an emergency distributed among the workforce and why has this approach been chosen? (First responder, radiation protection etc.)
	Are different preparedness levels at the facility and respectively different alarm procedures implemented?
Improvement opportunities and development	Have you encountered gaps or room for improvement over the years? (training scope and frequency, past unforeseen events)
	How do you evaluate and update the plan/procedures?
	Did you experience positive examples when procedures were efficient?
	Could you describe a situation where learning occurred?
Staff involvement and communication	How do you communicate emergency preparedness efforts among internal staff? How much do you involve the staff besides their normal work in emergency efforts?
End question	What do you find most challenging when realising emergency preparedness efforts?

3 APPENDIX – PARTICIPANT SURVEY TABLE TOP EXERCISE (TTX)

Participants Evaluation Form

Your feedback will assist us to maintain and improve the quality and relevance of future exercises.
This evaluation form is anonymous.

What was your function during the exercise?

- ○ Participant
- ○ Observer

Established Response Procedures to Radiological Emergencies

Please indicate your level of agreement with the follwoing statements

The established response procedures are proportionate to the current risk profile at the ESS facility

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The established response procedures are also felxible to other scenarios

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The distribution of responsibilities during a radiological emergency is clear

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The command structure during an emergency intervention is clear

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Exercise Outcomes

Please answer the following questions with the achieved outcomes.

Which training needs and future exercises have you identified?

Your answer

Which gaps and improvement opportunities did you identify for the response to radiological emergencies thoughout the exercise?

Your answer

4 APPENDIX – TABLE TOP EXERCISE (TTX) DOCUMENTS

Participants Guide

TABLETOP EXERCISE (TTX) FOR RADIOLOGICAL EMERGENCIES

11th of August 2020
09:00 am Vidyo Link: XXX

Overview

What is it?
The Tabletop Exercise (TTX) is a tool that has been developed to assist key stakeholders at ESS strengthening plans and procedures with the intention to successfully respond to radiological emergencies. The TTX is designed to support the use of the "Emergency Monitoring Plan for Ionising Radiation (EMPIR)" *(see in reference documents provided)*. This exercise uses a realistic scenario, as the base for a detailed discussion guided by the exercise facilitators.

During the TTX, there are no "real" actions carried out. The participants (based on their real-life function) explain and discuss among themselves how they would react to the scenario, without being required to execute those actions. Prior to starting the TTX, it is important that all participants know their roles and responsibilities in relation to the appropriate response plans.

Scenario

1. Session

Fictive date: Tuesday, 7th of December 2021, 09:00 am

Weather: -3°C, light snowfall

NCL Beam commissioning status: Beam up to Faraday Cup No.4 and the Beam is operating at 74MeV. In G01 area installation of the SCL part of the accelerator are ongoing. The machine protection system shuts down the beam. After first investigation of beam parameters the melting of the Faraday Cup is suspected.

2. Session

Progression of the scenario of the first session.

At 09:30, the gas and aerosol monitors alarm start in the supervised area next to the temporary shielding wall in G01. The alarm is triggering an evacuation of the whole G01 tunnel. Panic emerges during the evacuation and results in the following injuries in the SCL part of the tunnel:

- *Unconscious person with bleeding head wound*
- *Person with minor injuries, like scratches and bruises calling for help via radio*
- *One person in shock*

Exercise Objectives

The objectives of the TTX are to:

- Share information on the progress of your preparation, including response capabilities, plans and procedures to identify and respond to a radiological emergency scenario on the ESS premises.
- Identify areas of interdependence between involved actors
- Confirm arrangements for notification, coordination and internal communications
- Confirm procedures related to the management of the proposed scenario
- Identify gaps and improvement opportunities based on the Emergency Monitoring Plan for Ionising Radiation (EMPIR) *(see in reference documents)*

Outcomes

As a result of the exercise and debriefing activities, participants should:

- Identify the risks a scenario could pose to their current response procedures and capacities
- Identify and agree on next steps to strengthen preparedness
- Better understand the roles/responsibilities and methodologies to work with counterparts
- Be familiar with documentation and plans available to assist in planning and responding to a radiological emergency
- Team building, in support of managing a response to radiological and other emergencies
- Identify training and future exercise needs

As a result of the TTX and debriefing activities, facilitators should:

- Collect the identified training and future exercise needs
- Collect the identified gaps and improvement suggestions
- Review plans to clarify lines of accountability (roles & responsibilities) and communication to enable a timely, well-coordinated and effective response.

Exercise and Debriefing Timeline

The exercise scenario will evolve at an accelerated pace, compressing the real intervention time into a shorter timeframe.

All participating staff will be involved in both the exercise sessions, subsequent group discussions and the debriefing. The debriefing will be organized around the lessons learned from the exercise.

Time	Action	Performed by
8:55	Access Vidyo Conference	Participants, Observer and Facilitator
09:00	Start of Exercise: Introduction Scenario Presentation Exercise Objectives and “How to Play”	Facilitator
09:30	1st Session and Group Discussion	Participants and Facilitator
10:15	2nd Session and Group Discussion	Participants and Facilitator
10:45	Wrap up, Debriefing and Evaluation	Participants, Observer and Facilitator
11:30	End of Exercise	

Your *full* participation is requested for the entire duration of the exercise *as well as in the debriefing sessions*.

What to bring with you?

- Response plans (if any)
- The EMPIR document (see in reference documents)
- Laptop with camera, stable internet connection, headphones
- Vidyo App installed

Reference Material

- Emergency Monitoring Plan for Ionising Radiation (EMPIR)
- Emergency Contingency Plan
- Emergency Response Team (ERT) Intervention Plan
- Crisis Management Handbook

As only a limited amount of time will be given to screen the reference material during the exercise, you are encouraged as a participant to familiarize yourself with these documents before the exercise. A suggestion is to open the documents in the background during the exercise to enable quick access.

Basic Rules

- The TTX is not an individual test
- Respect the views of others
- Focus on solutions

Role of the facilitators

In addition to ensuring the smooth running of the exercise sessions and de-briefing, the task of the facilitator is to assist the participants in achieving the stated objectives of the exercise. To this end, the facilitator will not provide direct answers to questions raised or identified by the participants. Rather he/she will encourage a robust discussion by all participants while at the same time maintaining the overall flow of the session.

Your role

- There are no 'role plays'; each participant is required to be themselves based directly on the functions each of you are responsible for. Respond as you would during a real emergency.
- Establish the basis for your response based upon your expertise, data that you have on hand, as well as local procedures and response capacity, and other information about your work environment.
- For the purposes of the exercise, any data that you receive from facilitation team is to be considered correct, true, or 'fact'. Please do not challenge the scenario during the course of the session.
- Do NOT create additional fictional scenarios! Use the data presented in the session.
- The information you will receive through-out the course of the exercise provides you with ALL the data you will need. Do not invent numbers, figures etc. unless asked to

5 APPENDIX – DOSE LIMITS

Table 3 Summary of dose limits for each category of workers. Effective dose limits include both doses received from external and internal exposure. (Note: the dose limit for Category B workers is not a legal dose limit but a limit for worker categorisation).

Part of body	Dose quantity	Category A [3]"exposed worker" (for 12 consecutive months)	Category B [4]"exposed worker" (for 12 consecutive months)	Category "Non-Exposed" (annual)
Whole body	Effective	20 mSv	6 mSv	1 mSv
Skin[5]	Equivalent	500 mSv	150 mSv	50 mSv
Eye lens	Equivalent	20 mSv	15 mSv	15 mSv
Extremities (hands, feet)	Equivalent	500 mSv	150 mSv	-

Table 4 ESS General Safety Objectives

<table>
<tr><th colspan="5">ESS objectives (effective dose)</th></tr>
<tr><td>Operating conditions and likelihood (per year) of initiating event</td><td>Exposed worker with safety task</td><td>Exposed worker without safety task</td><td>Non-exposed worker</td><td>Public (off-site)</td></tr>
<tr><td>Normal operation, H1
(including events with $F \geq 1$)</td><td colspan="2">Dose limit
20 mSv/year
Dose constraints (*)
2 mSv/year</td><td>Dose limit
1 mSv/year
Dose constraints (*)
0.1 mSv/year</td><td>Dose limit
1 mSv/year
Dose constraint
0.1 mSv/year</td></tr>
<tr><td>Anticipated events, H2
$F \geq 10^{-2}$</td><td rowspan="3">Design criteria
20 mSv/event</td><td rowspan="3" colspan="2">Plan protective action
based on realistic estimations
for typical cases
and applying ALARA
via a respective ESS committee and
an established ESS guideline.</td><td>Design criteria
0.1 mSv/event</td></tr>
<tr><td>Unanticipated events, H3
$10^{-4} \leq F < 10^{-2}$</td><td>Design criteria
1 mSv/event</td></tr>
<tr><td>Improbable events, H4A
$10^{-6} \leq F < 10^{-4}$</td><td>Design criteria
20 mSv/event</td></tr>
</table>

---

[3] A worker shall belong to Category A if the worker can receive an annual radiation dose that:

a. the effective dose exceeds 6 mSv,
b. the equivalent dose to the eye lens exceeds 15 mSv,
c. the equivalent dose to extremities exceeds 150 mSv, or
d. the equivalent dose to the skin, as an average over one square centimetre, exceeds 150 mSv, regardless of how great a surface area is exposed. (SSM:2018) (EURATOM 2013/59).

[4] A worker shall belong to Category B if the worker can receive an annual radiation dose (as defined in 2.2 3§) such that:

a. the effective dose exceeds 1 mSv but not 6 mSv,
b. the equivalent dose to extremities exceeds 50 mSv but not 150 mSv, or
c. the equivalent dose to the skin, as an average over one square centimetre, exceeds 50 mSv but not 150 mSv, regardless of the surface area exposed. (SSM:2018) (EURATOM 2013/59).

[5] average equivalent dose to skin over any square centimetre of the skin independent of how large the area of exposure is.

Improbable events, H4B $10^{-4} \leq F$ *H2 and H3 combined with CCF*		N/A	N/A	Design criteria 20 mSv/event
Highly improbable events, H5 $10^{-7} \leq F < 10^{-6}$	Design criteria 100 mSv/event	Excluded from further evaluation since it is an acceptable residual risk.		Design criteria 100 mSv/event
Extremely improbable events $F < 10^{-7}$	Excluded from further evaluation since it is an acceptable residual risk.			

(*) Dose Constraints defined by ESS.

6 APPENDIX – DESIGN CRITERIA

This section provides the justifications and quotes underlying the presented design criteria.

Risk-based

The emergency preparedness process should be based on the assessed risks and the planning of resources. Mitigating consequences should be proportionate to the risks.

Prior to the planning process "accurate knowledge of the threat" (Perry & Lindell, 2003) should be gathered. This can be realized through risk assessments and hazard analysis (CCPS, 2010; NFPA, 2019), including usually an exhaustive assessment of what is likely to happen and what consequences can be expected until choosing "plausible scenarios" to base the design of efforts on (CCPS, 2010). The special conditions for ESS issued by SSM also demand to base the emergency preparedness on scenarios founded on events and circumstances in different event classes of different likelihood. For planning purposes, the worst case, as the SSM has proposed the ESS to apply and base preparedness on, is not yet applicable as the scenario is situated 5 years after beam on target, which is still far in the future and several commissioning stages beforehand pose less risk.

"Scenarios most likely [to occur, are] much more valuable to be sustainable and to be accepted because apparently it's a new topic for the company so worst case could be a bit scary and most likely could be well accepted to be a vehicle to move on forward" (Interviewee A4)

The NRCP (1991) states, "the magnitude and sophistication of the radiation protection program are dictated by the potential risk associated with the [...] radiation producing equipment, the operations involved, and the regulatory requirements". Similarly, the IAEA (2018) stated, that "the degree of planning [for emergency preparedness and response] should be commensurate with the nature and magnitude of the risks, and the feasibility of mitigating the consequences if an emergency were to occur" (p. 78).

Also, regulations for NPP and accelerator driven facilities can demand, that accidents at other, similar or comparable facilities are to be considered as well in the planning (SSM, 2018). To provide an example, the NPP 2 emergency preparedness is based on "a scenario which includes extraordinary events at all four reactors at the same time where one accident is a severe accident" (Interviewee NPP2). This approach can be understood as a preparedness for the "worst case" (Interviewee NPP2), whereas NPP1 does not design their efforts to an exact scenario, but rather to their time-related development:

"we have two main lines. The first is a very rapid accident without any warning, for example station blackout [...] and we also have a slow developing situation. One example is forecast of very heavy snowfall expected two meters of snow within 24 hours." (Interviewee NPP1)

Flexible

The emergency preparedness process should be flexible to enable adaptation to changing circumstances.

"People think what you plan will come through and that's not really the case - every unsafety can be covered with a procedure - no that's also not the case"
(Interviewee A4)

Alexander (2016) highlights that emergency planning should always be treated as a flexible exercise that enables to adapt to dynamic changing circumstances. There are four main motivations to create a rather flexible than rigid process. First, "it is impossible to foresee, plan and prepare for all contingencies, since for areas affected by technological hazards, the past is not always a good guide for the future, because new complex relationships evolve, the technology used constantly changes the pattern of risk" (Alexander, 2016: 45). Second, details, work flows and personnel changes and the information get out of date rapidly (Perry & Lindell, 2003). Third, if each function within the emergency planning is given the same attention and described with the same level of detail in the underlying plan, the resulting perception of equal importance might be misleading (ibid).

One Interviewee claims:
"You will always make mistakes and then the procedures will be counterproductive, because they will proof that you were wrong and that you followed procedures and as you can see on this page is written that you should do that in that case - why didn't you do it? so the procedure becomes an evidence of you doing wrong"
(Interviewee A4)

And lastly, more detail in the resulting plan but also in the planned procedures might create more complexity, which results in difficulties to apply (Interviewee A4, NPP2). Experience from one facility entails, that "big books were written in the beginning of this millennium, but nothing was fulfilled and never used" and" every plan will lose its value at the moment that something becomes real, because then you have to start to adapt" (Interviewee A4).

On the other hand, the introduction of flexible procedures but linked to precise action levels based on dose rates has proven to be very helpful in quick decision making at one NPP:

"they [Radiation Protection personnel] can look in the procedure and see: who is responsible for the decision whether we can make this intervention or not and it's very clear if his decision can be made on my level or at what level the command center has to be called to get decision from the RP manager" (Interviewee NPP 2)

Interoperable

The emergency preparedness process should be interoperable and compatible with equipment and procedures between different stakeholders.

"Key to surviving any emergency event will be the support of external resources" (Casavant, 2003: 115)
"we have already found out that it's not only us that is in the chain of command - we are not the only actors" (Interviewee A4).

The adequate involvement and coordination of external stakeholders is a critical interlink in preparedness and response, mentioned by three interviewees (A4, NPP1, NPP2). Difficulties of collaboration with external stakeholders are still identified among exercises or real interventions, for example with the police or hospitals. Whereas, one interviewee claims the difficulty is the communication during intervention and the other states it is the general absence of knowledge on existing preparedness of an external stakeholder:

"on the whole it was working well if you see to reactor accident management it worked well but the big issue was the contact and dialogue with the police was not very good" (Interviewee NPP1)

"the hospital, is perhaps not so prepared as we would like, or as we think or they think. we can be very well prepared and deliver a patient according to internal protocol, but there is a big question mark for the ambulance or hospital on how to receive"
(Interviewee A4)

One of the interviewees stated that they do not have a formal agreement with the closest hospital, but instead an agreement on frequent meetings and education regarding handling of contaminated patients and adequate response (Interviewee NPP1).

The terminology for the described efforts is adopted from Alexander (2016), where interoperability refers to "the compatibility of equipment, supplies, or procedures between different groups and organisations" (p 85). The internal interoperability between fire brigade and radiation protection was mentioned by one interviewee as "having a good connection", which originates "not so much from joined training but joined education" and:

"some colleagues of the fire brigade are almost on the same level of the knowledge level of those of radiation protection, which results in being equal in having a conversation about a specific topic"
(Interviewee A4)

It was then further mentioned that fire brigade and radiation protection are subject to the same management and both functions do exist since the establishment of the facility, which almost creates a "historical working relationship", but for emergency preparedness each function "should feel the urgency to prepare itself for emergencies if not I cannot do it for them" (Interviewee A4). However, researchers argue, that responders have to understand not merely what their own roles are but also what the roles of other party are and if these responsibilities are not apparent to everyone, this could negatively affect the response (Alexander, 2016; Grupen & Werthenbach, 2010).

NPP 1 states in a section in the accident contingency plan for regional authorities and organisations, including that after request may also radiation protection staff from non-affected power plants restored to the county administrative board available.

Clear in command

The emergency preparedness process should be clear in command and responsibility distribution.

Researchers do emphasize the necessity of clear command structures or chain of command, often in relation to clear responsibility distribution. Casavant (2003) states, "there must be a clear line of responsibility and command" (p. 115). And Erickson (1999) argues "there can be no proper emergency response without the existence of a practiced on site chain of command" (p. 56). Further decisions should be made already in the planning process on "who will make the decision to evacuate" for example (ibid). Gow and Kay (1988) also state, that "evacuation is a simple and straightforward word but can cause chaos if not handled correctly. There is a need in dealing with this type of incident to have a clearly defined role of command" (p. 131).

One interviewee state, that the power of decision is indisputable at their facility and that only the role of the "site emergency manager" can escalate the alarm and the radiation protection lead can only "strongly suggest actions" but not decide upon them (Interviewee NPP2). Command structures are clearly defined at the NPP interviewed.

Another interviewee compared the municipal fire brigade structure with the accelerator facilities structure and explains:

"When you look at emergency preparedness from the perspective of the fire brigade you have a certain set of defined actors that are used to work in the same content and context, so it's much easier to combine and coordinate them into working into a scenario towards a combined response, but at [the research facility] this is not the case. it is very scattered" (Interviewee A4)

At one facility a special command structure is imposed for emergencies, which is not in place during normal operations and instead of having area responsibilities very strong and high-level structures take over (Fieldnotes A5). Similarly, another interviewee refers also to the involvement of users of the facility:

"During normal operation there is a very informal hierarchy and the work with researchers especially at the facilities is not command style. However, during an emergency someone needs to take a lead, someone who has the experience and knowledge" (Interviewee A4)

This aspect was mentioned again, when asking about what is perceived as most challenging in emergency preparedness, the interviewee responded:

"*… on a daily basis there is quite a loose or consensus way of working instead of taking the lead giving directions making decisions. there are a lot of scientists and you don't tell them what to do but you* *convince them you coordinate them you give them in the way. But that's not the correct way on dealing with incidents and that is I think one of the most challenging parts of having a framework here that could be effective" (Interviewee A4)*

According to Erickson (1999) a lack of established command, lack of uniform command signals and lack of standard terminology are common causes of failure in emergency response operations.

Training-based

Emergency preparedness process should be trained, by creating safe learning environments. Personnel needs to gain routine on tasks performed during an emergency.

Three interviewees referred to regular training components in their preparedness efforts, either workplace specific hazard awareness training with internal and external response actors (Interviewee A1), radiological hazard specific training for firefighters provided from radiation protection expert functions (Interviewee A4) or emergency personnel training, which automatically functions as opportunity for new information sharing (NPP1). At one facility, media training is provided on a group leader level to ensure their competence and comfortability to give official statements. In addition, new members joining the emergency response team receive a desktop training to provide them with the access to relevant documents, which are accessible only for members of the team on an online SharePoint (Fieldnotes A5).

"we perform training for the personnel on regular basis and anyone most of the training courses must be given at least with a frequency of three years and one deal is within this training process is to communicate what's new in the organisation" (Interviewee NPP1)

The latter is also emphasized by Casavant (2003), as "a good chance for key support members to meet one another" (p. 139). Perry & Lindell (2003) guideline proposes a planning component incorporated in emergency preparedness plans, characterised by two different tiers, first one for information sharing among stakeholders and the second one for practical hands-on processes. If training is attended and integrated, is "is likely to yield high dividends in terms of the effectiveness of emergency response" (p. 346).

Integration of a training component does not indicate yet, what frequency of training is demanded to reach effective responses. One interviewee stated that the amount of training and prioritisation of education efforts, has been significantly influenced by the accident history in other NPP in the world leading to new regulations from the authority, causing the facility to train more, which lead to being satisfied with the training and education level, but exercises were forgotten (Interviewee NPP 2). Casavant (2003) describes training as a recurring event and argues for at least annual training, but in addition also when change occurs in processes, responsibilities, equipment or physical layout of the facility or policies affecting emergency planning (p. 140). In addition, "training should be conducted at a level that is consistent with employee job functions and responsibilities" (CCPS, 2010: 241).

A complaint was made during a field visit, that once acquired competencies for the job profile are believed to remain sufficient and always retrievable. But a recent accident has demanded decontamination procedures and special personal protective equipment handling. These activities are not performed on a daily basis and training of employees was not conducted, therefore the necessary routine was lacking, resulting in risky situation for employees (Fieldnotes A2).

An interviewee of another facility picks up this dilemma as well and mentions *“the goal is to eventually put this emergency preparedness framework and the outcomes of it and the products into the daily life, the daily work of the fire brigade, because if you don’t use procedures in daily life it will not be used and if you don’t use it in daily life it will fail of you really need it” (Interviewee A4).*

Ford & Schmidt (2000) have identified three main challenges of training and education for emergency management and preparedness and suggest a set of strategies how to overcome these, of which only one per strategy is presented here:

- Challenge: retention of training knowledge and skills over time, given limited opportunities to perform emergency response skills during normal operations; Strategy: e.g. create environments where improvement and trying new things is encouraged instead of normative evaluation of performance and competitive goals
- Challenge: effective generalisation of skills learned in training to the significantly different demands that could arise in an actual emergency – Strategy: “training needs to apply methods that facilitate the development of both routine and adaptive expertise” (p.205), e. g. error-based learning activities providing trainees with both correct and incorrect models which fosters the attention and development of more complex mental models
- Challenge: effective assimilation of individual efforts into a coordinated response; Strategy: Teamwork, e. g. development of shared mental models, which “refer to organized knowledge that is common among the team members” (p. 209)

Exercise-based

The emergency preparedness process should be exercised based, by conducting a set of realistic exercises of varying size and execution.

Either during observation or interviews, conversations or questions on how to acquire emergency preparedness lead towards exercises, for example full-scale exercises internally every two years and every four years with external stakeholders (A5), precisely with one external stakeholder at the time (A1), or with on-site fire brigade for each building at the time (A2). The NPP 2 performs an exercise with external rescue serves and lead by the country administrative board every fourth year. In addition, internal bigger exercises are performed every second year now, which used to be each year, because the number of smaller exercises at all levels including different teams increased (Interviewee NPP2).
Desktop exercise was also mentioned during one field visit, conducted in the intervening years between full-scale exercises due to timely and resource benefits (Fieldnotes A5). Casavant (2003) argues also for table top exercises as “an excellent way to train members of the team without disrupting the normal day-to-day activities of the organization” (p. 139).

One interviewee claims that bigger exercises do not imply necessarily more learning than smaller ones:

“But actually, we have seen its most of us being exercised think that these smaller exercises, functional exercises. so that's when you focus maybe on one team or on a cooperation between two

levels or different teams. it gives you much more learning than the bigger exercises" (Interviewee NPP2).

Further, these smaller exercises enable participants to stop the scenario and use the time to think, or reflect upon what everyone is doing and raise questions, which is not possible due to time constraints in big scale exercises (Interviewee NPP2). The same interviewee also argues for smarter exercises, which implies first more realistic scenarios by implementing information systems which can simulate emergency values. And second use as less resources of the emergency preparedness unit staff at making the exercises but at the same time get as most learning out of the exercise or drill as possible. This is achieved by involving the emergency preparedness organisation already in the planning of an exercise. Therefore, reflection and training already occur during the planning. "It usually makes more learning than participating during an exercise" (Interviewee NPP2).

Continuous

Emergency preparedness process should be continuous with ongoing activities.

All informants emphasized the continuous development of the emergency preparedness efforts.
In relation to training and exercises, one interviewee claims

"…and today everything is more. just an increase all the time" (Interviewee NPP2)

Whereas, another interviewee states:

"I would say it is developing all the time - you learn from the exercises, you learn from others - it is a continuous process" (Interviewee NPP 1)

Continuity was often mentioned in relation to exercises. The responses to the question on how exercises are evaluated and followed up, however, varied. The NPP have a similar approach:

"after every exercise and drill there is an evaluation report written. And the evaluation report goes through the exercise goals and show which goals were met and which kind of actions need to be taken. with a clearly stated time and who is responsible" (Interviewee NPP2)

and

"we have a larger exercise once a year and this exercise is evaluated very formal and documented and specific actions are decided when the evaluation is ready and will be followed up until its in place. its signed by the plant managers, so it's a high-status document" (NPP1).

Whereas, others find fault with their exercises not properly evaluated and follow up actions were not clearly decided upon, which lead to no apparent improvement for the next exercise. Their continuity manifests itself in mandatory monthly meetings, where incidents and threat levels are reviewed and the response and current capabilities are discussed (Fieldnotes A5).
Another interviewee explains:

"The maturity of observing and evaluating exercises at [the facility] is quite differently. The culture of giving feedback giving your observations back to the actors. So internally your own group is quite ok. When outsiders come into place the prudence and the political correctness becomes bigger and bigger. To the level let's see how we and if we are giving this feedback because it could hamper or

could damage our relation … the maturity on giving feedback to others than your own group - it's not so much evolved" (Interviewee A4).

Feedback and evaluation can serve to achieve the continuity aspect of preparedness, which ideally means that "incremental improvements of preparedness plans should gradually phase out inappropriate assumptions and recommendations as new knowledge and experience emerge" (Staupe-Delgado & Kruke, 2018: 217). Researchers coherently emphasize the importance of "ongoing activities" (PERI, 2001), engagement in continuous preparation (McConnel & Drennan, 2006), ensuring adaptiveness in the planning process by frequent revisions of established plans and procedures (Alexander, 2016: 46) and Perry and Lindell (2003) also argue, that after every incident or training the plan will improve. This encourages the need for active planning and readiness in comparison to symbolic readiness which then demands "openness and cognitive ability to change" (McConnel & Drennan, 2006: 62). In accordance with Staupe-Delgado & Kruke (2018), it was observed that some authors emphasise preparedness as a continuous cycle, but implicitly refer to it as reaching a "state of preparedness" (Gow and Kay, 1988; Perry and Lindell, 2003), which can be understood as an "desired end state" (p. 217). Staupe-Delgado & Kruke (2018) further mention, that it should not be ignored, that preparedness consists of ongoing activities: "drills, exercises, adjustments of risk and preparedness analyses and preparedness plans, as well as equipment purchases and upgrades" (p. 217).

7 APPENDIX – ACTIVITIES OF THE EMERGENCY PREPAREDNESS PROCESS

Table 5 Activities of the Emergency Preparedness Process idicating key methods/sources and considered underlying conditions and targeted design criteria

	Activity	Considered Underlying Condition	Targeted Design Criteria
Review of Legislative Framework			
Key Methods/Sources	Review of SSM special conditions (Buhr et al., 2019) Internal RP meeting on decisions, which conditions to address Review conditions & define actions already applicable for NCL commissioning and responsibility assignment (Appendix 8)	Legislative Framework	Risk-based Continuous
Key Results	32 out of 79 conditions were identified to be already achievable and necessary to address at this commissioning stage, of which 28 were addressed by end of August 2020 Action plan with conditions to address for NCL commissioning for upcoming commissioning stages		
Risk and Hazard Analysis			
Methods/Sources	Review of Hazard Analysis, Risk Analysis, Accident Analysis., Safety Analysis only for NCL section and implemented safety measures Snowball technique (Wohlin, 2014) and advice from ESS staff, which documents to consider		Risk based

Key Results	Radiation hazards associated with accelerator operations are: prompt radiation from operational or accidental beam losses, prompt radiation (X-razs) due to RF fields, residual radiation from activated components and fluids, activated tunnel air, contamination due to inventorz in activated components (ESS, 2020b) Due to low current and beam power the NCL commissioning and operation pose less radiological hazard potential than the upcoming commissioning stages. The combination of hazards was not addressed. To achieve a sufficient planning base malfunction of safety systems or human failure and also incidents originating from other hazard sources occurring in radiation areas were included. The postulated event, determined by SSM demanding off-site emergency response planning is not yet applicable for NCL commissioning. It is required with beam on target operations (Buhr et al., 2019). It will be considered as an outlook. Some of the present risks associated with the commissioning stage “are treated in more detail for the NCL commissioning phase due to the unique configuration and circumstances of the commissioning. In particular, the presence of workers in the tunnel downstream of the NCL warrants examination of possible impact to these workers. Hazards present due to events and circumstances related to beam interaction with a Faraday Cup, a device used as a beam stop during NCL beam commissioning, are addressed. These include prompt radiation and a possible release of inventory” (ESS, 2020b: 167).		
	Assessment of and Alignment with Established Plans & Procedures & Checklists & Available Staffing		
Key Method/Sources	Review RP related documents & accident, emergency and crisis management documents to make informed decisions on which are necessary to consider and respect for the design by applying the Snowball technique and keyword search Mapping of document infrastructure Meeting with authors of respective plans to clarify questions	Established Procedures Available Staffing	Risk based Clear in command Interoperable
Key Results	Identification of established plans and procedures to respect and entry points for the design Gain understanding of established command and emergency management structure Terminological ambiguity among accident, emergency and crisis, often results in difficulties to scale or classify scenarios 33 internal documents were identified as direct sources for emergency preparedness information		
	External Stakeholder Assessment		
Key Methods/Sources	Brainstorm and review of attendees of biannual meetings with ESS and external stakeholder Information through Email Meetings with Emergency Preparedness Laboratory in Malmö University Hospital		Interoperable Continuous

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Key Results	Hospital preparedness in the Skåne region is sufficient, ESS does not have to provide training or equipment to the hospitals. Joint exercises are worth considering Fire and Rescue services are already involved in the planning and exercises on site and are kept up to date on hazard potential Ambulance personnel needs guidance and cannot enter radiation areas Special CBRNE units are available in Skåne		
Concept of Operation			
Key Methods/ Sources	Meetings with operational RP group	Available Staffing	Flexible Interoperabl e Clear in command
Key Results	Identify key actions of RP in emergencies by clustering measures according to (CastroSilva & Medeiros, 2015): - Prompt assessment and projection of the likely evolution of the accident - Urgent protective measures - Rescue mechanisms and decontamination of persons in classified areas - Long-term actions to be taken after the accident RP internal command structure		
	Communication		
Key Methods/Sources	Obtain a radio for RPO and train radio communication Discussions in meetings (RP internal)		Clear in command Interoperabl e
Key Results	To guarantee, the Radiation Protection Officers availability and alarm readiness, the decision was made to have the Radiation Protection Officer on radio during presence on site. This is not necessarily common at other facilities, however, since the ERT at ESS operates on radio and the designated radiation areas are increasing gradually, rapid response can be guaranteed No clear communication and updating structure regarding emergency preparedness efforts yet		
	Equipment Audit		
Key Methods/Source	Conduct resource audit	Architecture and Planned Operation	Flexible
Key Results	Based on the available resources and long distances on site, it is suggested to obtain an emergency kit, which is containing protective equipment, measurement tools and other material to quickly respond to radiological emergencies. The RPO should pick it up, when		

	being alarmed at one of three locations on side		
	Assessment of Training Needs		
Key Methods/Sources	Meetings with operational RP group and ERT members	Available staffing	Training - based
Key Results	Training on radio communication (handling of devices, agreed terminology and routines) Training on handling of equipment of the emergency kit Training of decontamination procedures		
Training & Exercise			
Key Methods/	Training on radio communication for RPO Functional exercise to test the design, familiarise FR and RPO on duty, check established communication structure and identify adjustment potential		Exercise-based Flexible Interoperable Continuous
Key Results	More training necessary Procedure proposal for emergency electronic dosimeters for FR Strengthen interface, trust and understanding of responsibilities and capabilities among actors Only Swedish Language on radio causes difficulties for non-Swedish speaking RPO		
Writing of Plans, Procedures & Checklists			
Key Methods/Sou	Write a document collecting all pertinent information to collect preparedness aspects and provide references to other documents (incl. procedures and checklists) Adapt review questions and conditions (Casavant, 2003: 161)		Continuous Interoperable
Key Results	Many decisions are still pending and interdependencies are still to be clarified, therefore a colour-based system indicates sections “to be decided” Written plan demands continuous update, due to gradual design for commissioning stages and risk assessments will alter and demand new balance of resources The ESS internal decision was to name the respective document providing the preparedness efforts Emergency Monitoring Plan for Ionising Radiation (EMPIR). This title also prevents confusion with the emergency preparedness and contingency plans		
Distribute, notify & share			

Key Methods/So	Meetings and distribution of plan Review Process		Interoperable
Key Results	Decision on a wide range of reviewers, based on the apprehension that “if the emergency management team consists of employees with similar backgrounds, education, responsibilities, and job titles, the plan will be written in a vacuum” (Casavant, 2003: 114) Input and comments from a diverse group, including members of the radiation protection group, occupational health and safety, security, shift leader		

8 APPENDIX – SPECIAL CONDITIONS SPREADSHEET

Table 6 provides an overview of the special conditions developed by SSM. The three columns: Normal conducting linac (NCL), Super conducting linac (SCL) and Beam on target (BoT) refer to the foreseen commissioning phases of the accelerator. Bright green shading indicates that the conditions has been addressed. Striped green shading indicates that the condition has only partly been addressed but not completely. Light green shading indicates that the condition is foreseen to be addressed for the respective commissioning phase.

Table 6 Overview of SSM special conditions

	Condition	NCL	SCL	BoT	Addressed in…	Actions
B	**Emergency Preparedness Planning**					
	1. The facility's emergency preparedness and crisis management shall be based on scenarios founded on events and circumstances in event class H1-H5, but is not limited to these.				Radiological Risk Analysis for G Area – Prompt and Residual Radiation	
	2. The licensee's management system shall state where in the regular organisation the tasks, responsibilities and authorities for emergency preparedness planning are found. The licensee shall allocate sufficient resources for emergency preparedness activities. Experience from occurred events and discovered conditions that have occurred at similar facilities shall be taken into account when planning the crisis management.				Emergency Preparedness Plan Spallation 1 and Spallation 2 Emergency Contingency Plan	Reference
	3. A prepared crisis organisation shall be in place which is set up when there is a risk of, or in conjunction with, a radiological emergency at the facility.				Emergency Preparedness Plan Spallation 1 and Spallation 2 Emergency Contingency Plan Emergency Response Team Intervention Plan ESS Handbook for Crisis Management	Reference
	4. The licensee shall prepare a comprehensive document, an emergency preparedness plan, which:					
	a. describes the scenarios on which the emergency preparedness and crisis management are based,				Radiological Risk Analysis for G Area – Prompt and Residual Radiation Emergency Monitoring Plan for Ionising Radiation	Reference
	b. describes the crisis organisation and its main tasks, responsibilities, premises, resources and collaboration, as well as the foreseen activities in order to manage a radiological emergency at the facility, and				Emergency Monitoring Plan for Ionising Radiation	Concept of Operation of RPO on duty function

	c. gives references to the documentation that provides operational support for the crisis organisation.				Emergency Monitoring Plan for Ionising Radiation	
	5. The emergency preparedness plan and documents for operational support to personnel shall be kept up to date and tested, in the form of regular exercises.				Emergency Plan for Ionising Radiation Training activities for the Emergency Preparedness Plan	Exercises performed (functional 5th f May; table top exercise 11th of August) Training needs addressed in EMPIR
	6. The capability of the crisis organisation shall be verified via a full-scale drill before trial operations with intentional neutron production may commence.					
	7. The emergency preparedness plan shall be coordinated with procedures for operational service which are applied in the event of radiological emergencies, procedures for physical protection, and with other concerned parties' emergency preparedness plans.				Emergency Monitoring Plan for Ionising Radiation	Refer to Municipal Rescue Service Intervention in Refer to Hospital Arrangements
	8. The emergency preparedness plan shall be safety reviewed, in accordance with condition B2 in chapter 1, and approved by the Swedish Radiation Safety Authority before the facility may be taken into trial operations with intentional neutron production.					
	9. Alterations to the emergency preparedness plan of importance to safety shall be safety reviewed in accordance with condition B2 in chapter 1. Before the alterations may be applied, they shall be submitted to the Swedish Radiation Safety Authority.					
	10. The crisis organisation shall, with regard staffing, response time, sustainability, equipment, tools, appropriate premises and collaboration with concerned parties, be configured to be able to manage and limit the consequences of the scenarios which, in accordance with condition 4a, shall be described in the emergency preparedness plan.				Emergency Monitoring Plan for Ionising Radiation	Staffing not finalised

	11. The licensee shall take the measures necessary so that emergency services, the police, and other concerned parties that can be expected to arrive at the facility during a radiological emergency, are able to use their regular radio communication systems. The measures shall encompass the access restricted area, as well as the buildings and areas prioritised for access.				Emergency Radio Communication Plan Municipal rescue service intervention plan (in Swedish)	Reference in EMPIR
	12. The crisis organisation shall be able to manage a long-term radiological emergency until its activities transfer to an organisation for the continued care of the facility.				Emergency Monitoring Plan for Ionising Radiation ESS Handbook for Crisis Management	Reference and collaboration in EMPIR
C	**Alarms and Summoning of Personell**					
	1. The licensee shall develop criteria for decisions on alarm levels and levels for information that are adapted to the levels:					
	a. Alarm level area alarm Event or circumstance where emissions of radioactive material, which call for protective measures for the general public, have taken place, are ongoing, or cannot be ruled out.					
	b. Information on the incident Event or circumstance that cause damage or risk of injury to workers or facility has occurred. Specific support is needed in order to manage the event or the circumstance. No protective measures for the general public need to be taken.				Emergency Monitoring Plan for Ionising Radiation	Fill in Alarm levels of Radiation Monitors
	The criteria for alarms shall be safety reviewed, in accordance with condition B2 in chapter 1, and approved by the Swedish Radiation Safety Authority before the facility may be taken into trial operations with intentional neutron production. Changes in the criteria for alarms that are of importance to safety shall be submitted to the Swedish Radiation Safety Authority.					
	2. If a criterion for an alarm has been met, then:					
	a. An alarm shall be triggered, in accordance with condition C1a, and					
	a. the Swedish Radiation Safety Authority shall be notified within one hour with the information pertinent to condition C1 in chapter 8.				Emergency Preparedness Plan Spallation 1 and Spallation 2 Emergency Monitoring Plan for Ionising Radiation ESS Rules for Reporting Unplanned Events to	

					SSM	
	3. If a criterion for information has been met, the Swedish Radiation Safety Authority shall be notified as soon as possible.				ESS Rules for Reporting Unplanned Events to SSM	Refer to in EMPIR
	4. The licensee shall have equipment, as well as documented procedures, for triggering area alarms.				Radiation Monitoring For Normal-Conducting Linac	Refer to Radiation Monitoring Alarm levels
	5. The licensee shall have documented procedures and access to systems in order to summon the crisis organisation. Recurring verification of contactability and response time for workers in the crisis organisation shall be implemented and documented.				Emergency Monitoring Plan for Ionising Radiation ESS Crisis Management Handbook	Response time should be verified with exercises
	6. It shall be possible to give an alarm signal inside buildings, as well as outdoors throughout the access restricted area where immediate protective measures may be relevant. It shall be possible to make announcements at each meeting point in conjunction with an alarm signal.				Emergency Monitoring Plan for Ionising Radiation Site Evacuation Plan	Refer to Monitoring Alarms inside buildings for now
	7. It shall be possible to trigger an alarm signal from at least two, entirely separate, locations at the facility.					
	8. The alarm signalling system shall be regularly tested. The licensee shall have documented procedures for testing and inspecting the alarm signalling system.				Radiation Monitoring For Normal-Conducting Linac	
	9. During practices that involve the central control room being manned, there shall be workers in the staff who have the expertise to independently assess whether a criterion for alarm is met, and who has the authority to immediately decide on triggering an alarm at the appropriate level. In the event practices at the facility do not involve a need for staffing of the central control room, there shall be workers who are always reachable and have the power to immediately decide on triggering an alarm at the appropriate level. The worker shall be able to arrive at the facility within one hour.					to be further discussed
	10. The starting point for activating and setting up the crisis organisation shall be the conditions which, in accordance with condition B4a, shall be described in the emergency preparedness plan.				Emergency Monitoring Plan for Ionising Radiation Contingency Plan Emergency Preparedness Plan ESS Crisis Management Handbook	
D	**Permanent and Alternate Command Centre**					

	1. The licensee shall have a permanent command centre within or directly adjacent to the facility site, from where the crisis organisation normally can govern activities in the event of a radiological emergency.				ESS Handbook for Crisis Management Emergency Monitoring Plan for Ionising Radiation	Room is defined
	2. The licensee shall have an alternate off-site command centre, to which the management function can be relocated if the permanent command centre cannot be used. A documented instruction for the relocation shall be in place.					
	3. The licensee shall have documented procedures and equipment available to prevent contamination by radioactive substances in connection with entry into the permanent command centre, the alternate command centre, and the central control room.					
	4. The permanent command centre shall have access to back-up power.					
	5. An intercom system, which is independent of public communication systems and enables continuous verbal two-way communication, shall be located in the permanent and the alternate command centres.					
	6. A workstation for a representative from the Swedish Radiation Safety Authority shall be available in the permanent and the alternate command centres. This workstation shall have access to the Internet and telephony, as well as radio coverage for the Rakel communications system.					
E	**Meeting Point**					
	1. The licensee shall ensure that there are clearly marked meeting points at the facility, to which those people without designated tasks within the emergency preparedness organisation shall go in the event of an emergency.				ESS Site Evacuation Plan	Refer to in EMPIR
	2. At each meeting point, there shall be					
	a. documented instructions on which measures shall be taken at the meeting point,					
	b. communication devices that enable contact with both the permanent and the alternate command centres, and				ESS site Evacuation Plan Emergency Radio Communication Plan	Refer to in EMPIR - Radio communication Plan
	c. emergency lighting.					
F	**Iodine Tablets**					

	1. If there is a risk of emission of radioactive iodine, the licensee shall ensure that there are enough iodine tablets for those people located within the facility site.				Rule for Control Room: 2	
	2.There shall be documented instructions on how the tablets shall be stored, distributed and consumed.					
G	**Personal Protective Equipment**					
	1. The licensee shall ensure that personal protective equipment is available at, or in close proximity to, the facility for all personnel involved in, or called in to support, the crisis organisation.				Emergency Monitoring Plan for Ionising Radiation	Emergency Preparedness Equipmet needs to be listed for now only Electronic Personal Dosimeters
	2. The licensee shall have a documented action plan on how additional protective equipment can be supplied to personnel at the facility.				Equipment to support the emergency preparedness plan	
	3. The licensee shall have documented procedures for individual dosimetry in the event of a radiological emergency. The procedures shall include how the dosimeters and associated evaluation equipment shall be handled, and how doses to personnel shall be registered and monitored.				Emergency Monitoring Plan for Ionising Radiation ESS Proposal for Emergency Dosimetry (Rev 19 Feb)	Refer to in EMPIR
H	**Protective Measures**					
	1. In the event of a radiological emergency, the licencee shall:					
	a. take urgent protective measures according to a documented and tested plan,				Emergency Monitoring Plan for Ionising Radiation	Describe urgent protective measures in EMPIR
	b. in conjunction with an evacuation, as far as reasonably possible, verify that relevant areas and spaces have been evacuated;				ESS site Evacuation Plan	
	c. carry out contamination checks of individuals that are suspected of having been externally contaminated with radioactive substances. If contamination is ascertained, individual decontamination shall take place, in accordance with documented procedures, and				Emergency Monitoring Plan for Ionising Radiation Decontamination	Refer to the decontamination efforts in EMPIR and the Evacuation Plan To be decided: exact location
	d. take measures according to documented procedures in case of suspected acute radiation damage or suspected internal contamination.				Emergency Monitoring Plan for Ionising Radiation ESS Handbook for Radiation Protection Chapter 2. General Radiation Protection Rules Rues for medical reporting	Refer to in EMPIR
I	**Expertise, Training and Drills**					

	1. The licensee shall ensure that all individuals at the facility are informed on what alarm signals mean, where the meeting points are located, and which urgent protective measures may need to be implemented.				Safety Induction	
	2. The licensee shall have specified expertise requirements, as well as short- and long-term training and drill plans, for workers within the crisis organisation.				Training activities for the Emergency Preparedness Plan	Develop Training Plan for RP
	3. The participation of workers in training courses and drills shall be documented and preserved for each individual. Documented procedures shall be in place to monitor the expertise of workers in each position within the crisis organisation.					
	4. Experiences from completed drills shall be documented and form the basis for developing the crisis organisation.				Emergency Monitoring Plan for Ionising Radiation Emergency exercise Test Stand 2 Evaluation Report	Let EMPIR be influence during the developemnt by exercises
	5. All individuals who, during or after an emergency, may possibly carry out responses in places where there is risk of high radiation doses or extensive personal contamination by radioactive substances, shall have knowledge of the working methods and radiation protection measures that apply in such an environment.				ESS- 0044006 Emergency Monitoring Plan for Ionising Radiation	Refer in EMPIR to training for others - FR for example; referto standard training
J	**Contact with the Swedish Radiation Safety Authority**					
	1. In the event of an emergency when the crisis organisation has been set up, the licensee shall ensure that there are designated workers who are responsible for being in contact with the Swedish Radiation Safety Authority on matters concerning safety.				ESS Rules for reporting unplanned events to SSM ESS Handbook for Crisis Management Emergency Monitoring Plan for Ionising Radiation	Decide on designated workers
K	**Meteorological Data**					
	1. The facility shall be designed with equipment so that, as far as reasonably possible, measurement and monitoring of relevant meteorological data that is representative of the facilicty can occur.					Describe in Empir

	2. Current relevant meteorological data representative of the facility shall be continuously measured, recorded and transferred to the Swedish Radiation Safety Authority in the format and with the method determined by the Swedish Radiation Safety Authority. Appendix 1 specifies the requirements that meteorological equipment shall fulfil and how notification prior to interruptions, and reporting and documentation during and after interupptions, shall be done.					Describe in Empir
	3. It shall be possible to read registered meteorological data for the last 24 hours from the permanent surveillance centre, the permanent command centre, and from the central control room.					Describe in Empir
L	**Source Term Assessment and Dose Calculation**					
	1. The licensee shall ensure that expertise, tools and documented instructions are in place in order to be able to:				Emergency Monitoring Plan for Ionising Radiation	
	a. perform a source term assessment during a radiological emergency at the facility, and				Emergency Monitoring Plan for Ionising Radiation	Training is developed
	b. calculate and assess radiation doses in the event of emission of radioactive substances before, during and after a radiological emergency. It shall be possible to calculate and assess radiation doses within the access restricted area.				Emergency Monitoring Plan for Ionising Radiation	Training is developed
M	**Radiation Monitoring**					
	1. The licensee shall ensure that there is stationary measuring equipment, so that continuous radiation monitoring can take place in:				Emergency Monitoring Plan for Ionising Radiation	Refer to the ones already implemented
	a. the permanent command centre, the central control room, the surveillance centre and other areas that are expected to be manned long-term in conjunction with a radiological emergency.					
	b. spaces and areas that are prioritised during evacuation from the facility in conjunction with a radiological emergency, and					
	c. expected emission pathways for radioactive substances to the surrounding area of the facility in conjunction with a radiological emergency. Measurement values shall be recorded and be possible to read centrally from any location in the facility.					

	2. Measurement equipment, in accordance with condition 1a, shall also be designed with an alarm so that workers in the relevant area can be made aware of a radiation level above the set alarm limit.				Emergency Monitoring Plan for Ionising Radiation Radiation Monitoring Plan for NCL	
N	**Ventilation**					
	1. The facility shall be designed with filters which absorb radioactive substances in the ventilation pathways for the air supply to the central control room, permanent command centre, and surveillance centre.					Describe in Empir
O	**Quality Assurance of Equipment**					
	1. The licensee shall, in addition to what is stated in condition C8, ensure that equipment and tools which are part of the crisis organisation are subject to condition B8 in chapter 9 with regard maintenance, continuous supervision, and inspection.				Emergency Monitoring Plan for Ionising Radiation	alarm testing; equipment tests