NKS-303

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Addressing off-site consequence criteria using Level 3 PSA — Phase 1 Status Report

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Abstract

Based on an inquiry from the Nordic PSA Group (NPSAG) and the Nordic Nuclear Safety Research group (NKS), a consortium of Swedish nuclear risk consultancies (Lloyd's Register Consulting, ES-Konsult and Risk Pilot) and the Finnish research institute VTT has begun a multi-year study of Probabilistic Off-site Consequences Analysis, commonly referred to as Level 3 Probabilistic Safety Assessment (Level 3 PSA). Level 3 PSA is infrequently performed and generally regarded as a less developed analysis when compared to Level 1 and Level 2 PSA. Interest in the Nordic countries has been spurred based on new nuclear construction projects and plans. These activities have raised interest in objective, risk-based siting analyses for new nuclear reactors in order to better understand the risks of off-site consequences in the wake of the multi-unit disaster at the Fukushima Daiichi site. The objective of this study is to further develop understanding within the Nordic countries in the field of Level 3 PSA, in order to determine the scope of its application, its limitations, the appropriate risk metrics, and the overall need and requirements for performing a Level 3 PSA. The project's first year focused on the development and analysis of an industrial survey about Level 3 PSA, which included several workshops and meetings with Nordic utilities, regulators, and safety experts. Level 3 PSA risk metrics including health, environmental, and economic effects have been researched and discussed in the first year's project report. The project has generated significant interest internationally and has interfaced with international organizations including the IAEA and the American Nuclear Society. The long term objective of the work is to set the foundation for performing a "state-of-the art" Level 3 PSA for Nordic conditions.

Key words

PSA, PRA, Level 3 PSA, Probabilistic Consequence Analysis, Nuclear Power Plant Safety

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1. Introduction

Level 3 Probabilistic Safety Analysis (Level 3 PSA) provides a probabilistic assessment of off-site consequences from radioactive releases. The input to a standard Level 3 PSA is derived from several sources. The results from the identification and assessment of the accident sequences leading to core damages, which are provided by Level 1 PSA, and the severe accidents and radioactive source term analyses, which are provided by Level 2 PSA, are combined with meteorological, population and agricultural data to estimate the off-site societal, environmental, and economic risks posed by a nuclear facility.

The typical outputs of a Level 3 PSA can vary, but often include collective radioactive doses, health effects (e.g. early fatalities, latent cancers), economic impacts, and agricultural effects. Interest and activities in Level 3 PSA have increased recently for several reasons. The primary reason for the increased interest in Level 3 PSA is to better understand and characterize off-site consequences following the findings from the Fukushima accident, the obligations utilities have from insurance companies and shareholders, and the obligations regulators have to the public's health and safety.

The potential insights that could be gained through Level 3 PSA may assist utilities with operating plants, utilities pursuing new construction, regulatory bodies, public health organizations, and emergency preparedness networks. Therefore, as a structured study of Level 3 PSA, this project seeks to determine the requirements and overall utility of such an analysis. During the project there has been close interaction with utilities, regulators, and insurers which have been able to guide and influence the project execution through participation in project planning, meetings, and seminars.

1.1. Purpose

Interest in Level 3 off-site consequence PSA has risen within the Nordic region, and around the world as a consequence of the Fukushima accidents and the continuing interest in new reactors.

This interest has been reflected in the volume of recent activity in the area of Level 3 PSA at the International Atomic Energy Agency (IAEA) and ongoing projects in the United States, the Netherlands, South Africa, Japan, and elsewhere.

The goal of this study is to further Nordic understanding of the potential for Level 3 PSA to determine the influences and impacts of off-site consequences, the effectiveness of off-site emergency response, and the potential contributions of improved upstream Level 1 and Level 2 PSAs. Level 3 PSA provides a tool to assess the risks to society posed by a nuclear plant, and could be integral in making objective decisions related to the off-site risks of nuclear facilities.

1.2. Scope of project

The project will develop guidance on several significant topics. The reports and seminars will include guidance on the following topics:

1. A summary of the industrial purpose for performing Level 3 PSA
2. Recommended risk metrics for Level 3 PSA
3. Requirements on existing Level 1 & Level 2 studies set by the Level 3 PSA analysis.
4. Insights on abilities of existing Level 3 PSA tools/codes and possible needs for further development.
5. Collection of current regulations, guides and standards toward Level 3 PSA
6. Methodology guidance document

1.3. Project organization

The project includes separate tasks that are being conducted in parallel. Several of these tasks started during 2013, while others will start-up in 2014 and will be finalized in 2015. The project tasks address the following topics:

(0) Industry and Literature Survey, which is completed and the results are detailed in section 2,
(1) Appropriate Risk Metrics,
(2) Regulation, guides and standards,
(3) Development of a Guidance document
(4) Pilot Application including tools for dispersion and consequence analysis

1.4. Project interfaces

The project has had significant interaction with Nordic utilities and regulatory authorities. These include a Stakeholder Meeting where the project financiers provided input on the scope and direction of the project and the Task 0 survey. The stakeholders also responded to the questionnaire that was developed in Task 0, and then assisted in drawing conclusions from the questionnaire during a "Questionnaire Response Workshop". Finally, the working group held a seminar on January 21st, 2014 to summarize the progress during the first year of the project and to receive input on the pathway forward for the project.

The project has created interest in many international organizations and has fostered Nordic participation in several international Level 3 PSA activities. Currently, the IAEA is developing Level 3 PSA guidance through the drafting of a TECDOC. This project has allowed the working group to contribute to this effort through member participation in IAEA Technical Meeting & Consultant Meetings as well as an expert lecturer an IAEA Regional Workshop on Level 3 PSA. The project has also interfaced with groups such as OECD/NEA Working Group RISK and the ANS/ASME Level 3 PSA standard writing committee.

1.5. Report contents

This report describes the developments the working group has made during the calendar year, 2013. The following sections summarize the work performed under each of the separate Tasks outlined in Section 1.3. For further information full task reports will be written, describing more completely the work completed for each respective task.

1.6. Acknowledgements

The working group in this project would like to acknowledge the funding organizations that stand behind this project. Funders are found in several organizations such as the Nordic Nuclear Safety Research group (NKS) and the Nordic PSA Group. NPSAG is represented by the Swedish utilities Forsmark (FKA), Ringhals (RAB) and Oskarshamn (OKG) and the Swedish Radiation Safety Authority (SSM). Funding is also provided by and the Finnish Research Programme on Nuclear Power Plant Safety (SAFIR2014). NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this project possible.

1.7. Disclaimer

2. Task 0 – Industrial Questionnaire and literature study

2.1. Background

This section summarizes responses to the questionnaire developed in the project “Addressing off-site consequence criteria using Level 3 PSA”, in which the field of Probabilistic Consequence Analysis, often referred to as Level 3 PSA, are explored.

The purpose of the questionnaire was to collect base information about current international practices and motivations of utilities and regulators for Level 3 PSA. Even though Level 3 PSA is required only in a few countries, the interest is broader. The results from the questionnaire will contribute to the scope and contents of the Task 3 guidance document.

2.2. Methodology for Task 0

In the project plan for task 0 the following four sub-tasks were presented:

- Literature study and development of the questionnaire
- Implementation of the questionnaire
- Compilation of results
- Final report

2.2.1. Literature study and development of the questionnaire

The first step in task 0 included the formation of the industrial questionnaire and for this a literature study was performed. The questionnaire was founded from earlier similar studies and from discussions between the project group and stakeholders.

2.2.2. Implementation of the questionnaire

The implementation of the questionnaire was done by sending out the questionnaire by mail.

At first the questionnaire was sent out to several organizations where all of the respondents were categorized as “Experts” (authorities, nuclear industry and consultants).

When the responses were first discussed it was clear that it was important to receive answers from a broader public, including insurance companies. Hence, two nuclear insurance companies were contacted.

A list of all of the responding organization can be found in Appendix 1.

The Nuclear Regulatory Commission (USNRC) was not able to provide a response to the the questionnaire. Instead, their response came in terms of a reference to the latest revision of the PSA Use and Development report. Appendix 2, which shows the literature study performed under Task 0, contains an extract from the USNRC report that concerns Level 3 PSA.

2.2.3. Compilation of results

When all answers were received a compilation report was produced. Based on the compilation report a workshop was held.

At the workshop the project group and stakeholders were able to review the answers and the interpretation of them.

The workshop was based on the compilations (answers and draft conclusion) allowing the possibility to discuss and assess the answers to generate a final conclusion for each question. Under the workshop the participants were divided into working groups to allow for an active contribution from stakeholders and project working group members.

Final conclusion from the workshop allows for recommendations and prioritization off issues in responses for the continued work regarding Level 3 PSA.

The workshop discussion also included discussions regarding possible and appropriate risk metrics.

2.2.4. Final report

A final, Task 0 will be produced, which summarizes responses from nuclear experts and nuclear insurance companies and will be used in the following tasks of the project.

2.3. Literature study

The literature study was preformed prior to the development of the questionnaire as well as during the implementation and compilation of the answers to the questionnaire. Input to the literature study was also given by the respondents to the questionnaire and participates to the workshop.

The literature study is presented in appendix 2, with a short introducing text (summary) for each report/study.

2.4. Results of the Questionnaire

2.4.1. Risk comparison and development of Level 3 PSA

Risk comparisons for society made risks are possible to do in theory; however, this might not be possible in practice. One reason is the difficulty in finding comparable units, based on risk. If risk comparisons are to be done this must be done carefully.

There is a difference in voluntary contra involuntary risks as well as making risk comparisons at different perspectives, e.g. from an individual or society point of view.

When comparing the risk with a nuclear power plan to other types of society made risks the whole life cycle must be taken in to account (by making a life cycle analysis, LCA).

One possible comparable unit (risk metrics) for comparing the risk with a nuclear power plant to the risks from other types of energy sources is number of deaths (e.g. per produced TWh or per operating year).

Today the issue, whether or not comparisons to the risks with a nuclear power plant are needed, still needs to be decided.

2.4.2. Needs for Level 3 PSA

The scope for Level 3 PSA and the use of the results from this type of analysis need to be established before the "need" or value for Level 3 PSA can be fully defined. The main expected motivations for performing a Level 3 PSA are, however, to use the analysis as an objective guidance tool for decision making, e.g. regarding costs for rebuilds and emergency preparedness work.

By performing Level 3 PSA hopefully potential risk measures can be defined and help reduce the potential risk for a radioactive release.

The respondents attempted to define "unacceptable effects" of a nuclear accident. This was viewed differently between the nuclear "expert" respondents and the respondents from insurance companies. This indicated the needs for more clearly defining the scope for Level 3 PSA and the use of results.

Unacceptable health effects, from a nuclear expert’s point of view, could be defined from national and international safety standards, e.g. no immediate deaths caused by radiation. Possible, unacceptable, health effects in long term could be compared to other health risks, for example background radiation. There is also the possibility of defining unacceptable health effects by setting dose criteria.

An example of an unacceptable health effects, from an insurance company's point of view, could be: all kinds of health effects that require a visit to hospital and would not exist if the accident would not have happened, the general public should not have any adverse effect from the operation of a nuclear power plant.

Environmental effects could be defined in terms of, e.g. evacuation in short terms and contamination of land areas in long term. For the effects to be unacceptable, from a nuclear expert's point of view, the effects need to be in long terms (more than a couple of months) and affect a large area (larger than the plant site and close surroundings). From an insurance company's point of view, an environmental effect can be defined as unacceptable if the land is contaminated or if there are restrictions in land use and that would not exist if the accident would not have happened.

Environmental impact often leads to economic impact. Some studies have converted environmental effects to monetary value, for example business interruption in activities like fishing, tourism, food production, which is why these two impacts do not always need to be separated from one another.

Unacceptable economic impacts are difficult to define in general. One way to define unacceptable economic impact, from a nuclear expert's point of view, could be; when the "bills" are higher than the economic preparedness. From an insurance company's point of view, however, it could be defined as costs related to third parties such as compensation to people that have to evacuate and to move from their homes. The taxpayers should not be called upon to pay for the damages. From the answers to the questionnaire it can be noted that insurance companies are interested in the economic considerations for Level 3 PSA, while the Nuclear Safety Authorities were somewhat less interested in the question of economic impact.

One way of separating economical risk is to define the effects in terms of risks owned by plant organizations to be acceptable while effects outside the plant site are unacceptable.

2.4.3. Advantages of using Level 3 PSA and risk communication

If the use of Level 3 PSA could lead to defining the risk with nuclear power and expressing the risks in terms that are possible to compare, discuss and calculate (e.g. in monetary values) with other societal risks then the results would be communicable.

Making the risks communicable could help to improve the communication between the nuclear industry, authorities, insurance companies and the community.

The most important communication path consists of two parts. One consists of the communication from experts to authorities and the other one is from authorities to the community (e.g. private persons, non-governmental organizations, and media). However, the authorities (e.g. STUK and SSM) are in a double role because they are both experts and authorities. Communication by authorities is more important than communication by experts.

For the nuclear industry Level 3 PSA could help to:

- Communicate with insurance companies and the analysis could lead to better insurance possibilities
- Communicate with the society in large and thereby create higher acceptance for nuclear power in society
- Better understand societal risks of commercial nuclear power and thereby improve preparedness work
- Provide better design and siting considerations for new construction projects
- Cost benefit metric for plant retrofits

- Improve and extend earlier levels of PSA, Level 1 and 2, in creating a more holistic point of view (this is not a unified opinion).

2.4.4. Challenges with Level 3 PSA

There are several possible uncertainties involved in Level 3 PSA, e.g. uncertainties in the analyses, uncertainties when working with probabilities, uncertainties from ingoing parameters, difficulty to make comparisons between different reactors. The method might also be expensive and require a lot of work and there is also a risk for a large gap in time between performing Level 3 PSA studies which leads to problems with knowledge transfer.

Aside from this there is also, as earlier discussed, difficulties in communicating risks, as well as, different risk perceptions to take into consideration.

On the other hand, there are many possible advantages of performing a Level 3 PSA. One of the advantages that Level 3 PSA can provide is the possibility to compare negative impacts from different technologies. There is also a possibility to see the uncertainties with Level 3 PSA to be, in fact, one of the reasons that we need the analysis method. Level 3 PSA is needed due to the uncertainties.

This different point of view is important to take into consideration when deciding whether or not to work with Level 3 PSA.

“The challenges are also the reasons for performing a Level 3 PSA”.

In order to be able to uniformly work with Level 3 PSA, suitable risk metrics must be defined, together with safety criteria that shall be met. There is also a need for specifying guidelines on how to perform the analysis. The question on how to define an "unacceptable" release and how the results from a Level 3 PSA study should be used requires further discussion.

2.4.4.1. Risk metrics

Suitable risk metrics can be defined based on the possible risk effects; health effects, environmental effects and economic effects, in both short- and long-term.

The complete risk metric would be economic risk metric, since it will cover all the aspect of the risks, but it is the hardest one to use. It can be too much work to get it realistic due to difficulties to determine the economic value for the consequences.

Other possible risk metrics are doses and contamination of land. It is relatively easy to calculate fatalities from these metrics.

Different risk metrics are suitable for different parts of the society depending on the target group. For an insurance provider the economic analysis would be important, and relevant economic metrics would be of interest, while for authorities some other risk metric could be of greater interest.

At this stage of the project it can be difficult to decide which risk metrics is the most suitable; the scope of Level 3 PSA needs to be defined. Task 1, will focus on finding the appropriate risk metrics.

2.4.4.2. Safety criteria

Whether or not safety criteria are required for Level PSA have been debated during the work with task 0.

Some of the respondents felt that Level 3 PSA has not been performed or applied enough to define such criteria, or even to see the needs for such criteria. Those that felt criteria should exist were interested in using them as a means of defining the scope of the analysis.

The outcome from the discussions during the workshop was that safety criteria would assist in understanding the results of a Level 3 PSA. Such criteria would aid in the general understanding of the results, whether they are good/bad or acceptable/unacceptable. Such criteria could also provide focus to an analysis.

Possible safety criteria's should be the same for old and new plants.

The need for and definition of Level 3 PSA safety criteria's need to be further studied.

2.4.4.3. Unacceptable release

The definition of an unacceptable release for Level 3 PSA needs to be based on acceptance criteria's. Examples for this today are the ALARA principle and dose criteria's, determined from regulations by the authorities. There is also a need for defining reference values

From a nuclear expert's point of view a definition of an unacceptable release for Level 3 PSA should be related to how we define unacceptable release in Level 2 PSA. These can be developed based on reference values, e.g. background radiation and normal operation, accidents should result in no more than a set fraction of the normal operational or background radiation levels.

The responding insurance company's definition of an unacceptable release is; any release which will have an adverse effect should be deemed unacceptable.

Note that there is a risk that the work with minimizing the risks could be held up if we define what risks that is acceptable.

2.4.4.4. Use of results

Use of results from a Level 3 PSA study has been discussed in several different contexts related to the intended use.

The discussions have been regarding the use for communication to the public (if this is done carefully), the use in planning (e.g. emergency planning, accident management) and the use by increasing the knowledge about the possible effects from a nuclear accident and thereby to better prepare for or mitigate the risks that we are exposed to

The starting point for the development of a Level 3 PSA should be the intended use of the results.

2.4.4.5. Guidelines

If we are to use Level 3 PSA we are going to need guidelines.

Since there are so many ways to perform the analyses and evaluate the results, guidelines are needed to ensure that scenarios from one plant can be compared with scenarios from another plant.

The guidelines could, though, be written as suggestions rather than a strict, prescriptive, guidelines. The guideline should give some input on different ways of performing Level 3 PSA depending on the objectives. A guidance document from this project could specify recommendation on the use of international guidelines for the application of Level 3 PSA in Nordic countries.

2.4.4.6. Overall challenges

One of the challenges with the further work of Level 3 PSA is defining the scope for the analysis method. Finding the appropriate risk metrics and comparable units is another challenge.

When performing Level 3 PSA the challenges are related to necessary assumptions and uncertainties. The analysis method might also be expensive and complex to perform. There are also difficulties to make right comparisons between different reactors.

Communication of the results from a Level 3 PSA study is a challenge in itself. However, the challenges of performing a Level 3 PSA might also be the reasons for performing Level 3 PSA. At this point there is a limited experience basis behind Level 3 PSA. The insights and understanding that may come from performing a Level 3 PSA may provide significant justification for performing a Level 3 PSA. Some of the items that have been highlighted as challenges would become better understood and perhaps mitigated or accounted for given additional experience in Level 3 PSA.

3. Task 1 – Risk metrics

3.1. Introduction

The main goal of task 1 was to discuss which could be the appropriate risk metrics for Level 3 PSA. The results from the task will contribute to the ultimate objective and outcome of the project in total, a guiding document to provide clear and applied guidance towards regulators, utilities and Level 3 practitioners.

No safety goals, i.e., no numerical criteria, were explicitly connected to the risk metrics presented. However, safety goals were touched upon as a reference to which risk metrics that could be used.

In the previous performed work in the NKS/NPSAG Safety Goals project (Holmberg & Knochenhauer, 2007), information can be found on what safety goals are being used in different countries and industries, together with arguments and historical background on why different criteria are being used in these countries. Some of the safety goals are related to Level 3 PSA.

3.2. Off-site consequence criterion – Safety Goal project

There are a number of countries worldwide which have more or less clear safety goals or off-site consequence criterion connected to Level 3 PSA or risks with hazardous industries. Examples can be found in (Holmberg & Knochenhauer, 2007), (Caldwell, 2012), (OECD/NEA, 2009) and (OECD/NEA, 2007) and are presented in Table 1 without the numerical criterion itself presented.

Table 1. Definition of different off-site consequence criteria (safety goals) used in different countries.

Country	Individual risk	Societal Risk	Other
UK	The individual risk of death to a person off the site, from on-site accidents that result in exposure to ionising radiation.	The total risk of 100 or more fatalities, either immediate or eventual, from on-site accidents that result in exposure to ionising radiation	Frequency dose The total predicted frequencies of accidents on an individual facility, which could give doses to a person off the site.
The Netherlands	The individual risk of death as a consequence of the operation of a certain installation. The individual risk shall be calculated for one-year-old children, since this is, in general, the most vulnerable group of the population.	The risk of 10 or more casualties, which are directly attributable to the accident. F/N-curve	
US	Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that individuals bear no significant additional risk to life and health.	The risk to society from generating electricity using nuclear power is compared with that from generating electricity by other techniques. It is also compared with other societal risks (sum of cancer fatalities from other sources)	
Sweden*	There shall be no short-term fatalities in acute radiation syndrome (sickness)	Long-term ground contamination of large areas shall be avoided.	
Japan	Average risk of acute fatality for individuals in the vicinity if the site boundary. Average risk of latent fatality for individuals living within a certain distance from the facility.		
Canada	Average risk of latent effects (per site)		

* In Sweden, no level 3 PSA is required. The safety goals shown here are related to acceptance criteria for the mitigating systems for a severe accident (SKI / SSI, 1985)

Most of the off-site consequence criterions used in different countries is related to health effects both to individuals and to the society at large. For numerical criteria, see e.g. (OECD/NEA, 2007).

3.3. Risk metrics for Level 3 PSA

Risk metrics for Level 3 PSA have two components: 1) probability metric and 2) consequence (or impact) metric. Regarding the probability metric, it is matter of choosing the normalization unit for risk comparison purposes. The consequence metric is associated with the impacts which are quantified in the consequence assessment part of a Level 3 PSA. The following main group of consequence metrics have been identified:

- Health effects — Dose
- Environmental impact
- Economic impact (can include every other risk metric).

3.3.1. Probability units

The results of a PSA, at any level (1, 2 and 3), are typically presented as probabilities of the unwanted events (core damage, large release, offsite impact) per year, and, therefore, can be interpreted as a frequency. The interpretation of the probability per year is that it represents the average risk for a certain nuclear plant that has been analyzed by PSA methods and, if it is a full-scope PSA, the numbers should have been integrated over different plant operating states taking into account the fraction of operating time spent in these different operating states. “Probability per year” is the unit which is used in the regulatory framework and it is almost always associated with a single reactor, since operating licenses are reactor specific. However, in some countries a ”probability per year per site” is used (see (Pascucci-Cahen & Momal)).

In living PSA applications, other probability units may be applied, like probability per an event, probability per a specific time period or probability per expected (remaining) lifetime. The probability per expected lifetime should be relevant from the investment decision making point of view.

From the risk comparison point of view, probabilities could also normalized by the produced amount of energy, e.g., per TWh (or TWhe). An example comparing the full fuel life cycle risks of different energy options can be found in (IAEA, 2009).

Since “probability per year per reactor” is the probability unit applied in the regulatory context, the probability metric is mainly considered in this report. Probability units “per lifetime” and “per produced energy over the complete fuel life cycle” can be considered for risk comparison purposes

3.3.2. Health effects — Dose

3.3.2.1. Input

INES

The International Nuclear and Radiological Event Scale (INES) is used for communicating to the public the safety significance of events associated with sources of radiation (IAEA, 2009). The scale is developed by international experts convened by the IAEA. Events are classified on the scale at seven levels: Levels 4–7 are termed “accidents” and Levels 1–3 “incidents”.

The rating of events is based on both qualitative (e.g. barriers broken in defence-in-depth) and quantitative criteria (e.g. dose estimation). The dose criteria given in INES are listed in

Table 2. Release criteria are given for INES-classes 4–7 which involve radiological releases. Doses to individuals are defined for INES-classes 1–4. It should be noted that these are not the only criteria to be used in the classification of events and that in many cases conversion factors need to be used to find the equivalent class, see (IAEA, 2009) for guidance. For instance, a multiplication factor 40 should be used for a Cs-137 release to obtain the radiological equivalence to I-131 release.

In (Saji, 2003), a safety goal framework is proposed in the framework of INES. A probabilistic scale associated with source terms (noble gas, iodine, and cesium) are defined. Importantly, the safety goals of this approach are deployed to an individual plant and require site-specific assessments

Table 2. Dose criteria related INES-classes. For technical details see (IAEA, 2009).

INES-class		Equivalent I-131 release	Doses to individuals
7	Major accident	More than several tens of thousands of tera-becquerels	
6	Serious accident	The order of thousands to tens of thousands of tera-becquerels	
5	Accident with off-site risks	The order of hundreds to thousands of tera-becquerels	
4	Accident mainly in installation	The order of tens to hundreds of terabecquerels	(1)The occurrence of a lethal deterministic effect; or (2) The likely occurrence of a lethal deterministic effect as a result of whole body exposure, leading to an absorbed dose of the order of a few Gy.
3	Serious incident		(1) The occurrence or likely occurrence of a non-lethal deterministic effect; or (2) Exposure leading to an effective dose greater than ten times the statutory annual whole body dose limit for workers.
2	Incident		(1) Exposure of a member of the public leading to an effective dose in excess of 10 mSv; or (2) Exposure of a worker in excess of statutory annual dose limit
1	Anomaly		(1) Exposure of a member of the public in excess of statutory annual dose limits; or (2) Exposure of a worker in excess of dose constraints

Euratom FP7 project ASAMPSA2 — Best-practices guidelines for L2 PA development and applications

The ASAMPSA2 final report (volume 2) states that in an extended Level 2 PSA one can use the offsite dose calculated using simplified deterministic methods as risk metrics (ASAMPSA2, 2013). It is mentioned that the French 900 MWe NPP ISRN uses the total effective dose equivalent, integrated over 15 days to a one year old child 2 km from the damage plant as risk metric.

Realistic radiological consequences in Swedish NPPs

At the Swedish NPPs a project related to realistic radiological consequences have been performed during 2010–11 according to regulations from SSM. The project calculated realistic radiological consequences for anticipated operational transients and design basis accidents events (Vattenfall R & D). Two different risk metrics related to dose were used in the project.

- Effective dose (sum of effective dose from external radiation from radionuclides in the air, internal radiation during 50 years from inhaled radionuclides and external radiation over 30 days from radionuclides on the ground).

- Equivalent dose to the thyroid of a one-year old child due to inhaled radioactive iodine.

The values for the risk metrics were calculated for different distances off-site from the plant.

WENRA

The Reactor Harmonization Working Group (RHWG) of Western European Nuclear Regulator's Association (WENRA) has released a report on safety of new NPP designs (WENRA, 2013). WENRA has issued safety objectives for new reactors including objective for accidents with core melt. The following criteria are stated:

- Accidents with core melt which would lead to early or large releases have to be practically eliminated.
- For accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited protective measures in area and time are needed for the public (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in food consumption) and that sufficient time is available to implement these measures.

To meet the criteria Level 3 PSA can be used as one tool to show that an accident is practically eliminated. In connection to the second criteria some risk metrics are mentioned, i.e., dose and ground contamination.

Safety goal project

In section 3.2 different safety goals are presented for some countries worldwide. Some of them are related to health effects and are mostly related to individual or collective dose or fatalities (OECD/NEA, 2009).

3.3.2.2. Identified metrics

Based on the above references a metric connected to health effects and dose is relevant. Both individual dose and collective dose are of interest for both short-term and long-term effects. From the individual short-term and collective long-term dose both prompt fatalities and cancer fatalities can be calculated, se section 3.3.2.3.

The following metrics related to health effects are identified:

- Collective dose/individual dose (short- and long-term) [mSv]
- Prompt fatalities (short term)
- Cancer fatalities (long term).

3.3.2.3. Fatal dose level

In order to estimate the prompt fatalities from dose exposure, one needs to define the dose level at which acute radiation syndrome occurs or where the risk for it increases (deterministic effects). The Swedish industry has set 1 Sv as the short-term dose limit for acute radiation sickness causing death to occur. This is in line with the threshold value given in a University textbook about basic radiation physics (Isaksson, 2011) and education material from KSU (KSU, 2007). The risk of death is about 50 % (LD_{50} , median Lethal Dose) if a short-term whole-body dose of approximately 4 Sv is received and 100 % (LD_{100}) if a short-term whole-body dose of approximately 6 Sv is received, and if no treatment is given. In order for acute radiation syndrome to occur, the dose rate has to be in the order of Sv/min.

In Figure 1 the relationship between risk of death and received whole body dose exposure is shown. Using the information above it is relatively easy to connect the individual dose to prompt fatalities from acute radiation sickness. It should be noted that the threshold value for foetus is much lower, approximately 100 mSv (0,1 Gy as stated in (Isaksson, 2011)).

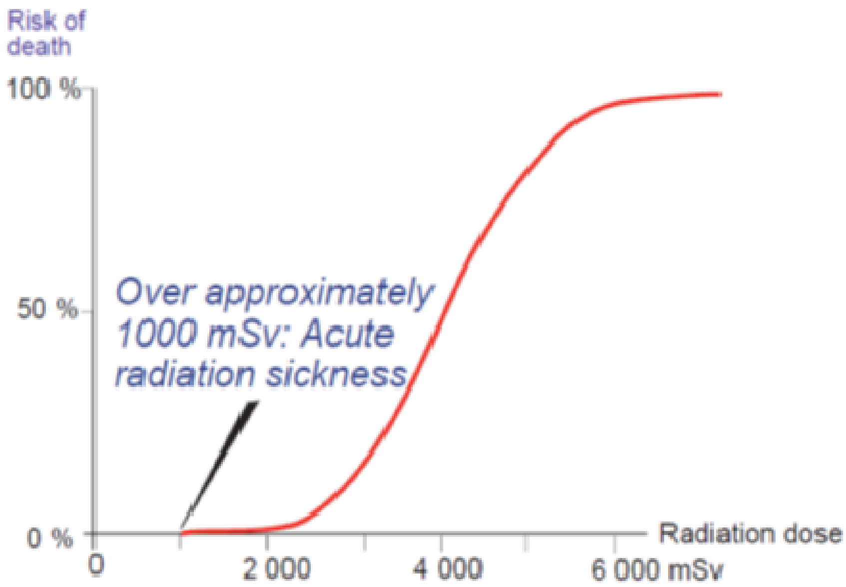

Figure 1. Risk of death in acute radiation sickness due to different radiation dose exposure.

In order to estimate the long-term fatalities from dose exposure one needs to define the dose level at which the risk for cancer increases (stochastic effects). In ICRP103, (ICRP, 2007), and also in (Isaksson, 2011) it is stated that the risk for cancer increases with 5 % per Sv in long-term for low exposure (up to 200 mSv) and 10 % per Sv for high exposure (from 200 mSv). This can be related to the collective dose:

> # of death cause by cancer = collective dose (manSv) x 0,05 (1/Sv), for individual exposure ≤ 200 mSv.
>
> or
>
> # of death cause by cancer = collective dose (manSv) x 0,10 (1/Sv), for individual exposure > 200 mSv).

Hence, the total risk for death by cancer due to radiation exposure is independent on the individual dose exposure and only connected to the collective dose exposure. As an example a collective dose of 20 manSv results in one death due to cancer irrespectively if it is 20 000 people receiving 1 mSv or 200 people receiving 100 mSv as long as the maximum individual dose is less than 200 mSv.

3.3.2.4. Advantages, disadvantages and uncertainties

The advantage with the dose related metric is that it is rather straight forward to calculate from the release of radioactive material following a nuclear accident. The dose metric can also be connected to fatalities both in short and long term. It should also be easy to define consequence criterion to the dose risk metric. Both the individual and societal consequence can be estimated using dose risk metric (or fatality risk metric). The dose metric can also be used to improve plant design and emergency preparedness.

The disadvantage with the dose related metric is that it does not cover the complete consequences of a nuclear accident. The impact to the biosphere is not captured with the dose related risk metric, e.g. contamination/restrictions (evacuation) on land and sea, impact on wildlife is not covered by the dose related metric.

The uncertainties connected to dose and fatalities are the general uncertainties with respect to dispersion calculations (which also affect all other risk metrics). Once the release and dispersion of radioactive material is calculated it is rather straight forward to calculate the dose exposure both on an individual and collective level if population densities are available. From the dose exposure it is easy to estimate fatalities. There are, however, uncertainties related to the validity of the linear, no threshold hypothesis used in the proposed way of calculating cancer deaths.

3.3.2.5. F/N-curve

An F/N-curve can be used to present the risk metric related to fatalities using a cumulative distribution function. Normally N is the number of fatalities and F is the frequency for N or more fatalities to occur. By using this risk metric one can compare the risk from a nuclear power plant with the risk from other hazardous industries.

The F/N-curve can also be used to express the dose risk metric by using collective dose or dose interval as N instead of fatalities.

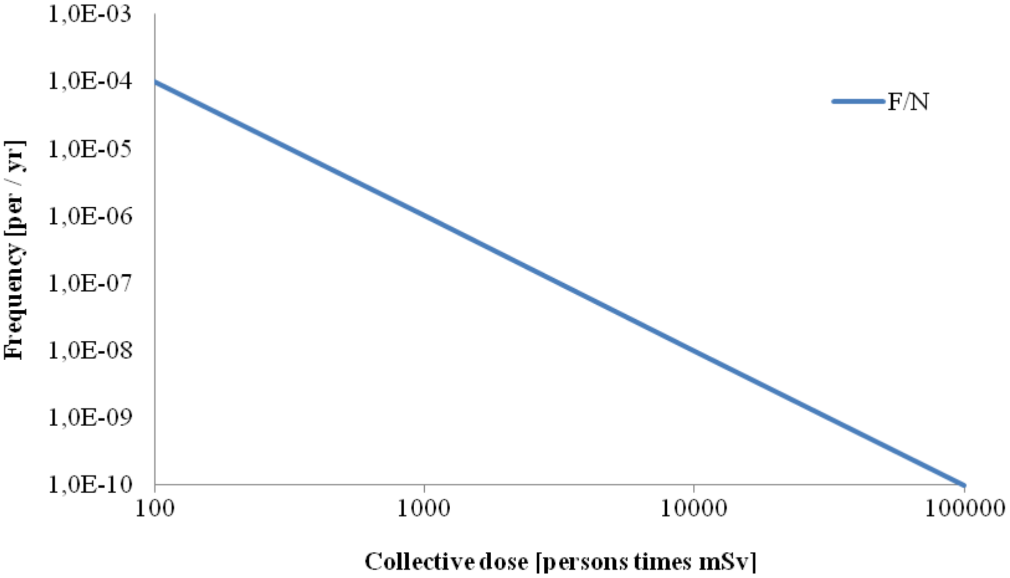

Figure 2. Example of an F/N-curve.

3.3.3. Environmental impact

3.3.3.1. Input

Realistic radiological consequences in Swedish NPPs

As mentioned above a project related to realistic radiological consequences has been performed during 2010–11 at the Swedish NPPs according to regulations from SSM. The project calculated realistic radiological consequences for anticipated operational transients and design basis accidents events events, (Vattenfall R & D). The following metric was used in the project;

- Ground contamination level due to Cs-134 and Cs-137 [Bq]

The metric is connected to the requirement established by the Swedish government for severe accidents. This is judged to be fulfilled if the radioactive release after a severe accident is limited to 0,1 % of the inventory of the caesium isotopes Cs-134 and Cs-137 in a core of 1800 MWth (SKI / SSI, 1985).

Fatal contamination level

Prompt fatalities can be related to the contamination of land. According to SKI/SSI (SKI / SSI, 1985) no short-term fatalities in acute radiation syndrome occurs if the radioactive release after a severe accident is limited to below 1 % of the inventory of a core of 1800 MWth, excluding noble gases. Hence, the contamination metric can be related to the dose metric of prompt fatalities.

Safety goal project

In section 3.2 different safety goals are presented for some countries worldwide. WENRA has set a qualitative safety goal that design provisions have to be taken so that only limited protective measures in area and time are needed for the public (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in food consumption) and that sufficient time is available to implement these measures. In Sweden long-term ground contamination of large areas shall be avoided. Guidance suggests that up to 0.1% of core Cs released is deemed acceptable so some long term contamination is allowed.

3.3.3.2. Identified metrics

Different levels of contamination can be used. One level of contamination could result in a restriction for living within a certain area and another level of contamination could result in restrictions from farming and harvest within a certain area.

The following metrics related to environmental impact are identified:

- Ground contamination level due to Cs-134 and Cs-137 [Bq/m^2] or [mSv/year]
- Non-usable areal of land and sea [km^2]

3.3.3.3. Conversion between contamination level and dose

Once the contamination level is estimated [kBq/m^2] a dose rate can be estimated using conversion factors.. Dose conversion factors can be found in (IAEA, 2000) for different radionuclide, e.g for Cs-134 the conversion factor is 5,4E-6 mSv/h/(kBq/m^2).

3.3.3.4. Contamination to different types of land

The contaminated land area based metric could be further refined into different types of land. Main categories are populated areas, sea, non-populated areas (wildlife) and agricultural areas (farming). The valuation between different types of land is a matter of economic risk metric (see ch. 3.3.4).

It should be further noted that this metric is dependent on the contamination or dose based criteria applied for the restrictions in land use and food consumption.

3.3.3.5. Advantages, disadvantages and uncertainties

Similar to dose related metric, it is rather straightforward to calculate the environmental metric at least in terms of affected land area (sea may be more challenging). This metric can be further refined from the time perspective point of view (temporary land use restrictions and long term restrictions) and the type of land point of view. Environmental metric is in many respect closely related to the health based metric and these two metrics could be evaluated i an integrated manner. Environmental metric thus compensates part of the disadvantages of health impact metric.

The disadvantage is that there is not yet any commonly agreed approach to valuate different environmental impacts. A single number measuring the area of restricted land use does not reflect the differences between site locations. Type of land and time period of impact are relevant factors to be accounted, but then conversion factors need to be defined if the results are to be compared. This leads to the definition of economic metric.

The uncertainties connected to environmental impact are the general uncertainties with respect to dispersion calculations as well as the estimation of the long term impact on environment. The first issue is common to all other impact metrics, and the second one depends on the quality of environmental impact models. In practice, there should be sufficient input data for environmental impact estimation but the models include uncertainties, e.g., given that the release and dispersion can be calculated and given that the characteristics of the contaminated land area are known, it may be difficult to predict the time periods for land use restrictions and the significance for biosphere. Release to sea or river is even more complex to quantify but the air pathway is usually much more important than the sea pathway. Uncertainties are thus related to the definitions of the surrogate environmental impact metric that need to be applied.

3.3.4. Economic impact

3.3.4.1. Input

OECD/NEA

In late 1990's, en expert group established by OECD/NEA prepared a guidance document for the consequence assessment of nuclear accidents (OECD/NEA, 2000). The document provides a number of cost elements to be accounted (see

Table 3) and discussion on cost assessment perspectives.

The economic effects associated with these consequences can be generally classified into two categories: direct and indirect. Direct economic consequences can be described in terms of cost of the implementation of countermeasures. The indirect economic consequences would cover the effects which are produced out of the areas directly impacted by the contamination, as for instance the impact on non-contaminated food marketing, on tourism, or on the nation's nuclear programme. Indirect consequences are normally difficult to quantify a priori, but they are amenable to an a posteriori evaluation. The report provides some examples of previous cost estimates, cost assessment approaches and a review of models and codes (OECD/NEA, 2000). Rather obvious conclusions of the report are that there is no single cost of an accident and there is a large variation in the estimates.

There is also an ongoing activity at OECD/NEA to develop methodologies for estimating the costs of nuclear accidents. An expert group was established in 2013, and a study is expected to be finalised by the end of 2014.

Table 3. Cost categories of nuclear reactor accidents (OECD/NEA, 2000).

On-site Costs
Cost of decommissioning and decontamination Loss of capital (e.g. installed capacity)
Cost of countermeasures to reduce doses
Population movement - Transport away from the affected area - Temporary accommodation and food - Supervision of the evacuated area and monitoring of people - Loss of income for people unable to reach the workplace - Lost capital value and investment on land and property - Psychological effects of worry and upheaval Agricultural restrictions and countermeasures Decontamination - Cost of cleaning process, including the necessary equipment and materials, and the disposal and transportation of generated waste - Cost of labour - Cost of health effects induced in the workforce
Radiation-induced health effects in the exposed population
Cost of radiation-induced health effects: (1) early effects, (2) latent effects, (3) hereditary effects - Direct health care costs - Indirect costs, due to the loss of earnings during treatment and convalescence or of the total - Non-monetary costs, such as pain, grief and suffering associated with each effect
Psychological effects
Impact on the activity with which the installation is associated, for example the power programme
Impact on economic factors: employment, revenues, losses of capital, etc.
Long-term social and political impact
Environmental and ecological impact

IRSN

IRSN, Institut de radioprotection et de sûreté nucléaire, has done a work on estimating the costs of nuclear accidents (Pascucci-Cahen & Momal). The work states that cost estimates should be comprehensive and if cost estimates are underestimated the value of accident prevention will also be underestimated. IRSN opposed the "consequence" approach which implies "zero Becquerel = zero cost" and the "economic" approach which considers a complete list of the effects of nuclear crisis including some cost items which correspond to zero Becquerel situations. Cost of an accident is divided into:

- On-site costs
- Off-site radiological costs
- Contaminated land areas
- Image costs
- Costs related to power production
- Additional costs

3.3.4.2. Identified metrics

The following metrics related to economic impact are identified:

- Total cost of accident, EUR

3.3.4.3. Estimation of different economic impact

Estimation of different economic inputs consists of two major issues: selection of impacts to be included in the estimation and the conversion factors for non-monetary impacts (impacts primarily estimated in non-monetary scales).

Ideally, all costs of an accident should be accounted for, but this is practically impossible due to the multitude of stakeholders involved. Some perspective should be chosen for the estimation, e.g., the utility, the nuclear industry, the power production industry, national level impact. Global impact is very difficult to estimate and may not be meaningful.

The list of economic impacts considered in the OECD/NEA (OECD/NEA, 2000) or IRSN study (Pascucci-Cahen & Momal) could be used as references.

Depending on the decision making, some of these costs may be ignored. According to insurance companies the cost for loss of capital and image should not be included since it is an assumed risk for the company that has chosen to act in the nuclear area, (Nordqvist, 2013). This is however of major interest for the nuclear organizations.

3.3.4.4. Advantages, disadvantages and uncertainties

Economic impact has the obvious theoretical advantage that all impacts of an accident can be converted into a single metric, which allows consistent risk comparisons and cost-benefit analyses. In principle, this kind of metric should be applied in decision making, while the other impact metrics are surrogates to it.

In practice, it can be difficult to agree on what should be included in the quantification of economic impact and how to convert different impacts in a monetary scale. This is a general problem for risk decision making and not specific to nuclear power plant risk analysis, although nuclear accidents have specific complicating aspects such as multitude of impacts and involved stakeholders and the low probability of an accident.

Despite the difficulties to evaluate economic impact, it should be sufficient to estimate the order of magnitude of different kinds of accidents, e.g., the Three Mile Island type of core damage accident with practically no external release would mean certain economic impact. Depending on the order of magnitude of release and direction of dispersion some other orders of magnitude of economic impact could be assumed. Knowledge from costs of other natural or industrial catastrophes could be also used as references to estimate the order of magnitude of a nuclear accident.

Despite possible difficulties to convert non-monetary impacts to monetary scale, it might nevertheless be useful to do this exercise, i.e., to try find some commonly agreed conversion factors. This process should lead to increased understanding of risks and facilitate risk communication. Given an economic impact assessment with explicit (parameterized) conversion factors, it is always possible to do sensitivity studies to determine the items that would be most critical to the economic impacts – even with the presence of uncertainties. Example for a multi-criteria decision analysis related to health, environmental, economic and societal impacts, see (Keeney, 1994).

Since the economic impact assessment includes any consequences, the range of uncertainties is large and covers all kinds of uncertainties from the incompleteness issues, modelling uncertainties to parametric uncertainties.

3.3.5. Risk metrics for different stakeholder

Different stakeholder may need different risk metrics. Health effect and environmental impact metrics should be relevant to all stakeholders, but the way economic impact is assessed is more stakeholder dependent. The issue in selecting risk metrics for different stakeholders is thus mainly the question which costs are taken into account and in which way they are weighted. For instance, the safety authority may not necessarily want to take any position on the economic impact, while the utility and the insurance company may look at the economic impact on different risk perspectives.

It may be assumed that the level 3 PSA is primarily done by the licensee and it would be advisable to consider a wide range of risk metrics (health effects, environmental and economic impact). The aggregation of different risk metrics into single risk metrics should be done explicitly with parametric models, which allows different weightings. The issue of selecting risk metrics can be reduced to the discussion on weightings of risk metrics.

3.4. Comparison with level 1 and 2 PSA risk metrics

The risk metrics related to level 1(core damage frequency) and 2 (unacceptable release frequency) PSA are to large extent non-depending on the siting (location) of the plant. The only impact from the location of the site in level 1 and 2 PSA is from the determination of external events which to some extent are dependent of the location. In level 3 PSA the location of the site is of paramount importance since e.g. metrological data and distance to population and agriculture areas are affecting the output. Hence, level 3 PSA can give useful information about siting issues. Basically, level 1 PSA analyses the plant systems which are designed to prevent core damage and level 2 analyses the plant systems design to prevent and mitigate the consequences of a severe accident. Level 3 PSA will give useful information about both off-site emergency response or preparedness and plant safety systems.

Risk metrics for level 2 PSA can be applicable as surrogates for level 3 PSA risk metrics. There is a strong correlation between the release magnitude/timing metric and the health effect/environmental impact risk metrics. The correlation is site-specific. In practice, at certain site it is only the effect of dispersion and evacuation which give variation in the consequence scale given certain release category.

Core damage risk metric of level 1 PSA is not a sufficient surrogate risk metric for level 3 PSA purposes. On the other hand, if economic impact will be considered in level 3 PSA, it would be consistent to consider economic impacts event at level 1 PSA, i.e., to expand the consequence categories of level 1 PSA to include even major economic losses (without a core damage). From the risk comparison point of view, there may be economically significant consequences without external release or even without core/fuel damage.

3.5. Conclusions and suggestions

A risk metric has two components: 1) probability metric and 2) consequence (or impact) metric. Regarding the probability metric, it is a matter of choosing the normalization unit for risk comparison purposes. The consequence metric is associated with the impacts that are quantified in the consequence assessment part of Level 3 PSA.

Table 4 summarizes main consequence metric categories (health effects, environmental impact and economic impact), their advantages, disadvantages and associated uncertainties as well as purposes.

Table 4. Parameter, advantages, disadvantages, uncertainties and purpose for different consequence metrics.

	Consequence metric		
	Health effects	**Environmental impact**	**Economic impact**
Parameter or value	Dose [Sv] or [manSv] Fatalities (#) Short- and long-term effect	Contamination level [kBq/area] or [mSv/year] Restricted land and sea areal or "non-usable" land and sea areal (area)	Monetary units (e.g. [EUR] or [SEK]) Different cost are to be included depending on stakeholder (owner or insurance company)
Advantage	Relatively easy to estimate dose and connect dose to fatalities.	Relatively easy to estimate contamination of land and sea. Complements well the health effect based risk metric.	Most complete risk metric, everything is accounted for.
Disadvantage	Does not consider the total impact of a nuclear accident.	Contaminated area as a single metric does not characterise the site location. Use of multiple metric requires conversion factors between different environmental impacts.	Laborious to assess comprehensively and the impact is stakeholder dependent. May be difficult to agree on conversion factors for non-monetary costs.
Uncertainties	Long term health effect over the population is statistical estimate	Conversion factors between different environmental impacts	Large uncertainties in the estimation of cost. Which cost are to be included. How to estimate the cost of different factors. Political factors can affect the results.
Purpose	Improve plant design and emergency preparedness Requirements form authorities	Improve plant design and emergency preparedness Requirements from authorities	Improve plant design and emergency preparedness Communication with society Communication with insurance company Optimization of safety improvements

Health effects and environmental impact are rather similar metrics from the estimation and purpose point of view. The assessment of these metrics should be of interest for all stakeholders. It could be expected that even internationally the stakeholders could agree on which metric to use and risk criteria to be applied. At least for health effects, there are references for safety goals and associated numerical criteria. For the environmental impact, numerical criteria may not be necessary.

There are a number of open issues to be further explored, e.g., how far in time and place the estimations need to be done, i.e., what is the time frame for the consequence metrics and how far away from the plant should the impact be accounted for? The pilot study, which is planned within the project, should elaborate more on these consequence metrics when the scope of the study is determined. The pilot study should also elaborate how level 2 PSA release category related consequence metrics could be used as surrogates for level 3 PSA criteria.

Economic impact is an ideal metric from decision making point of view and it would allow cost-benefit studies. In practice, it can be difficult to agree on what to include in the quantification of economic impact and how to convert different impacts into monetary scale. Despite the difficulties to evaluate economic impact, one possibility could be to apply some simplified categorisation of economic impacts in terms of order of magnitude. It should be sufficient to estimate whether the cost is ~10^9 € or ~10^{10} €. It is suggested that the pilot study should include at least a discussion of economic impacts to be accounted in a licensee's risk analysis. This discussion should also cover exploration of conversion of non-monetary impacts to a monetary scale, e.g., doses and environmental impacts to Euros. The main use of economic impact may in cost-benefit assessments instead of being used in connection with numerical risk criteria.

4. Task 2 – Regulations, guides, and standards

4.1. Introduction

The probabilistic assessment of off-site consequences, often referred to as Level 3 PSA, has been the subject of many large studies and international interest in the late 1980s, Organizations such as the IAEA, NEA, European Commission, and USNRC published reports or funded Level 3 PSA programs and studies. It was observed that very little has been done in the field since that time, but activities have started within some of these same organizations (Caldwell, 2012). The purpose of Task 2 is to provide the ability to observe and influence the development of Level 3 PSA regulations, guides, and standards. This task has also provided input to the Task 0 and Task 1 activities, as well as, provided feedback to external organizations based on the findings of the working group's activities.

This report describes the work that has been performed within task 2 of the project over the past year, specifically, the work performed toward the ANS/ASME Standard 58.25, and two IAEA activities.

4.1.1. Background

Activity in the field of probabilistic offsite consequence analysis has had many peaks and valleys over the years. Internationally, and within the Nordic countries there was a large effort in the field of Level 3 PSA in the late 1980s, which included significant Probabilistic Consequence Analysis (PCA) methods work, large scope studies, and IAEA meetings and publications.

Several countries have been performing Level 3 PSA consistently for many years (e.g. the Netherlands, South Africa). However, generally speaking there was a significant drop-off in the work performed on Level 3 PSA methods and number of studies performed since the work of the late 1980s and early 1990s.

The interest in Level 3 PSA has risen in the last several years. This is based on several reasons, the fact that many of the large-scope well known studies are aging, the development and construction of new reactor units, and perhaps most significantly, the disasters at Fukushima. These reasons have prompted many in the Nuclear Safety Community to re-investigate Level 3 PSA.

4.1.2. Scope of work

At the onset of the project the primary focus of this task was to follow the ongoing work regarding the peer review standards ANS/ASME 58.24 (Level 2 PSA) and ANS/ASME 58.25 (Level 3 PSA). These standards have been under development in writing committee over the past several years. It is anticipated that it will take at least 1-2 years until these standards will be published. It was envisioned that this task will allow the project to influence and report on the progress of these standards.

The work performed under this task has also include monitoring and if possible participation in the development of international guides and regulations. This includes any developments made by the IAEA, the United State Nuclear Regulatory Commission, and similar organizations.

Finally, any additional, applicable regulations, and standards will be included in this task, particularly those identified in the work performed for Task 0 and Task 1. The extent that additional regulations and standards will be explored depends on the level of activity and involvement within the ANS and IAEA activities and available resources.

4.2. ANS/ASME Level 3 PSA standard 58.25

The ANS Standards 58.24 and 58.25 regarding Level 2 PSA and Level 3 PSA respectively have been under active development for several years. During this time a member of the working group has been actively involved in the 58.25 writing committee. This project will be integral in providing the resources to continue to engage in the ongoing work and report on the progress of these standards.

Since the work is relatively modest over the past year a large majority of the work to date in the area of the ANS/ASME 28.25 standard was provided in the thesis work provided in reference (Caldwell, 2012). The following is an excerpt from that report:

The standard is being written by a committee of American Nuclear Society (ANS) and American Society of Mechanical Engineers (ASME) members. The committee was first funded and assembled in the early 2004. Since that time, a draft standard has been completed and released for review. To date, approximately 800 responses have been collected critiquing the draft version of the standard.

The ANS/ASME-58.25 standard provides requirements for application of risk-informed decisions related to the consequences of accidents involving release of radioactive materials to the environment. The consequences to be addressed include health effects (early and late) and longer term environmental impacts. These requirements are articulated for a range of technical Level 3 PSA areas in a specific structure. This structure is consistent with previously published ANS/ASME risk standards.

The structure of the Level 3 standard, and the earlier PSA standards, is based on a hierarchy of technical elements and requirements. The framework for organizing the requirements first defines a set of *Technical Elements* of the analysis; Technical elements define significant fundamental tasks that are either important or necessary to perform for an analysis. For each technical element, High Level Requirements (HLRs) and subordinate Supporting Requirements (SRs) are defined. The High Level Requirements provide over-arching goals of each technical element. These HLR usually pertain to the data, modelling, and documentation, while the Supporting Requirements refer to specific actions while implementing the models, interpreting the data, or writing the documentation and presenting the results. Finally, each SR is divided into descriptions of minimum standards to fulfill three different "Capability Categories" (CCs). Each successive CC is defined for increased realism and site-specificity. Examples of the Technical elements are Release Categories, Protective Action Parameters, Dosimetry, Health Effects, and other broad processes that are integral to performing a Level 3 PSA. The Capability categories define somewhat specific details of the minimum requirement to achieve each of the three levels.

The standard is progressing, but still undergoing major revision. The balloting of the draft standard has provided a substantial number of comments (approximately 800). This is, in part, because this standard is being written concurrently with a level 2 standard and ongoing addendums are being written for relevant-published standards, and this is also because the standard writing committee is relatively inexperienced with drafting standards. Due to the substantial volume of comments, and the extent of the revision to the draft Standard, it is somewhat apparent that the Standard will continue to be revised and reviewed for a few years before it is published. The draft document and specific text from the standard are not available for distribution at this time. (Caldwell, 2012)

4.3. IAEA activities in Level 3 PSA

The IAEA issued a procedure guide on Level 3 PSA in 1996, IAEA Safety Series No. 50-P-12, "Procedures for Conducting Probabilistic Safety Assessments of Nuclear Power Plants (Level 3)," following significant work performed in the US, Europe, and Japan in the field of Level 3 PSA methods. The IAEA has recently reopened the issue of Level 3 PSA with an IAEA Technical Meeting on Level 3 PSA, which took place in July of 2012. The meeting was the first activity specifically discussing Level 3 PSA since the publication of the IAEA Safety Series No. 50-P-12. The purpose of the meeting was to articulate the work performed during this meeting, monitor any further IAEA developments and also follow and discuss similar developments in international and national organizations.

Following the IAEA Technical Meeting, two further IAEA activities have taken place. The first was an Eastern European Regional Workshop on Level 3 PSA, and the second was a Consultant Meeting on Level 3 PSA. The funding provided by the project allowed the working group to participate in both activities.

4.3.1. IAEA Consultant's Meeting (CM) on Level 3 PSA

An IAEA consultants meeting on Level 3 PSA took place in Vienna Austria from November 25-28, 2013. The meeting included several individuals from countries with active Level 3 PSA projects.

The guidance from the attendees of the technical meeting guidance was that the IAEA should provide further guidance on Level 3 PSA. The purpose of the IAEA Consultant's meeting was to determine in what form the IAEAs guidance on Level 3 PSA should take.

4.3.1.1. Participants

There were nine participants in total from the IAEA, North America, Europe, and Africa. Each of the participants have been involved in recent Level 3 PSA work.

4.3.1.2. The objectives of the TECDOC

The objectives of the TECDOC are the following:

- Outline the methodology and indicate the techniques most widely used to date
- Provide general guidance for conducting a Level 3 PSA with description of major technical elements (e.g. interface between Level 2 and Level 3 PSA, atmospheric dispersion, countermeasures, consequence results interpretation)
- Survey of current practices and computer codes available for consequence assessment (real difficulties learned by Level-3 PSA analysts)
- Provide information on the use of Level 3 PSA and applications, and effective presentation of the results
- Identify areas of further research
- Update previous (now outdated) IAEA of the previous IAEA Level 3 PSA publication.

4.3.1.3. Scope:

- Level 3 PSA for nuclear power plants considering all facilities at the NPP site is in focus
- However, the general methodology may be also applicable for other parts of the nuclear fuel cycle, such as reprocessing plants and spent fuel storage installations, and also for research reactors, although specific aspects of Level 2 and Level 3 analysis

may be quite different for such installations and appropriate models would need to be used.

- Not prescriptive document

The general scope of the TECDOC should not be completely different from the scope outlined in the IAEA Safety Series No. 50-P-12, publication:

The main emphasis in this Safety Practices document is on the procedural steps of a PSA, rather than on the details of corresponding methods. This document is primarily intended to assist technical personnel with responsibilities in managing or performing PSAs. A particular aim is to promote a standardized framework, terminology and form of documentation for PSAs so as to facilitate external review of the results of such studies. The report outlines the methodology and indicates the techniques most widely used to date.

In general, this document seeks to provide sufficient detail to define unambiguously the methods to be used, while avoiding prescriptive detail at a level that would inhibit the flexibility of the user in applying available resources, recognizing that the resources available to various studies will vary widely. The publication of this report is therefore not intended to pre-empt the use of new or alternative methods; on the contrary, the advancement of all methods of achieving the objectives of PSA is encouraged. (IAEA, 1996).

4.3.1.4. Intended audience

This document is primarily intended to assist technical personnel with responsibilities in managing, performing or reviewing PSAs. The document is also intended to provide supporting information for users (e.g. decision makers) of Level 3 PSA results.

4.3.2. IAEA TC RER915 Regional Workshop on "Level 3 PSA development and related issues"

This meeting was valuable in showing the thoughts and competencies in the Eastern European region, as well as those from the other expert contributors, which were from the Netherlands, United Kingdom and Sweden.

This meeting marked the first IAEA Workshop on Level 3 PSA, and was held following the IAEA Technical Meeting on Level 3 PSA that took place in July of 2012, which was the first activity specifically discussing Level 3 PSA since the publication of the IAEA Safety Series No. 50-P-12 Publication titled, "Procedures for Conducting Probabilistic Safety Assessments of Nuclear Power Plants (Level 3).

The motivation for the meeting was due to the relative difficulty in finding information on Level 3 PSA. Due to this difficulty and many open questions in the Region, a 3-day workshop could provide significant insight into the basic constituents, uses, and scope of a Level 3 PSA.

4.3.2.1. Objective

The objectives of the meeting were stated by Artur Lyubarskiy:

- Present and discuss recent developments
- Current practices
- Application of Level 3 PSAs
    - Focus on NPP
- Available standards

4.3.2.2. Participants

The meeting included an IAEA representative and three subject matter experts from the United Kingdom, Netherlands, and Sweden.

The meeting also included more than 30 participants from 15 different eastern European countries. These participants had either significant Level 1 & 2 experience, or deterministic radiological consequence analysis experience. There was almost no prior Level 3 PSA experience in the group of participating individuals.

4.3.2.3. IAEA & expert prepared presentations

The workshop consisted of lectures provided by the IAEA and subject matter experts, presentations provided by the participating countries, and a Question and answer section on the final day of the meeting. This section describes the two IAEA lectures, and five expert lectures.

The IAEA presented a review of the IAEA Technical Meeting that was held in July of 2012 in Vienna Austria. The purpose of the technical meeting was to establish what the current practices are for Level 3 PSA, where Level 3 PSA is performed and to develop some structured guidance on what the IAEA should pursue for future activities for Level 3 PSA. During the course of the meeting is become very apparent how widely varying the approaches and opinions surrounding Level 3 PSA were among the group of participating member states. As a result of the Technical meeting the IAEA decided to pursue further guidance through the Development of a TECDOC (IAEA Technical Document). The details of the document were discussed in Section 4.3.1.

A presentation providing an overview of Level 3 PSA methodology, guides, and standards was presented. This presentation discussed some of the general constituents of Level 3 PSA methodology, a brief glimpse at the history of Level 3 PSA, and the current work that is being performed around the world. Following this discussion was a detailed explanation of the scope and progress of the Level 3 PSA standard, which was discussed in Section 4.2.

Level 3 PSA practices in the Netherlands, and United Kingdom were also presented. It was described that in the UK, "TOR – Tolerability of Risk from NPP" is a central framework for risk regulation in UK. It is important to note that this framework is not CDF/LERF based, but rather, Level 3 PSA metric based.

Numerical Risk Criteria have two defined categories:

BSL – Basic Safety Level,

BSO – Basic Safety Objective,

LL – Legal Levels (denoted by BSL)

UK risk criteria are separated into worker/on-site personnel risk criteria, individual risk criteria, and societal risk criteria.

Individual Risk – Individual risk of death to a person off the site:

BSL: 10e-04 person/year, BSO: 10e-06 person/year

Typical compliance for individual risk is shown through plume calculation as applied in the UK is somewhat simple. Regulations are imposed on site boundary

Societal Risk – Total risk of 100 or more (early or late) deaths from on–site accidents:

BSL: 10e-05 person/year, BSO: 10e-07 person/year

Compliance with societal risk metric necessarily implies Level 3 PSA type calculation.

Additional information on how considerations must be made for the varied UK fleet, which is a combination of PWR and AGR plants), and considerations for new constructions between AP1000 and EPR are provided in the presentation materials attached to this report.

In the Netherlands a standardized analysis procedure has been established and an acceptance criteria for individual and societal risks are placed on the results of COYSMA program calculations. These risk criteria are based on the baseline individual mortality rate.

4.3.2.4. Participant presentations

Each of the participating countries provided presentations on the state of practice in terms of PSA, and radiological analyses. To a large extent these were limited to Level 1 and Level 2 PSA, which have been generally performed by each of the participating countries that currently have civilian nuclear power programs. A notable exception was Belarus, which has an active Level 3 PSA methods development program and is incorporating Level 3 PSA into the regulatory framework of Belarus.

4.4. Conclusions

The work in the Task 2 area will continue through 2014. The focus on the continuation of these activities will be the development of the IAEA Level 3 PSA TECDOC, which will have several Consultant meetings over the coming years.

Progress on the Level 3 PSA standard has been modest over the past year. The Standard writing committee began work on the standard in 2004, and progress has been somewhat uneven over the past several years. The standard has had periods of significant progress, and periods of somewhat slow development. At the current state of the Level 3 PSA Standard and the related Level 3 PSA standard, and with the relatively models progress in the development of the standard there are several years before each standard will be completed.

IAEA work is poised to continue through the next several years. The IAEA TECDOC is in the very early stages of development, and several more Consultant Meetings will be required to continue and eventually complete it. The IAEA has also discussed the possibility of additional regional workshops, but it is possible that there will be no additional regional workshops.

Internationally there is significantly more work being done in Level 3 PSA. Countries such as the Netherlands and South Africa continue to maintain Level 3 PSA models as it is part of their regulatory requirements. A large scale USNRC study is underway and preliminary results will begin to be discussed and later published in the coming years. Development of a possible replacement to the COYSMA program “PACE” is underway and being discussed. There is also significant interest in this NPSAG / NKS project on Level 3 PSA and the next year seminar shall be planned at least 6 months in advance to accommodate the international participants.

5. Task 4 – Pilot Project

The pilot project will be completed in two parts, a Finnish project that will utilize Finnish tools and methods, which is also incorporated in the SAFIR program, and a Swedish project, which will utilize Swedish tools and methods. The Finnish project began during 2013, while the Swedish portion of the project will begin during 2014. This section details the progress of the Finnish project during this past year.

5.1. Goal

The goals of the Finnish pilot study are

- to gain experience in the application of the IDPSA methodology (originally developed for level 2) to level 3 studies, and to evaluate its usefulness on level 3
- to apply and evaluate risk measures identified in the NKS project in a case study
- to develop methods for taking into account multiple source terms at different times and from different sources (as was the case in Fukushima)
- to gain experience in conducting level 3 analysis for the development of a new level 3 code
- to study how uncertainties proliferate through level 3 analysis

The pilot allows also other uses. For example, comparisons between the Integrated Deterministic Probabilistic Safety Analayis (IDPSA) approach and the current Swedish approach might be made. The pilot will also give perspective on what input should be expected from PSA level 2 analyses. Such uses may be implemented in later years.

The goal of the first year in Task 4 was to create a plan for the pilot study (Rossi et. al., 2014).

5.2. Description

The scope of the Finnish pilot study is to estimate population doses and related health effects caused by atmospheric dispersion of the radioactive release in the selected case. Emphasis will be on short-term health effects. A metric that will be studied is the averted dose, that is, the dose averted by the population due to countermeasure(s). This averted dose will be compared with recommended maximum radiation doses. Also the number of persons whose received dose exceeds a certain limit will be examined as a metric. Other consequences, such as land contamination through radioactive fall-out, may be considered.

5.3. Methods

In IDPSA, deterministic methods and tools are used to address computationally heavy parts of the system (such as plant response on level 2 PSA), and probabilistic methods are used to handle uncertainty. Normally the deterministic and probabilistic parts are integrated in the way that the needs of the probabilistic part determine what kind of computations are done in the deterministic part, and some central results of the deterministic part (such as timing information) are fed to the probabilistic part.

In the Finnish pilot study, the division of labor between the deterministic and probabilistic parts goes so that atmospheric dispersion of the release is handled in the deterministic part, and variables involving considerable a priori uncertainty (weather, countermeasure decisions and timing, population behavior, dose calculations) are handled in the probabilistic part.

The deterministic part will be handled by an atmospheric program. There are several such programs freely available. A potential candidate is AERMOD, which has been developed by the U.S. Environmental Protection Agency.

The probabilistic part will be handled by developing event trees in SPSA (STUK PSA). It is essentially a PSA level 2 program that supports event tree analysis, and fault tree analysis related to it. It was originally developed as STUK, the Finnish Radiation Safety Authority, but its development has been transferred to VTT. This program is normally used to calculate the source terms and their probabilities on level 2. In this pilot, SPSA is also used to support level 3 analysis by handling and assessment of uncertainty. Modeling with SPSA is based on graphical event tree approach common in PSA applications.

Risk metrics will be calculated for short-term health effects. Here, the inputs from the project's task 1 (Sunde & Holmberg, 2014) will be valuable.

5.4. Modelling

A central issue in modelling the Fukushima Daiichi disaster is data acquisition. There are several estimates of source terms in the scientific literature, and they vary widely. Weather data seems to be available. The population density of the area is an issue; the populations of nearby cities are given in a USNRC briefing, but one has to take into account that large parts of the area were depopulated due to the tsunami. The realized short term countermeasures (sheltering and evacuation) are known from news accounts.

5.5. Conclusions

The main result of Task 4 in the first year was a plan for the Finnish pilot study. In it, the IDPSA methodology will be applied to the Fukushima Daiichi NPP disaster. It seems that this is the first time when IDPSA is applied on level 3, and therefore valuable experience on the application may be obtained.

There are several issues concerning Fukushima. The first is that there were several source terms at different times from different sources (reactors and used fuel storage). Significant sources of uncertainty include source terms and the amount of population in the affected area. All of these issues have to be addressed computationally in the pilot.

6. Conclusions

The project is planned to continue through 2015. A significant amount of work was completed during 2013. Task 0, the questionnaire, was completed and a large portion of Task 1, covering risk metrics, and Task 2, covering regulations and standards, were completed during the year. The Finnish portion of the Task 4 pilot project also began during 2013.

Task 3, which is the task allocated for developing the final guidance document, and the Swedish part of the Task 4 pilot project will begin during 2014.

6.1. Task 0 - Questionnaire

The results of the questionnaire highlighted many varied insights, interests, and concerns for Level 3 PSA.

Risk comparisons for society made risks are possible to do in theory; however, this might not be possible in practice. One reason is the difficulty in finding comparable units, based on risk. If risk comparisons are to be done this must be done carefully.

The respondents to the questionnaire felt that the need for Level 3 PSA could not be adequately assessed at this stage of the project. The scope, levels of uncertainty, and definition of acceptable effects need to be addressed in order to make such a judgement.

The possible advantages of Level 3 PSA were summarized as follows:

- Facilitate communication with insurance companies and the analysis could lead to better insurance possibilities
- Facilitate communication with the society in large and thereby create higher acceptance for nuclear power in society
- Better understanding of societal risks of commercial nuclear power and thereby improve preparedness work
- Provide better design and siting considerations for new construction projects
- Cost benefit metric for plant retrofits
- Improve and extend earlier levels of PSA, Level 1 and 2, in creating a more holistic point of view (this is not a unified opinion).

The respondents cited that the main challenge to Level 3 PSA are the uncertainties involved in the calculation, which themselves may be difficult to quantify. Since the challenges to Level 3 PSA are still somewhat undefined further study into the capability of Level 3 PSA is warranted.

6.2. Task 1 – Risk Metrics

A risk metric has two components: 1) probability metric and 2) consequence (or impact) metric. Regarding the probability metric, it is a matter of choosing the normalization unit for risk comparison purposes. The consequence metric is associated with the impacts that are quantified in the consequence assessment part of Level 3 PSA.

Consequence metrics were categorized into health effects, environmental impact, and economic impacts. Health effects and environmental impact are rather similar impact metrics from the estimation and purpose point of view. The assessment of these impact metrics should be of interest for all stakeholders. It could be expected that even internationally the stakeholders could agree on which metric to use and risk criteria to be applied. At least for health effects, there are references for safety goals and associated numerical criteria. For the environmental impact, numerical criteria may not be necessary.

There are a number of open issues to be further explored, e.g., how far in time and place the estimations need to be done, i.e., what is the time frame for the risk metrics and how far away from the plant should the impact be accounted for? The pilot study, which is planned within the project, should elaborate more on these risk metrics when the scope of the study is determined. The pilot study should also elaborate how level 2 PSA release category related risk metrics could be used as surrogates for level 3 PSA criteria.

Economic impact is an ideal metric from a decision making point of view and it would allow cost-benefit studies. In practice, it can be difficult to agree on what to include in the quantification of economic impact and how to convert different impacts into a monetary scale. Despite the difficulties to evaluate economic impact, one possibility could be to apply some simplified categorization of economic impacts in terms of order of magnitude. It is suggested that the pilot study should include at least a discussion of economic impacts to be accounted in a licensee’s risk analysis. This discussion should also explore ways of assigning of a monetary value on non-monetary impacts, e.g., doses and environmental impacts to euros. Main use of economic impact may be in cost-benefit assessments instead of being used in connection with numerical risk criteria.

6.3. Task 2 – Regulations, guides, and standards

The work in the Task 2 area will continue through 2014. The focus on the continuation of these activities will be the development of the IAEA Level 3 PSA TECDOC, which will have several Consultant meetings over the coming years.

Progress on the Level 3 PSA standard has been modest over the past year. The Standard writing committee began work on the standard in 2004, and progress has been somewhat uneven over the past several years. The standard has had periods of significant progress, and periods of somewhat slow development. Judging based on the current status of the Level 3 PSA standard, the related Level 2 PSA standard, and the relatively modest progress of each during the past year, the completion of the ANS/ASME guidance on Level 2 and Level 3 PSA will take several more years.

The IAEA work will continue the next several years. The IAEA TECDOC is in the very early stages of development, and several more Consultant Meetings will be required to continue and eventually complete it. The IAEA has also discussed the possibility of additional regional workshops, but it is possible that there will be no additional regional workshops.

Internationally there is significantly more work being done in Level 3 PSA. Countries such as the Netherlands and South Africa continue to maintain Level 3 PSA models as it is part of their regulatory requirements. A Large scale USNRC study is underway and preliminary results will begin to be discussed and later published in the coming years. Development of a possible replacement to the COYSMA program “PACE” is underway and being discussed. There is also significant interest in this NPSAG / NKS project on Level 3 PSA and the next year seminar shall be planned at least 6 months in advance to accommodate the international participants.

6.4. Task 4 – Finnish pilot project

The main result of Task 4 in the first year is a plan for a pilot study. In it, the IDPSA methodology will be applied to the Fukushima Daiichi NPP disaster. It seems that this is the first time when IDPSA is applied on level 3, and therefore valuable experience on the application may be obtained.

There are several issues concerning Fukushima. The first is that there were several source terms at different times from different sources (reactors and used fuel storage). Significant sources of uncertainty include source terms and the amount of population in the affected area. All of these issues have to be addressed computationally in the pilot study.

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Appendix 1 – Task 0, Responding organizations

Name of organization	**Category of identification**
FKA	Experts
RAB	Experts
ES-konsult	Experts
SSM	Experts
RiskPilot	Experts
STUK	Experts
UJV Rez	Experts
VUJE	Experts
Fortum	Experts
OKG	Experts
AON	Insurance company
Elini	Insurance company

Appendix 2 – Task 0, Literature study

The literature study is presented below consisting of a short introducing text (summary) for each report/study.

Probabilistic Safety Goals for Nuclear Power Plants

The outcome of a probabilistic safety assessment (PSA) for a nuclear power plant is a combination of qualitative and quantitative results. Quantitative results are typically presented as the Core Damage Frequency (CDF) and as the frequency of an unacceptable radioactive release. In order to judge the acceptability of PSA results, criteria for the interpretation of results and the assessment of their acceptability need to be defined.

Safety goals are defined in different ways in different countries and also used differently. Many countries are presently developing them in connection to the transfer to risk-informed regulation of both operating nuclear power plants (NPP) and new designs. However, it is far from self-evident how probabilistic safety criteria should be defined and used. On one hand, experience indicates that safety goals are valuable tools for the interpretation of results from a probabilistic safety assessment (PSA), and they tend to enhance the realism of a risk assessment. On the other hand, strict use of probabilistic criteria is usually avoided. A major problem is the large number of different uncertainties in a PSA model, which makes it difficult to demonstrate the compliance with a probabilistic criterion. Further, it has been seen that PSA results can change a lot over time due to scope extensions, revised operating experience data, method development, changes in system requirements, or increases of level of detail, mostly leading to an increase of the frequency of the calculated risk. This can cause a problem of consistency in the judgments.

The first phase of the project (2006) provided a general description of the issue of probabilistic safety goals for nuclear power plants, of important concepts related to the definition and application of safety goals, and of experiences in Finland and Sweden. The second, third and fourth phases (2007–2009) have been concerned with providing guidance related to the resolution of some of the problems identified, such as the problem of consistency in judgment, comparability of safety goals used in different industries, the relationship between criteria on different levels, and relations between criteria for level 2 and 3 PSA. In parallel, additional context information has been provided. This was achieved by extending the international overview by contributing to and benefiting from a survey on PSA safety criteria which was initiated in 2006 within the OECD/NEA Working Group Risk. Finally, a separate report has been issued providing general guidance concerning the formulation, application and interpretation of probabilistic criteria.

The results from the project can be used as a platform for discussions at the utilities on how to define and use quantitative safety goals. The results can also be used by safety authorities as a reference for risk-informed regulation.

The outcome can have an impact on the requirements on PSA, e.g., regarding quality, scope, level of detail, and documentation. Finally, the results can be expected to support on-going activities concerning risk-informed applications.

Bengtsson, L., Holmberg, J.-E., Rossi, J., & Knochenhauer, M. (2010). Research 2010:35 Probabilistic Saftey Goals for Nuclear Power Plants. Swedish Radiation Saftey Authority.

Analysis of the impact on society by radioactive emissions in Japan in 2011

Only two major releases of radioactive substances from nuclear accidents that have occurred over the world. One of them are the nuclear accident that occurred in Japan in 2011 and it is therefore of interest to study the social impacts from this large accident.

The analysis, made by MSB, shows that the largest and most serious consequences from the accident I Japan are:

• The concern over the future at an individual level, about the health risks of ionizing radiation, residents in the long term and questions about economic benefits.

• Decontaminate from a social organizational perspective. It is expensive, requires collaboration and takes time to resolve. No reconstruction can begin in contaminated areas until it is resolved.

• Analyses for possibilities to replace nuclear energy from a technology and resource perspective. Sampling of food and control of radiation doses in humans in the affected area is extensive.

• Management of costs from the economic perspective. Expenses are expected to be very large and the Government of Japan has begun to make changes in the state budget for managing and allocating the costs of the community.

The analysis preformed in the report is also meant to be used as a basis for the further development of the Civil Contingencies with respect to large radioactive release.

MSB. (2012). Analys av samhällskonsekvenser efter radioaktiva utsläpp i Japan 2011.

RAMA II, RAMA III

RAMA II and RAMA III was both included in the Swedish program for consequence mitigation measures for severe reactor accidents, along with the projects FILTRA and RAMA. The program ended in 1988.

The aim for the program was to:

- Build a knowledge base for understanding of the important processes during a severe reactor accident
- Further develop and validate a tool for calculating failure analysis with site-specific adaptation
- Document the knowledge that formed the basis for the development and implementation of the mitigating measures at the Swedish NPPs

RAMA were to act as a complement to the utilities plant specific analyses and find appropriate means for protecting the environment in case of severe reactor accident.

The purpose of the project RAMA II was to develop the analytical tool for the analysis of severe accidents, to be employed by the utilities in their plant specific studies and to validate the analytical tool and to consolidate the scientific basis for the conclusions of the RAMA project.

RAMA II. (1987). Final report. Nyköping: Studsvik Library.

RAMA III. (1989). Handbok över haveriförlopp i svenska reaktorer. Nyköping: Studsvik Library.

Air quality guidelines

Health effects from particles were discussed during the workshop. One good overview is the air quality guidelines published by the World Health Organization. The report is large, but the summary table on the best risk estimates for PM exposure is found on page 275 (table 5).

World Health Organization (2005). Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. (http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide)

Wenra documents

One of the objectives for WENRA is to develop a harmonized approach to nuclear safety and radiation protection issues and their regulation.

A significant contribution to this objective was the publication, in 2006, of a report on harmonization of reactor safety in WENRA countries. This report addresses the nuclear power plants that were in operation at that time in those countries.

Since then, the construction of new nuclear power plants has begun or is being envisaged in the short term in several European countries. Furthermore, some plants whose construction had been halted several years ago are now under completion. Despite all these plants were not addressed in the study published in 2006, it is expected that, as a minimum, they should meet the corresponding "Safety Reference Levels".

These "Safety Reference Levels" were designed to be demanding for existing reactors. However, in line with the continuous improvement of nuclear safety that WENRA members aim for, new reactors are expected to achieve higher levels of safety than existing ones, meaning that in some safety areas, fulfillment of the "Safety Reference Levels" defined for existing reactors may not be sufficient.

Hence, it has been considered timely for WENRA to define and express a common view on the safety of new reactors, so that:

- new reactors to be licensed across Europe in the next years offer improved levels of protection compared to existing ones;
- regulators press for safety improvements in the same direction and ensure that these new reactors will have high and comparable levels of safety;
- applicants take into account this common view when formulating their regulatory submissions.

Title	Addressing off-site consequence criteria using Level 3 PSA — Phase 1 Status Report
Author(s)	[1]Andrew Wallin Caldwell, [1]Anders Olsson, [2]Malin Nordqvist, [2]Gunnar Johanson, [3]Jan-Erik Holmberg, [3]Carl Sunde, [4]Ilkka Karanta
Affiliation(s)	[1]Lloyd's Register Consulting, [2]ES Konsult, [3]RiskPilot, [4]VTT
ISBN	978-87-7893-380-5
Date	March 2014
Project	NKS-R L3PSA (Contract: AFT/NKS-R(13)109/12)
No. of pages	44
No. of tables	4
No. of illustrations	2
No. of references	26

Abstract
max. 2000 characters

Based on an inquiry from the Nordic PSA Group (NPSAG) and the Nordic Nuclear Safety Research group (NKS), a consortium of Swedish nuclear risk consultancies (Lloyd's Register Consulting, ES-Konsult and Risk Pilot) and the Finnish research institute VTT has begun a multi-year study of Probabilistic Off-site Consequences Analysis, commonly referred to as Level 3 Probabilistic Safety Assessment (Level 3 PSA). Level 3 PSA is infrequently performed and generally regarded as a less developed analysis when compared to Level 1 and Level 2 PSA. Interest in the Nordic countries has been spurred based on new nuclear construction projects and plans. These activities have raised interest in objective, risk-based siting analyses for new nuclear reactors in order to better understand the risks of off-site consequences in the wake of the multi-unit disaster at the Fukushima Daiichi site. The objective of this study is to further develop understanding within the Nordic countries in the field of Level 3 PSA, in order to determine the scope of its application, its limitations, the appropriate risk metrics, and the overall need and requirements for performing a Level 3 PSA. The project's first year focused on the development and analysis of an industrial survey about Level 3 PSA, which included several workshops and meetings with Nordic utilities, regulators, and safety experts. Level 3 PSA risk metrics including health, environmental, and economic effects have been researched and discussed in the first year's project report. The project has generated significant interest internationally and has interfaced with international organizations including the IAEA and the American Nuclear Society. The long term objective of the work is to set the foundation for performing a "state-of-the art" Level 3 PSA for Nordic conditions.

Key words PSA, PRA, Level 3 PSA, Probabilistic Consequence Analysis, Nuclear Power Plant Safety

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