Safety requirements at nuclear power plant in the UK and Sweden

- Identified similarities and differences

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Abstract
The aim with this master thesis is to identify similarities and differences between the UK and Swedish safety requirements for hazards at the plant level. It is also to investigate the underlying requirements for the safety documentation of those hazards. The method in the report is picked from literature studies, such as internal documents and the information published by the UK´s and Sweden's countries' nuclear authorities. Semi-structure interviews have been conducted. The report is strictly dealing with internal and external hazards. In addition, the study is only made on one Light water reactor in each of the following countries, Sizewell B in the UK and unit O2 at OKG, Sweden. An important conclusion is that the main differences are based on different ideological approaches to managing risk in the law and how each country assesses the hazards. The similarities are above all, the identified hazards as well as the safety analysis that has to be done, both deterministic and PSA. Moreover, those who own the risks are ultimately responsible for preventing a nuclear accident.

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Preface

This Master Thesis was written as a Master Science Thesis at the Department of Fire Safety Engineering and Systems Safety at Lund University. This Master Thesis has been written in co-operation with Scandpower AB at the Malmö office. Scandpower AB is also the main financier in addition some of the financing has been done by Lloyd´s Register, such as accommodation in London.

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I would also like to express my gratitude to the company Scandpower and especially the office in Malmö for their practical assistance and for letting me be a part of the team. I am also very grateful to Lloyd´s Register and their office in London, where I was situated for 10 weeks.

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Big thanks to the Swedish Radiation Safety Authority, SSM, for their openness. The information was both interesting and necessary. And especially thanks to Ninos Garis and Lars Gunsell for letting me conduct interviews. I will also take the opportunity to thank Geoff Grint at the Health and Safety Executive, HSE, for a warm welcome in Liverpool and for sharing useful information with me during the interview.

Finally, Bo Liwång, Hanna Bühler, and Linda Pehkonen thank you for all of your support and crucial comments.

Thank you!

Evelynn Brattström

Summary
The nuclear industry can be hazardous for health and the environment and is therefore one of the most regulated businesses in the world. To avoid accidents, a number of safety requirements are attached to the nuclear power plants. One safety requirement is to divide hazards into external and internal hazards. External hazards are those that affect safety, but it originates outside the facility. Internal hazards are those which have their origin in the construction area, such as fire, internal flooding, or dropped loads.

The purpose of this Master thesis is to descriptively explain the biggest differences and similarities in safety requirements on the plant level between the UK and Sweden and how they are handled in the safety documentation. This study also seeks to deepen the knowledge of nuclear technology and level of safety at nuclear power plants in the UK and Sweden.

The report intends to investigate:

- *What are the similarities and differences between the UK and Sweden when dealing with safety requirements for hazards and what are their underlying requirements for the safety documentation of those hazards?*

Today´s nuclear activities are global and many activities extend beyond national borders. Many Swedish companies currently have interest in implementing their skills in the UK's nuclear power plants, as the UK's reactors are to be changed and replaced with new ones since the plants have reached their designed lifetime. Because of this interesting fact, the UK will be used as a benchmark against Sweden.

The life of a nuclear power plant is divided into several phases, of which output increase or major modernizations are classified to belong to the operation phase. This report has been limited to external and internal hazards to keep the report within reasonable proportions.

Nuclear power plants are required to document safety using Safety Reports. Safety documentation is a fundamental requirement to maintain and operate a nuclear power plant. The safety documentation is primarily seen as a summary of nuclear power design safety, and how the licensee prevents radiation risks. Moreover, it is used as an argument for the licensee to prove safety for the regulators and to the public.

In the UK, an application for the thermal uprate will be examined and evaluated using the Safety Case to see whether the safety at the plant level is acceptable or not. In Sweden, this process corresponds to something called the Preliminary Safety Analysis Report, PSAR. Both the Safety Case and PSAR will later be considered acceptable content in a Safety Report.

Safety is not a "social construct" – it is something that you describe. In order to describe and compare safety laws and regulations, safety documentation and interviews are selected as descriptive parameters. Laws and regulations relating to the national view on how safety and more specifically how the hazards should be handled. This study of safety documentation has been done on two nuclear power plants, Sizewell B in the UK and unit O2 at OKG in Sweden. The safety documentation is designed to provide answers to how the owner of the plant adheres to laws and the internal rules are implemented in the Safety Report. Every part, legislation, safety documentation, and interviews are reviewed systematically and compared across the two countries and what requirements they have on hazards.

The interviews are designed primarily to provide answers to how the hazards are handled in the safety documentation and underlying requirements for the hazards, but also how a licensee can be sure that the safety is satisfactory.

The biggest *similarities* for the countries are that the hazards aim to cover the whole risk spectra. Both countries have similar requirements on the identified external and internal hazards, such as protection against fire, earthquake, flooding, extreme weather, and missiles. These requirements have become more and more similar over the years, through international co-operation and exchange of research and experiences.

The biggest *differences* are in the ways that the hazards are assessed. The UK assesses hazards against the ALARP principal, which is law in the UK, and is using guidelines for the regulators that are translating the ALARP principal into Numerical Targets. In Sweden, the licensee (plant owner) is assessed against the laws that are more detailed and focused on requirements, while the UK focuses on the hazards. Another difference is that Sweden requires higher regulations for the environment. The third big difference is that Sweden and the UK have different acceptance criteria for what they think is good safety at nuclear plants.

The *underlying requirements* to those similarities and differences for hazards and how they are handled is based on historical differences and different national approaches to evaluate risk. In the UK, the national approach for the nuclear industry is clear, using a “top down” approach for tolerability of risk. This approach is not just for nuclear power, but involves all risks in the society. In Sweden there are no limits or numbers for risks when evaluating the risks of a nuclear power plant specified in the laws. Instead there are more recommendations for the licensee that are based on historical and practical use in some documents published by the Swedish Radiation Safety Authority. Also the licensee has to prove for the authority that they can provide good risk limits for the risks.

Sammanfattning

Kärnkraftsindustrin kan orsaka stor risk för hälsa och miljö och är därmed en av de mest reglerade industrierna i världen. För att undvika en olycka finns ett stort antal säkerhetskrav som skall förbättra säkerheten på kärnkraftverk. En kategori säkerhetskrav är externa och interna risker. Externa risker är sådana som påverkar säkerheten, men har sitt ursprung utanför anläggningen. Interna risker är sådana risker som har sitt ursprung i anläggningsområdet, såsom brand, översvämning, tappade laster, etc.

Målet med denna rapport är att identifiera de största skillnaderna och likheterna mellan Storbritannien och Sverige vad gäller säkerhetskrav på anläggningsnivå och hur de skall hanteras i det som kallas säkerhetsdokumentation. Syftet är att skapa en fördjupad kunskap inom kärnteknisk säkerhet vid kärnkraftverk i både Storbritannien och Sverige.

Dagens nukleära verksamhet är global. Många svenska företag har för närvarande intresse av att genomföra sina färdigheter i Storbritanniens kärnkraftverk, då många av Storbritanniens nuvarande reaktorer skall ersättas med nya, eftersom reaktorerna har nått sin tekniska livslängd. På grund av detta intressanta faktum, har Storbritannien valts att jämföras med Sverige.

Rapporten har som avsikt att svara på:

- *Vilka skillnader och likheter finns det mellan Storbritannien och Sverige ställda säkerhetskrav och vad är de grundläggande kraven för säkerhetsdokumentation i detta fall?*

Ett kärnkraftsverk tekniska livslängd delas upp i flera olika faser, varav effekthöjning eller större moderniseringar klassas tillhöra en fas bland många andra. Denna rapport kommer att fokusera på effekthöjningar samt större moderniseringar. Rapporten har även avgränsats till att bara behandla de säkerhetskrav som reglerar externa och interna risker. Dessa avgränsningar är nödvändiga för att rapporten skall inneha rimliga proportioner.

I Storbritannien behandlas de externa och interna riskerna i något som kallas Safety Case. För att kunna utgöra en effekthöjning eller större modernisering skall tillståndshavaren diskutera detta med HSE, myndigheten som behandlar kärnkraft bland många andra samhälliga risker. I Sverige skall motsvarande process behandlas i något som kallas Preliminär säkerhetsredovisning, PSAR. Tillståndshavaren är skylig att ansöka om en effekthöjning eller större modernisering hos regeringen och hos SSM, kärnkraftsmyndigheten i Sverige. Både Safety Case och PSAR kommer efter godkännande av ansvarig myndighet/regeringen att sedan ersätta den befintliga säkerhetsdokumentationens innehåll som alla kärnkraftsverk innehar.

Säkerhet är inte en mätbar storhet, utan det är något som man beskriver. För att beskriva och jämföra skillnader och likheter mellan länderna har lagar och regelverk, interna säkerhetsdokumentationer på två kärnkraftsverk (Sizewell B i Storbritannien och Enhet O2 på OKG i Sverige) i respektive land och intervjuer valts som beskrivande parametrar. Lagar och regelverk ger framförallt svar på hur respektive land ser på säkerhet. De interna säkerhetsdokumentationerna ger framför allt svar på hur säkerheten skall hanteras på anläggningen samt hur interna regler påverkar säkerheten. Intervjuerna är främst avsedda att ge svar på hur riskerna hanteras i säkerhetsdokumentationen och underliggande krav för risker. Men också hur en tillståndshavare kan vara säker på att säkerheten är tillräckligt bra. Varje del, lagstiftning, säkerhetsdokumentation och intervjuer behandlas systematiskt och jämföras mellan de två länderna, Storbritannien och Sverige, och vilka krav de har på interna och externa risker.

De största *likheterna* mellan Storbritannien och Sverige är att de identifierade riskerna syftar till att täcka hela riskspektrat samt att testa om anläggningen är robust. Båda länderna ställer liknande

säkerhetskrav vad gäller de identifierade externa och interna riskerna, exempelvis mot brand, jordbävning, översvämning, extrema väderförhållanden m.fl. Dessa krav har blivit mer och mer lika genom åren på grund av ett ökat internationellt samarbete och utbyte av forskningsresultat och drifterfarenheter.

De största *skillnaderna* mellan Storbritannien och Sverige finns i hur säkerheten bedöms. I Storbritannien bedöms risker mot ALARP som konkretiseras med hjälp av kvantifierande riktlinjer uppställda av HSE och kallas Numerical Targets. I Sverige bedöms tillståndshavaren mot de lagar som reglerar kärnkraften, vilka är mer detaljerade än Storbritanniens. Säkerheten bedöms dessutom mer efter de krav som ställs i lagen, medan Storbritannien fokuserar mer på riskidentifiering. En annan skillnad är att Sverige ställer högre krav på miljön. Den tredje stora skillnaden är att Sverige och Storbritannien har olika acceptanskriterier för vad de tycker är tillräckligt bra säkerhet på kärnkraftverk.

De *bakomliggande kraven* till dessa likheter och skillnader för interna och externa riskerna och hur de hanteras i säkerhetsdokumentationen är baserade på historiska skillnader och olika nationella strategier för att behandla säkerhet. I Storbritannien är den nationella strategin för kärnkraftsindustrin och dess säkerhet styrd av framför allt parlamentet med en så kallad "top down"-metod. Det är ett nationellt ställningstagande för hur risker skall behandlas i Storbritannien. Detta tillvägagångssätt är inte bara applicerbart på kärnkraft, utan används i hela det brittiska samhället. I Sverige finns det ingen uttalad modell för att bedöma säkerheten på ett kärnkraftverk utan de gränser som finns har en historisk bakgrund och en uttalad praxis att luta sig mot. SSM har utgivit dokument med rekommendationer för hur tillståndshavaren skall värdera sin risk men dessa gränser finns inte specificerade i lagstiftning. Tillståndshavaren har därmed en skyldighet att bevisa för SSM att de kan uppfylla god säkerhet och tillräckliga gränser för riskerna.

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Chapter 1 - Introduction

Nuclear safety is all about taking control over the ionizing radiation that comes from the process of splitting Uranium atoms, Uran-235 (OKG 4). The process creates risks, which are extensive and span over several thousand years. This means that safety must be a central issue for creating a secure future.

For safety to be maintained it requires continuous and extensive investments in safety. Investments include, but are not limited to replacing worn parts, modernization, and adapting the plant to the new standards generated through research and international collaboration. This, together with the safety requirements of a nuclear power plant requires extensive documentation.

1.1 Background

The nuclear industry can cause big issues for the health and environment and is therefore one of the most regulated businesses in the world. An accident can cause ionizing radiation and damage the public environment. There are a large number of safety requirements attached to nuclear power plants to avoid an accident causing ionizing radiation. The safety work on nuclear power plants is a result of experiences from other high risk areas and also from earlier experiences from the nuclear industry. The strategy of the safety work is to avoid core damage in the reactor, as that is where the radiation is mostly based. The likeliness of a small "emission release" during normal operation is much higher than the risk of a big accident (SSM 4).

Today about 15 percent of the world's electricity is generated by nuclear power (WNA 2). But, there is great uncertainty as to how the world will respond to nuclear power in the future. However, there are indications saying that the number of countries using nuclear power will increase from the present 30 to around 50 countries within the near future (Gåhlin et.al, 2010). The policy regarding nuclear power plants has been, and is still widely discussed. That has, among other things, led to a situation where the licensees (the holders of licences for running nuclear power plants), have focused on expanding and making the existing plants more effective. This is called thermal uprating or power uprating, which gives higher profits as more electricity can be produced. Sometimes the thermal uprating is a consequence of higher safety requirements of nuclear power plants. Such efficiency upratings have pressed the nuclear power plants to extract more energy, which may in some cases cause a higher risk for accidents. These changes, however, are tightly controlled and must be reported and documented according to strict principles to ensure that safety is not compromised. To meet legal requirements and other rules, the changes and the requirements are documented through safety analysis statements. The documentation is summarized and reformulated into a so called Safety Report, which is intended to show the authorities and the public that the safety of the nuclear power is satisfactory. A Safety Report shall be reviewed whenever a change is implemented.

Today's nuclear activities are global and many activities extend beyond national borders. Many Swedish companies currently have interest in implementing their skills in the UK's nuclear power plants, as the UK's reactors are to be changed and replaced with new ones, since the plants have reached their designed lifetime. Because of this interesting fact, the UK will be used as a benchmark against Sweden. The UK currently has 19 reactors which account for about one fifth of the total energy production.

The UK was one of the first countries in the world to produce civil nuclear power, and because of that they have many reactors in the decommission stage. In general, the nuclear industry has decreased since the Chernobyl accident in 1986. But nowadays the UK has made a clear statement to continue with nuclear power. A large program for nuclear energy is taking form, which will play an important role for the country´s infrastructure in the future. In Sweden nuclear power represents nearly half of the total energy consumption and has ten nuclear power stations that are in operation status. Most power plants have been through a power uprating process or a larger modernization process several years ago. As late as summer 2010 the Swedish government voted on a big issue for the nuclear industry and decided that new power stations may be built, but the total number of power stations cannot exceed ten.

The purpose of this Master thesis is to deepen the knowledge about nuclear technology and level of safety at the nuclear power plants in the UK and Sweden. The objective of the report is to identify and analyse the differences and similarities between the UK's and Sweden's safety regarding internal and external hazards at the plant level for power uprating or major modernization in a nuclear power plant. The identified and analysed differences and similarities may constitute a basis for creating understanding in the UK and Sweden in the establishment or application for handling safety documentation.

With the background in mind, legislation, internal safety documents on a nuclear power plant in each country will be studied and interviews of the nuclear authority will be done to compare the UK and Sweden. To study the safety documentation in the UK, Sizewell B was selected and in Sweden Oskarshamns Kraftgrupp AB, OKG, unit O2 was chosen.

The master thesis will focus on the differences and similarities of safety at the plant level and on the safety assessments of power uprating or bigger modernization during the license renewal application.

1.2 Source Criticism, reference management and target

This report is based largely on primary sources. This means that references will largely come from nuclear regulators in the UK and in Sweden. The content of the report is also based on the source of internal documents, which are considered very reliable, they are however difficult to control by outsiders. Articles from relevant scientists have also been used. It is important to highlight that this is a changeable industry where things change very fast over time and now days a lot of new technology is introduced on the market and also “New build” programs for countries that chose a nuclear power future. In order to secure the content of this report, appropriate people have read and approved the material and given their comments, which provides a certain level of creditability to the report and its content.

References are handled according to the rules of the Harvard system. This means that references appear in the text, listed by surname or editor. The year of publication is listed in parenthesis after the reference word (Arvidzon, 2010). In the reference list, which appears at the end of the report, prior to the appendix, the references are listed in alphabetical order. There is no indication on which type of document is referred to, although internal documents are referred to in a special way. These references appear within ”hook parenthesis” with a letter and a digit in it. The letter indicates for example: A=UK and B =Sweden. The number indicates which part of the document is referred to. See section 9.1 – Internal references.

The target audience of this report is mainly consultants who work in the UK or Sweden, who would need a deeper understanding of nuclear safety, safety requirements, and documentation. The report even invites other audiences such as students and the general population to take to gain a deeper understanding of nuclear power and the industry, and especially to learn about difference and similarities between the UK and Sweden.

1.3 Report Outline

To clarify the report's approach, a brief description of the content in each chapter's will be presented below. However, this section is preceded by a Summary and Table of content, i.e. a classic introduction to a report of this kind.

Chapter 2 – *Background and Description* gives a brief introduction to nuclear power in the UK and in Sweden. This is followed by theory which gives background to how each country is documenting safety in the Safety Report. Finally, the legislation and regulations that regulate nuclear safety is described.

Chapter 3 – *Research questions* describe the main purpose and the aim of the report.

Chapter 4 – *Method and technique* describes the scientific approach of the report.

Chapter 5 – *Analysis* This chapter is the heart of the report. In this chapter Sizewell B (UK) and unit O2 (Sweden) are compared. This represents how each country handles safety at the plant level. The case study has been divided into different sections: Safety documentation, Safety requirements, Safety analysis, and finely Acceptance criteria.

Chapter 6 – *Summery of the analysis*. This chapter intends to answer the research question. It presents similarities and differences between the UK and the Swedish way of relating to safety requirements for hazards.

Chapter 7 – *Discussion and Perspective* gathers and discusses the basic data that the report is based on. This chapter even discusses various factors that may have affected the outcome. Nuclear power and future is illustrated as well, to put the report in a larger context.

Chapter 8 – *Conclusions* summarizes the report findings and gives an answer to the research question. This part also summarizes whether the report's main objectives have been achieved or not.

Chapter 9 – *References.*

Explanations of expressions and abbreviations are presented in *Appendix A – Explanations of expressions and abbreviations*. More appendices can be found at the end of the report.

Chapter 2 – Background and Description

In the following chapter an overall description of nuclear power in the UK and Sweden is given, followed by a theory chapter over how each country has chosen to present their Safety report. Legislation and regulations will be covered at the end of the chapter.

2.1 Nuclear Power plants and status

This section presents an overview and systematic review of each country's nuclear industry.

2.1.1 UK

The UK has 19 reactors that provide the country with nearly a fifth, 11 000 Gwe, of the total power supply. All of them will be shut down by 2023, see figure 1 below. The UK´s first nuclear power plant, Calder Hall of the model Magnox[1], started to operate in 1956 and was the first civil commercial nuclear power station in the world (WNA 1). During the 1980s another reactor generation developed, called AGR[2]. The majority of the nuclear power plants in the UK today are this type; see *Appendix B – Status on Nuclear reactors*. The latest power station that was built in the UK was built in the year 1995. The model of this one is “PWR” and it is called Sizewell B (British Energy 3).

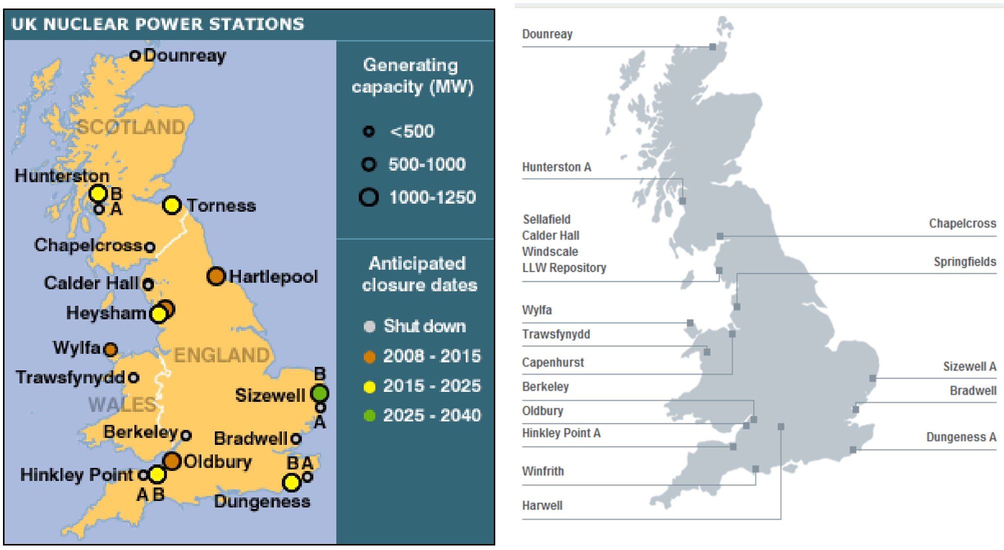

Figure 1 To the right: Geographical overview of nuclear power plants in the UK (BBC 1). To the left: Decommissioning nuclear power plants or ongoing decommissioning power plants (NDA 2). Sizewell B is located were Sizewell A is shown in the figure. Sizewell A is now an old nuclear power plant and is currently in the decommissioning stage right now.

The status of UK reactors is varying. Nearly a third of all old power plants will need to be replaced by new ones in the future. Already in year 2023 the UK needs to start replacing a few nuclear power stations, or they will have to undergo a major modernization. This is because the current plants are approaching the end of their technical lifetime; see *Appendix B – Status on Nuclear reactors* for details. Because of the decreasing number of nuclear power plants in the future, the UK has been forced to take a position regarding energy resources in the future. Nuclear power will be one of the

[1] *Magnox is a gas-cooled reactor that uses metallic natural uranium as fuel. The fuel is cooled by carbon dioxide and the moderator is graphite. This model was developed in England, as well as the AGR model (Analysgruppen, 2008).*

[2] *AGRs predecessor is Magnox. Moderator and coolant is, like Magnox, of graphite and carbon dioxide. The fuel consists of slightly enriched uranium dioxide, which is encased in stainless steel (Analysgruppen, 2008).*

UKs energy supplies (WNA 1). The UK expects that four to five new nuclear power plants will start to operate already in 2020 (Analysgruppen, 2008).

2.1.2 Sweden

The first commercial reactor in Sweden was built in Oskarshamn in 1972 and the last one in Forsmark in 1985 (Kärnkraftsinformation 1). Sweden currently has a total of ten units in operation which accounts for half all Swedish electricity produced. There are furthermore two reactors that are located in Barsebäck in the south of Sweden, but they were closed down in 1999 and 2005, respectively (SSM 1), see figure 2 below. Those reactors were closed down based on an earlier political decision to decrease nuclear power in Sweden.

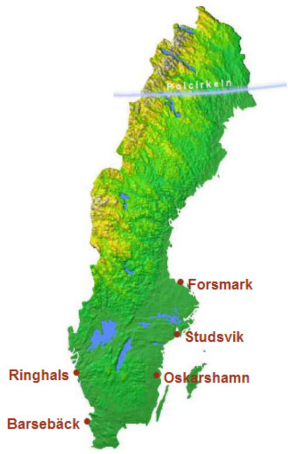

Figure 2 Geographical overview of Swedish nuclear power plants (Analysgruppen, 2008). Studsvik is also shown on the map even though there are currently no commercial nuclear power plants there today. Studsvik was first in the country with nuclear research and therefore has a historical significance for Swedish nuclear power. Studsvik nuclear AB has decided to phase out the two research reactors, generated 50 000 kW respective 1000 kW (OECD 2).

Sweden's nuclear power plants are characterized largely by the effect of modernization and increases in existing plants (Wiberg, 2010). Many major modernization and uprating projects have been initiated, including unit O2s uprating (OKG 3). The Bulletin "*Nuclear published in our world*" writes that Sweden has undergone a historic decision with regard to nuclear power. Namely, to lift ban on new building come June 17, 2010, after 30 years of prohibition (Wiberg, 2010). In *Appendix B – Status on Nuclear reactors,* Swedish nuclear power status is presented.

2.2 Laws and regulations

Below in section 2.2.1 laws and regulations of the UK will be presented, followed by Swedish laws and regulations in section 2.2.2.

2.2.1 UK

The outline laws that control power uprating or major modernization in the UK nuclear power plants will be described in this section. Each subchapter will partly illustrate what the law intends to say and some legal text will be highlighted to further illustrate important paragraphs related to safety documentation and safety requirements. Legislation in the UK originates from 1946 and has evolved step by step as civilian nuclear power has been more and more requested (OECD 1).

In 1974 there was a revolutionary change in how the country should assess risk and safety and how this should be controlled. This change resulted in a new law, Health and Safety at Work etc Act 1974. This is the UKs main law when it comes to regulating safety. The law put the responsibility for safety on the owner. This requires the owner to demonstrate and manage the nuclear power plant in a safe way [3]. The change also made safety and risk more closely related to ALARP; see *Appendix D – Levels of risk UK* and *Appendix E – ALARP* for further reading. In the UK there is a relatively clear distinction between the laws and regulations governing the protection of people and the environment, and the regulations governing nuclear installation (OECD 1).

In UK the Nuclear Directorate, ND[4], which is part of HSE is responsible for regulating the safety of nuclear power installations. ND is not at all connected to the parliament. The Nuclear Installation Inspectorate, NII, is part of ND which inspects and assess the nuclear industry to ensure that the licensee is complying with the law (HSE 1).

Table 1 below outlines the laws and regulations related to safety at nuclear power plants from a hierarchical perspective (HSE 1). The main UK nuclear safety laws are divided into:

- Nuclear safety management by controlling the installation and operation of nuclear installations such as the Nuclear Installation Act 1965.
- Ionising radiations protection of workers and the public from work activities involving i radiations, such as the Ionising Radiations Regulations 1999.
- Radioactive substances discharge and disposal consent for the protection of the environment; such as the Radioactive Substances Act 1993.

Table 1 Overview of the UK nuclear hierarchic laws and regulations.

UK law and Regulations	Health and Safety at Work etc. Act 1974, Nuclear Installation Act 1965, Energy Act 1983, The Environment Act 1995 (England and Wales). Ionising Radiations Regulations 1999
Guidelines for regulators HSE/ ND	Safety Assessment Principles, SAPs and Technical Assessment Guidelines, TAGs[5]

To secure the national reference level of laws in the UK a combination of national laws and license conditions are attached to all nuclear sites, SAPs, TAGs and other forms of guidance (HSE 1, p.2).

2.2.1.1 Health and Safety at Work etc. Act 1974

The operators of a nuclear power plant are required to follow the Health and Safety at Work etc Act 1974, HSWA. The Act is a comprehensive law and can be explained by paragraph 2: ”every person is to ensure, as far as reasonably practical, the health, safety, and welfare at work of all his employees”. When power uprating or during a major modernization this law is matter of fact as the Safety Case will be evaluated according to ALARP.

In the document *Reducing Risks, protecting people, R2P2,* the HSW Act is described as a fundamental principle like “...those who create risk at work activity are responsible of protecting the workers and the public from the consequences of these risks.” (HSE 10, p.15 paragraph 7).

[3] *Nuclear Product Development Manager, King Lee, Lloyd´s Register, conversation 2010-06-24.*
[4] *ND, acting for the HSE, are responsible for regulating the safety of nuclear installations in UK and can make decisions without the parliament.*
[5] *SAPs and TAGs are not laws but should only be seen as guidelines for the regulators. But in practical they are basically followed like laws by the licensee at the nuclear power stations (Nuclear Product Development Manager, King Lee, Lloyd´s Register, conversation 2010-06-24).*

The law is important to understand since the HSE inspectors assess the licensee very much according to this law. Which places the onus on the duty holder, in this case the licensee, to demonstrate that they have met the law. The HSW Act is non-prescriptive so the licensee has choices in how they go about satisfying they legal duty. This means that the power plant has to operate very openly towards the HSE.

2.2.1.2 Nuclear Installation Act 1965

The most important regulations for the secure operation of a nuclear power plant are presented in the Nuclear Installation Act 1965, NIA65 (WNA 1). Nuclear Installation Act 1965, NIA65, is sub oriented to the HSWA as described above in section 2.2.1.1.

One of the key purposes of the law is that the licensee is obliged to have a license to operate a nuclear power plant (NIA65, sections 1, 3 - 6 and 24A), and the HSE is responsible for making sure that regulations are followed (WNA 1). A license can only be given to a juridical person (NIA65, section 3). The licence cannot be overtaken or transferred to anyone and it is just valid for one specific power plant.

The Nuclear Installation Act 1965 give the HSE power to attach to each nuclear site licence such conditions as it considers necessary to ensure safety. HSE has developed a standard set of 36 conditions which are attached to all nuclear site licences. For example that the Site Licence Condition 14 Safety Documentation is to ensure that the licensee sets up arrangements for the preparation and assessment of the safety related documentation used to justify safety during design, construction, manufacture, commissioning, operation and decommissioning. This requirement includes the arrangement for safety assessment reports shall be performed by the licensee. LC36 shall be followed by all nuclear installations (HSE 3; OECD 1), see also section 2.2.1.6 below.

2.2.1.3 The Environment Act 1995 (England and Wales)

The purpose of this law is to control radioactive material, and the main purpose is to protect the environment and store radioactive waste in a controlled way (OECD 1 p. 5), for a durable development (OECD 1 p.30). The law created the Environment Agencies, EA, in England and Wales, and the Environment Protection Agency in Scotland. In Northern Ireland it is carried out by the Environment and heritage Service through Industrial Pollution and radiochemical Inspectorate, IPRI (OECD 1). The Environmental Agencies have a responsibility in the legislative process for uprating in the nuclear sites because the uprate causes more radioactive waste and a higher risk of radiation release into the environment.

The Energy Agency/SEPA and the HSE have a number of mutual areas of interest, for example (HSE 1 p.137):

- Plant sites, modification of existing nuclear power plants that can affect the ionizing radiation.
- Permit of radioactive discharges
- Periodic Safety Reviews, PSR
- Inspections, near-accident and near-accident that can affect other authorities.

The co-operation between the agencies will probably increase in the future because of the UKs “New build program”. This program is the nuclear power future in the UK. The *Safety Assessment Principles* gives a short explanation to how both the regulators are related to each other, explained in the following quotation (HSE 1 p.139):

"The responsibilities of "HSE' are centred to the regulation of the source of direct radiation shine from normal operations and of the prevention of accidental releases of radioactivity; and EA and SEPA's responsibilities centred on the regulation of discharges and disposals from normal operations."

Substances Act 1993, RSA 1993

The law is a consequence of The Environment Act 1995, see above section 2.2.1.3. It regulates usage and disposal of radioactive material along with the current Environment Agency. In case of a power uprate or major modernization this law can be enforced, in agreement with other laws such as The Environment Act 1995 and the HSW Act (OECD 1). All licensees of nuclear power plant have an obligation in RSA 1993 to minimize discharges of nuclear waste (OECD 1 p.9).

2.2.1.5 The Ionizing Radiations Regulations 1999, IRR

This law was founded to protect the public against ionizing radiation. The main purpose is to set basic safety standards for health protection against dangerous ionizing radiation. When thermal uprating or major modernization is taking place, this law, IRR is firmly enforced since a risk of higher radiation is involved. The law regulates all enterprises that are in contact with the regulation of radiation. The HSE is the responsible authority. The regulation contains directions of hazard identification, risk evaluation, emergency plans, as well as public information (OECD 1 p.10).

The Ionising Radiations Regulations 1999 support NIA65 and demand the radiation exposure to be kept down as low as practicable and with specified limits (WNA 1). Radiation to the public is not to exceed 0.3 mSv, see *Appendix A – Explanations of expressions and abbreviation* for more reading of millisievert (HSE 1, paragraph 530).

2.2.1.6 Site Licence Condition, LC36

License conditions 36, LC36, have to be followed by all nuclear power stations. The HSE is responsible for them and they also have to develop them. Nuclear directorate, ND, is responsible for making each nuclear plant follow the license conditions (Alastair, 2008 p.29).

The Licence conditions cover safety related functions (Alastair, 2008) for technical details (HSE 3). In the report "*The licensing of nuclear installations*" published by HSE, explains LC36 as following (HSE 3, paragraph 1.13):

"They are non-perspective and set out goals that the licensee is responsible of meeting, amongst other things by applying detailed safety standards and procedures for the facility. The arrangements, which a licensee develops to meet the requirements of the Licence conditions, constitute elements of a nuclear safety management system"

The table 2 below contains a few of the most important Licence conditions when power uprating or major modernization. LC14 set out requirements that safety documentation has to be performed (HSE 11).

Table 2 Example of the LC36 developed by HSE. The ones shown in the table are related to hazards, analysis. and safety documentation (HSE 6; Alastair, 2008).

Name of Licence Conditions	The purpose	How it's affected when power uprating or with major modernization?
LC 14 Safety documentation	To make the licensee aware of all risks during the whole technical life an independent review of the documentation must also be done.	The Safety Case has to be a living document and when power uprating or with major modernization the documentation has to follow the changes.
LC 18 Radiological protection	Measurements of emissions should be done continuously and the effective dose should not exceed 0.3 mSv. This is supported also by the law IRR	Power uprating is affecting the fuel, and safety margins can thereby be reduced. The results are a greater probability of radioactive releases.
LC 20 Modification to design of plant under constriction	No changes may be made unless the HSE / ND have been contacted. The change must be discussed and safety must be justified.	-
LC 22 Modification or experiment on existing plant	The licensee must stay in control of all changes affecting safety. The ND assesses whether the licensee has taken adequate action.	Safety systems and safety margins are affected and must carefully be controlled to make sure they meet the requirements after completion of output increase and modernization.
LC 23 Operating rules	The purpose is to ensure that the licensee has identified all potential risks and that there is an agreement for that all hazards has been identifying. The method for doing this is to create a Safety Case.	Uprating or major modernizations can change conditions at the plant. Thereby new risks and hazards have to be overviewed.
LC 28 Examination, inspection, maintenance and testing	The plant shall automatically obtain evaluation and inspection and results of the tests should be kept in a protocol.	The robustness of the plant is important and has to be overviewed again after a big change.

Each License condition set a goal and it is up to each duty holder to meet the goal. Alastair (2008) expresses the following about the LC36: "The non-prescriptive licensing regime in the UK ensures that the duty holders recognize and accept their responsibilities, allowing them to determine their own methods for complying with the law." (Alastair, 2008 p.29).

2.2.1.7 Safety Assessment Principles

Safety Assessment Principles, SAPs, and TAGs, see section 2.2.1.8 below) are *guidelines for the regulator* in their assessment and inspection of the owner rather than guidance as an interpretation of the laws and regulations. They serve as a kind of guidance for inspectors as they make decisions for any modernization, power uprating, or new building situation[6], although in practice they are used by UK industry as guidance for compliance with UK nuclear laws and regulations since it could be seen as an interpretation of the HSE on how a licensee should cope with the laws[7]. The SAP is a top level document and the purpose is to minimize the risk As Low As Reasonably Practicable, ALARP. The SAPs (and the TAGs) can be seen in this context (HSE 1 p.4).

SAPs for nuclear power plants were first published in 1979 with a background in the HSWA (HSE 9, paragraphs 3.1 & 5.5). A person called French Layfield recommended that the HSE develop a report

[6] *Nuclear Product Development Manager, King Lee, Lloyd´s Register, conversation 2010-06-24.*
[7] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, interview 2010-07-26.*

on how they thought risk would be assessed. The HSE responded by publishing *The Tolerability of risks from nuclear power station* which was first published in 1988. This document was reduced in 1992. In connection with this, the SAP was also revised. The goal of the release of SAP was to harmonize with the international regulatory framework as well as to harmonize with the writing *The Tolerability of risk in nuclear power stations*. In 2001 the HSE published another letter on tolerance for risk in nuclear power plants, *Reducing Risks, Protecting People: HSE Decision Making process.* This explains the decision process that a contractor can expect. In addition to SAPs, the risk must comply with the ALARP. The SAP was further revised in 2006 in order to harmonize more with IAEA Safety Standards and with Western European Nuclear Regulations Association, WENRA, reference level[8]. The development of SAPs has also taken technical interests into account but the final results are made by the HSE (HSE 1 p.5).

SAPs are based principles covering a wide range of technical areas, such as Radiation Protecting, fault analysis, Numerical targets, legal limits, etc. It is only the principles involved in a power uprating or major modernization that will be taken into account. The HSE is clear that they want to see the licence work on a balanced comprehensive risk profile (HSE 1).

Nuclear power plants built before the new SAPs were published in 2006, i.e. includes all plants in the UK. These plants are assessed against the SAPs to establish shortfalls against modern standards but it is recognized that it may be unreasonable to raise the demands on an existing facility to the level of those that would be expected for an new one. This test of “reasonable practicability” is at the heart of the ALARP process. An excellent possibility for the licensee to provide better solutions for safety is in the performance of the PSR[9] (HSE 1, paragraph 31). If the contractor departs from the SAPs there is a strong likelihood of being reviewed with more scrutiny by the Nuclear Installations Inspectorate, NII. With such alternative solutions, however, the licensee has to demonstrate that the alternative is at least as good as the SAP's (HSE 1, paragraph 38).

2.2.1.8 Technical Assessment Guides

The Technical Assessment Guides, TAGs, intend to provide further guidance, in addition to the SAPs, on the NII assessment of the safety of a nuclear power plant. TAGs represent current good practice for managing nuclear safety and they are use as guidelines by inspector when they are going to judge how well the licensee follows the law at the nuclear power plant[10]. The TAGs are covering a wide range of rules and safety management systems. The TAGs are relatively detailed and was in the beginning amended to support an earlier version of today’s SAPs (HSE 2). The content of the TAGs is also treated in the License Conditions 36.

The most important TAGs to take into account when power uprating are likely to be[11]: ND ALARP (005), Deterministic safety analysis, DSA, (006), Safety Case (051), External Hazard (013), Internal Hazard (014), and Probabilistic safety Analysis, PSA, (030). These are described below.

ND ALARP (005) is one of the most fundamental TAGs since it contains the requirements for the licensee to met risks according to ALARP. This means in economic terms that measures should be taken if not unreasonably costly (HSE 9).

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[8] *WENRA is a network for European countries that have nuclear power. WENRA want to develop a safe nuclear future and a common approach for nuclear power (WENRA).*

[9] *PSR is required by the LC15. PSR is a regular basis and has to be produced by the licensee every 10th year. It is a wide ranging review of the Safety Case and the plants safety (HSE 1, paragraph 32). Also the Swedish nuclear power stations have this requirement (OECD 2).*

[10] *Nuclear Product Development Manager, King Lee, Lloyd´s Register, conversation 2010-06-24.*

[11] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, interview 2010-07-26.*

The *Deterministic safety analysis, DSA, (006)* will be used to give the plant a robust demonstration and integrated concept of plant fault tolerance. This concept is mostly related to the plant design.

External hazards (013) relate to earthquake, flooding, extreme weather etc that could affect the nuclear power plant and safety. The licensee has to prove that the risks from external hazards are minimized, removed, or tolerable.

Internal hazards (014) have to be identified and their effects on safety have to be demonstrated. Internal hazards are those that affect the structures, boundary site, or damage the reactor. The licensee has to prove that internal hazards are minimized, removed, or tolerable.

Probabilistic safety Analysis, PSA, (030): These analyses cover a whole range of disciplines and it is important when decision making for the NII as they judge if the risks are ALARP or not. This TAG is thereby close to "Numerical targets", which is a frame that is used to quantify ALARP. It is developed by the HSE; see section 5.2.6.1 for reference numbers.

Safety Case (051): This TAG describes the content, quality, structure etc. that is important to add into a Safety Case. See also section 2.3.2 where it is described more exhaustively.

The final note in this section is to stress that a licensee is going to be judged against the law and the SAPs and TAGs are guidance which informs that judgement.

2.2.2 Sweden

In Sweden the Government is responsible for regulating the safety of nuclear power plants (SSM 6). However, it has delegated certain responsibilities to the Swedish Radiation Safety Authority, SSM, so that they are thereby responsible for radiation protection and nuclear safety. The SSM has been managed under the Ministry of the Environment since 1 July 2008. Before that they were two separate Authorities, the Swedish radiation Protection Institute and the Swedish Nuclear Power Inspectorate (OECD 2).

The most current laws governing power uprate or major modernization will be presented in this section. Each subsection will partly illustrate what the law consists of and some important text, highlighted to further illustrate the important paragraphs or passages related to safety reporting and safety requirements when performing a power uprating or major modernization. The laws of Sweden have been discussed and a working group composed of elements from the SSM has studied whether two of the head laws, the Nuclear Activities Act and the Radiation Protection Act, could be adapted to just one law (SSM 7).

The Swedish legislation regulating nuclear power is complemented by U.S. safety standards. Among other things, the U.S. nuclear Authority, NRC, has produced design criteria called General Design Criteria, GDC. Those ones have been used as inspiration for the Swedish laws and regulations [A5]. In table 3 below laws and regulations are presented that have impact on safety documentation and hazards. They are presented in a hierarchy perspective (Weightman, 2008).

For existing power plants new requirements are not normally retroactively applicable. But when power uprating or with major modernization new possibilities will open up and the SSM can see some great opportunities where the plant can be tested and measured to more recently updated legislation when possible [A5].

Table 3 Overview of the Swedish legislation on nuclear power [B3].

Swedish law	Nuclear Activities Act (SFS 1983:3), Radiation Protection Act (SFS 1988:220) and The Environmental Code (SFS 1998:808)
Swedish regulation published by SSM	Several regulations, SSMFS 2008:1 to 2008:53
Safety related design requirements (no formal requirements)	Legislation from U.S like US 10 CFR 50, US 10 CFR 100. Document published by NRC and other international obligations
Other general standards	Fire standards and specified building standards etc.

In the following sections 2.2.2.1 – 2.2.2.4 the legislation that cover safety at nuclear power stations, important when power uprate or major modernization will be presented.

2.2.2.1 Nuclear Activities Act (SFS 1984:3)

The most comprehensive law dealing with nuclear technology safety is the Nuclear Activities Act (SFS 1984:3), and its regulation (SSM 7). The purpose of it is to regulate nuclear safety and prevent spreading of radioactive material (SFS 1984:3 section 3).

In the preamble to the Act it can be read that the safety within nuclear power must be long-term and focused on protecting people and the environment. The licensee must also ensure that sufficient expertise is available to operate the plant. In case of an accident, the consequences need to be reduced as far as possible (Proposition 1983/84: 60, pp. 80 -81).

In order to conduct a nuclear power business a license is required (SFS 1984:3 section 5): "... Licence applications are reviewed by the Government or an authority that the Government designates...".The regulation describes that an application for a licence of the Nuclear Activities Act must be made in written text and then addressed to the SSM [B4]. In order to increase the thermal effect a new licence is needed, which also has to be approved by the Government (SFS 1984:3 section 5) using observations from the SSM.

When power uprate probation is done the Environmental Code and an Environmental Impact Assessment has to be taken. For more details on the requirements, see section 2.3.2.3 below.

General obligations for licensees are set out in paragraph ten. The licensee must not only comply with regulations but also be present to take action as needed to establish safety. The SSM is clear that the risks must be reduced as far as possible to prevent nuclear accident to protect the environment and life (SSM 7).

The regulation (1984:14) gives the SSM authorization to perform technical inspections, and also to compose regulations. They shall also provide supervision over the law. If they find it necessary more requirements can be demanded. Decisions from SSM should be considered valid immediately (SFS 1984:3 section 22-23).

2.2.2.2 Radiation Protection Act (SFS 1988:220)

When power uprate or major modernization will take part, the Radiation Protection Act has to be taken into account. It is very enforced because the safety margins etc are affected and the ionizing radiation causes a higher risk for an accident. This law is always important because of the radioactivity that the business is surrounded by.

The law is an outline law and it is explained more in detail in the regulations that the SSM have published (SSM 7). The aim of the law is to achieve a radiation safe society. The law should provide as good radiation protection as possible in the society and has been limited to only provide protection against harmful radiation, however, both non-ionizing and ionizing radiation (SSM 7).

On the SSM homepage it is written that the radioactivity from the nuclear power plant should be kept down as much as possible (SSM 1).

2.2.2.3 Environmental Code (SFS 1998:808)

The Environmental Code is the first and only law in Sweden that covers environmental responsibility. It covers a wide area and it is an outline law (Ministry of the Environment 1).

The Environmental Code shall be applied in parallel with other legislation covering nuclear power (SSM 7) and include all activities that may harm human health or the environment (chapter 2). It was applied on January 1, 1999 (Ministry of the Environment 1). According to legislative history of the Code, nuclear power is included in the category of environmentally hazardous activities, which this Code regulates (SSM 7).

There are several rules in the Environmental Code to consider when examining power uprate or major modernization, see the rules of consideration in the text in *Appendix F - The Environmental Code, General Provisions*. The rules of consideration are based on several principles: Knowledge requirements, Precautionary, Best possible technology, Appropriate location, Resource management and ecocycle, Product choice, and Reasonableness (SSM 7 p. 41-43).

When power uprating a new licence from the Environmental Code is needed. Swedish nuclear power plants thereby have to apply for two different licences when power uprating, one according to the Nuclear Activities Act and one according to the Environmental Code (SSM 7). Licences from the Environmental Code are tested by the Ministry of the Environment. During the examination under this Code the rules have been taken into account, see above and also an Environmental Impact Assessment has to be done.

It is mainly chapter 6 in the law that is dealing with the Environmental Impact Assessment. In SFS 1998:808 Ch 6 section 3 the following can be read: "The purpose of an environmental impact assessment is to establish and describe the direct and indirect impact of a planned activity or measure on people, animals, plants, land, water, air, the climate, the landscape and the cultural environment, on the managing of land, water and the physical environment in general, and raw materials and energy. Another purpose is to enable an overall assessment to be made of this impact on human health and the environment".

2.2.2.4 Regulations

Regulations in Sweden are binding and must be followed by the activities affected by its content. They are published by the Swedish Radiation Safety Authority, including general guidelines. General guidelines should be seen as recommendations, and are not binding (SSM 8; [B5]). They exemplify the level that the Swedish Radiation Safety Authority works on.

The main regulation when power uprating or with major modernization is SSMFS 2008:1 dealing with safety at nuclear plants. More specifics regarding the technical design of the reactor can be found in SSMFS 2008:17 (Frid et.al, 2009). It is of great importance as it seeks to maintain the safety and performance of the construction as far as is reasonably possible in order to mitigate the consequences of an accident (SSMFS 2008:17, section 1). Other rules are important as well.

The following significant regulations are:

- **SSMFS 2008:1** The Regulations of Swedish Nuclear Power Inspectorate concerning Safety in Nuclear facilities
- **SSMFS 2008:6** The Swedish Radiation Safety Authority´s general recommendations concerning section 5 of the Act (1984:3) on Nuclear Activities
- **SSMFS 2008:17** The Swedish Nuclear Power Inspectorate´s Regulations concerning the Design and Construction of Nuclear Power reactors
- **SSMFS 2008:23** Regulations on radiation protection of human Health and the Environment from the releases of Radioactive Substances from Certain Nuclear Facilities

Below is a description of what each regulation contains that is important for power upgrades or major modernizations.

In the regulation **SSMFS 2008:1**, requirements for safety at nuclear power installations, such as barriers, defense in depth and integrity of the reactor, and other safety measures of construction can be found. Section ten in SSMFS 2008:1 describes that the safety has to be ongoing and analysed. If an accident occurs, measures shall be taken to mitigate the consequences. The safety on a nuclear power plant has to be documented in a Safety Report and analyses has to be done regularly and kept updated (SSMFS 2008:1Ch 4 section 2). The premises and limitation for the analyses has to be shown ([B6]; SSMFS 2008:1Ch 4 section 1-2). The selection of analyses must be done systematically and classified into Event classes (Frid et.al, 2009 p.6), see section 5.2.5.2 for Event classes and their divisions. Under the regulation data, methods and modes, and associated uncertainties must be validated. The regulation also requires that the safety documentation has to be updated according to changes and that a conclusion must be made regarding the safety. SSMFS 2008:1 Ch 4 section 1-2).

There are demands on how the analyses should be performed in **SSMFS 2008:1** Ch 4 Section 1. The initial events need to be divided into event classes. The event classes will cover normal operating, anticipated operating, unanticipated operating, improbable operating, and highly improbable events, i.e. the corresponding H1-H5. Finally in the regulation SSMFS 2008:1 section 26 mentions that there is a fixed limit on the normal operations effect.

This regulation, **SSMFS 2008:6**, is a clarification to the law, Nuclear Activities (1984:3), and consists only of the General Council (SSMFS 2008:6 section 5). It deals with the licensing of nuclear activities and approval of contractors, etc. which is relevant when power uprating. This is because two licenses are necessary; one license from the law, Nuclear Activities, and one from the Environmental Code (SSM 7).

A prerequisite for the implementation of the power uprates is to ensure that the improvement of the safety-enhancing measures in **SSMFS 2008:17** are met [B6]. Basic safety requirements for a nuclear installation are the functions reactivity control, integrity in the reactor system, emergency core cooling, residual heat removal, and containment performance which are affected in stages during a power uprating. In addition, the defense of the reactor in depth will be ensured by including redundancy, diversification and natural separation etc.

The regulation **SSMFS 2008:23** intends to address the release of radioactive material and the acceptance criteria. SSM believes that the requirement to control radioactive materials should be done with the best technique available (SSMFS 2008:23 section 2) and optimization of radiological protection where cost has to be considered (SSMFS 2008:23 section 4) .The effective dose to a critical group shall not exceed 0.1 mSv and the effective dose will be integrated over a period of 50 years (SSMFS

2008:23 section 5). Each licensee shall establish acceptance criteria for reference and discuss those ones with the SSM.

Before a power uprate or major modernization begins, the pathways or sources of radiation that are affected by the changes have to be controlled and summarized. After that they will be examined by the SSM (SSMFS 2008:23 section 11).

2.2.2.5 Relation between Swedish and US legislation

The design of Swedish nuclear power plants has been based on Swedish norms, standards, and practice. The U.S. safety requirements have supported the Swedish legislation system with construction and design. However, there is no formal link between the Swedish and U.S. law, but there is a connection that is rather historically oriented. In Sweden a philosophy has evolved that can be presented as: When a section of law is not to be found on a question or matter in Swedish law or other standards, the rules formulated by the Nuclear Regulatory Commission, NRC will be used [B3].

The American influence on Swedish nuclear power plants depends largely on the fact that the United States has been a leading nation in Light water reactor technology. They have also been diligent in issuing laws, standards, criteria, and guidelines.

One important standard is the one that controls the safety category of the plant ANSI/ANS-52.1-1983 from NRC in the U.S. It is called "Nuclear Safety Criteria for the Design of Stationary Boiling Water Reactors Plants" [B3].

2.3 Safety documentation

In a regulated business such as nuclear power, safety must be demonstrated in a structured manner and cover the whole technical lifetime of the plant. The safety has to be documented thoroughly in a so called Safety Report. This Safety Report has to cover the entire technical lifetime of the plant, and the different phases that the power plant is divided into. This section briefly describes these phases. However, the operation phase is described more in detail as it is in the phase where power upgrades or major upgrades are included. It is the licensees (plant owner) responsibility to see that adequate safety is achieved and they have the entire responsibility for this. Thus, it is up to each country's authority to ensure that the licensee takes full responsibility.

In the UK, an application for the thermal uprate will be examined and evaluated using the Safety Case, to see whether safety at the plant level is acceptable or not (HSE 3). In Sweden, this process corresponds to something called the Preliminary Safety Analysis Report, PSAR. Both the Safety Case and PSAR are considered acceptable as content of the Safety report after the Authority has given their permission.

The meaning of risk is used in different ways and different definitions are used depending on how the users are seeing the world. Risk is a term and it’s important to be sure how it is used by the licensee because it is often an intention to make decisions, for example safety within nuclear power. To take control over risk is all about taking control over the uncertainties but it is also about probabilities, unknowns, and knowns (Kaplan & Garrick, 1981). An often used technical definition of risk is the one that Kaplan and Garrick (1981) postulates, the “triplets”.

What the triplets mean:

- What can happen?
- How likely is it that it will happen?
- If it does happen, what are the consequences?

The triplets describe a quantitative scenario and the probability of the scenarios outcome. Both the UK and Sweden are using the triplets when making decisions about risk and how risks are seen in society.

Below in section 2.3.1, a short description follows of the different phases that the safety documentation has to cover in both the UK and Sweden. In section 2.3.2 and section 2.3.3 the UK and the Swedish way of documenting the safety requirements for hazards and safety analysis is described.

2.3.1 Technical phases for a nuclear power plant

This section provides a structured overview of how the different technical phases are handled within nuclear power. Those phases give the licensee and the authorities a structured overview of how safety and risks will be controlled within the nuclear power technical lifetime, at a specific plant. The UK has specific laws on the separation of phases. The safety documentation has to be handed in to the Authorities in the different stages (HSE 3). In Sweden, there is no fixed classification of how a licensee should share information with the authority in relation to the different phases. Even without fixed classification the phases seem to be categorized in quite a similar way between Sweden and the UK. An example of this is that the Safety report has to cover the whole technical lifetime of the plant (SSMFS 2008:1), however there is a description of how an uprating shall be assessed, and how the paperwork should be handled. Table 4 below shows how the technical phases are divided.

Table 4 Overview over the technical phases in both UK and Sweden. Those phases have to cover the whole technical lifetime for a nuclear power plant.

Phases (HSE 11)	Early design	Pre- Construction and Installation (including modifications)	Commissioning	Operation	Decommissioning
Short description	To make a statement of how the plant will be designed and operated. Also demonstrating how safety criteria and objectives will be archived.[12]	The phase will primly demonstrate that the plant is capable of operating within safety criteria's. The design and safety systems will be controlled by safety analysis. (HSE 11).	This stage is a kind of control point where the plant will be checked so that it meets the safety requirements and relevant safety criteria (HSE 11).	This phase includes thermal uprating or major modernization. See section 2.3.2.1 below for further reading.	This phase includes planning how the nuclear power plant can be phased out and how the radioactive waste will be stored.

[12] *In the UK this early design phase is a long and time consuming period and no license can be given without HSE/ND examine. HSE/ND has to be sure that the licensee understands all the risks and responsibility with the nuclear power over all the technical phases from early stages to decommissioning. At the moment the UK is develope a "New build program" for how the country will deal with new built reactors in the future. In Sweden no rules are covering this stage because it has been forbidden to build new reactors in Sweden for many years.*

Thermal uprating is included in the Operation phase and hence, a deeper explanation will be given on the efficiency improvement mechanisms and the impact on safety margins in the section 2.3.2.1 below.

2.3.1.1 Operating phase - Power uprating

Power uprating and major modernization are often planned simultaneously. This is because a modernization is often done to increase the robustness or to add some new safety systems. In these circumstances, when the nuclear power plant is already involved in changes a power uprating can be done within the same project. Power uprating or major modernization can also be a consequence from an analysis that has been done which has shown that the safety margins are too small, and therefore action is needed.

The power uprate can be done in two different ways, by reactor core optimizing or by increasing the amount of fissile material. Reactor core optimizing means that the effect of the reactor fuel bundle with small load bundle will increase and the ones with much load will continue with the same load as before. The consequence of this is that more fuel elements need to be loaded when core reloading. Fissile material will be increased by raising the concentrate on the fuel. The power uprate can also be done in a third way, which means that an increase is taking place in the fuel bundles with a maximum load by using fuel with better performance. This method requires that safety margins are still followed, as is often clarified through better use of analysis [B4].

In a Pressurised Water Reactor, PWR, the thermal effect is increased primarily by pumping an increased water flow into the core or by a higher temperature leap over the reactor core. A combination of these two methods can also be used when production of more heat energy causes more steam in the steam generator [B4].

In a Boiling Water Reactor, BWR, the thermal growth is treated by increasing the feeding water and steam flow. Either by maintaining a circulatory flow and then increasing steam concentration, or reverse, named that recirculation flow increases and steam is maintained. A combination of these two is also useful. The higher steam flow transported to the turbine must be provided with open throttle valves which can lead to a larger amount of electrical power being generated [B4].

The thermal power uprating affects the plant with a number of varying factors, depending on power upgrades. In order to meet the appropriate safety margins a few parameters that may affect safety have to be analyzed and identified (B6). In table 5 below the affects on the plant, consequences of power uprating and fitting measures are presented [B4].

Table 5 Affects on the nuclear power plant when power uprating and proposed measures to increase the safety margins [B4].

Affect on the plant	Consequence	Measurement
The mean power will increase in the reactor core	Smaller safety margins against dry out	Use fuel with better performance
Increasing share of steam from the steam generator	Higher load on certain components and systems	Improved monitoring and new analysis, among vibration in the piping and in the reactor pressure piping
Some transient events increased the pressure	Increased likelihood on certain accident sequence	Require new analysis on some safety systems
Increased load on the safety systems and the times for operator intervention can be increased	The residual power can increase	New safety analysis. Need to update the Technical Specification, STF, education and management systems need to be controlled
Increased pressure and temperature in the reactor containment	Mass- and energy release to the reactor containment can increase and also the corrosion tendency	New safety analysis for robustness needs to be produced

When smaller power upratings are occurring then the above parameters are affected to a smaller extent compared to bigger power upgrading projects.

There are further implications that need to be reviewed. Among other things, affected shutdown margins, which lead to the power uprating needing to be analysed and new strategies for core reloading, are required. There is also an increased neutron radiation, which requires a program to control the stress corrosion cracking, and other things need to be taken into account as well. [B4].

2.3.2 UK – Safety Case

When power uprate or major modernization is done a dialogue between the licensee and HSE/ND has to take place. The licensee needs to show how the plant is going to be affected. This is shown by a Safety Case that later will be summarized and adapted into the Safety Report[13] (HSE 4). The Safety Case will then be used as an argument to the HSE to prove the plant safety.

Bloomfield has written about Safety Cases, and he defines Safety Case as follows (Bishop & Bloomfield, 1995 p.1): "A documented body of evidence that provides a convincing and valid argument saying that a system is adequately safe for a given application in a given environment". A Safety Case is all the documented information and the result of safety at the plant (HSE 3, paragraph 1.17). It contains a written proof saying that the plant is following the laws and regulations and that the risk has been eliminated as low as reasonably practicable, ALARP. ALARP means that the risk shall be reduced, in relation to the sacrifice (in time, trouble and cost) involved in reducing that risk, The dutyholder must show that the sacrifice in reducing the risk further is grossly disproportionate to that risk reduction (HSE 11). The HSE will aim to ensure that the Safety Case is balanced on eight different keywords, which are: Complete, Clear, Rational, Accurate, Objective, Appropriate, Integrated, Current, and Forward looking (HSE 11).

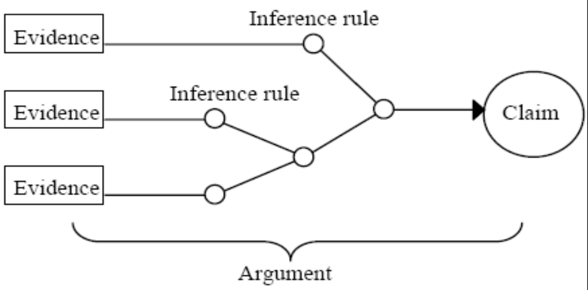
The main purpose of the Safety Case is, according to the law (Licensing Condition 23), to provide those who will manage safety with the accurate information needed to operate the plant and being able to have a safe management on site. Another purpose is to make it possible to study the safety in different levels and then get a better idea of safety (Bishop & Bloomfield, 1995 p.2).

[13] *Technical Specification Specialist, Nuclear Safety Group, technical and Safety Support, Colin Tucker, Sizewell B Power Station British Energy, conversation 2010-07-08.*

A Safety Case structure shall be worked out parallel to the planning about the power uprate or major modernization. This is often done through an iterative process that takes place between the licensee and the Authority. This is to give everybody a fair chance to fully understand the final product. A Safety Case, in this context, deals with those parts that are going to be changed through the power uprating and shall be seen as a "living document", which means that the Safety Case should be updated throughout the life time of a plant[14]. The structure is based on claims[15], arguments[16], and evidence[17] that are connecting with the inference rules[18]. According to Bishop and Bloomfield the following is needed to produce a Safety Case, (Bishop & Bloomfield, 1995 p.1):

- make an explicit set of claims on the system,
- produce the supporting evidence,
- provide a set of safety arguments that link the claims to the evidence,
- make clear assumptions and judgements underlying the arguments,
- allow different viewpoints and levels of detail.

Below in figure 3 the principle of a Safety Case is described. There is a great variation of what a Safety Case can look like. See *Appendix K – Safety Case* for more details.



Claim: "…a claim is about a property of the system or some subsystem" (Bishop & Bloomfield, 1995 p. 2)

Evidence: "…is used as the basis of the safety management" (Bishop & Bloomfield, 1995 p. 2)

Argument· "…linking the evidence to the claim" (Bishop & Bloomfield, 1995 p. 2)

Inference: "…inference mechanism that provides the transformational rules for the argument" (Bishop & Bloomfield, 1995 p. 2)

Figure 3 A Safety Case is based upon a claim-evidence structure. The licensee wants to be able to demonstrate one main statement for example Claim: The risk is ALARP! (Bishop & Bloomfield, 1995).

For more information and more detailed description, see *Appendix K – Safety Case*.

2.3.3 Sweden – PSAR

It is required that the Safety Report should be continuously updated and revised as changes are made, such as power uprating or major modernizations, (SFS 1984:3 section 24). During these changes, a Preliminary Safety Analysis Report, PSAR, or renewed Safety Report has to be produced [B6]. Work connected to PSAR must be examined by the Authority, SSM, and they send a statement to the Government which then makes a decision regarding approval. Upon approval the PSAR composes an updated version of the existing Safety Report. However, the PSAR has to build on the same structure as the already existing Safety Reports structure on the plant (Garis & Skånberg, 2009 p.6).

[14] *Usually the safety argument and the basic structure are together but the status of the evidence will change over time (Bishop & Bloomfield, 1998).*

[15] *A claim describes a characteristic of the system or the subsystems (Bishop & Bloomfield, 1995). The claims split down to different attributes like reliability and availability, security, functional correctness, time response and maintainability etc (Bishop & Bloomfield, 1998),*

[16] *Argument can vary depending on the design of the system and the safety structure of the Safety Case. The argument could be: Deterministic, Probabilistic or Qualitative. The argument is linking the evidence to the claim and inference rule*

[17] *Evidence is used as the basis of the safety argument (Bishop & Bloomfield, 1995).*

[18] *Inference means the mechanism that provides the transformational rules for the argument (Bishop & Bloomfield, 1998).*

The PSAR is therefore very similar to the existing Safety report, which shortened is called SAR. To understand a PSAR structure it is necessary to describe how the SARs structure is founded. A SAR is rather extensive and it consists of several parts which together constitute the safety of the plant (SSMFS 2008:1). The licensee also uses this document to demonstrate that the plant is safe for the authorities and that the plant is designed according to updated laws and regulations. All this safety management is to assure that the environment and the public will be protected against an ionizing radiation accident. See figure 4 below for a typical structure of a SAR.

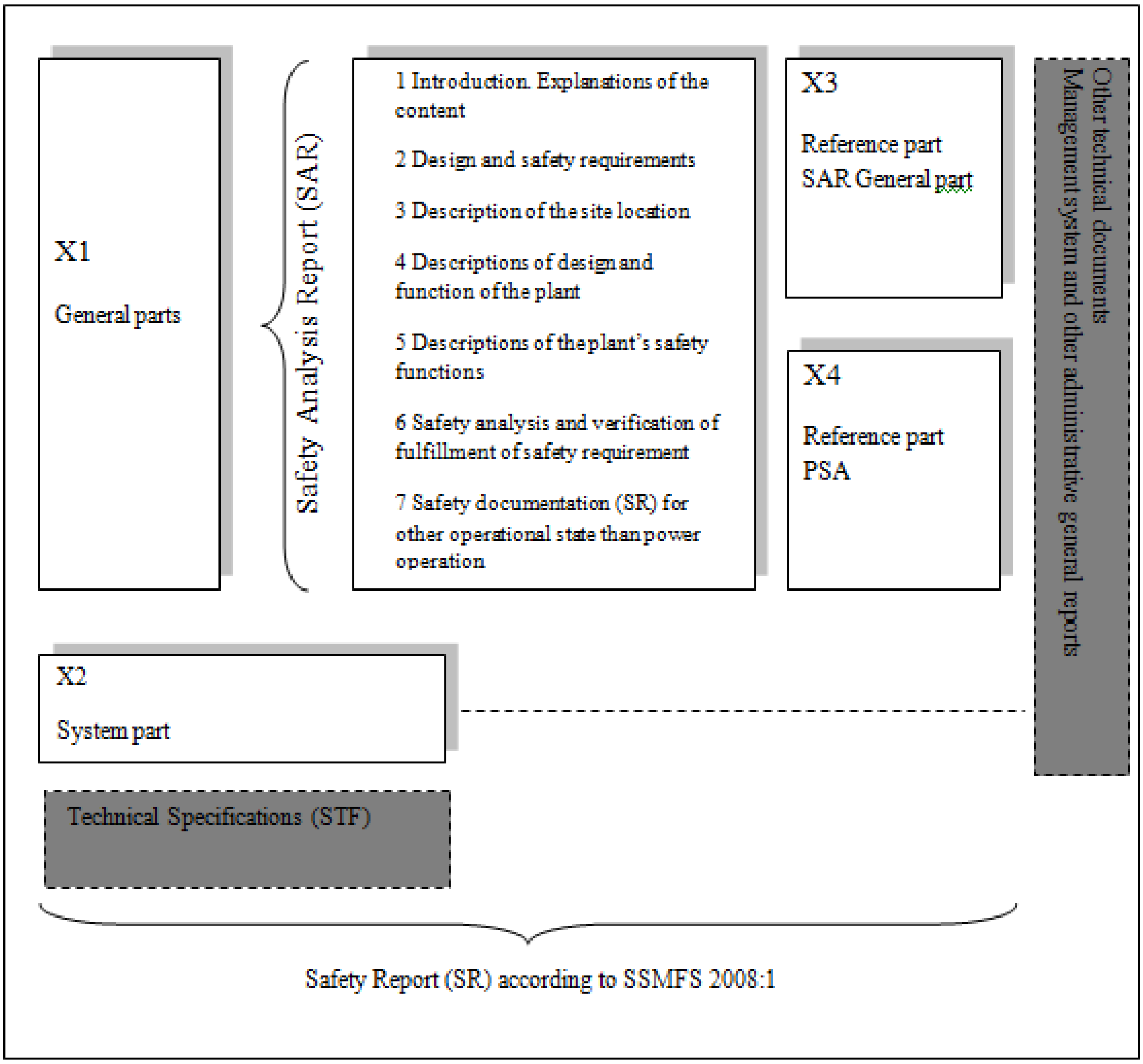


Figure 4 Example of a typical Safety report according to the regulation SSMFS 2008:1. Box X1 describes the general parts that are attached to the plant and will then be basis for the analyses. Box X2 contains details and description on all the systems. Box X3-X4 contains all the safety analyses that build on the requirements in box X1. All the grey boxes explain how the plant should be ruled, examined and developed according to the management systems. The purpose with the management system is to assure that the safety on the plant will be controlled (SSMFS Ch 4 section 8). The operational Limits and Conditions will among other things give instructions to the staff and guidelines to the operators (SSMFS 2008:1 Ch 5 section1).

Chapter 3 – Research questions

The background that has been described in chapter two is now leading up to the report's issue. The nuclear powers risks are multi-coated and this report will address the similarities and differences between the UK and Sweden in terms of internal and external hazards and then explore how these are reflected in the management of safety documentation.

3.1 Aims

The purpose of this study is to deepen the knowledge about nuclear technology and the level of safety at the nuclear power plants in the UK and Sweden. To satisfy this purpose, laws and legislation have been reviewed as well as safety documentation, and interviews have been done. The laws and legislation are compared between the two countries as well as the safety documentations at a nuclear power plant in each country. The interviews will among other things give information of underlying causes of the differences and similarities between the countries.

3.2 Objectives

The objective of the report is to identify and analyse the differences and similarities between the UK's and Sweden's safety regarding internal and external hazards at the plant level for power uprating or major modernization in a nuclear power plant. The identified and analysed differences and similarities may constitute a basis for creating understanding of how the countries handle safety in the UK and Sweden. But also in the establishment or application for handling safety documentation.

The report is expected to provide information to consultants and companies that will work on safety reporting within the nuclear power safety area.

3.2.1 Research questions

- What are the similarities and differences between the UK and Sweden in safety requirements for hazards and what are their underlying requirements for safety documentations for those hazards?

In order to answer this question, the following sub-questions need to be addressed (for both the UK and Sweden):

- What safety requirements for hazards are attached to nuclear power plants and where are they specified?
- Are there significant differences in laws and regulations?
- Are there differences in requirements of the specification of the hazards in the safety documentation?
- Are there differences in the way the licensee decides if safety requirements are fulfilled? (In the decision criteria and assessment process)

3.3 Limitations

Nuclear power is one of the most regulated industries in the world. It places great demands on satisfactory safety, which is accompanied by extensive requirements and controls that are summarized and presented in something called safety documentation. For the thesis to include reasonable proportions, major distinctions will be made. The study will only compare Safety reports from two nuclear power plants: the Sizewell B reactor in the UK and unit O2 at OKG in Sweden. To illustrate the differences and similarities between the two countries, only current parts of the Safety Report that deal with internal and external hazards, and regulations that deal with safety will be studied. This is necessary in order to maintain the quality of the work since Safety Reports are very extensive documents. The thesis is also defined to only cover the safety requirements of the following areas power uprating and major modernization. A nuclear power plant involves a variety of safety requirements, such as physical protection and radiation safety. This report is limited to cover the safety requirements of internal and external hazards. External hazards are those that affect safety, but have their origins outside the facility. Internal hazards are those risks that have their origin in the design area, such as fire, internal flooding, dropped loads, etc.

Plant level intends to only include the building that contains the reactor and its elementary systems. The facility, external buildings etc. are not further investigated.

The report will not address the requirements of the work environment law, the insurance companies, or financial risks. Only civilian nuclear power will be addressed. This applies especially to the UK, which possesses nuclear weapons.

It is also worth noting that the nuclear industry's future is unclear and much debated. Thus, this report is seen as a snapshot of how nuclear safety will be treated in the future. There are constant changes that also affect how laws and legislation are interpreted, which must be taken into account when the report is considered and used. As recently as June 17, 2010 the Swedish Government passed a law, permitting the building of new nuclear power plants on already existing sites (Wiberg, 2010).

Chapter 4 - Method and technique

In order to answer the research questions properly, this chapter will give background and an explanation of the method and technique that was used for this study. This Master thesis has primly descriptive purposes; the main purpose is to explain the biggest differences and similarities between the UK's and Sweden's identified safety requirements on the plant level, and how they are shown in the safety documentation. Laws and legislation as well as, safety documentation have been studied and interviews with the Health and Safety Executive and Swedish Radiation Safety Authority have been used to identify the similarities and differences. Safety documentation has been used from two nuclear power plants, one in each country: Sizewell B in the UK and unit O2 at OKG in Sweden.

With this as a background, together with literature studies within the nuclear safety area and other relevant literature – the hope is to create an understanding of the UK and Sweden, and how they treat safety requirements at the plant level in their respective safety documentation.

4.1 Scientific perspective

Backman (2008) describes a reality based on the traditional approach, to study reality from an objective context. For the researcher this means that one observes and measures reality based on how it looks. Safety is not a "social construct" - but something that you describe. In order to describe and compare the safety, laws and regulations, safety documentation, and interviews have been selected as descriptive parameters. Laws and regulations intend to give the national view on how safety, and specifically how hazards should be handled. To study the safety documentation in the UK, Sizewell B was selected and in Sweden OKG unit O2 was chosen. Sizewell B in the UK is considered a suitable choice since it is the only Light water reactor, more specifically a PWR. Other nuclear plants in the UK are based largely on a graphite core. In Sweden, OKG was selected as comparison because of its current uprating, and because of the possibility of access to plant Safety reports. OKG is also a Light water reactor but is a BWR. The safety documentation at each nuclear power plant is designed to provide answers to how the owner or the plant applies the laws and how the internal rules are implemented in the safety documentation. The interviews are designed primarily to provide answers to how the hazards are handled in the safety documentation and what the underlying requirements are for the hazards. But also to address how a licensee can be sure that the safety is satisfied at a plant. Each part: the legislation, safety documentation, and the interviews are reviewed systematically and compare the two countries and what requirements they have on hazards.

The information in this report is largely based on each country's nuclear regulator, the HSE and the SSM. Despite this, objectivity throughout the report is pursued. The three ways to study the safety, laws, safety documentations, and interviews seem to outweigh the otherwise one-sided information from the authorities.

4.2 Scientific method

Laws and regulations, safety documentation from the nuclear power plant Sizewell B and unit O2 at OKG, and interviews form the major part of information in this master thesis. All three components will be systematically reviewed in order to identify the main differences and similarities of how countries are handling and setting requirements for hazards. Only relevant parts of the safety documentation will be studied. The studied parts will represent a larger context, i.e. the UK's and Sweden's view of hazards. It is not manageable to study a larger sample of the safety documentations since they are very comprehensive documents.

4.3 Research method

Research method includes how the report bases its content on what is known as scientific technology (Ejvegård, 2003). This report uses the scientific technique mainly through literary studies, but also by using semi-structured interviews.

4.3.1 Literature Studies

The thesis is based largely on literature studies. The literature covers a wide area but primary focus is on the technical field of nuclear safety. In addition, the current elements of the safety documentation are studied extensively and are described in detail in Chapter 5. General literature relating to nuclear power has also been studied. Laws and regulations have further been studied and systematically compared to highlight how each country handles and sets requirements for hazards.

4.3.2 Interviews

To complement and broaden the perspective of the study, interviews have been conducted. The interviews were designed to provide an overview of the underlying causes of the similarities and differences of the countries, and also to provide factual details that are difficult to capture through literature. The interviews were semi-structured. The interviewed person was pre-selected and had expertise in the studied area. The interviewed persons came from the HSE in the UK and the SSM in Sweden. Key issues were defined in advance and were shown to the people who were interviewed. This method of interviewing was considered appropriate since it opens up for discussion and the interview is not driven to the same extent as an advance on specific questions would entail[19].

The major advantages of semi-structured interview questions are that they may be adapted over time and more detailed questions can be asked where deemed appropriate. Another advantage often high-lighted by a semi-structure is that it provides clarity over the whole business as seen by the person being interviewed rather than individual opinions[20].

For the interview, the HSE appointed expert in the UK and the experts from the SSM in Sweden were selected. These individuals are current experts within the nuclear safety area and have many years of experience. Before the interview, the main topics were shared with them, and a detailed explanation was given as to why the interview was considered necessary. The structure of the interviews was hence planned in advance, but the details were open and known by the interviewees. The interview began with repeating the purpose of the interview and highlighting that the person would be allowed to approve and review the interpretations made. Those interviewed were able to consult the full report before completion and were asked to review and provide comments, questions or information that may have been left out.

4.4 Workflow

After the initial literature review, case studies were conducted. The case studies were structured around a number of issues that provide comprehensive answers to each studied nuclear power plant, and ultimately provide comprehensive understanding and responses to questions. See introduction part at Chapter 5 for a more detailed description of the safety documentation study.

[19] *Professor Kurt Petersen, Department of Fire Safety Engineering and Systems Safety, LTH, conversation 2010-05-31*
[20] *ibid*

Chapter 5 - Analysis

In this chapter, analysis of formal safety legislation, analysis of safety documentation, and interviews will be handled. The analysis of legislation intends to answer the questions regarding how hazards and safety documentation are treated in the legislation, and highlight the differences and similarities between the countries. This section and the interviews will be the smallest part of the analysis, while the case study will make up the biggest part. The case study is divided into two parts, called Sizewell B and OKG. The case study intends to describe the differences and similarities of the UK's and Sweden's safety requirements for hazards for power uprating or major modernization. Each part intends thereby to clarify the overall responses for each country. The interviews serve as a complement to the other above mentioned methods, and also give information from another perspective.

The three different analysis parts strive to give answer to the research question:

- *What are the similarities and differences between the UK and Sweden in safety requirements for hazards and what are their underlying requirements for safety documentations for those hazards?*

The majority of the sources used in the case study are internal documents. These references are marked by brackets, [...], see section 9.1.1-9.1.2 for complete reference.

5.1 Analysis of formal safety legislation

This section will cover legislation and regulatory framework that deal with safety at nuclear power plants. The purpose of this section is to identify what the law says about the hazards, but as legislation is very comprehensive, it is impossible not to broaden the perspective and see how safety is managed. The focus, however, attempts to target hazards, safety analysis, acceptance criteria, and safety documentation for power uprating or major modernization.

5.1.1 UK

In the UK, there is a law that regulates all safety, regardless of which business, in the society and it is called the *Health and Safety at Work etc Act 1974.* The law describes the rules around safety in general and points out how the society is going to work with risks and safety, and what to do to minimize the risk according to ALARP. The initial chapter of the law says that in order to ensure the protection of health, safety, and welfare of workers, the risk a worker may be exposed to shall be minimized. Certain emissions into the atmosphere and dangerous substances must be controlled.

Sections 2 and 3 of the act are also fundamental to how the UK sees and treats risks. Especially sections two specify requirements that the duty of every employer is to ensure, so far as it is reasonably practicable, the health, safety, and welfare of workers. It is also the employer's responsibility to ensure that the workers, so far as is reasonably practicable, are not exposed to unnecessary risks.

The law, *Nuclear Installation Act 1965,* continues in the same way as Health and Safety at Work etc Act 1974, HSWA to be comprehensive. However the law only deals with nuclear power except from the HSWA. The law declares that the safety of the nuclear power plant has to be guaranteed by the licensee. The law also requires "soft" safety requirements which are in close relation to hazards because it is one of the bases of handling risk in a nuclear power plant in the UK. The licensee shall secure that: no colleague shall be injured or damaged from any radioactive properties; no radiation emitted during the licensee responsibility; no waste discharged from the site cause injury or damage to any person, and no person outside the nuclear power site should suffer.

In the *Licence conditions 36*, LC36, hazards are addressed for the first time and it requires that hazards are documented. Licence condition 7 means that for external hazards records shall be kept of the occurrence and relevant hazards. Internal hazards that can cause incidents on the site should also have records of the occurrence of hazards. Licence condition 14 requires documentation of both internal and external hazards. Licence condition 18 contains an assessment of radiation. This condition is complementary to the Ionising Radiations Regulations of 1999 and deals with adequate arrangements for the assessments of effective dose. Licence condition 23 contains operating rules and requires that the licensee shall produce a Safety Case to demonstrate the safety at the plant level and that the Safety Case shall identify limits and conditions that are of interest for safety. License condition 23 continues to say that the Safety Case shall include extreme weather, explosions etc., in other words, external and internal hazards.

Safety Assessment Principles and *Technical Assessment Guides*, SAPs and TAGs all address external and internal hazards more in detail. The SAPs and TAGs are not requirements, but rather recommendations and guidelines for the regulations published by the HSE. The SAPs address external and internal hazards in the section EHA.1 – Engineering principles, and describe hazards as following: "External and internal hazards that could affect the safety of the facility should be identified and treated as events that can give rise to possible initiating faults." Furthermore, SAPs require that external and internal hazards shall be identified and considered in the licensee safety assessment. The threats from the external and internal hazards in the safety assessment should be tolerated, minimized, or removed (HSE 1, paragraphs 1.2; 1.5). This can be done by using good engineering, keeping hazards materials at a minimum and having good safety management practices (HSE 1, paragraphs 1.3).

SAPs apply to the Safety Case and explain that the documentation will demonstrate the high standards of nuclear safety (HSE 1, paragraphs 1). Paragraph 88-89 in the SAPs further describes that a Safety Case has to be demonstrated for each life-cycle stage and that radiological hazards have to be demonstrated in a valid Safety Case. The Safety Case has to take into account the past and the implications for previous stages. The basis and fundamental requirements for a licensee to produce an adequate Safety Case is normally based on good engineering, operations, and safety management (HSE 1, paragraphs 13). The Safety Case shall be assessed by the nuclear installation inspectors regardless if the risk is ALARP or not.

The TAGs are the most detailed guidelines that are available for inspectors in the UK. There are TAGs that specifically deal with external and internal hazards and safety documentation like Safety Cases. TAGs no 013 – "External hazards" describes the HSE's approach to external hazards. Internal and external hazards have to be defined by deterministic and probabilistic criteria to verify that the safety criteria have been met. The inspectors, NII, shall look for arguments of the safety from the licensee, such as that the safety is demonstrated as tolerable or "So Far As Is Reasonably Practicable" (HSE 16, paragraphs 3.3). TAG no 014 – "Internal hazards" continues to say that internal hazards may include toxic or asphyxiating gases, explosion, fire, missiles, flooding, release of flammable materials, and impacts from dropped loads or from vehicular transport (HSE 16, paragraphs 3.4). Hazards have to be documented and justified (HSE 16, paragraphs 3.8).

5.1.2 Sweden

The law *Nuclear Activities Act (SFS 1984:3)* is very comprehensive and is just regulating nuclear power plants. The law describes safety in general and not in detail at all. The safety is described in chapter four and requires that measure has to be taken against accidents and to prevent faults in equipment, faults in safety management, sabotage, or other things that can cause a radiological release.

The Radiation Protection Act (SFS 1988:220) is also very general, limited to covering and dealing with ionizing radiation. Ionizing radiation is one of the identified hazards in Sweden but the law is not focused on the specific hazards, it's instead quite general. The closest description of safety in the law is the General obligations (section 6) in the law that summarises how a business with ionizing radiation has to look after the risks and some measures that need to be taken to protect the public, animals, and the environment. Radiation has to be controlled and technical systems have to be well taken care of to avoid an accident.

The treatment of hazards in the Environmental Code (SFS 1998:808) is covered in section two and is called the rules of consideration. One of those is the *Knowledge requirement*. This means that the licensee is responsible for the risks that the plant contributes and the risks that the plant creates. Another rule of consideration is the precautionary that concerns hazards where emissions must be reduced and the best possible technology should be used. Also the resource management must be balanced against the costs.

The most current regulations with power uprating or major modernization deal with safety documentation and requirements for safety. The regulation SSMFS 2008:1 refers to maintaining safety as far as reasonable with regard to the best technology to prevent nuclear accident. The safety shall be secured by using defence in depth, see *Appendix A - Explanations of expressions and abbreviations* for deeper explanation. Furthermore the regulations require that a facility shall set up internal safety goals and safety management to avoid accidents (SSMFS 2008:1 Ch 2 section 9-10). The threats against a nuclear power plant, identified hazards, shall be prevented by physical protection. Chapter 3 in the regulation says that safety should be maintained by robust solutions. Valuation and documentation of safety at the plant should be done by safety analysis that needs to be updated regularly. Consequences however, should be prevented by using defence in depth. The safety at the plant has to be documented in a Safety report (SSMFS 2008:1 Ch 4 section 1-2). In the regulation 2008:17 the construction will, as far as it is possible and with the best engineering techniques, prevent radiology accidents. This is to be achieved by means of redundancy, diversity and separation.

Section 13-14 in the regulation 2008:17 deals with hazards such as dynamic effects and rupture at the pipes and that a reactor must be prepared for natural phenomena that could damage the system and lead to nuclear accidents. The reactor must also meet the environmental requirements that are set on it. Moreover the regulation continues to describe that the safety has to be analysed and divided into event classes with predetermined conditions and acceptance criteria. The regulation 2008:23 describes that the radiation safety shall be optimized and determined into reference values for each reactor emissions per year (section 6). When power uprating or with major modernization reports from the plant on the new size of the release and composition shall be performed. The SSM which will examine whether the new emissions are good enough will follow the ALARA principle, i.e. As Low As Reasonably Achievable[21] for assess if the changes (2008:23 section 11).

[21] *ALARP and ALARA are synonymous word, see Appendix A – Explanations of expressions and abbreviations.*

5.1.3 Summary

Generally speaking, the laws of UK and Sweden are very comprehensive and cover large areas ranging from general obligations, license and safety, etc. It is not until further down the hierarchy, that regulations and guidelines for the Inspectors that involve hazards are discussed. However, it is clear that the UK wishes to see some specific hazards of a Safety Case, while Sweden is not term specific. This might be because Sweden is using current International laws and standards because of the absence of legal means in the Swedish system. In addition the Swedish legal system related to safety in nuclear power plants is based on resistance to accidents, while the UK uses a different approach to safety. Therefore the so called no hazards are specified in Sweden, as they are in the UK guidelines. In the UK the laws are based on hazards and analyze what measurements could prevent radiological accidents. In the UK there is an umbrella law that addresses safety throughout the whole society and covers nuclear energy. In Sweden there is no corresponding law, but nuclear power is treated completely separate from the safety of other organizations in the community. Sweden has the Environmental Code which is unique in its kind and there is no counterpart in the UK.

The Environmental Code does not impose specific requirements on the hazards, but some of the rules of consideration can be used on the hazards that are identified and selected to be treated by the licensee. The other laws relating to nuclear power show no significant differences between the two countries. The same titles and contents can be found at both NIA65 and the Nuclear Activities Act. Radiation protection laws in the two countries are also similar, but the requirements for emissions are slightly lower in the UK than in Sweden.

5.2 Analysis of safety documentation

The case study has been done on one nuclear power station in each country, Sizewell B in the UK and unit O2 at OKG in Sweden. This section contains the biggest part of the analysis and is handling the safety documentation that deals with hazards that refer to safety requirements, safety analysis, and acceptance criteria. Since the safety documentation is diverse and very extensive and some parts even confidential, it has been impossible to study the entire document. Some references in this section are from interviews as well as safety documentation, which was inevitable while trying to create a clear understanding of what this section attempts to attain. This has been unavoidable due to the confidentiality of the documents involved.

The study intends to partly answer the research questions. Hoping to create a structure for the reader, a number of issues, beyond the research question have been used and formed the basis of the information presented below. The questions below intend to give answers to the following points below:

- What safety requirements for hazards are attached to the nuclear power plant and where are they specified?
  - What is the purpose of safety documentation and how does it relate to safety?
  - What are the requirements? The purposes and why?

- Are there any differences in the required specifications of hazards in the safety documentation?
  - How are the differences treated in the safety documentation?
  - What does a Safety report contain and what role does it have?

- Are there differences in the way the licensee decides if safety requirements are fulfilled? Decision criteria and assessment process?
  - How will the hazards be assessed?

Safety is based on how each country defines safety and what model they use to evaluate whether the safety is satisfactory or not. The above issues are to be found in section 5.2.2-5.3.3.

5.2.1 Description of the objects

The case study includes two different nuclear power plants: Sizewell B in the UK and unit O2, belonging to OKG in Sweden. These two nuclear power plants have been selected for various reasons. Sizewell B because it is the UKs only Light water reactor and therefore is a fitting comparison to Sweden, since the Light water reactor model is the only one used in Sweden. Unit O2, OKG, has been a suitable choice to compare with because of the availability of information. Unit O2 is also undergoing a major uprate and is therefore an interesting power plant to focus on.

5.2.1.1 Sizewell B

Figure 5 To the left: pictures of Sizewell B. To the right: geographical location, see the point in the southeast corner, the nearest area is Suffolk (NDA 1).

Sizewell B, SZB, is the UK's newest nuclear power station. Being a PWR model, Sizewell B is the UK´s only Light water reactor and it's located in the southeast corner of the UK, see figure 5 above. Westinghouse[22] built the power plant and the commercial operation of it started in 1995. The total production is 1200 MW which represents about three percent of the UKs total electricity production (British Energy 1, WNA 1). The licensee holder of the nuclear power station is British Energy, BE (HSE 4). In the plant area there is also one decommissioned Magnox reactor which generated energy from 1966 to 2006, called Sizewell A (NDA 1).

Already in 1978 a decision was made to allow to construction to Sizewell B (British Energy 1). SZB is a four-loop level power plant, of the model Standardised Nuclear Unit Power Plant System, SNUPPS (HSE 4).

The nuclear waste from the reactor is stored on the plant site. There is currently no plan to move the waste to Sellafielld, where most of the UK's nuclear waste normally is placed[23].

[22] *Westinghouse is a company that is focused on nuclear technology and provide among other things service and plant design for the commercial nuclear power (Westinghouse).*

[23] *Technical Specifications Specialist, Nuclear Safety Group, Technical and Safety Support, Colin Tucker, Sizewell B Power Station British Energy, conversation 2010-07-08.*

5.2.1.2 Oskarshamns kraftgrupp, OKG

Figure 6 Picture of OKGs three reactors. Geographical position of OKG is on the Swedish east coast, 30 km north of Oskarshamn (OKG 1).

OKG (Oskarshamns kraftgrupp) AB is the owner of three reactors of the BWR type, known as unit O1, unit O2, and unit O3 in everyday speech. Together they produce a total power of 2215 MW, equivalent to ten percent of Sweden's total electricity production (OKG 2). The licensee for the nuclear power plant is OKG AB (SSM 2). In OKG's plant area Clab is also found, which is Swedens central storage facility for nuclear waste, see figure 6 above. The owners of Clab are the Swedish Nuclear Fuel and Waste Management Company, SKB (SSM 2).

In 1967 unit O2 in Oskarshamn was to be built, and the contract went to ASEA Atom, now known as Westinghouse. The building procedure took off in 1969 and it was phased into the commercial network in 1974. Already in 1982 a power uprating took place, from 580 MW to 630 MW. The unit O2 continues to be modernized and in the next few years, an extensive modernization and uprating, called Plex, is ongoing (OKG 3). Project Plex means increasing the reactor safety and ensuring higher availability for another 30 years of operation. In addition, some modernization has to be made since unit O2 does not quite fulfil certain new requirements from the authority SSM [B6].

In the following sections 5.2.2 the role of the safety documentation of each nuclear plant is presented. However, it is necessary to add some information on how safety procedures concerning nuclear power are handled in general in the two countries.

5.2.2 Safety report rule at Sizewell B

When power uprating or with major modernization the licensee will use a Safety Case, which will later turn into a Safety Report once the authorities have assessed the Safety Case. To give the HSE/ND a chance to keep up with changes at a power uprating process, the licensee has to communicate with the HSE/ND using a Safety Case in an early stage. This is important in order to currently document the changes in the Safety Report, for fulfilling the requirements of being a living document. The licensee has to provide the ND with all the changes in functions and systems that are affected currently. The Safety Case will be used as a head document until the ND has made an assessment. Once the safety case for a modification or change has been accpetd by the regulator it will become part of the overall Safety Case for the plant and should be incorporated in the Safety Report[24].

The purpose of the Safety Report is to show the authorities and public that all hazards have been identified and that fundamental nuclear safety principles have been followed [A5].

The aim with the Safety Case is to prove that safety margins are good enough and that the power plant will be operating without risk for operators or the public. The Safety Case for power uprating includes

[24] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, interview 2010-07-26.*

all the safety requirements and safety analysis that is needed to show that risk will be ALARP. The Safety Case or Safety Report also helps the licensee to control or observe long term risks.

The structure of the Sizewell B Safety Report is clearly built on the typical Safety Case approach as described in section 2.3.2 above. The document contains 18 chapters and mainly describes the as-built design and safety approach for operation of the plant. It also describes safety management and how the stations safety culture should be established [A5]. The Safety Report has been formed by the Central Electricity Generating Board, CEGB, and Design Safety Criteria. The CEGB provides design and safety principles that can be applicable to all nuclear power plants. It also takes the Safety Assessment Principles, SAPs into account [A1].

5.2.3 Safety documentation at OKG

When a licensee for a nuclear power plant wish to realize a power uprate or a major modernization the licensee has to write a letter to the Government, addressed to the SSM where the licensee will prepare information for the government about the project, and ask for permission. The licensee will after the application start to produce a Preliminary Safety Analysis Report, PSAR, which will be the base documentation for the governments' judgment of the application to operate the plant within a higher thermal effect (Garis & Skånberg, 2009).

The purpose of the safety documentation, the PSAR, is to demonstrate to the public and authorities that the safety at plant level is sufficient to protect humans and the environment from radiation in case of nuclear power accidents [B6]. The SSM says the safety documentation when making a power uprate is important in order to sustain safety and that the licensee should be aware of their responsibility for long term risks (Garis & Skånberg, 2009).

The purpose of PSARs is to describe the requirements for nuclear safety and radiation protection that the legislation require. PSARs form and deal with the part of the plant that is being transformed and is treated separately from the already approved Safety Analysis Report[25].

The contents and requirements of the SAR or PSAR are not specified in detail and it is up to each licensee to convince the SSM that the safety is satisfactory. SSM is a relatively small agency, so they do not have the resources to check the fulfilment of all individual rules in detail[26]. There is a letter issued by the SSI[27], *Dnr 560/3150/03 Redovisningskrav från Statens Strålskyddsinstitut vid höjning av den termiska effekten vid ett kärnkraftsblock,* which describes what the authority wants to see: a technical description of how power should be increased, analysis of potential impacts, and safety documentation of any changes at plant level.

Today the authorities also encourages that the safety documentation must be a living document. In earlier days the safety documentation tended to be viewed as a stack of documents to be given to the authorities that was not updated and the plant was operated from a completely separate document[28].

Before a PSAR can be accepted and applicable, and then replace the existing Safety Analysis Report, SAR, it is required to be examined. The SSM review and verify that the documents margins are provided and that the law has been taken into account. The review examines the underlying design

[25] *Analyst – Reactor technology, Ninos Garis, Swedish Radiation Safety Authority, interview 2010-07-14.*
[26] *Investigator – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, phone call 2010-06-15.*
[27] *Now days SSI belongs to SSM. A few years ago SSI and SKI were two separated authorities. One of them was responsible for ionizing radiation and the other one were responsible for nuclear safety.*
[28] *Investigator – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, phone call 2010-06-15.*

criteria and analysis but also the change in design of the plant. After this step, the PSAR is then called a renewed Safety Analysis Report and is to be reviewed again by the SSM [B4].

The renewed Safety Analysis Report, SAR, for OKG and unit O2 is comprised of many parts, see section 2.3.3. This design and specially the content are based on, as mentioned before, the U.S. standards together with demands from the SSM. The structure and even some content are also inspired from the American Guide 1:070, published by the NRC [B4].

5.2.4 Analysis of hazards

The purpose of this section is to find answers to the safety requirements and special hazards that are attached to all nuclear power plants. A lot of information related to this section can be found in *Appendix G – Sizewell B hazard* and *Appendix H – Unit O2 at OKG hazard*. Those appendixes present hazards of each nuclear power station and more information on them.

Some of the differences between the countries are due to some project-specific conditions, i.e. different geographic conditions, which of course vary etc. There are also differences between companies and vendors that have been owners or contractors during a specific time. These differences are taken into account in Chapter 6 – Summery of the analysis.

The section 5.2.4.1 and 5.2.4.2 below presents identified hazards of Sizewell B and unit O2 at OKG.

5.2.4.1 Hazards for Sizewell B

In the UK the identified hazards are based on the UKs “The fundamental safety principles ". It basically means that a nuclear power plant should be capable of operating without safeguarding the health and safety of operators or the public. The fundamental safety principles are [A1]:

- A person shall not be exposed to radiation doses higher than what is found in the Ionising Radiation Regulations (IRR), see also section 2.2.1.5.
- The exposure of radiation shall be kept as low as possible, ALARP.
- The collective and effective radiation dose to operators and the public must be kept as low as possible
- All reasonable and possible measures shall be taken to prevent accident
- All reasonable and possible measures shall be taken to minimize the radiological consequences of an accident.

Before a nuclear power plant, like Sizewell B, can be ready to comply with these principles, a number of internal and external hazards need to be identified. The hazards are based on Safety requirements in the laws and regulations but also from recommendation of the International Atomic Energy Agency, IAEA ([A1]; IAEA 2).

In the Sizewell B SSR the identified hazards can be found and they are presented in one chapter. When power uprating there are no recommendations that Sizewell B adhere to requirements that have to be met in the SSR. But the licensee has to prove that safety has been achieved even after the change. The identified internal and external hazards are as follows [A3]:

- Fire,
- Pressurised component failure,
- Internal missiles,
- Internal flooding,
- Seismic,
- Extreme external environmental conditions,
- Miscellaneous hazards.

The HSE points out that the list of internal and external hazards will be considered in general to be as comprehensive as possible. The licensee should identify all of them and then possibly screen some of them out on the grounds of physical impossibility - e.g. avalanche hazard for a site on flat ground with no mountains where snow can build up. For internal hazards the licensee might screen out dropped loads where there are no lifting operations carried out[29].

The identified hazards are based on feedback and experience from nuclear power, such as accidents and incidents. But they are also based on studies of other countries' experiences and management, their research, and increased technical knowledge. It is also important to note that the IAEA issues a list of faults and hazards which they think should be considered on a nuclear power plant. These considerations have informed licensees, (including Sizewell B) safety cases production process in the UK[30]. In the document *The tolerability of risk from nuclear power stations,* the principles and philosophy that are interpret legislation are supported by international discussions and reviews of the IAEA and the OECD and other relevant international obligations. The ND takes account of discussions with experienced companies and regulators in other countries where bilateral agreements have been set up (HSE 13 paragraph 50). The aim is that the UK´s reactors will be operating with high safety and that the risk will be kept ALARP (HSE 13).

All the faults and hazards should be included within the Safety Case and a holistic assessment of the Safety Case takes place. The HSWA requires the activity to be ALARP and the licensee to demonstrate that the risks are ALARP to the regulators. For the hazards, example fire, assessments are made to ensure that the probability for a fire is ALARP, safe shutdown can be achieved, protect the design, and that operating personal can be safe in case of fire. The purpose of the assessment is to ensure that no damage that is sustained will lead to radioactive release [A3].

5.2.4.2 Hazards for unit O2 at OKG

In Sweden the identified hazards are based on a basic principle for safety called “Defence in depth”, see also *Appendix A - Explanations of expressions and abbreviations*. The Defence in depth will cover up for the various faults that humans may cause, but also technical faults. Measurement shall give robust solutions, i.e. long-term durable solutions, to prove that the reactor plant has multiple barriers against the release of radiological emissions. Many of the other safety measurements are based on protecting the Defence in depth, protection of the barriers and mitigating the consequences if the Defence in depth should be penetrated [B5].

The purpose of the identified hazards is that they should represent safety and be supported by safety analysis that later on will be evaluated against established acceptance criteria[31].

[29] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, mail correspondence 2010-08-11.*
[30] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, interview 2010-07-26.*
[31] *Analyst – Reactor technology, Ninos Garis, Swedish Radiation Safety Authority, interview 2010-07-14.*

In Sweden the identified hazards are to be found in the General part of the Safety Analysis Report, also known as a part of the SAR. In the OKG SAR, known as PSAR, when power uprating or major modernization, one chapter is dealing with hazards. The hazards are split up in twelve different sections; see also *Appendix H - Unit O2 at OKG hazard* for more details [B2]. The identified hazards are listed below.

- Global and local effects (pipe breaks),
- Fire,
- Seismic,
- External events,
- Internal events,
- Very unlikely events (H5).

Each hazard is divided into different classes of events, more on this in section 5.2.5.2 below. The classes of events are often presented in an interval that goes from normal operation to highly improbable events where the core is negatively affected.

An analysis that has been done on the Swedish nuclear power plants shows that there is a relatively large variation in the assumptions and the fulfilment of how the hazards and general safety requirements are fulfilled. The nuclear power industry has also influenced the safety and hazards at the plants, which is mainly based on the IAEA Safety Standards (Frid et.al, 2006).

5.2.5 Safety analysis

The information that is presented in this section has the intention to form an overall structure of how the countries conduct and validate hazards by means of safety analysis. For more detailed information, see *Appendix I – Sizewell B safety analysis* and *Appendix J – Unit O2 at OKG safety analysis.*

5.2.5.1 Safety analysis for Sizewell B

The goal of the safety analyses in the report is to cover a basic strategy for how the licensee can prove that the fundamental safety principals and hazards have been met [A1], and also to reflect on the design and operation of the plant (HSE 14).

The analysis also assists in the judgment to secure and compare against the acceptance criteria [A1]. I TAGs 051- *Guidance on the purpose, scope, and content of nuclear Safety Cases* describe that deterministic and probabilistic analysis may be used to underpin the safety arguments (HSE 11). See section 2.3.2 and *Appendix K - Safety Case* for deeper understanding of Safety Case and arguments. The analysis is also for the inspector so that they can assess the Safety Case. The probabilistic analysis, PSA, may also include three different levels 1, 2, and 3. The three different levels represent the three different levels that the plant can be split into. An example of the levels 1, 2, and 3 are: Core damage, release of ionizing radiation respectively, and risk to the public[32].

A basic safety objective in the design is to prove that the nuclear plant ensure that no radioactive risk will cause danger to the operators or the public As Low As Reasonably Practicable. A normal approach to reach ALARP is through robust engineering and defence-in-depth[33] design. This is achieved through safety analysis, both deterministic and probabilistic analysis, so the licensee can prove that the plant meets the ALARP goal [A6]. The results have to prove that the risk to the public is lower than 10^{-6} per reactor year [A6].

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32 *Technical Specifications Specialist, Nuclear Safety Group, Technical and Safety Support, Colin Tucker, Sizewell B Power Station British Energy, conversation 2010-07-08.*

33 *See Appendix A – Explanations of expressions and abbreviations.*

The analyses that are performed are based on a structured process in which different scenarios are considered and reviewed in order to select what needs to be analyzed and what is needed to protect at cause, a risk to the environment and to the public. Then each sub-section deals with safety significance of the hazard, characteristics of the hazard, design approach, major design and results from implementation of the design, operational requirements and assessments, and analyses to summarize that the plant is adequately safe against hazard [A3]. The sub-sections take different operation stages and frequencies into account (HSE 4). Sizewell B has integrated the analysis throughout the whole Safety report[34]. Every hazard is worked through and then the analysis is made to see if the safety requirements are met. Then the safety analysis will be compared against the acceptance criteria (HSE 1).

When the HSE are going to assess the analyses they are clear that "priority should be given to achieve an overall balance of safety rather than satisfying each SAP or making an ALARP assessment against each SAP"(HSE 9 paragraph 3.1). The assessments are also based on the document *The tolerability of risk in nuclear industries* (TOR) that are published by the HSE. This document is describing the "TOR philosophy" which means that ALARP has been translated into numerical targets called Basic Safety Levels (BSLs) and Basic Safety Objectives (BSOs) (HSE 9) though it is important to recognize that meeting numerical targets is not sufficient on its own, proper consideration has to be given to deterministic, engineering and operational elements of the safety justification..

If a CBA is submitted in support of a licensee's safety case, The HSE requires that the licensee presents sensitivity analysis, both in risk and cost terms, and a discussion on the significance of these factors to the overall conclusions. This is to be able to create a robust quantitative argument and come up with a good solution (HSE 9 paragraph 6.2). It is also important to show sensitivity analyses when quantitative methods are used.

5.2.5.2 Safety analysis on unit O2 at OKG

OKG writes in the report, *Ansökan om tillstånd för höjning av termisk effekt* that the purpose of the analysis is to verify that the nuclear power plant really meets the acceptance criteria [B6]. Furthermore, the implementation of safety analysis is a precondition for receiving an examination of the authority with power uprate or major modernization [B6]. The safety analyses that are done with power uprate or major modernization broadly follow the existing Safety Analysis Report. If the PSAR do not follow the safety analysis OKG demands that the changes are clearly explained [B6].

To give the authority a comprehensive view of the safety both deterministic and probabilistic analysis need to be performed. The two analytical methods are considered to cover up for each other's weaknesses and provide a good picture of the safety [B4]. In the SSMs general advice PSA tests should be done in two different levels, analysis of the probability for core damage, called Level 1 and analysis of the probability of ionizing radiation release to the environment, called Level 2 (SSMFS 2008:1 General Advice p.12). Analysis of Level 3 is not considered necessary, as the operation license attached to the plant already has done some measurements [B34].

The analyses that are carried out are based on a number of event classes and to any event class quantitative analysis shall be performed (SSMFS 2008:1 Ch 4 section 1). OKG and Sweden has chosen to do this using six different groups, called event classes[35], see the paragraphs below. The classes indicate different intervals of events that reflect the expected probability of events to occur. The analyses have to take the possible operating situations into account and thus have varying frequencies. This is solved

[34] *Technical Specifications Specialist, Nuclear Safety Group, Technical and Safety Support, Colin Tucker, Sizewell B Power Station British Energy, conversation 2010-07-08.*
[35] *Analyst – Reactor technology, Ninos Garis, Swedish Radiation Safety Authority, interview 2010-07-14.*

by similar risks and hazards divided into different classes and value by the class, that they have previously given frequency range (SSMFS 2008:1 General advice p.12). The classes are listed below along with a brief definition of each class.

- **H1**- Normal operation [B1]. Includes all the natural stages that the reactor can operate within. Examples are: cold closed reactor, warm closed reactor, heating up, and operation etc. [B9].
- **H2** – Expected events [B1]. Includes those events that are expected to happen during the nuclear power plants life cycle [B9].
- **H3** – Not expected events [B1]. Comprise those events that not are expected to happen during the life cycle of one specific nuclear power plants but are expected to happen during the operation time of several nuclear power stations. Examples are: smaller loss of coolant, dropped control rod, pipe break that do not affect the primary system etc. [B9].
- **H4** – Unlikely events [B1]. Those events that are expected to occur at some time during operation of several nuclear power plants [B9]. Examples are: Pipe break in the primary system, dropped control rod, extreme external events etc. [B9].
- **H5** – Very unlikely events [B1]. Events that occur outside the initiating event sequences. H5 events including three specific events: earthquake, RAMA-events that include core damage [B9].
- **Extreme unlikely events**[36] [B1], also called rest risks (SSMFS 2008:17 section 2). Comprise those events that are so unlikely to happen that they are not required to be handled as initiating events when safety analysis are processed (Frid et.al, 2009). Example of events in this class is crashed airplanes, spontaneous break on the reactor vessels and meteorites [B9].

Each event class shall be assessed and verified according to quantitative analysis[37] to show that the safety margins are good enough compared to the law Ionizing Radiation Act (1988:220) (SSMFS 2008:1 Ch 4 section 1). The SSM is clear that the uncertainties have to be shown and also the methods that are used in the analysis. Limitations also have to be presented in the safety documentation. Furthermore assumptions and logical structure has to be described (2008:1 General advice p.12).

5.2.6 Acceptance criteria

It is by showing the results from the safety analysis and then comparing them against the acceptance criteria that the licensee can demonstrate if the safety requirements are met and that the risk has been minimised to a tolerable level. The following sections 5.2.6.1 and 5.2.6.2 describe the UK and Swedish acceptance criteria by studying the Sizewell B and unit O2 at OKG's safety documentation.

5.2.6.1 Acceptance criteria for Sizewell B

The acceptance criteria are directly set out and relevant to protect the public and the operators on site and show that all risk is ALARP (HSE 1). The UK arrange, as named before, a ”top down” approach, see *Appendix D - Levels of risk UK* for levels of risk in the UK. The HSE is clear on that a small change of a number to just pass into the tolerable area is not enough, as the problem still will be present (HSE 1), see *Appendix D – Levels of risk UK* for tolerability area. Sizewell B is more demand-

[36] *According to Lars Gunsell (2010-07-15), no event shall be classified to be totally without probability. This is because we have limited knowledge of certain events and thus this class can be motivated. For example, nobody thought that TMI accident would happen.*
[37] *Quantitative methods according to Nilsson (2003) are numeric and based on uncertainties in the modeling and input data. Uncertainty is taken into account throughout the simulated process and provides an assessment of the uncertainties in the final result. Quantitative analysis can be performed in both deterministic and probabilistic analysis (Nilsson, 2003).*

ing on the plant than the national laws require [A3]. The licensee has to justify for the authority that their risks are within tolerability and that the criteria are met (for example quality of fire barriers)[38].

To help create some structures around ALARP and to make it more palpable a number of Numerical targets have been developed and are quantified values of the risk. Essentially they translate the ALARP into numbers. These are called Basic Safety Level, BSL, and Basic Safety Objective, BSO. Both BSL and BSO are defined in individual- and societal risk, basic design analysis, and normal operation. The BSL targets are supported by the Ionising Radiation Regulation and the HSE policy is the BSL that is used for new nuclear power plants and for existing plants. BSO is a recommendation from HSE that they think should be use as modern safety in nuclear power stations. By meeting the BSO and BSL targets, the risk may not harmonise with ALARP. The risk may be possible to drive lower then the BSO and BSL according to ALARP. Thereby the ALARP assessments have to be on a case-to-case basis (HSE 1, paragraph 568- 573). BSL also have something called BSL (LL), which are targets that harmonise with the IRR.

The inspectors at NII will judge whether the licensee is controlling the hazards to keep the risks ALARP. Most targets and limits are not mandatory, except from some that are formulated in the law IRR and are called BSL (LL). Even a more strong argument has to be made to show why no further safety measurements are implemented (HSE 1, paragraph 571). The HSE/NII is clear on that they are going to look for valid assumption and limits for the safety analysis and irrespective of the numerical results will always ask the licensee what they could do to further reduce the risk[39] and if there are things which are reasonablt practicable, i.e the sacrifice is not grossly disproportionate, the licensee will be required to implement those things The inspectors will also take into account the uncertainties, the claims accuracy, and precision in Numerical targets. This has to be made in sensitivity analysis as appropriate (HSE 1, paragraph 575).

The dose rates that are used are primly taken from similar operating PWR as Sizewell B which have provided different data. Inspiration of the dose and yields are especially from operating SNUPPS[40] and EdF plants. Sizewell B has tried to be conservative in relation to the dose rates and also in relation to some criteria from Japan and the U.S. This could possibly cause differences in materials, layout, design, and chemistry from the already existing nuclear power plants [A4].

The Numerical targets in the SAPs are derived from the document called TOR and have been extended in another document called R2P2 (HSE 1, paragraph 569). The release criteria are based on the fact that the fundamental objective risks must be ALARP [A2]. Table 6 below shows the different targets that the case will judge against.

[38] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, mail correspondence 2010-08-11.*
[39] *Nuclear Product Development Manager, King Lee, Lloyd´s Register, conversation 2010-06-24.*
[40] *Sizewell B is also a SNUPPS design plant. See section 5.2.1.1 for further information.*

Table 6 Shows the UKs acceptance criteria on nuclear power plants for ionizing radiation. The acceptance criteria shows the criteria in an interval from modern standards like BSO and legal limits and ALARP, which benchmark against BSL (HSE 1).

Numerical Targets	**Short description**	**Frequencies (relates to BSL and BSO) [per annum, pa; Millisievert, mSv]**	**Effective Dose [mSv], include both BSL and BSO**
Target 1- Normal operation – any person on the site	These targets are a legal limit for effective dose in a calendar year on the site and are working with ionizing radiation.	No frequencies are available, just BSL and BSO	Employers working with ionizing radiation: BSL(LL): 20 mSv BSO: 0.1 mSv (IRR)
Target 2 – Normal operation – any group on the site	Average effective dose during a calendar year and for people working with ionizing radiation	No frequencies are available, just BSL and BSO	BSL: 10 mSv BSO: 0.5 mSv
Target 3 – Normal operation – any person off the site	Effective dose in a calendar year for any person off the site.	No frequencies are available, just BSL and BSO	BSL(LL): 1 mSv BSO: 0.02 mSv
Target 4 – Design basis fault sequences – any person	The effective dose from a design basis fault sequence and for any person.	On-site, BSL: $1x10^{-3}$ pa (20 mSv) $1x10^{-3}$ - $1x10^{-4}$ pa (200 mSv) $1x10^{-4}$ pa (500 mSv) and BSO: 0.1 mSv Off-site, BSL: $1x10^{-3}$ pa (1 mSv) $1x10^{-3}$ - $1x10\text{-}^{4}$ pa (10 mSv) $1x10^{-4}$ pa (100 mSv) and BSO: 0.01 mSv	
Target 5 – Individual risk of death from on-site accidents – any person on the site	Individual risk of death to person on-site and from an on the site accident	BSL: $1x10^{-4}$ pa BSO: $1x10^{-6}$ pa	-
Target 6 – Frequency dose targets for any single accident – any person on the site	Frequency of any single accident in the facility to a person on the site.	BSL: BSO: $1x10^{-1}$ - $1x10^{-3}$ pa $1x10^{-2}$ - $1x10^{-4}$ pa $1x10^{-3}$ - $1x10^{-5}$ pa $1x10^{-4}$ - $1x10^{-6}$ pa	2-20 mSv 20-200 mSv 200-2000 mSv >2000 mSv
Target 7 – Individual risk to people off the site from accidents	The individual risk to a person off the site from an accident on the site.	BSL: $1x10^{-4}$ pa BSO: $1x10^{-6}$ pa	-
Target 8 – Frequency dose targets for accidents on an individual facility – any person off the site	Include the total pre-dicted frequencies of an individual facility and could give any doses to a person off the site.	BSL: BSO: $1x10^{-1}$ - 10^{-2} pa $1x10^{-1}$ - $1x10^{-3}$ pa $1x10^{-2}$ - $1x10^{-4}$ pa $1x10^{-3}$ - $1x10^{-5}$ pa $1x10^{-4}$ - $1x10^{-6}$ pa	BSL - BSO: 0.1 - 1 mSv 1 - 10 mSv 10 – 100 mSv 100 – 1000 mSv >1000 mSv
Target 9 – Total risk of 100 or more fatalities	The total risk of 100 or more fatalities, from on site that are exposed to ionizing radiation.	BSL: $1x10^{-5}$ pa BSO: $1x10^{-7}$ pa	-

5.2.6.2 Acceptance criteria for unit O2 at OKG

The acceptance criteria are primly set out to protect the public and the environment against radiation. The requirements are quite general and they are presented in the regulation SSMFS 2008:23. This regulation does not set out any Numerical targets but treats the criteria more in general. It is up to the licensee to set out reference numbers (Numerical targets) and then work to reach them [B9]. The SSM require that the technique that is used on the nuclear power plant has to be from the best available technology (BAT), ALARA[41], and that environmental monitoring has to be performed (SSMFS 2008:23 section 7).

The Swedish nuclear power plants have, with this in mind, set out their own reference criteria and a practice has been used [B1]. Each event class have predetermined acceptable consequences, based on how much impact is allowed on the barriers. To the acceptance criteria is also added some requirements for method and critical variables that need to be met [B9]. The authority strives to lead the licensee to focus to create a balanced risk profile and thereby optimize the design on the plant [B9].

In addition to the acceptance criteria shown in table 7 below, there are criteria specified for dose allowed to the operators, radiological environmental impacts, barrier integrity, mechanical stress, buildings, and nuclear material. Those criteria follow the same structure as the ones in table 7 below and are also categorized by six event classes [B9].

[41] *Investigator – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, phone call 2010-06-15.*

Table 7 Show the acceptance criteria for the different event classes. When needed a short comment is attached to the event class or to the acceptance criteria. The criteria is valid for nuclear plant consequences.

Event classes	**Acceptance criteria. Frequencies, F [pa][42] [B9].**	**Short description [B9]**
H1	Normal operation	Require that the automatic systems should be available and regulate when some limits are reached. Safety margins at those limits need to be met.
H2	$F \geq 10^{-2}$ Reference level: 1 mSv	Within these class barriers functions shall be met even in case of accident. The consequence should generally be a scram and then back to normal operation.
H3	$10^{-2} > F \geq 10^{-4}$ Reference level: 10 mSv	An accident should in general not lead to serious consequences, for example loss of the containment barrier. The measurements should in general be a scram. An accident can lead to some part of the core needing to be changed.
H4	10^{-4} $F \geq 10^{-6}$ Reference level: 100 mSv	An event in this class shall not affect the safety functions to ensure the containment barrier. An event can lead to the plant needing to be shut down for a while and that the majority of the fuel needs to be replaced.
H5	Earthquake, RAMA-event that can cause core damage. $10^{-6} \leq F < 10^{-7}$ (Frid et.al, 2006) Reference level: approximately 1000 mSv	No further acceptance criteria within this event class, except from the one that had been presented in event class H1-H4.
Extreme unlikely events	$F < 10^{-7}$	Events that earlier were called residual risks are crashed aircrafts, spontaneous break downs of the reactor vessel, and meteorite impacts. Crashed aircrafts have shown that the probability is so low that it is not considered.

In normal operation the event classes H1-H5 are determined not to exceed 0.1 mSv to the critical group (SSMFS 2008:23). Proposed dose criteria prepared by the SSM are listed in table 7 above, which shows the reference value for radiological releases. Note that there is no valuable dose criteria for normal operation, i.e. event classes H1, and there is no requirement from the SSM for this event class.

The SSM intends to assess a nuclear power plant based on the document "*Radiological surroundings consequences of disturbances and breakdowns in nuclear reactors - Proposals for reference numbers and analysis assumptions."* The requirements from the SSM are to see restrictions of the radiological emissions of the allowable emissions from a given source or specify dose criteria for a fictional group

[42] *Those criteria are based on criteria from U.S. and are called ANSI/ANS 51.1/52.1. SSM have not made any decisions if those event classes shall harmonize with those frequencies or not.*

under given assumptions. For events within the H5 SSM consider that the FILTRA-requirements[43] should be available (Frid et.al, 2006).

Engineering and analysis of radiological release should be performed using the "best-estimate", which can also be regarded as the best modern engineering. The document published by the SSM considers that sensitive analyses need to be shown for the SSM, even for Extreme values (Frid et.al, 2006).

Lately there have been requests from the licensees that the SSM should specify acceptance criteria of how they will be reviewed. This led to a team being assembled to investigate the above questions, which resulted in the publication "*Radiological environmental consequences of disturbances and breakdowns in nuclear power reactors - Proposals for benchmarks and analysis assumptions*." (Frid et.al, 2006).

The knowledge that today is linked to the acceptance criteria for radiological emissions is based largely on experiments conducted in the U.S. in the 1950s [B1]. Since the accident at Three Mile Island in 1979 the SSM have been looking at the existing plant SAR and international comparison of acceptance criteria, and above all by the *U.S. NRC Code of Federal Regulations, Title 10, Part 100th* (Frid et.al, 2006).

5.3 Analysis of the interviews

This part is based on interview questions and the section consists of questions followed by a more detailed answer, which are summarized by the responses. At the end of the section there is an interpreting summary of the interviews.

For the interviews, appropriate persons have been selected at the HSE and SSM, along with supervisors and experts in the nuclear industry. The interviews are not intended to only relate to Sizewell B and unit O2 as the above case study focused on. The interviews are constructed to cover respectively the countries view of hazards. Although, the verbal references have been necessary for several reasons since it can provide answers from a different perspective and give answers to some information that are difficult to get through documents. Another reason is because of the complexity and diversity with the safety documentation. Some parts are confidential, which is why it has been impossible to study the entire document.

The answers are formed by the following questions:

- What are the underlying requirements to the safety requirements on hazards?
- Are there differences in the way the licensee decides if safety requirements are fulfilled? Decision criteria and assessment process?
    - o How will the hazards be assessed?
- How can safety be satisfactory?

These questions are presented in section 5.3.1 and 5.3.2 below.

[43] *The FILTRA-requirement involves that a nuclear power plant needs to add some extra safety functions at the plant – press relief throughout a filter. This is to mitigate measures against core damage. The requirement is a consequence of the TMI accident 1979.*

5.3.1 UK

In this section the interview with the HSE in Liverpool, UK, is summarized. The interview has been done with Geoff Grint who is *Principal inspector Nuclear Installations* at HSE in Liverpool. But also some references are from employers at Sizewell B and Lloyd´s Register in London, UK.

- **What is the background to the Safety Report and the safety structure?**

In the UK the licensee can design the nuclear power plant in a specific structure, as long as following the requirements of laws and regulations. Thereby the licensee can produce a Safety Case that suits its own company and later summarise it into a Safety Report. The HSE/ND does present requirements that the licensee must comply with as follow the UK ALARP principle. The requirements are described in the License conditions 36 that the risk has to be minimized to tolerable risks. It is also important to note that safety documentation can look differently depending on which phase of the nuclear technical life cycle the documentation is performed in[44], see section 2.3.1.

- **What is the background of the identified hazards?**

The identified hazards are based on feedback and experience from nuclear power plants, such as accidents and incidents but also from studies of other countries' experiences, research, and increased technical knowledge. It is also important to note that the IAEA issues a list of hazards that they think should be used as internal and external hazards on a nuclear power plant. This list has inspired many licensees in the UK[45] such as Sizewell B.

- **What will the assessment of the hazards look like?**

Assessment will be carried out using SAPs and TAGs. The criteria for determining whatever ALARP is required in relation to the SAPs are not set out in absolute terms. Geoff Grint explained that the primary expectation was that Relevant Good Practice should be met, and that to help underpin this, the TOR philosophy had been embodied in numerical BSOs, which represent broadly acceptable levels, and BSLs, which were levels of risk which not be acceptable under normal circumstances.

In terms of the Numerical targets, the internal and external hazards are treated as initiating faults in the PSA and their frequencies combined with failure probabilities for the systems performing the safety functions (taking into account that the hazard might increase the failure probability - e.g. a fire might burn some of the safety equipment so it is not available to help protect the plant). This gives a contribution to the risks for comparison with the Numerical targets[46].

For all Numerical Targets, BSO and BSL, the licensee has to prove for the ND that the risk can not reduce further; the ALARP principle. This can include quantitative arguments based on risk estimation or quantitative features deterministic engineering principles. The licensee will always receive questions from the ND such as: Why is there a nuclear risk and are there alternatives (justification)? Is it safety enough (limitation)? Can you do any extra to make it even safer (optimisation)?[47].

Furthermore the ND does not just assess the license after fulfilling of Numerical Target, also an overall assessment of the Safety Case is required. All technical phases will not be covered by a Safety

[44] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, interview 2010-07-26.*
[45] *ibid*
[46] *ibid*
[47] *Nuclear Product Development Manager, King Lee, Lloyd´s Register, conversation 2010-06-24.*

Case that is produced for a power uprate or major modernization by the licensee. It is up to the licensee to justify the phases that have not be taken into account[48].

With a Power uprate the HSE/NII can be slightly harder in the judgments on the site because they accept more updated solutions and more effective systems. The licensees have to communicate with the HSE/NII during specific stages to keep them updated and integrated in their new systems.

Geoff Grint concludes by saying that the HSE/ND is not able to examine everything without sampling occurring. However, they can always retrospectively examine the licensee if it is deemed to be reasonable.

- **What are the underlying reasons for the analysis of the hazards?**

The underlying requirements for the analysis build on many years of experience, other studies, research, and review of other systems in other high risk industries. The HSE and the UK have also been inspired by the IAEA in the last ten years and try to encompass their requirements and meet their expectations that they provide on the list[49].

- **How can the authority be convinced that the safety is good enough?**

The HSE/NII expect that a licensee will explore possibilities of risk, using past experience from similar facilities, both national and international, taking research and other studies into account, to identify rare events that might not be represented in the operational experience. Also to undertake a thorough systematic analysis to identify what might go wrong on the plant (e.g. using FMEA, HAZOP, master logic diagrams)[50].

In general the list of internal and external hazards is to be considered and should be as comprehensive as possible. The licensee ought to identify all of them and then possibly screen some of them out on the grounds of physical impossibility - e.g. avalanche hazard for a site on flat ground with no mountains where snow can build up. For internal hazards the licensee might screen out dropped loads where there are no lifting operations carried out. Sizewell B even looks at the SAPs and receives inspiration from what the inspectors point at during inspection[51].

According to the HSE assessment of the safety analysis shall be done with good practice, best engineering techniques, and ALARP. But the judgments on what is reasonably practicable may change over time because of technological innovation, cost changes, and knowledge of different hazards[52].

5.3.2 Sweden

In this section the interview with SSM is summarized. The interviews have been done with Lars Gunsell who is *Analyst in System Assessment* and Ninos Garis who is *Analyst in Reactor technology.*

- **What is the background to the Safety report and PSAR structure?**

Swedish nuclear power plants have developed a Swedish version of safety from the documentations that U.S. nuclear authorities have created and mainly depending on the vendor. There are thus no clear

[48] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, mail correspondence 2010-08-11.*
[49] *Principal inspector Nuclear Installations, Geoff Grint, Health and Safety Executive, interview 2010-07-26.*
[50] *ibid*
[51] *ibid*
[52] *Technical Specifications Specialist, Nuclear Safety Group, Technical and Safety Support, Colin Tucker, Sizewell B Power Station British Energy, interview 2010-07-08.*

requirements for the structure of the Swedish Safety report and PSAR. Their structure is more of historical nature than anything that is regulated in the legislation. Since there was no clear details of the structure and the content, there was room for the licensee to develop its own version of the Safety report and PSAR, but this must be approved by the authority. Recently influences from the IAEA have affected the Safety reports and PSAR. This is because the IAEA has developed in expertises and as an organisation over the past ten years and thus began to set higher standards for nuclear safety. Also the regulation has become more detailed about the content of SAR.

During the 1970s the nuclear industry developed greatly in technology and the United States and the NRC (Agency for nuclear power in the U.S.) published a lot of material similar to the regulations and laws that Sweden during this period used as inspiration for their new design of nuclear power plants. This led to nuclear power plants being built in Sweden during this period had no available material to use so they picked different parts and developed their own interpretation of the U.S. rules. For example the OKG and unit O2 Safety Reports differ from the other nuclear power plant Safety reports. Lars Gunsell continues to explain that there are twelve nuclear power plants in Sweden (two of them are permanently shut down) and also twelve separate Safety Reports. In the 1970s there was room for the various owners of a nuclear power plant to choose standards on SAR and to decide how much money they would want to spend on the SAR. For example, OKG unit O3 and Forsmark unit F3 are very similar design wise, but their Safety reports vary in structure and in some requirements[53].

- **What is the background of the identified hazards?**

Underlying causes of the requirements are based primarily on the requirements from the U.S. Over the years experience, international knowledge, and increased knowledge within the nuclear safety area has developed a lot.

All nuclear power plants in Sweden are constructed before 1980 and thus the design is based on the most current regulations at that time, primarily based on U.S. regulations[54].

- **What will the assessment of the hazards look like?**

Lars Gunsell explains that SSM wants to see the way of thinking, the argumentation and the assumptions made, in the Safety Report and PSAR. He continues to say that if a different approach will be used of a licensee then it is important that exceptions and uncertainties also need to be identified and easily explained. In short, the licensee needs to show why the acceptance criteria are satisfied, but how they do it is up to the licensee[55].

Each licensee is to set out their own acceptance criteria, which later will be controlled and judged by the SSM. The Radiation protection will be assessed with the ALARA, which is a consequence of the Environmental Code[56].

- **What are the underlying reasons for the analysis of the hazards?**

The events that are selected to be analysed have been developed by experience, research, international knowledge, and inspiration by U.S. regulations[57]. The specific event that has been analysed has

[53] *Investigator – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, phone call 2010-06-15.*
[54] *ibid*
[55] *ibid*
[56] *Investigator – Reactor technology, Ninos Garis, Swedish Radiation Safety Authority, interview 2010-07-14.*
[57] *ibid*

undergone a selection process and represents the majority of events. It is called "Umbrella event" [58]. The selection of events must also be preceded by a systematic inventory of events, event happenings, and circumstances that can cause damage[59]. The background to the selection process is taken from U.S. regulations (ANSI / ANS 52.1 - 1983) and is today considered by the SSM to be a sufficiently balanced way to analyse nuclear power plant risks. In addition the considered event classes form the basis of a balanced risk profile, i.e. high probabilities are low frequency and vice versa[60].

- **How can the authority be convinced the safety is good enough?**

Since nuclear power operations started, the demand for verification of safety has become higher thanks to better knowledge, technologies, and through empirical work. The accidents at Chernobyl and the reactor accident in Three Mile Island have had great significance for strengthening the regulatory framework for environmental qualification, and technical requirements etc. The progressively more extensive requirements are putting a bigger pressure to use a wider range of initial events, which can be simply described as; the plants must endure with a wider range of events[61]. The safeties also are confirmed by all safety documentations having a third-part reviewer, i.e. an independent reviewer[62].

Lars Gunsell says that we have to remind ourselves again and again that an accident can happen even if everybody thinks that it's impossible. For example, the Three Mile Island, TMI, accident is an example of just such a scenario. Another area is fire, were knowledge has developed over the years. In the beginning not much was known about the hazards of fire and the protection in the power plants were insufficient. Also an incident at one of the Forsmarks reactors in 2006 is a reminder that we don't know about the future. Before this accident nobody understood what damage the interference from the external grid could cause on the safety systems.

5.3.3 Summary and interpretation of the interviews

The background of the safety documentation in the UK is based on historical tradition and on the IAEAs recommendations for safety. The hazards that are identified in the safety documentation have to be minimised and the safety will be assessed against the ALARP principle by using the SAPs and the TAGs. The HSE/ND has published Numerical Targets that intend to transfer the ALARP principles into quantifiable numbers. Those levels are expressed in intervals that are from the lowest level like the laws to the highest level that are international and other solutions from nuclear power stations worldwide.

In Sweden the background of the structure of the safety documentation and its content comes from the U.S. and the structure that the vendors choose. The nuclear power plants have then developed their own structure so that today all safety documentation looks different at all nuclear power plants. Inspiration for the identified hazards has been taken from the U.S and most recently, in the last 10 years, from the IAEA. The assessment will be compared to the laws and legislation and the authority will look for logical arguments and best engineering techniques.

During the interviews, in both the UK and Sweden, it was clear that there is humility and respect to see that the safety is satisfactory and the risks tolerable. All risks that a nuclear power plant is exposed to are widely complex and the understanding if the risks have been minimised to a tolerability level, which is very difficult to assess. The interviewed persons were very careful about saying that all risk

[58] *Investigator – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, phone call 2010-06-15.*
[59] *Investigator – Reactor technology, Ninos Garis, Swedish Radiation Safety Authority, interview 2010-07-14.*
[60] *Investigator – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, interview 2010-07-15.*
[61] *Investigator – Reactor technology, Ninos Garis, Swedish Radiation Safety Authority, interview 2010-07-14.*
[62] *Investigator – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, interview 2010-07-15.*

has been eliminated to a tolerable level. Another observation is that international experience and research is taken more and more into account and that exchange of experience is independent of company or country. It is clear that the safety is very important for everybody within the nuclear power industry and that they try as hard as they can to take control of the risks.

The regulations about safety are extended since more experience of uncertainties and knowledge of the technique are being developed. The design of a nuclear power plant has to be performed, in both countries, by good engineering principles and by best engineering techniques.

Chapter 6 –Summery of the analysis

This chapter is based on the previous chapters and will identify differences and similarities between the countries. The chapter intends to present results based on the research questions:

- *What are the similarities and differences between the UK and Sweden in safety requirements for hazards and what are their underlying requirements for safety documentation for those hazards?*

Throughout the whole report and the work with the research question above, it is very clear that there is a consensus in the nuclear industry about the attitude towards safety. The consensus is that the risks shall be minimized and that the safety work should be in focus. However, to reach good safety standards, the countries UK and Sweden have slightly different approaches. The results from the analysis are presented in section 6.1 - 6.3 below.

6.1 Results from laws and regulations

The UK's laws that govern nuclear safety have a hierarchical structure and are controlled primarily by two laws: HSWA and NIA65. The first law, HSWA, is applied to all workplaces where risk may occur and regulates that the employer needs to comply with the ALARP. NIA65 is more technically designed and is aimed only at nuclear facilities. However, NIA65 does not contain technical requirements and specifications. The more detailed interpretation of requirements for hazards are handled in the SAPs and TAGs. The LC36 contains more technical requirements and is non-perspective. The UK's laws are based on a philosophy in which everything regarding safety shall be regulated against the ALARP principle. The law in the UK, gives the licensee a "freedom" to design the plant according to, for example, a specific company's legal structure, and to individually decide how to meet safety requirements as regulated by LC36, they must however be able to demonstrate that they have met the overall requirements. However, it is important to note that the HSE/ND will assess a Safety Case along more detailed requirements of the SAPs and TAGs but will allow the Licensee to use alternative methods as long as they can justify those methods.

The Swedish legislation that regulates nuclear power safety is governed by three main laws: The Nuclear Activities Act, The Radiation Protection Act, and The Environmental Code. These laws are relatively general and do not specify anything on hazards. The laws just contain general safety management although The Environmental Code handles some principles that are affecting the hazards. SSMs Regulations present detailed requirements, apart from certain areas where the requirements are general, such as acceptance criteria. The acceptance criteria are based on historical and practical use and are up to each licensee to determine (with the approval of SSM).The regulations are designed to assist decisions and help the licensee to comply with laws.

A similarity between the countries is that the hazards are not addressed until further down in the hierarchical structure of laws. Another apparent similarity between the countries is that they take international knowledge and experience into account to prevent safety issues. The UK has even gone so far as to harmonize their assessment model, SAP, according to the IAEA safety standards. If power uprating or major modernization occurs, Sweden also sees the possibility to improve safety requirements that harmonize with international safety experiences and knowledge. Both countries require that the best available technology should be used and that the radiological radiation should be kept as low as practicable.

The UK has however clarified and specified the ALARP principle through Numerical Targets, which is not done or used in Sweden, except for minimization of radiation as ALARA. The closest Sweden has gotten to introducing a clear safety management standard is to publish a document containing safety management guidelines with the name *Radiological surroundings consequences of disturbances and breakdowns in nuclear reactors – Proposals for reference numbers and analysis assumptions*. However, this document is so far only a study on international safety management and does not take a clear stance on how safety will be assessed.

A clear difference between the two countries is how environmental requirements shall be adjusted to the licensee. Sweden is unique in its requirements through the Environmental Code. The UK has no equivalent to this. The UK is however working to expand its environmental requirements and to have a closer collaboration between the HSE/ND and Environment Agencies in Wales and England and the Environment Protection Agency in Scotland than they currently have. The Environmental Code is very comprehensive and includes all activities that could be classified as environmentally hazardous activities, as well as private individuals. According to the Environmental Code, a separate licence for approval of a power uprate application is required.

6.2 Results from the Safety documentation

This section analyzes the results of the laws, the safety documentations at Sizewell B and O2 at OKG, and the interviews. The results of the safety documentation are an attempt to expand and include what stance the two countries the UK and Sweden take to hazards, rather than focusing on each nuclear plant's performance.

6.2.1 Safety documentation

The safety documentation is a fundamental requirement to maintain and operate a nuclear power plant. The safety documentation is primarily seen as a summary of the nuclear power design, safety, and how the licensee prevents radiation risks. Moreover, it is used as an argument for the licensee to prove the safety for the regulators and the public.

Both the UK and Sweden have to analyze and assess their risks before a power uprate or any major modernization can occur. The countries are also clear in demonstrating that those who own the risk are also responsible for eliminating it. The purpose and objective of each country's safety documentation are therefore similar, i.e. identifying hazards to be analyzed (both PSA and deterministic analysis), and later compared and evaluated against the acceptance criteria. The Safety documentation and Safety Case in the UK and PSAR in Sweden should be seen as a living document and will cover the whole technical lifetime of a nuclear power plant.

Differences between the countries may be identified in how they choose to structure the Safety documentation and how to handle a power uprating or major modernization. The UK uses a Safety Case while Sweden applies PSAR. The main difference is how the logical explanation leads to safety. The general Safety Case structure should be developed in parallel with the design and structured in a logical manner. It evolves and becomes more precise when the work progresses and the ND are integrated in this process. The structure is built on claims, argument, and evidence that are linked together with inference rules. The claims, argument, and evidence can nearly be translated with acceptance criteria, safety analysis, and safety requirements respectively. The Swedish PSAR builds on the existing nuclear power plants Safety report and is thereby structured in a historical manner. The structure of the Safety report is partly inspired by U.S. safety standards, which are very detailed.

6.2.2 Are there any significant differences or similarities between the safety requirements?

In the UK, there is a national approach to safety, which is the basis of how the hazards are handled. The approach is called The Fundamental Safety Principles and the purpose is to minimize or eliminate the risk of radioactive radiation according to ALARP. In Sweden, the safety on a nuclear power plant is evaluated according to the Defense in Depth Principle. In principle, all the safety components and commitments can be derived to that all safety system should protect the barriers surrounding the reactor. The UK also applies Defense in Depth, but not in the same way as Sweden does. The UK's approach, according to documents, focuses on radiation and protecting the public, while Sweden chooses to discuss this matter through the reactor's robustness and ability to withstand an accident.

The UK starts with identified hazards in order to examine how the hazards may influence systems, components, and functions in case something goes wrong. In Sweden, on the other hand, hazards are handled in terms of requirements based on regulations, and then different safety systems are described to explain how safety can be guaranteed based on the requirements.

The hazards that have been identified in the two countries have both similarities and differences. At first glance, both countries have nearly the same identified hazards but after a while it becomes clear that Sweden applies a broader definition of the hazards. Sweden also takes into account hazards that they called extremely unlikely events. In the UK they do not identify those extremely unlikely events like hazards. Sweden has unique requirements (through RAMA requirements) on the primary system integrity of pipe breakage, environmental requirements, and water chemistry requirements. These requirements are rarely dealt with in the UK and are not among their identified hazards.

The UK's approach on ALARP means that their radiation safety is always in focus and all identified hazards include radiation, while in Sweden they are only addressed in one chapter. Sweden also deals with seismic design and protection against highly unlikely events, H5 (see table 7), but does not analyze these any further. This is because the measurements that have been taken for event classes H1-H4 to promote the Defense in Depth Principles are considered sufficient. Equivalent events to H5 in the UK are however dealt with in much more depth. A lot of financial resources have been spent to prevent these conditions. The UK also summarizes all the hazards in a concluding chapter, Design Assessment, in which all identified hazards are compiled and measured against each other - a comprehensive view of all hazards. Sweden has no equivalent chapter.

6.2.3 How will the hazards be analyzed?

Both the UK and Sweden perform safety analyses to validate the requirements against safety criteria to protect the operators, the public, and the environment against radiation release. But the analyses are also done to prove that the licensees operate within the safety margins.

The selection of which hazards and risks should be analyzed in Sweden is made through a competitive selection process where similar probabilities and frequencies are clustered together. After that a risk is chosen to represent other risks, called "covering event", the UK applies a similar process, but it has chosen to analyze even more in detail, i.e. not use the "covering events" to the same extent. Both countries also intend to perform uncertainties analyses and sensitivity analyses to test for the variables' variations and the effect of the insecurity variables.

The analysis methods that are used in both countries are deterministic and PSA analysis. One difference between the two countries is that Sweden does not perform PSA analyses of level 3, which is done in the UK. This is because Sweden and the authorities maintain that the measurements that have been implemented to protect the nuclear power plant from extremely unlikely events cover the events that are used for analysis of level 3. These events are mainly earthquakes, pipe rupture, and extreme external impact. In the UK, the analysis is compared against the ALARP principle, while in Sweden the purpose of the analyses is to pursue a balanced risk profile and robust engineering.

6.2.3 How will the hazards be assessed?

The assessment of the hazards in the UK will be determined from a "top down" approach, which is explained in the document "*The tolerability of risk in the nuclear industry*". Top down means that on a national standpoint, risks shall be treated in a special way regardless of which business they refer to. This approach is directly set out to protect the public and the operators at the nuclear plant, and is applied to all high-risk facilities in the country. The level of risk in the UK also implies that risks shall be assessed against the ALARP principle. During normal operation, a random person from the public shall not be exposed to a risk higher then 10^{-6} pa (= per annum). For a licensee, the ALARP is transferred into something called Numerical Targets which are quantified values of the risks. It is however important that the risk is reduced further than what BSO and BSL require if possible.

No equivalent national approach, similar to the "top down" approach in the UK, can be found within the nuclear power in Sweden. Sweden has instead decided that each licensee of a nuclear power plant shall specify and set out its own acceptance criteria, which should then be discussed with the SSM. However, Sweden has the six event classes to lean on, which have predetermined frequencies. This is not to say that Sweden does not have any numerical values, since they partially compare with and benchmark against international levels and reference values. The radiation risks in Sweden shall be applied according to the ALARA and discharges must be prevented with the Best Available Techniques, BAT. The SSM, which is the responsible authority in Sweden, is clear that for any safety assessment performed to determine if the safety is satisfactory, a balanced risk profile and robust measurements shall be pursued. Optimization of radiation protection shall be done with the best possible technology.

Each country has determined critical radiation doses which are acceptable to the public. Sweden has opted for a fixed value while the UK has a range, from the absolute requirement to a value which is considered to follow modern nuclear power plants. The effective dose to an individual in the critical group in Sweden should not exceed 0.1 mSv per year. In the UK, the effective dose should not exceed 0.3 mSv pa, according to the IRR Act. The HSE has extended this range further by their Numerical Targets and in accordance with BSL (LL), the limit is 1 mSv pa and with BSO it is 0.02 mSv pa.

6.3 Interviews

The interviews have primly contributed knowledge about underlying requirements to the hazards and how they are assessed. Another important and interesting aspect that was learned from the interview is how the licensee and authority can be mutually satisfied that the safety measurements are good enough.

The hazards are identified in each country through experience (national and international), expert knowledge, and research. The UK aims to harmonize its safety requirements with the international UN agency IAEA safety standards. Sweden does not have the same approach or goal to align with the IAEA. Sweden bases its hazards and safety requirements on NRC, the nuclear authority in the U.S. For power uprating or major modernization both countries believe that international knowledge or other modern safety technology should be implemented. This is important because most power plants were built before the laws and regulations were put in place for nuclear power plants.

When assessing the hazards, there is a responsiveness to consider new knowledge and international experience. The UK is however clear that they will assess according to good practice, best engineering, and the ALARP principle. In Sweden there is also the traceability of these attitudes, but most of the authority leans against the law which requires more detailed solutions than the UK.

The licensee and the authority try to satisfy the safety by exposing a nuclear power plant to a number of initializing events and hazards. By analyzing these events and then comparing them against established acceptance criteria, a plant is considered secure. The results of the analysis should however show that there are enough safety margins in the results to make up for uncertainties and inaccurate assumptions. Both countries' authorities are wary of whether all risks are identified, but there are indications that the licensees try to design the facilities according to higher standards than those that are required by law.

Chapter 7 - Discussion and Perspective

In this chapter similarities and differences, safety at nuclear power plants, and sources of error are discussed. An approach to describe the research question in a wider perspective than just focusing on the UK and Sweden will also be given.

7.1 Similarities and differences between the UK and Sweden

The UK and Sweden operate on different ideologies when it comes how each country handles safety and therefore different strategies are used for safety precautions at nuclear power plants. This is the background to the differences that exist between the countries and how they handle hazards. The UK values safety according to the ALARP principle, while Sweden values safety according to clarity of the legislations and the requirements that are identified in the laws. The countries seem to view risks from different perspectives. These differences are due to different views and ideas' regarding what risk is. The UK has put much effort into getting an overall picture of the country's risks and has treated nuclear risks in the same area as other risks in the society. Sweden has treated nuclear risk individually and does not integrate safety management with the rest of the society. Sweden seems to gather and consider knowledge from other countries and is thereby not implementing a system with ALARP as the UK has done. It does seems as though the UK is emulating Sweden's detailed requirements, since safety is applied according to SAPs and TAGs, which are extremely detailed and are used in practice to design nuclear plants and safety systems etc.

It is quite easy to think that the ALARP principles and Safety Case are a creative process, which could be very good for safety precautions in a nuclear power plant. In practice it seems that the ALARP principle in the UK gets quite restricted while the licensee uses the relatively detailed SAPs and the TAGs to design and implement different safety systems. The creativity in a design process could be very important in order to see risks from a different perspective, but this process also puts more pressure on the persons or team that are going to produce a Safety Case in the UK. In Sweden it seems like the formal process is more focused on the specified requirements and also because a PSAR builds on the existing safety documentation, which may not be considered as modern today.

In the UK, the HSE regulates all risks and safety for the whole country and they can make independent decisions without permission from the Parliament, which is not the case with the SSM in Sweden. Sweden does not have an equivalent authority to the HSE in the UK. The management of safety in the UK can therefore be said to be more hierarchical and the communication between the licensee and the authority is not as close as the Swedish licensees are with the SSM. In the UK, all industries with high risk must compare their risks against ALARP and all those industries are regulated by the HSE when the safety is assessed. Somehow the entire society in the UK has taken a mutual decision to regulate the safety. A likely consequence of the countries different approaches for managing risks can probably effect how much the owners of a nuclear power plants are willing to devote resources to safety and competence in the nuclear power industry.

Another difference between the countries is the hierarchy of laws and regulations. This is reflected in how each country's regulatory authority, the HSE and SSM, are constructed and what their positions of power are. In the UK's legislation, there is the Health and Safety Work etc Act, HSWA, which governs all safety in the society. In Sweden, there is no comparable law. Sweden regulates and tests the nuclear power totally isolated from a societal perspective. The Swedish nuclear authority, SSM, co-operates with the Ministry of Environment, where the Environmental Code is generated. This means that the Swedish nuclear power in comparison to the UK, manages environmental risks from a broader perspective.

A similarity between the countries is that both countries' authorities are clear about the fact that the licensees have the ultimate responsibility for safety.

7.2 Safety at nuclear power plants

It is clear that safety is an important factor in nuclear power and that a high level of safety is desirable. There are tendencies which show that many countries are working together to enhance safety and that countries exchange knowledge with each other about safety experiences. To keep a high level of safety, international knowledge needs to be taken into account. One sign of this is that the UK intends to harmonize their SAPs and TAGs with IAEAs Safety Standards. Also, Sweden shows that international co-operation is important since it is a member in many international organizations that work for high safety standards at nuclear power plants worldwide. Even the UK is a member in those kinds of organizations.

Safety precautions are a cost issue, which may affect the safety at nuclear power plants. The owner of a nuclear power plant is 100 percent responsible (in the UK and Sweden at least) for all the cost in the case of a nuclear accident, which motivates owners, licensees, and companies to co-operate over national borders and between companies. A basic philosophy should reasonably be that those who own the risks, the licensees in the nuclear industry, should not to be able to determine how safety shall be regulated. In the UK, it is the industry that owns the nuclear power plants to a large extent, while in Sweden it is a mix of ownerships between the government and the industry. There is a risk that the national responsibility for safety might be affected if it is the same body that makes the laws and that bares the costs of improving safety. For example, this problem may be found in Sweden. The risk is when a state owns the nuclear power. Then the state must perform according to laws while at the same time be responsible for creating and maintaining the safety regulations for the nuclear power plants. When more costly safety requirements exist, the profit may decrease for the owners. Whether there is a real risk that the regulations are affected by this has not been examined, but there is a potential risk.

Since the risks of the world's most regulated industry carry significant costs, an apparent trend is that larger and larger companies buy and own the nuclear power plants. There is no way for smaller companies to manage these high financial costs. In the UK where the risks are measured against ALARP, cost-benefit, there may be a risk that the larger companies, that seem to be the future owners of nuclear power plants, will get greater power to regulate safety through the justification that certain risks cost more than what the measurements can provide in terms of safety improvements. Of course countries, the UK in this case, could implement some regulations against this possible scenario when ALARP docksides the safety level. A positive aspect of having larger companies to own nuclear power plants - instead of having a state as the owner, as is the case in Sweden - is that there is no natural relation between the legislature and the owner of the work. More discussion about this is in the section above.

Internationally, the UK and Sweden belong to similar organizations that work to develop a safer future in nuclear power. Both countries will contribute with knowledge to such organizations. Sweden and the UK even have bilateral agreements with neighboring countries, and there are conventions that aim to promote nuclear safety technology that Sweden, the UK, and other countries have signed. The international organizations are, among other, trying to collect information and develop research, etc. This means that more and more countries are using the same materials, for instance, information on preventing a certain threat. It is noteworthy that there is a potential risk that the knowledge is not really growing nationally when the organizations only refer to another organization for information, since that organization may actually have the same individuals as members.

7.3 Source of error

The report is based on literature studies, consisting of laws and internal documents, Safety Reports, from two nuclear power plants in the UK and Sweden, as well as interviews with authorities that regulate nuclear power in the UK and Sweden. Since the areas of nuclear safety are very extensive, and so is the law, it has been impossible to study them in detail and study all the laws that deal with nuclear power. The most adequate laws have therefore been chosen to study. The studies of the safety documents were used as representatives for how the two countries are working with the hazards and the safety. Since the sample only consists of two Safety Reports, there are of course aspects and factors that these documents do not address, that may have been present if another plant were chosen. Moreover, large parts of these documents are confidential, which means that large areas of information have not been available. However, the interviews conducted make-up for some pieces of information that were difficult to obtain by studying the literature.

There are differences between the studied nuclear power plants such as geographic location, years of operation, the reactor model (Sizewell B is a PWR and units O2 at OKG is a BWR), and the fact that they were built by different companies - Westinghouse and Asea Atom. Other differences between the nuclear power plants are that Sizewell B has not carried out any major modernization or power uprating since it only has been in use since 1995. Sizewell B has only increased the power effect by one percent, which occurred relatively early in the power plants technical lifetime. This is not considered to pose major problems as the UK does not impose any specific requirements beyond those provided in the planning.

During the interviews, sensitive information may have been left out by those who were interviewed, since large parts of the safety documentations are confidential. It may also be that the interviewees did not want to tell the truth as they could reveal a weakness in the authority or in how the country manages hazards. Moreover, the questions asked during the interviews could have been more specific in terms of specific hazards, which could have lead to more distinct results in differences between the two countries - had they been identified.

Finally, it is important to note that this report is a snapshot of how the nuclear power in the UK and Sweden handle the hazards nowadays. It is likely that new methods and techniques to regulate hazards and safety will be developed and implemented in the nuclear industry.

Chapter 8 – Conclusions

Conclusions and responses to the research questions in this report are based on qualitative reasoning, which is supported by results from earlier chapters like 5, 6, and 7. The author has focused on the strength of the identified differences and similarities between the countries through literature, internal documents, and interviews. All this was performed in an objective manner. However, it is inevitable that this chapter is sometimes tinted with the author's views of the field.

8.1 Answer to the research question

The aim with this Master thesis has been to identify similarities and differences between the UK and Sweden with regards to internal and external hazards. Also underlying causes to the safety documentation for those hazards was an aim to identify. The research question has been answered on the surface but a lot more work can be done to find out even more similarities and differences between the two countries. The identified similarities and differences can be a wake up call for the licensee and the authority. This could perhaps give another perspective how to handle systems and problems within the nuclear power plant. The two countries, the UK and Sweden, can learn from each other through awareness about their differences. The main differences are historical differences and nowadays the differences are primarily laws and regulations. The UK and their "top-down" approach and HSE view of how to handle hazards can make it easier for the licensee to know what they need to do to follow good safety. Sweden does not have the same national approach to handle hazards but it might put even more responsibility of the licensee to really keep good safety on the nuclear power plant. The licensee really need to analyze and have no recommendation to follow accept from other countries like U.S. In the UK the licensee follows the SAPs and the TAGs.

The identified similarities and differences can give a good picture over how the two countries treat the nuclear power and how they take care of and assess the safety. It seems like the differences will in the future become more similar since big companies purchase more and more of the nuclear power plants in the world.

The biggest *similarities* for the countries are that the hazards aim to and have the purpose to cover the whole risk spectra. Both countries have similar requirements on the identified external and internal hazards, such as protection against fire, earthquake, flooding, extreme weather, and missiles. These requirements have become more and more similar over the years, through international co-operation and exchange of research and experiences.

The biggest *differences* are in the ways that the hazards are assessed. The UK assesses hazards against the ALARP principal and is using guidelines for the regulators that are translating the ALARP principal into Numerical Targets. In Sweden, the licensee is assessed against the laws that are more detailed and focused on requirements, while the UK focuses on the hazards. Another difference is that Sweden requires higher regulations for the environment. The third big difference is that Sweden and the UK have different acceptance criteria for what they think is good safety at nuclear plants.

The *underlying requirements* to those similarities and differences for hazards and how they are handled are based on historical differences and different national approaches to evaluate risk. In the UK, the national approach for the nuclear industry is clear and they are using a "top down" approach for tolerability of risk. This approach is not just for nuclear power, but involves all risks in the society. In Sweden there are no limits or numbers used for evaluating the risks of a nuclear power plant. It is instead up to the licensee to prove to the authority that the safety is good enough.

8.2 Answering the sub-question

In the section 3.2.1 there are four formulated sub-questions. Those questions will be answered below in section 8.2.1 – 8.2.4.

8.2.1 What safety requirements for hazards are attached to a nuclear power plant and where are they specified?

The requirements that are attached to a nuclear power plant are based on international knowledge, research and experience. The identified hazards in the UK and Sweden are based on the case study at Sizewell B and unit O2 at OKG and are presented in table 8.

Table 8 Identified hazards to the nuclear power plants Sizewell B and unit O2 at OKG.

UK (Sizewell B)	Sweden (unit O2 at OKG)
Fire	Global and local effects, pipe-breaks
Pressurised component failure	Fire
Internal missiles	Seismic
Internal flooding	External events
Seismic	Internal events
Extreme external environmental conditions	Very unlikely events, H5
Miscellaneous hazards	-

For power uprating or major modernization the hazards are treated in the safety documentation, for the UK in the Safety Case and in Sweden in the PSAR. In the UK the hazards are identified from the threats that the licensee can identify. In Sweden the legislation and regulations are quite detailed and the protections from the hazards are built on these system. As such, the countries are handling the hazards in the safety documentation differently.

A Safety Case is built on a claim, evidence, and arguments which can closely be translated as acceptance criteria, analyses, and requirements respectively.

In Sweden the PSAR is based on the existing Safety Analysis Report where the requirements are addressed in a chapter, and later analyzed together in another chapter. The acceptance criteria are then established based on the analysis.

8.2.2 Are there significant differences in laws and regulations?

The UK's and Sweden's legislation denote that the risk and safety must be controlled and that safety requirements need to be attached to all nuclear power plants. The legislation systems differ in how the safety need is assessed. In the UK the licensee is assessed against the ALARP with the help of the SAPs and TAGs. Those are non-perspectives and are essentially guidelines for the regulators. In Sweden the hazards are assessed against relatively detailed safety legislation. The Swedish laws are inspired by the U.S standards.

A power uprate or major modernization in the UK shall only be communicated with the HSE/ND. The laws governing the nuclear safety in the UK are HSWA, NIA65 and LC36. In Sweden the government has the responsibility for regulating the nuclear power. For power uprating or major modernization it is primly three laws that regulate the nuclear power, The Nuclear Activity Act, The Ionising Radiation Act, and The Environmental Code. There are also regulations published by the SSM that support the laws dealing with safety and design. The Swedish legislation and regulations are described in much detail, except for some areas where requirements are completely missing.

8.2.3 Are there differences in requirements of the specification of the hazards in the safety documentation?

In both countries, safety analysis has to be both deterministic and PSA. PSA analysis contains three different levels: 1, 2, and 3. In the UK the hazards are analysed on all three levels, while Sweden is just using level 1 and 2 for analysing the hazards since it believes that the measurements that have been taken are satisfactory and the probability of an accident occurring is low.

8.2.4 Are there differences in the way the licensee decides if safety requirements are fulfilled? What are the decision criteria and the assessment process?

In the UK the acceptance criteria are set according to a national approach called the “top down” approach. The risk has to be lower than 10^{-6} and the ALARP principle is translated into Numerical targets that are specified after 8 different scenarios.

In Sweden the acceptance criteria have no legal limits just recommendations from the SSM. The licensee has to compare the risk with similar nuclear power plants and international experience, and then decide the goal for their specific plant. Next, they communicate with the SSM and create a plan for how they will reach those goals.

Chapter 9 - References

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9.1 Internal references

9.1.1 Sizewell B

Reference number	**Name of report**	**Report umber**	**Kind of report**	**Date**	**Rev. date**
A1	Sizewell B Power Station, Station safety report - Chapter 2 section 2 - Fundamental safety principles and their interpretation	SXB-IP-72001-536	Station Safety Report	2009-02-17	First Edition
A2	Sizewell B Power Station, Station safety report - Chapter 2 section 5 - fault Analysis approach	SXB-IP-72001-752	Station Safety Report	2009-02-20	First Edition
A3	Sizewell B Power Station, Station safety report - Chapter 3 section 8 - hazardous protection implementation	SXB-IP-772001-594	Station Safety Report	July 2001	2008-11-11
A4	Sizewell B Power Station, Station safety report - Chapter 12 section 5	SXB-IP-772001-787	Station Safety Report	July 1999	2008-09-26
A5	Sizewell B Power Station - station safety report - Chapter 1 section 2 - Station safety report overview	SXB-IP-772001-520	Station Safety Report	2001-06-26	First Edition
A6	Sizewell B Power Station - station safety report - Chapter 15 section 2	SXB-IP-772001-802	Station Safety Report	June 2008	2009-02-16

9.1.2 OKG

Reference number	Name of report	Report number	Kind of report	Date	Rev. date
B1	Oskarshamn 2 - Inledning och beskrivning av säkerhetsredovisningen (SR)	2001-10885	Safety Analysis Report –SAR A1 General part	2006-11-26	Fourth Edition
B2	Oskarshamn 2 - Säkerhetsrapport - Kapitel 2 - Avsnitt 2.1 - Inledning	2005-07127	Safety Analysis Report –SAR A1 General part	2006-04-11	First Edition
B3	Oskarshamn 2 - Säkerhetsrapport - Kapitel 2 - Avsnitt 2.2 - Kravhierarki	2004-12867	Safety Analysis Report –SAR A1 General part	2004-12-02	First Edition
B4	Granskning och annan tillsyn vid höjning av den termisk effekt i kärnkraftsreaktorer	SKI-PM 04:11	Report	2004-11-01	-
B5	Oskarshamn 2 – Avsnitt 2.3 - Säkerhetsrelaterade konstruktionskrav, 2.3.2 Svensk lag, 2.3.3 SKI-krav	2004-12922	Safety Analysis Report –SAR A1 General part	2007-02-15	Second Edition
B6	Oskarshamn 2 - Projekt Plex - Ansökan om tillstånd för höjning av termisk effekt	2007-01507	Applying for a licence	2007-06-20	First edition
B8	Oskarshamn 2 - Klassning av byggnader, system och komponenter	2005-07378	Safety Analysis Report –SAR A1 General part	2006-03-03	Second Edition
B9	Oskarshamn 2 – Säkerhetsrapport – Kapitel 2 Avsnitt 2.5 Konstruktionsstyrande händelseförlopp och acceptanskriterier	2/A1/0012	Safety Analysis Report –SAR A1 General part	2009-09-22	Fourth Edition
B10	Oskarshamn 2 – Säkerhetsredovisning SAR – Avsnitt 2.6 – Krav för skydd mot globala och dynamiska effekter vid rörbrott	2002-01586	Safety Analysis Report –SAR A1 General part	2002-02-08	First Edition
B11	Oskarshamn 2 - Strål-skyddskrav	2002-05797	Safety Analysis Report –SAR A1 General part	2004-11-30	Second Edition
B12	Oskarshamn 2 – Konstruktionskrav och dimensioneringsförutsättningar för härden	2005-09936	Safety Analysis Report –SAR A1 General part	2007-03-19	Second Edition
B13	Oskarshamn 2 – Säkerhetsredovisning – SAR Avsnitt 2.9 – Brandskyddskrav	2/A1/0011	Safety Analysis Report –SAR	1999-07-09	First Edition

			A1 General part		
B14	Säkerhetsredovisning - SAR Avsnitt 2.10 - Seismisk konstruktion	NTC95-327	Safety Analysis Report –SAR A1 General part	1995-11-02	Second Edition
B15	Säkerhetsredovisning - SAR Avsnitt 2.11 - Skydd mot yttre påverkan	NTC96-056	Safety Analysis Report –SAR A1 General part	1996-11-27	Third Edition
B16	Oskarshamn 2 – Skydd mot inre händelser	2006-04236	Safety Analysis Report –SAR A1 General part	2006-04-24	First Edition
B17	Oskarshamn 2 - Krav på skydd vid mycket osannolika händelser (H5)	2005-13565	Safety Analysis Report –SAR A1 General part	2006-02-20	Second Edition
B18	Oskarshamn 2 – Säkerhetsrapport – Kapitel 2 Avsnitt 2.14 Kriterier för miljökvalificering av komponenter	2007-14849	Safety Analysis Report –SAR A1 General part	2008-03-18	Second Edition
B19	Oskarshamn 1, 2 och 3 – Säkerhetsrapport – Kapitel 2 Avsnitt 2.15 Fysiskt skydd	2008-12-15	Safety Analysis Report –SAR A1 General part	2008-12-15	Second Edition
B20	Oskarshamn 1, 2 och 3 – Säkerhetsrapport – Kapitel 2 Avsnitt 2.16 Vattenkemiska krav	2008-31799	Safety Analysis Report –SAR A1 General part	2008-11-17	First Edition
B21	Oskarshamn 2 – Säkerhetsredovisning – SAR Avsnitt 2.17 – Periodisk provning av säkerhetsutrustning	2001-11083	Safety Analysis Report –SAR A1 General part	2002-02-28	First Edition
B22	Oskarshamn 2 - Säkerhetsrapport - Kapitel 6 Avsnitt 6.1 - Felfunktioner i reaktorn	2/A1/0026	Safety Analysis Report –SAR A1 General part	2010-02-25	Fourth Edition

Appendix A – Explanations of expressions and abbreviations

Below you will find terms and abbreviations, which are necessary in order to understand the meaning and the content of the report. Expressions are thoroughly described while the terms are listed and the abbreviations of terms are written in complete form. There are many different glossaries that explain the expressions and abbreviations. In the UK, NDA has published a glossary, which can be found at: http://www.nda.gov.uk/help/glossary.cfm and in the U.S has NRC developed a glossary which can be found at: http://www.nrc.gov/reading-rm/basic-ref/glossary.html#top.

A1 Explanations of expression

Barrier	Used to prevent radiological releases into the atmosphere. A nuclear power plant is covered by several barriers. If a barrier is going to be damaged, the next barrier will then take over and prevents radiological releases. Fixed barrier protective functions can be: reactivity control, emergency core cooling, pressure relief of the reactor's primary system, residual heat removal, emergency ventilation, and cooling of the fuel bundles [B1].
Critical group	According to SSMFS 2008:23 paragraphs 2, it explains that it is representative of real or hypothetical groups of people from the public which expect to absorb the highest ionizing radiation.
Defense-in-depth	“An approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon. Defense-in-depth includes the use of access controls, physical barriers, redundant and diverse key safety functions, and emergency response measures.” (NRC 3).
DNB	“The point at which the heat transfer from a fuel rod rapidly decreases due to the insulating effect of a steam blanket that forms on the rod surface when the temperature continues to increase.” (NRC 2).
Dryout	Is a phenomenon in Boiling water Reactors which occurs when the liquid film of water on the fuel surfers disappears, which causes a temperature increase where the fuel cladding can get damages.
Effective dose	Paragraphs 2 in the SSMFS 2008:23, is the effective dose, the summery of all equivalent doses that have been observed of the organ and tissue, divided by how sensitive they are for radiation.
Fuel assembly	“A structured group of fuel rods (long, slender, metal tubes containing pellets of fissionable material, which provide fuel for nuclear reactors). Depending on the design, each reactor vessel may have dozens of fuel assemblies (also known as fuel bundles), each of which may contain 200 or more fuel rods.” (NRC 1).

Hazards	"Hazard is the potential for harm from an intrinsic property or disposition of something that can cause detriment, and risk is the chance that someone or something is adversely affected in a particular manner by the hazard." (HSE 1, paragraph 9).
IAEA	The International Atomic Energy Agency, IAEA, is an independent intergovernmental United Nations organization. IAEA planning for that nuclear power should only be used in civil purposes. The IAEA inspects nuclear facilities all around the world, but mostly in the States. They also develop nuclear safety standards and promote the achievements and maintenance for a high level of safety applications (IAEA 2).
Optimizing of radiation Protection	According to SSMFS 2008:23 paragraph 2 this means that the limiting of radiation doses to humans shall be as low reasonably determined. Both economical and social factors need to be taken into account.

A2 Abbreviations

AGR	Advanced Gas-cooled Reactor.
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable. Synonymous words are ALARA and SFAIRP.
BAT	Best Available Techniques.
BE	British Energy.
BSLs	Basic Safety Levels.
BSOs	Basic Safety Objectives.
BWR	Boiling Water Reactor, see also *Appendix C – Light water reactors*.
CCF	Common Cause Failure.
CEGB	Central Electricity Generating Board.
DfT	Dangerous Goods Division for Transport´s Radioactive Materials Transport Team. They are operating in UK.
DNB	Departure from Nucleate Boiling.
EA	Environment Agencies
EC	European Commission.
EdF	Electricité de France.
EU	European Union.
HSE	Health and Safety Executive.
HSWA	Health and Safety at Work etc. Act 1974.
IAEA	International Atomic Energy Agency.
INRA	International Nuclear Regulators Association.
IRR	The Ionising Radiation Regulations 1999.
LC36	Licence Conditions 36.
mSv	Millisievert. Millisievert is defined in the SI system as "the average accumulated background radiation dose to an individual for 1 year, exclusive of radon, in the United States." (SI).
ND	Nuclear Directorate a part of HSE. They are responsible for the nuclear safety in the UK.
NEA	Nuclear Energy Agency.
NII	Nuclear Installation Inspectorate, a part of HSE (UK). They are the nuclear inspectors at nuclear power plants.
NRC	Nuclear Regulatory Commission.
OECD	Organisation for Economic Co-operation and Development.
OKG	Oskarshamns Kraftgrupp AB.

ONR	The Office for Nuclear Regulation. This is a proposed name of the new regulators in theUK nuclear industry. A program has been set up to fit the future and meets the challenges of an increasing nuclear industry in the UK.
pa	Per Annum.
Plex	Plant Life Extension. This is the project name that OKG is used when the power and modernization is made of unit O2 [B6].
PSA	Probabilistic Safety Analysis.
PSAR	Preliminary Safety Analysis Report.
PSR	Periodic Safety Report.
PWR	Pressurized Water Reactor, se also *Appendix C – Light water reactors*.
R2P2	Reducing Risk and Protecting People. This is a document published by HSE (UK) and explains how statutory bodies that are responsible for the risk under HSWA will approach the decision of risk.
RAMA	Reactor Accident Mitigation Analyses. Project name for OKG to implement safety systems in all nuclear power plants [B9].
RCPB	Reactor Primary System [B9].
SAR	Safety Analysis Report.
SSM	Swedish Radiation Safety Authority.
STF	Technical specification.
SZB	Sizewell B.
SAR	Safety Analysis Report. Uses of the Swedish nuclear power plants, the purpose is to show safety to the public and for the authority.
SR	Safety Report.
SNUPPS	Standardised Nuclear Unit Power Plant System.
SSR	Station Safety Report.
TMI	Three Mile Island.
TOR	"The Tolerability of risk from nuclear power stations". A document published by HSE in the UK.
UK	United Kingdom. Include England, Wales, Scotland and North Ireland (National Statistics).
UKSO	UK Safeguards Office.
WENRA	Western European Nuclear Regulators Association.

Appendix B – Status on Nuclear reactors

Below, table B1 show the UKs all nuclear power plants. Take not of Hartlepool 1 & 2 and Haysam 1 & 2 on theirs expected shut down date to 2014. The government is currently deciding if they will still be a part of the future for nuclear power in the UK (BBC 2).

Table B1 Status on nuclear power station in the UK (WNA 1).

Reactors	Type	Net capacity each (MW)	Start Operat-ing	Expected shutdown	Owner
Oldbury 1 & 2	Magnox	220	1968	Dec 2010	Magnox North
Wylfa 1 & 2	Magnox	490	1971-72	Dec 2010	Magnox North
Dungeness B 1 & 2	AGR	545	1985-86	2018	British Energy
Hartlepool 1 & 2	AGR	595	1984-85	2014 (2019?)	British Energy
Heysham 1 & 2	AGR	615	1985-86	2014 (2019?)	British Energy
Heysham 3 & 4	AGR	615	1988-89	2023	British Energy
Hinkley Point B 1 & 2	AGR	620 and 600	1976-78	2016	British Energy
Hunterston B 1 & 2	AGR	610 and 605	1976-77	2016	British Energy
Torness 1 & 2	AGR	625	1988-89	2023	British Energy
Sizewell B	PWR	1200	1995	2035	British Energy

Below, table B2 shows all of Swedens nuclear power plants.

Tabell B2 Status on nuclear power station in Sweden (OKG 1; Vattenfall 1; Vattenfall 2).

Reactors	Type	Net capacity each (MW)	Start Operat-ing	Expected shutdown	Owner
Forsmark, 1, 2 & 3	BWR	978, 990, 1170	1980-85	The aim is to let the reactor operate for 60 years	Vattenfall (66 %), Mellansvensk Kraftsgrupp (25,5 %), E.ON (8,5 %)
Oskarshamn 1, 2 & 3	BWR	491, 617, 1400	1972-83	The aim is to let the reactor operate for 60 years	E.ON (54,5 %), Fortum-koncernen (45,5 %)
Ringhals 1, 2, 3 & 4	1 BWR & 3 PWR	855, 866, 1043, 935	1976-83	The aim is to let the reactor operate for 60 years	Vattenfall (70,4 %), E.ON (29,6 %)

Appendix C – Light water reactors

There are two types of Light water reactors, Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWRs). It works in the same way because both are based on heating the water so that steam is formed which then drives a turbine and a generator, where electricity is produced (SSM 3). Both reactor types have uranium dioxide enriched in zirconium tubes (British Energy 2).

Below, in figure C1, the principle of the PWR is shown. PWR is the most typical reactor; nearly 60 % of the civil nuclear reactors have this type. The efficiency is about 32 % (British Energy 2). On the British Energy's homepage PWR is explained as follows (British Energy 2):

"Pressurised water acts as both moderator and coolant and heats water in a secondary circuit via a steam generator to produce steam. The reactor is encased in a concrete biological shield within a secondary containment."

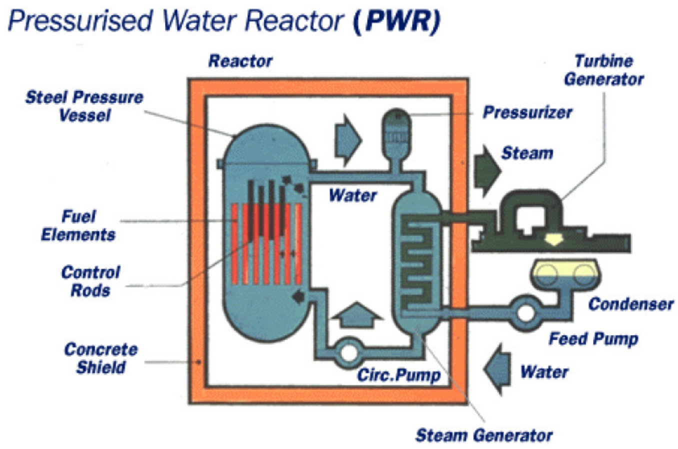

Figure C1 A picture of the PWR process (British Energy 2).

Below, in figure C2, the principle of the BWR is shown. BWR has exactly the same thermal efficiency as the PWR, 32 %, see figure C1. On the British Energy's homepage BWR is explained as follows (British Energy 2):

" Water is pumped through the core, again acting as both moderator and coolant, inside a pressure vessel. About 10% of the water is converted to steam and passed to steam turbines. After condensing it returns to the pressure vessel to complete the circuit."

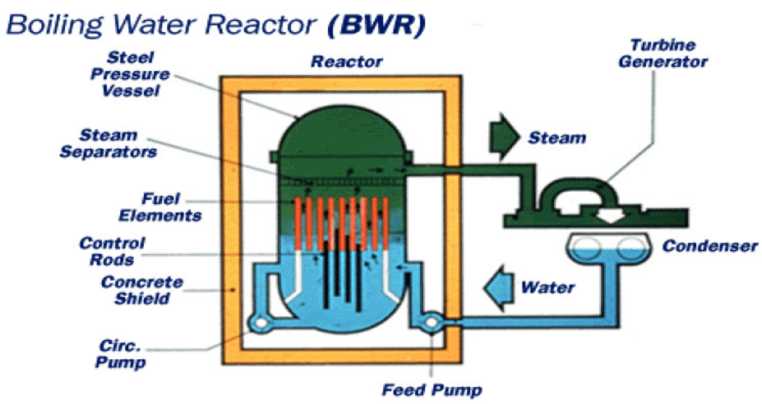

Figure C2 A picture of the PWR process (British Energy 2).

Appendix D – Levels of risk in the UK

The framework that HSE uses when assessing a Safety Case is illustrated in figure D1 below. (HSE 10, paragraph 122).

HSE explain the ALARP principle and the figure C1 as following (HSE 10, paragraph 122):

"The triangle represents increasing level of 'risk' for a particular hazardous activity (measured by the individual risk and societal concerns it engenders) as we move from the bottom of the triangle towards the top. The dark zone at the top represents an unacceptable region. For practical purposes, a particular risk falling into that region is regarded as unacceptable whatever the level of benefits associated with the activity. Any activity or practice giving rise to risks falling in that region would, as a matter of principle, be ruled out unless the activity or practice can be modified to reduce the degree of risk so that it falls in one of the regions below, or there are exceptional reasons for the activity or practice to be retained."

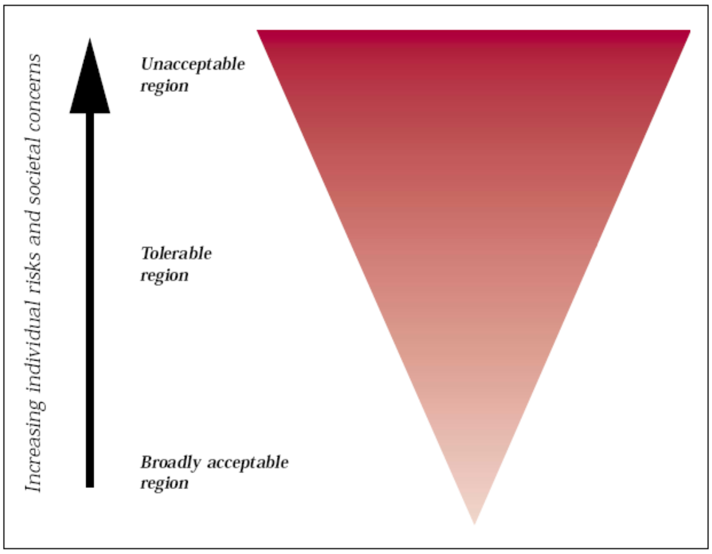

Figure D1 HSEs framework for the tolerability of risk (HSE 10, paragraph 122).

Figure D2 below shows the same principle as the figure D1 above but is more detailed. A risk has to be within the "ALARP zone" to be classified as a tolerability risk.

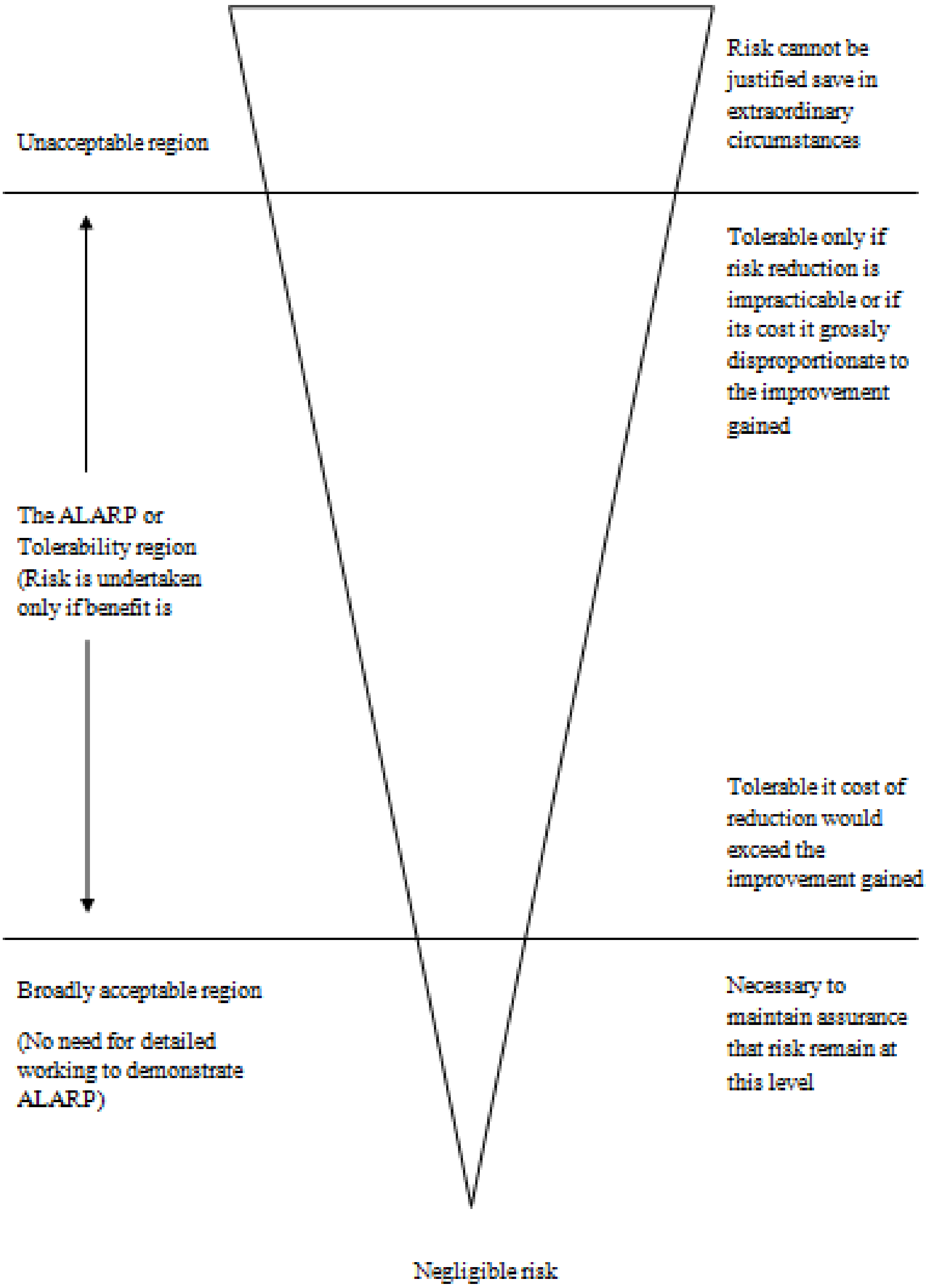

Figure D2 Levels of risk and ALARP (HSE 13).

Figure D3 below shows HSEs assessment of how a random person in the public can be exposed to tolerability of risk from nuclear power plants.

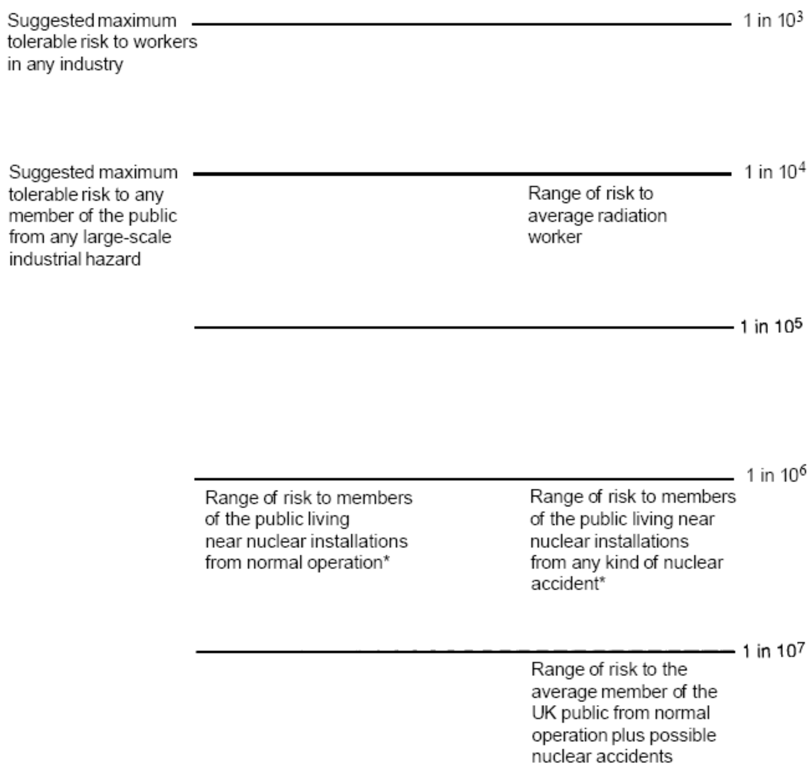

Figure D3 Tolerable risk to operators and to the public (HSE 13, p.38). Observe that the quantitative numbers do miss out on the potency, i.e. read 1 in 10^4 as 1×10^{-4}.

Appendix E – ALARP

This appendix is a summery done by the HSE and ND for proposed approaches of safety assessment at nuclear power plants and to keep the risks As Low As Reasonably practicable, ALARP. The text below is taken from one of the Technical Assessment Guides, TAGs, which also are provided and developed by the HSE. When power uprating or with major modernizations the licensees have to show that the measurements are based on good practice and best engineering techniques. Therefore a document called, *ALARP for new civil nuclear reactors* is of significant importance (HSE 9).

The HSE will assess a Safety Case after the ALARP principle and focus on the list below which is directly taken from the Technical Assessment Guide 005 Annex 3 (HSE 9).

"1 There is a clear conclusion that there are **no further reasonable practicable improvements** that could be implemented, and therefore the risk has been reduced ALARP.

2 **Relevant good practice**: This is the basic requirement of demonstrating that designs meet the law. The Requesting Party (RP) must set out the standards and codes used and justify them to the extent that we can 'deem' them Relevant Good Practice when viewed against our SAPs (see paragraph 3.5, 5.1 and 5.5). This justification is expected to include a comparison with other international/ national standards. Clearly the standards and codes adopted by the RP must be shown to have been met.

3 **Options**: This will comprise two stages: Firstly an examination of the RP's rationale for the evolution of the design, using its forerunners as a baseline, why certain features were selected and others rejected and that this process has resulted in an improved design from the safety aspect. Secondly the Requesting Party needs to address the question "what more could be done?" and provide an argument of "why they can't do it" (i.e. it is not reasonably practicable). This second element could be done by postulating further options for improvement (previously discarded options may be suitable candidates) and evaluating them, or by showing that it is only worth spending trivial amounts of money (see para 5.21). Clearly if an option was shown to be Reasonably Practicable that option should have been taken or where it is found to be worth spending non trivial amounts to improve safety, then further avenues for risk reduction should be explored.

4 **Risk assessment**: The use of risk targets in isolation is not an acceptable means of demonstrating ALARP and we expect to see risk assessments used to identify potential engineering and/or operational improvements as well as confirming numerical levels of safety. The BSOs in the SAPs represent broadly acceptable levels below which we have said that we expect to confine ourselves to considering the validity of the arguments that the BSOs have actually been met. We have also made it clear that the way in which we apply these numerical targets will depend heavily on the views we form on the engineering (and at a later stage operational practices) and that meeting the BSOs is not a green light for requesting parties to forgo further ALARP considerations. Nevertheless, well supported numerical risk figures that show BSOs to be met can be an important element of support to the overall ALARP demonstration."

Appendix F – The Environmental Code, General Provisions

In Ch 2 in the Environmental Code the general provisions can be found. They have to be taken into account when a power uprate or a major modernization is taking place. The principals are following:

- **The principle about best possible technology, BAT, Ch 2 section 1:**
  "In connection with the consideration of matters relating to permissibility, permits, approvals and exemptions and of conditions other than those relating to compensation, and in connection with supervision pursuant to this Code, persons who pursue an activity or take a measure, or intend to do so, shall show that the obligations arising out of this chapter have been complied with. This shall also apply to persons who have pursued activities that may have caused damage or detriment to the environment. For the purposes of this chapter, 'measures' shall mean measures that are not of negligible significance in individual cases."
-
- **Knowledge requirement principle, Ch 2 section 2:**
  "Persons who pursue an activity or take a measure, or intend to do so, must possess the knowledge that is necessary in view of the nature and scope of the activity or measure to protect human health and the environment against damage or detriment."
- **The precautionary principle, Ch 2 section 3:**
  "Persons who pursue an activity or take a measure, or intend to do so, shall implement protective measures, comply with restrictions and take any other precautions that are necessary in order to prevent, hinder or combat damage or detriment to human health or the environment as a result of the activity or measure. For the same reason, the best possible technology shall be used in connection with professional activities. Such precautions shall be taken as soon as there is cause to assume that an activity or measure may cause damage or detriment to human health or the environment."
- **The product choice principle, Ch 2 section 4:**
  " In the case of activities and measures for whose purposes land or water areas are used, unless on a purely temporary basis, a suitable site shall be selected with regard to the provisions of chapter 1, section 1 and chapters 3 and 4. Sites for activities and measures shall always be chosen in such a way as to make it possible to achieve their purpose with a minimum of damage or detriment to human health and the environment."
- **The resource management and ecocycle principle, Ch 2 section 5:**
  " Persons who pursue an activity or take a measure shall conserve raw materials and energy and reuse and recycle them wherever possible. Preference shall be given to renewable energy sources."
- **The appropriate location principle, Ch 2 section 6:**
  "Persons who pursue an activity or take a measure, or intend to do so, shall avoid using or selling chemical products or biotechnical organisms that may involve risks to human health or the environment if products or organisms that are assumed to be less dangerous can be used instead. The same requirement shall apply to goods that contain or are treated with a chemical product or a biotechnical organism."
- **The reasonableness principle, Ch 2 section 7:**
  " The rules of consideration laid down in sections 2 to 6 shall be applicable where compliance cannot be deemed unreasonable. Particular importance shall be attached in this connection to the benefits of protective measures and other precautions in relation to their cost. The cost-benefit relationship shall also be taken into account in assessments relating to total defense activities or where a total defense measure is necessary. A decision reached in accordance with the first paragraph must not entail infringement of an environmental quality standard referred to in chapter 5."

Appendix G – Sizewell B hazards

Table G Identified hazards in the Sizewell B Safety report.

Safety requirements	Short description	Rules and regulations	Purpose	Assessment
Fire [A3]	Cover the whole spectra that can cause any fire. From were fire can start and were fire can cause any danger or damage. Includes both internal and external.	HSW Act 1974. This law is to conform to the ALARP principle.	ALARP Fire protection is necessary to ensure that no fault is caused by fire and that no equipment will be damage.	The fire protection assessment is to ensure that the probability for a fire is ALARP, safe shutdown can be achieved, protect the design and operating, and personal safety in case of fire.
Pressurised component failure [A3]	The hazards from pressurized component failure include, pipe whip, jet impingement, missiles, blast effect and compartment pressurization, flooding, fluid, spray, heating and condensation, and water hammer.	HSW Act 1974. Key sections is 2 and 3	To prevent radioactivity to the environmental and damage on other components that may occur if a pressurised component fails.	The assessment is made of many components that can affect the safety, environmental, operation aspects, inside and outside Containment, design approach etc.
Missiles [A3]	This hazardous cold is generated by the following: rotating component failure, pressurized component failure, turbine disintegration, dropped load, explosive effect of electrical fault, and wind generated missiles.	HSW Act 1974. Key sections is 2 and 3	"A design objective is to reduce the likelihood of missile generation to ALARP." [A3, p.42]	The assessment has been done by the help of single failure analysis and PSA.
Internal flooding [A3]	Internal flooding defines if water is generated by any source in the station building. The defence with segregation equipment and design of barriers will avoid failure in case of flood.	HSW Act 1974. Key sections is 2 and 3	To protect equipment that will be damaged in case of contact with water.	A number of assessments have been undertaken with help of result from single failure analysis and PSA. As well as flood assessment to check that the equipment, barriers etc. can withstand internal flooding.
Seismic [A3]	To protect the plant from motions caused by flexing and shaking , "sloshing" of	HSW Act 1974. Key sections is 2 and 3		A number of measurements have been taken to be sure that the design can withstand this

	liquids in vessels and tanks, differential movement between buildings etc.			hazard.
Extreme external environmental conditions [A3]	Extreme external conditions includes external environmental hazards considerations to the design like air temperature and humidity, sea water temperature, wind and wind generated missiles, precipitation, flooding and lightning.	HSW Act 1974. Key sections is 2 and 3	Each hazard has the potential to damage safety related systems and equipment and the objectives of protection is thereby to protect the safety barriers between the hazards and the equipment.	Every hazard is assessed on its own and with an overall design approach to adequate hazard protection. The ND will base some assessment on TAGs 013.
Miscellaneous hazards [A3]	Miscellaneous can be one or more of the following: dropped loads, aircraft crash, Sizewell A, On-site and off-site hazardous substances, electrical and electromagnetic interference, turbine disintegration, explosive effects of electrical faults, water pollution, wildlife, and sabotage.	HSW Act 1974. Key sections is 2 and 3	Each hazard has the potential to affect important equipment and therefore protection is necessary.	For these hazards the frequency and appropriate measures have been discussed in a logical manner. Although probabilistic analysis hr done for those who consider appropriate.

Appendix H – Unit O2 at OKG hazard

In this appendix two different tables are presented, table H1 and table H2. Table H1 presents the identified hazards and table H2 presents other events that are often treated in the same way as hazards in Sweden.

Table H1 Identified hazards on the unit O2 at OKG Safety report.

Safety requirements	Short description	Legislation	Purpose	Assessment
Global and local effects, pipebreaks [B10]	These hazards include small pipe break to guillotine break. Proposed measurements have to be tested against negative consequences. Inspiration of this comes from GDC 4, from the genera U.S. law 10CFR50.	• SSMFS 2008:1 Ch 3 section 1 • SSMFS 2008:17 section 12-13	To protect the safety systems.	For all event classes a description is given of how the reactors are affected and if it can be accepted.
Fire [B13]	A fire needs to be controlled so that no safety systems will be damage. Especially no damage on the barriers, because they will protect the reactor from any damage. This will be done by fire cell classification and try to keep a high standard on the materials.	• SSMFS 2008:1 • SSMFS 2008:17 **Support documents:** • SBF72 • Regulatory Guide 1.189	Protect the operator and the public from radiological radiation that have been caused by fire.	Assessments are based on analyses and the regulation 2008:17 section 14 but also on fire protection laws and guidelines.
Seismic [B14]	Buildings system and components need to be designed to withstand external events like tornadoes, floods, and earthquakes.	• SSMFS 2008:17 section 14	To protect multiple components in case of an accident. The reactor needs to be protected against natural phenomena.	Treated as an H5 event. Needs to be analysed and verified.
External events [B15]	In external events the nuclear power plant shall withstand impacts from natural events and other events that may lead to a radiological accident. Examples are cooling water, extreme water conditions, polluted atmosphere, extreme precipitation, lightning etc.	• SSMFS 2008:1 Ch 3 section 1 • SSMFS 2008:17 section 14	The reactor should be protected against external hazards.	Judgement will include Swedish building regulation SBN-67, BBR 94 and BKR 94. The assessment is also made of how the nuclear power plant can withstand external hazards.
Internal events [B16]	Equipment with	• SSMFS	The reactor	Assessment with

	safety function shall perform its functions even when there are direct impacts on the equipment. Demands on mechanical devices, among other are required. The design needs to withstand the relieve the steam, water and gas at inland flooding, foaming roads, isolation, internal missiles etc.	2008:17 section 3, 7, 12, 14, 17	should be protected against internal hazards.	help of analysis in both H4 and H5 event classes.
Very unlikely events (H5) [B17]	This requirement is a consequence after the TMI accident.	The overarching requirement is given in the Government decision 12 February 27, 1986, "Villkor för fortsatt tillstånd enligt 5 § lagen (1984:3) om kärnteknisk verksamhet att driva kärnkraftreaktorerna Oskarshamn I, II och III." • SSMFS 2008:17 section 5, 6, 8, 18	No event is too low in probability to happen[63]. Protection against core damage.	Analysis within the event class H5.

Supported initializing events are often treated in the same way as the hazards. Those ones are presented in a separated table H2 below.

Table H2 Other events that are often treated in the the same way as the hazards in Sweden.

Safety requirements	Short description	Legislation	Purpose	Assessment
Initiating event sequences [B9]	The initiating events includes from normal operation to very unlikely events where the core gets negatively affected. This technical method is based on ANSI/ANS 52.1-1984.	• SSMFS 2008:17 section 22.	Aims to provide a basis for analysis, with a balanced risk profile.	For every event class a description is given of how the reactor is affected and if it can be accepted.
Radiation [B11]	The operation shall be performed so that the ionizing radiation reduces as far as reasonable according to ALARA.	• The Radiation Protection Act • SSMFS 2008:26 • SSMFS 2008:51 • EUs directive 96/29/Euratom	Protect the operator and the public from radiological radiation.	Will be assessed against the ALARA. Assess against dose limits and also reference to the effective dose needs to be done.
Design requirements[B12]	Includes the safety requirements and the fuel. Two strategies	Various criteria and guidelines except for those ones below are	Avoid core damage.	The assessment is based on maximum allowable

[63] *Analyst – System Assessment, Lars Gunsell, Swedish Radiation Safety Authority, phone call 2010-06-15.*

	are used: Instability needs to be discovered automatic and measurement against bad fuel needs to be taken.	treating those criteria. Most relevant are: • SSMFS 2008:1 Ch 3 section 1 • SSMFS 2008:12 section 23-27 **Support documents:** • Multiple parts from 10CFR50.		limit, core damage control, and analyses.
Criteria for environmental components [B18]	Deals with the environmental factors that account for the environmental qualification. Environmental qualification means that comptometer used in the initial events to perform their tasks in the environment they are used in.	• SSMFS 2008:1 Ch 3 section 2 • SSMFS 2008:17 section 17 **Support documents:** • Inspiration from GDC 4 the 10CFR50 and regulatory Guide 1.89 That Describe the 1EEE Std 323-1974	The aim is to ensure that building parts shall have environmental classification against environmental effects.	Various tests to verify that the systems and components meet the environmental qualification requirements.
Physical protection [B19]	Provided technical, administrative and organizational measures to protect the plant against sabotage and the intrusion or other factors that may lead to a release or accident. Action shall be based on threats against the nuclear power plant.	• Nuclear Activities Act section 4 • SKIFS 2004:1 • SKIFS 2004:2 • SKIFS 2005:1	To prevent unauthorized persons to access or contact with radioactive materials.	The threat of the plant must be analyzed and then form the basis for taken action.
Water chemistry requirements [20]	These requirements are set out to protect the water chemistry for the reactor coolant and the primary systems activity level.	• SKIFS 2005:2 Ch 2 section 4	Protect the reactor from pollutions.	The assessment wants to prove that pollution that affects the reactor is controlled. The pollution may not lead to adverse impacts on the inside or on the outside of the site.
Periodic testing of safety classified equipments [B21]	Sets overall operation requirements verification and interpretation of the safety design requirements. Divided into two categories, design requirements and operational requirements.	• SSMFS 2008:1 Ch 5 section 3 + Appendix 3 • SSMFS 2008:13 **Support documents:** • Inspiration from US 10CFR50.	The aim is to regularly test and verify that all functions are good enough to fulfil their job until the next test will occur.	Safety analysis.

Appendix I – Sizewell B safety analysis

In table I below a rough summary of the Sizewell B safety analysis for hazards are made. Which roughly means that the details are omitted and the focus is directly on the chosen scenarios and the analysis? Table I intends to give knowledge over what kind of scenarios and hazards are analyzed. The analysis applies both to the early designs and constructing commission phase and thus is considered to be representative of the output increase or major modernization.

Table I The Sizewell B analyses for identified external and internal hazards.

Safety Analysis	Short description	Analysis method (all included analysis for plant walk downs)	Consequences	Assessment[64]
Fire [A3]	The analysis have three different objectives: provide sufficient systems, ensure the design and operation in case of fire and take all necessary and practicable steps to ensure personal safety.	The main analyse method have been Single Failure Analysis, Fire Hazard Criteria Assessment, and PSA. They showed redundancy and separation, adequately implemented criteria respective of the risk of nuclear accident caused by fire.	To protect the segregation system from any damage and to prevent a nuclear accident caused by fire.	ALARP
Pressurised component failure [A3]	The analyses ensure that safe shutdown can be achieved and that those pressurized failure in combination with other hazards at fault not give unacceptable risk.	Single failure Analysis, PSA, Pressurised Component Failure Criteria Assessment.	To ensure that important protection required have fulfilled their function. Ensure the public is safe from risk of health from radiology accident.	ALARP
Missiles [A3]	The analysis mostly covers missile damage on the design of structural barriers and also in combination with fire.	Single failure Analysis and PSA to ensure safe shutdown and that other hazard do not cause failure in combination with missiles.	Damage the segregation barriers.	ALARP
Internal flooding [A3]	Analyses have been done to evaluate the effectiveness of the protection.	Single failure analysis, Fault Analysis, and Flood Assessment.	Protection for direct damage on equipment in particular the defence of redundant segregated safety classified equip-	ALARP

[64] *The assessment have an background of the document Reducing Risk and Protection People, R2P2.R2P2 set out the framework for ND guidance making and try to ad a coherence across decision making of risks that HSWA cover. The assessment of risk is also based on the "Tolerability of Risk from Nuclear Power Stations", TOR (HSE 9).*

			ment.	
Seismic [A3]	The analysis is done to estimate the annual probability of seismic motion and also to show that margins are good enough.	Seismic fault analysis and discussion for all seismic criteria.	To protect the building from (for example) structural rupture leading, pipe or vessel rupture, loss of electrical connections etc. Uncontrolled radiation release.	ALARP
Extreme external environmental conditions [A3]	To be sure that the building and barriers can stand extreme conditions and operate safe under dose conditions.	PSA, Hazard Criteria Assessment, Lifetime Assessments.	Damage on safety related systems and equipment.	ALARP. General probability of this hazard level is 10^{-4}.
Miscellaneous hazards [A3]	Analyses have included severity and frequency of occurrence.	Probabilistic studies have been done to decide frequencies.	Protection from radiology release.	ALARP

Appendix J – Unit O2 at OKG safety analysis

In table J below a rough summary of the unit O2 at OKG safety analyses for hazards are made. Roughly it means that the details are omitted and the focus is directly on the choice of scenarios and the analysis. The title of the covering event is shown under the consequences. Table J refers hence to reproduce an image of the safety analyses that OKG choose to do. The analyses are done on those parts of the plant that are affected by a power uprate or major modernization. Observe that the results are supposed to be within the intervals in the column *"Assessment"*.

Table J The unit O2 at OKG analyses for identified external and internal hazards when application for power uprate.

Safety Analysis	Short description	Event class	Consequence	Assessment
Malfunctions in the reactor [B6]	Includes flow transients like increasing/reducing of the main flow or dropped control road drop that affect the core transients.	H2-H4.	Dryout	$10^{-2} – 10^{-6}$
Feedwater system malfuntions [B6]	Includes failure affecting feedwater temperature or other feedwater flow.	H2 or H3.	Can give consequences that affects the core by the reactivity increases and increases the dryout factor but also the reactor can be top filled.	10^{-2} - 10^{-4}
Malfunction in the steam line [B6]	Functions that can affect the steam flow.	H2 but verificates against the acceptance criteria for H3 or H4.	Risk of substantial increase in pressure in the reactor and the challenges therefore, the pressure relief of the primary system.	Assess against H3 or H4. This is OKG requirements.
Pipe break outside the reactor containment [B6]	Affects the reactor cooling system and floods.	Loss of coolant – H3 Guillotine break – H4.	The core cooling system verifies the 20-ton criteria[65], Steam line ventilator and pressure on the plant.	Assess against H3 or H4.
Pipe break within the reactor containment [B6]	This differs from the above by the event of breakage, they cannot be isolated. Cooling of the reactor must therefore be via core cooling system. Through time, this risk is seen as the biggest threat reactor.	H3 or H4. In combination with large leakage between the diaphragm floor this will be within the H5 event.	Increase of pressure- and temperature in the reactor containment which can lead to radiological release.	Assess against H3 or H4.
Malfunction in systems for radiological waste	The analyses are carried out exclusively for the fire and the	H3	Break in the Retention tank 341T1	Assess against H3.

[65] *In case of pipe rupture outside the reactor containment shell valves close before 20 tones of water is flowing out [B9].*

[B6]	consequences for break. Moreover, they do not fit into any specific event where they intend to analyze the environmental consequences of large spills.		Fire in the filter 341C1-C4.	
Malfunction in turbine systems [B6]	Can affect the reactor and thus the effect of fuel development and cooling.	H2 or H3 Turbine (H2) Turbine missile (H3) Pipe break in the turbine building (H3).	Affect the fuel and the cooling of the fuel.	Control if the plant's safety systems have good safety margins. Assess against H2-H3.
Malfunction in other systems [B6]	This category instru-mentation and mal-functions of the cooling water system are reported.	H2 or H3.	Risk of affecting the coolant system and some instrumenta-tion.	Assess against H2-H3.
Misadventure when fuel handling [B6]	Includes two aspects, risk for unplanned events and mechanical damage on the fuel. Also transport of radiological waste and storage of radiological waste are included in this Misadventure when fuel handling.	H2-H4.	Mechanical fuel damage and the risk of unplanned nuclear criticality.	The room is con-trolled against conservative assump-tions. Assess against H2-H4.
Earthquake[B6]	OKG was not designed to withstand earth-quakes. In 1986 a Government decision about Severe accidents was made, which resulted in the OKG extending its protec-tion. The requirements are inspired of Regulatory Guide 1.60 (NRC).	H5. Despite the probability an earthquake is classified as an H4 event.	Collapse	The analysis need to show that the reactor can withstand an earthquake.
Fire [B6]	In case of fire the reactor needs to be switched to a safe mode.	-	Cable burns, no signal, pump and fan stops, etc. In worst case even the barriers are affected.	The reactor needs to be able to return to a safe control and satisfied the primary system.
Reduction of scram systems in normal operation [B6]	Fault of the scram system includes primly the pressure relief system.	H2	Steam line stop.	Assess against H2.
External events [B6]	Mainly influence of the outer barrier. Examples are wind and snow but also cooling water.	Involves the majority of the event classes since this includes a wide area.	Affecting of the external barrier.	Assessments are done on the safe operation.
Internal events [B6]	Analyses include floods, dropped loads etc. Internal events	H2-H4	Threats of safety.	Assessments are done on the safe operation.

	could be caused by faults within the facility.			
Analysis for normal operation limits [B6]	Includes refuelling and reactor performance and conditions must be carefully controlled.	-	Effect of reactor and the fuel.	-
Severe accidents [B6]	Requirements related to Severe accidents sequence were added in 1986 at the request of the Government. Includes mitigating systems.	Classified outside the event class system.	Core damage.	Analysis of the installed mitigating systems and how they can cope with large strain.
Probabilistic analysis [B6]	PSA analysis of level 1 and 2. Level 1: The probability of core damage, level 2: Likelihood of radioactive emissions. Each level includes power operation, the bottom-up time and maintenance outage. Complement the deterministic analysis.	-	-	Recommendation limits are: Core damage $\leq 10^{-5}$ Radiological release $\leq 10^{-7}$

Appendix K – Safety Case

The Safety Case structure was developed in a project with the name SHIP and was sponsored by the EU Environment Programme. The objective of the SHIP project was to ensure that the nuclear power plants will be safe in the present and in the future and to remain current with the changes that happen over time. The general structure of a Safety Case for safety is presented with an argument together with models for system failure that can be used as the basis for quantified reliability estimates. The approach is illustrated using plant and computer based examples (Bishop & Bloomfield, 1995).

HSE and the SAPs 2006 explained Safety Case as follows: (HSE 1, paragraphs 76 s. 15):

"A Safety Case is a logical and hierarchical set of documents that describes the radiological hazards in terms of the facility, site and the modes of operation, including potential undesired modes, and those reasonably practicable measures that need to be implemented to prevent harm being incurred. It takes account of experience from the past, is written in the present, and sets expectations and guidance for the processes that should operate in the future if hazards are to be successfully controlled."

A simple Safety Case such as the one show in section 2.2.2 is uncommon. Usually it looks more like figure K below and is very complex. It often contains a number of claims, which do not have to be or look like each other. So the system is often evaluated from both deterministic and probabilistic. In addition, they need different claims seen at different levels of detail. Often it is proposed that the Safety Case structure is using different hierarchy of claim as shown in figure K below (Bishop & Bloomfield, 1995).

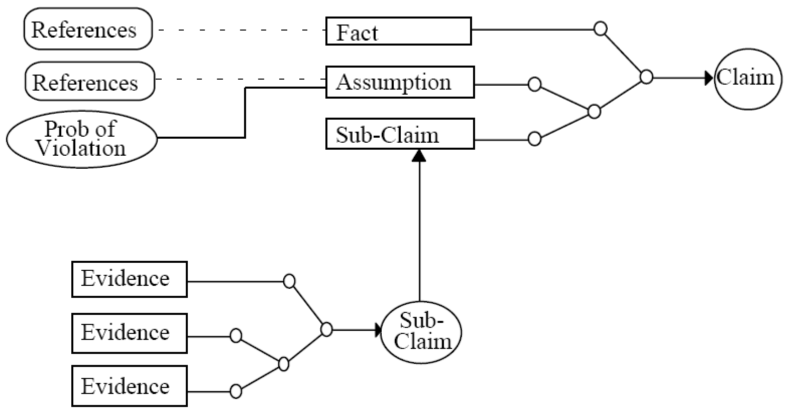

Figure K Hierarchic argument Structure (Bishop & Bloomfield, 1995 p.3).

HSE are clear that a Safety Case will answer following eleven questions (HSE 9, p.8):

“1) What is the Safety Case for (a new site/facility, plant extension, modification)?

2) What does the site/plant, etc. look like (site layout, design, key features)?

3) What must be right and why (e.g. structural integrity, performance)?

4) How is this achieved (e.g. codes, standards, specifications)?

5) What can go wrong (faults, hazards)?

6) What prevents/mitigates against it going wrong (e.g. protection systems, redundancy, diversity, procedures)?

7) What if it still goes wrong (risk/consequences, emergency arrangements)?

8) What could be done to make it safer ("Optioneering" and ALARP considerations)?

9) What must be done to implement the Safety Case (e.g. operating procedures, limits and conditions, maintenance)?

10) How long will the Safety Case be valid (e.g. full life time or shorter due to life limiting features)?

11) What happens at the end-of-life (decommissioning principles / strategy)?"

A Safety Case shall have a holistic approach with living frames and underpins all safety related decisions made by the licensee.

The bullet list below shows what HSE wants to see in a Safety Case (HSE 9).

- Health and safety management systems, monitoring, review, and audit
- Safety culture
- Safe working practices
- Quality assurance plans and procedures
- Staff qualification and training programme
- Adequate resources and staffing leaves
- Operating rules and instructions
- Operating rules and instructions
- Examination, maintenance, testing, and inspection programme
- Plant severe accident management plans
- Site emergency plan
- Radioactive waste management policy and strategy
- Transport details for radioactive and other hazardous substances.