THE DEVELOPMENT OF NORDIC GUIDANCE IN LEVEL 3 PSA

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Probabilistic Off-site Consequences Analysis, commonly referred to as Level 3 Probabilistic Safety Assessment (Level 3 PSA), has been infrequently performed and is generally poorly represented in the literature in comparison with Level 1 and Level 2 PSA. Due to new nuclear construction projects and the multi-unit accident at the Fukushima Daiichi site, there is a renewed interest in Level 3 in general and what risk insights that can be gained from Level 3 PSA compared to Level 1 and 2. Based on an inquiry from the Nordic Nuclear Safety Research (NKS) and Nordic PSA Group (NPSAG), a consortium of Swedish nuclear risk consultancies (Lloyd's Register Consulting, ÅF, Risk Pilot and Vattenfall) and the Finnish research institute VTT have performed a multi-year study of Level 3 PSA. The objective of the project has been to further develop understanding within the Nordic countries in the field of Level 3 PSA, the scope of its application, its limitations, appropriate risk metrics, and the overall need and requirements for Level 3 PSA. This paper describes the project and its results.

During the project, targeted discussions between consultancies, utilities, regulators, and insurance companies on the subject of Level 3 PSA have taken place. Part of the project has also been to participate in ongoing international activities with the International Atomic Energy Agency (IAEA) and the American Nuclear Society (ANS). Other important parts of the project have been to perform an international industrial survey, a study of appropriate risk metrics, and two pilot studies. The main objective of the pilot studies was to gain practical experience that, together with insights from the other tasks included in the project, could be transferred to recommendations in a final guidance document directed to satisfy the needs for the Nordic nuclear power industry.

The first pilot study was made by using IDPSA methodology (Integrated Deterministic and Probabilistic Analysis). In this pilot the atmospheric release from the Fukushima accident was studied using weather conditions typical of Japan. The other pilot was performed using a more traditional approach by studying the potential health effects of a release from a generic Nordic plant site considering atmospheric release below, near and above Level 2 PSA regulatory limits, using source terms for the UK EPR (which are publicly available).

The end result of the project is a guidance document that aims to provide clear and applied guidance on Level 3 PSA studies toward regulators, utilities, and practitioners based on the conclusions made over the course of the work.

During the course of the project a deeper understanding has been developed within the Nordic countries in the field of Level 3 PSA, the scope of its application, its limitations, appropriate risk metrics, and the overall need and requirements for performing a Level 3 PSA. In the short term this experience will be valuable for increasing quality to Level 1 and 2 PSA (e.g. reduced conservatism). In the longer term, the work will set the foundation for performing state-of-the-art Level 3 PSA.

I. INTRODUCTION

I.A. Background

Interest in Probabilistic Consequence Analysis (PCA), also referred to as Level 3 Probabilistic Safety Assessment (PSA) has been sparked in recent years by two major factors: the multi-unit severe accidents at Fukushima Daiichi and safety considerations for new nuclear power plant construction. Areas where Level 3 PSA may be useful are risk-informed decision-making, risk assessment and public communication. New studies are emerging in the field of probabilistic consequence analysis and many international meetings and workshops regarding the public health effects of severe accidents are being held. At the time of writing of this guidance document an ASME/ANS standard for Level 3 PSA is being developed.

The Nordic PSA Group (NPSAG) and the Nordic Nuclear Safety Research (NKS) have contributed to this research area over several years by funding the Level 3 Project titled, "Addressing off-site consequence criteria using Level 3 PSA." The project includes five of the leading Nuclear Risk Analysis consultancies in the Nordic countries. The project has enabled targeted discussions between consultancies, utilities, regulators, and insurance companies on the subject of Level 3 PSA. The project has also provided support for the participation in several ongoing international activities at the International Atomic Energy Agency (IAEA) and the American Nuclear Society (ANS).

A significant part of the project was research performed in Finland, funded within the SAFIR research programme. Within SAFIR, a unique and significant step in Level 3 PSA has been made by performing a Level 3 PSA pilot study using the IDPSA methodology (Integrated Deterministic and Probabilistic Analysis). The Finnish Pilot study and the Swedish Pilot study have been used in formulating considerations and practical recommendations outlined in the report.

The objective of the project has been to further develop understanding within the Nordic countries in the field of Level 3 PSA, the scope of its application, its limitations, appropriate risk metrics, and the overall need and requirements for performing a Level 3 PSA. In the short term this experience will be valuable for adding quality to Level 1 and 2 PSA. The final reporting of the project is a guidance document that aims to provide clear and applied guidance on Level 3 studies toward regulators, utilities, and Level 3 PSA practitioners based on the conclusions made over the course of the work.

The scope of the guide is limited to radiation effects due to an accident. Health consequences due to radiation are accounted for as well as lost land due to radiation. Other aspects, such as psychological health consequences, are deemed outside the scope of the guidance document. The high-level goals of the guidance document are to aid in the following:

- Harmonization of Level 3 PSA methodology
- Highlight key considerations
- Provide understanding of the risks/consequences presented in a Level 3 PSA

The objective of the guidance document is to describe the:

- Value/benefits for Level 3 PSA
- Limitations of Level 3 PSA
- Regulatory framework, Nordic and international
- Present Level 3 PSA common elements and recommendations for Nordic countries

I.C. Risk Metrics

A risk metric has 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 that are quantified in the consequence assessment part of Level 3 PSA. Table I summarises the main consequence metric categories (health effects, environmental impact and economic impact), their advantages, disadvantages and associated uncertainties as well as uses.

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 a monetary scale. Main use of economic impact risk metric may be in cost-benefit assessments instead of being used in connection with numerical risk criteria.

TABLE I. Metric, advantages, disadvantages, uncertainties and use for different consequence categories. [2]

	Consequence category		
	Health effects	Environmental impact	Economic impact
Metric	Dose [Sv] or [person-Sv] 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]) Different costs 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 metric.	Most complete 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	Risk models applied (convert dose to health effects) include large uncertainties	Conversion factors which are needed to compare 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.
Use	Improve plant design and emergency preparedness Regulatory requirement	Improve plant design and emergency preparedness In some cases regulatory requirement	Improve plant design and emergency preparedness Communication with insurance company Optimization of safety improvements

II. THE PRACTICAL GUIDE – CONSIDERATIONS AND RECOMMENDATIONS

In developing the guidance document for Nordic conditions, it became apparent that the possible goals of a Level 3 PSA and consequences of interest can vary, and the important considerations when performing a Level 3 PSA depend on the risk metrics of interest. In order to achieve a practical guide, a structure of the guidance document is developed based on three cases which aim at covering a spectrum of Level 3 PSA consequences. For each case, attributes (elements) needed from Level 2 PSA and other sources when performing Level 3 PSA are defined in Table II. The cases are:

- Case A: Size of land area with significant Cesium contamination (environmental risk)
- Case B: Risk of (early) death to maximum exposed individual (individual risk)
- Case C: Number of lethal cancers (late effects) (population risk)

TABLE II. Investigated attributes (elements) for a Level 3 PSA (per case)

Attributes (elements) \ Cases		Case A: Size of land area with significant Cesium contamination	Case B: Risk of (early) death to maximum exposed individual	Case C: Number of lethal Cancers (late effects)
Objectives	Type of output / Maximum impact (best estimate) & uncertainties	Area of lost land	Number of fatalities (short term)	Number of evacuated and number of fatalities (long term)
	Type of risk metric	Environmental	Health	Health
Input data / prerequisites	Source term	Release Categories including Cs	Contributing Release Categories from large early releases	All Release Categories
	Atmospheric & metrological data	Results depend on how these weather input data interact with source terms.		
	Population, land-use & economic data	Population and land-use not needed.	Ingestion pathway not contributing.	
Countermeasures	Short or long term [3]	Decontamination and land use restrictions	Prompt evacuation or sheltering	Depending on situation, all countermeasures influence the results
Level 3 Consequences, presentation of results	For discussion on recommendations for Level 3 PSA results presentation see section II.D			

II.A. Input data and prerequisites

The input data required for a Level 3 PSA study depends on several factors. These factors include the consideration of the consequences to be assessed, input requirements of the calculation tools to be used, the level of detail of the modelling, and the underlying assumptions that are made for the study. Even relatively simple Level 3 PSA studies require a significant amount of input data. At a minimum the following types of data are usually considered: source term data, atmospheric and meteorological data, population data, and countermeasure data. Each of these will be briefly discussed in this section. References to further discussion are provided for more detailed discussion on these and other potentially important input considerations.

II.A.1. Source term / Level 2 PSA interface

When looking at Level 2 PSA output it is important to focus on the aspects that affect how radiation is transported. Historically, atmospheric transport has been the primary mechanism considered in Level 3 PSA. For this reason Level 2 PSA generally provides information regarding:

- Magnitude of release of radioactive material to the atmosphere.
- Release timing.
- Energy of the release (i.e. heat).
- Release location (e.g. release height, coordinates).
- Release frequency.

The impact of localized effects, such as building wake effects, can have a large impact on the cross-section of the plume very near the plant. Accounting for these effects is difficult in the rather simple methods employed for most probabilistic off-site consequence studies. For this reason, Level 3 PSA is usually not recommended for making assertions very near the release location, e.g. actions for onsite personnel, since the local effects would dominate results.

The end-states most Level 2 PSAs are the definitions of releases categories. These release categories may be derived using various methods. For example, release categories may be developed by grouping similar failure sequences in a containment event tree. It is important for the Level 3 PSA analysis that the categories that are developed are composed of releases with similar source term characteristics (i.e. the bulleted list mentioned above).

What is important to capture in the Level 2 source terms is that each of the grouped sequences would result in releases with roughly the same timing, and approximately the same release fractions for each of the isotopic groups. Through the lens of the cases outlined in Table II, one can outline certain valid assumptions for each as follows:

- Case A: In case A one is interested in the contaminated land values. This means that smaller release, which still have the potential for significant low-level contamination may be relevant. Depending on the risk criteria applied, it may be important to include large and small releases. However, if one is interested in specific contamination, for example caesium contamination, releases limited to noble gases may be irrelevant (e.g. filtered releases)
- Case B: Very significant releases are needed to cause acute health effects. It is likely that most of the accident sequences for release categories in a Level 2 PSA study will allow for evacuation and sheltering which will limit, if not eliminate, acute health effects. Therefore, it may be sufficient to focus efforts on very large early releases even if they are substantially less probable.
- Case C: Latent cancer fatalities are the focus of Case C. Since lower doses than those considered for acute radiation effects can cause cancers, smaller and later releases may be important. The extent of relevant modeling considerations depends on the modelling assumptions, i.e. if a linear no-threshold model is used then very small doses can still be postulated to cause cancer cases, however a model with a threshold may imply that very small releases are unlikely to cause latent cancer fatalities.

II.A.2. Atmospheric and meteorological data

Historically, the focus of Level 3 PSA dispersion calculations has been on atmospheric dispersion since this is the dominant transport mechanism contributing to off-site health effects. The reason this is true is simply because atmospheric transport provides the quickest transport mechanism for an appreciable amount of radioactive material to reach the population. Therefore, for the determination of health effects, it is often seen as sufficient to focus on atmospheric dispersion to capture the frequencies or probabilities for health effects to the population [1]. In addition, ingestion pathways and ground water contamination as a result of the atmospheric dispersion are commonly used to determine the impact of restrictions on food and drinking water. When performing detailed studies of contamination, impact on food stuffs or economic studies other transport mechanisms such as aqueous transport mechanisms may make appreciable impacts on the results. These other types of transport may be especially important if one is trying to capture low-level contamination.

In Level 3 PSA analysis it is common to use Gaussian plume or Gaussian-puff dispersion. Gaussian dispersion models have been shown to have reasonable applicability, under ideal conditions, for the range of several km (1-5 km) out to approximately 50-100 km. In order to accurately analyse the on-site doses or the doses and deposition out much further than 100 km more advanced methods than a simple Gaussian model would be required [4].

II.B. Countermeasures

The consideration of countermeasures can dramatically impact the results of a Level 3 PSA study, especially on the health effects risk metrics. Countermeasures can also have an impact on the economics of an accident, however, economic considerations are not discussed in the recommendations provided in this section. A Level 3 PSA analyst's ability to incorporate and study various countermeasures is highly dependent on the tools and models available. Advanced Level 3 PSA tools (e.g. MACCS and COSYMA) provide many customizable models for various countermeasures.

In probabilistic off-site consequence assessments, countermeasures can be considered as follows, depending on the scope of the assessment:

a) Not included. The effect of counter-measures to limit public exposure is not included. Use this approach either if only contamination of land is of interest or if worst case scenarios should be calculated (no countermeasure successful).
b) Rudimentarily included: for example assume a successful evacuation of the emergency zone before the release and no countermeasures outside of the emergency zone. Assume that food and drinking water are taken from a region not contaminated, i.e. no dose from the ingestion pathway.
c) Include countermeasures probabilistically. Each, in the analysis included countermeasure, are assumed (or assessed) to be successful/partly successful/not successful with a given probability. An uncertainty distribution is then coupled to the probability. Note that a countermeasure only should be executed if certain criterion is fulfilled.

In Nordic applications, the adoption of a countermeasure should be governed by the dose criteria as presented in Table III. In order to rapidly respond to an emergency the dose criteria are transformed to measurable quantities like e.g. dose rates.

These triggers are usually referred to as Operational Intervention Levels (OIL). A discussion of Nordic OILs and guidelines for protective measures is provided in reference [3].

TABLE III Dose criteria for countermeasures [3].

Phase	Countermeasure	Dose[1] criteria
Early phase	Sheltering indoors	if the total dose is estimated to exceed 10 mSv in two days
	Partial sheltering indoors	if the total dose is estimated to be 1 - 10 mSv in two days
	Iodine prophylaxis	if the dose to the thyroid gland is estimated to be over 50 mGy for adults, and over 10 mGy for children under 18.
	Evacuation	if the total dose is estimated to be over 20 mSv in one week after the accident and if it can be anticipated already in this phase that sheltering indoors will last longer than two days.
Intermediate phase	Sheltering indoors	if the total dose is estimated to exceed 10 mSv in two days.
	Partial sheltering indoors	if the total dose is higher than 10 mSv in the first month after the accident but still below 10 mSv in two days.[2]
	Lifting the sheltering indoors	can be lifted when the total dose is below 10 mSv per month.[2]
Intermediate phase (cont.)	Evacuation	if the total dose is estimated to exceed 20 mSv in one week after the accident.
	Relocation	should be considered if the total dose exceeds 10 mSv in one month after the decontamination of the area.
	Lifting evacuation or relocation	when the dose is less than 10 mSv in the first month after return.[2]

[1] Projected dose to an unprotected person except for iodine prophylaxis dose criteria
[2] Requires that the exposure will decrease rapidly or can be decreased effectively by e.g. decontamination.

One important element that should be considered is that a “conservative” assumption in terms of dose criteria (or other set points) when a certain countermeasure is implemented might lead to suboptimal actions (for example, evacuation when sheltering is more justified). In sophisticated Level 3 PSA models, the distances or extent countermeasures are implemented and timing (starting and lifting of a countermeasure) can often be varied, which may be part of a sensitivity analysis.

The design of the countermeasure assessment in a Level 3 PSA study should include the following aspects:

- which countermeasures should be included
- when selected countermeasures are applied (time frame, dose criteria)
- to whom or in what area a countermeasure is adopted (countermeasure scope)
- the effectiveness or success of the countermeasures

II.C. Level 3 Consequences

II.C.1. Health effects (case B and C)

Health effects metrics considered in Level 3 PSA can either be expressed in terms of radiological risk (dose) or as radiation detriment such as acute radiation sickness in the short term and cancers in the long term. Non-radiological health effects, such as the consequences of stress to the population, are not usually addressed in Level 3 PSA studies.

External exposure comes from “cloud shine” (most important noble gases and iodine), “ground shine” (most important Cs) and radioactive material deposited on skin and/or clothes. Internal radiation comes from radioactive material inhaled (either directly from the passing plume or from re-suspension of deposition) or ingested from contaminated food and/or liquid. The important radionuclide in the case of inhalation is iodine due its absorption in the thyroid and a large dose coefficient and for ingestion caesium play a major role. Depending on the time frame of the dose calculation, i.e. is it a life time dose or a two week dose that is interesting, different exposure pathways will be important. For lifetime doses the ingestion pathway is most likely dominant, if people continuously eat and drink contaminated food/water.

The calculated dose is a measure of the risk for health effects. To convert the dose to actual health effects or, as in most Level 3 PSA studies, number of deaths, a risk model need to be applied. There are different risk models for early and late health effects. In the SOARCA study different approaches of estimating the risk of latent cancer death due to low exposure is presented. A linear no-threshold model is compared against several different threshold models, where below a certain threshold-dose the risk of death is assumed to be zero. Since a large number of the latent cancer deaths are attributed to low doses over long periods of time, the result of the threshold models shows a significantly reduction in the number of cancer fatalities [5].

The linear no-threshold (LNT) model with its risk coefficient of 0.05 for cancer deaths from population dose may be applied as a coarse estimate of late health effects. Due to the uncertainty and questioning of available risk models one should consider expressing the Level 3 PSA consequences in terms of doses, either as the only result or in addition to the estimated number of deaths.

II.C.2. Environmental impact (case A)

Recently there has been significant interest in the calculation of environmental effects and specifically the land areas associated with certain contamination levels without the more controversial extensions to health effects and economic effects, which may have significant uncertainties. The impact to the environment of a nuclear accident can vary significantly based on factors such as specifics of the radioactive materials found at the facility that is undergoing the accident, the characteristics and timing of the accident, the weather conditions during the accident, the distribution of land and water surrounding the facility, etc. This means that it is potentially difficult to generalize relevant criteria and methodology for assessing environmental impact due to a nuclear accident. Despite these difficulties there are some commonalities and generalizations that can be analysed using Level 3 PSA.

Precipitation plays a significant role in the distribution of radiological materials following an accident. High levels of precipitation correlates to higher levels of contamination in the near vicinity of the accident site and lower at further distances. It will also affect water-runoff (land contamination that is transported by rain water to water ways) and contamination of water ways, which is either coarsely approximated or often not incorporated in current Level 3 PSA.

Generalized Level 3 PSA methods in their current state are well suited for performing short term land contamination and surface water contamination studies in the vicinity of a plant (10s of km). Generalized methodologies to assess contamination to bodies of water and ground water are perhaps less applicable due to the significant variations from site to site.

Determining the effects of a nuclear accident to agriculture, food production and consumption, and even health effects with significant accuracy is quite difficult. The effects may depend significantly social actions and food production and consumption patterns which are hard to predict. For this reason, it may be less controversial to describe the severity of an accident through the area and magnitude of area contaminated above certain thresholds.

II.C.3. Economic impact (case A-C)

As previously concluded economic impact is an ideal metric from decision making point of view and it would allow for 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. Liability, for example, is very different for different owners. The main use of economic impact risk metric may be in cost-benefit assessments instead of being used in connection with numerical risk criteria.

There are many ways to assess the economic risks, and significant work is being performed currently as a result of Fukushima findings. Rather than deeply investigate economic risks, the guidance document references simplified approaches. In order to correlate the radioactive release to a level of economic impact, a scale of radioactive release is presented in [6], where each "Release level" category corresponds to an INES level [1] as shown in Table IV.

The radioactive release levels (R) property damage categories (D) used in Table IV are defined as follows:

R1 – Acceptable releases and Tens of TBq^{131}
R2 – Unacceptable releases and Hundreds of TBq^{131}
R3 – Large releases and Early large release and Thousands of TBq^{131}
R4 – Several tens of thousands TBq^{131}
D1 – Damage on reactor core
D2 – Severe damage on the core and significant effects on RCPB
D3 - Severe damage on the core, RCP and surrounding systems, limited damage on the containment
D4 – Severe damage on the core, the RCPB and the containment as well as the surrounding systems

[1] http://www-ns.iaea.org/tech-areas/emergency/ines.asp

TABLE IV Estimated damage cost related per INES level

Event Scale	Damage level	Fatalities	Damage cost ($G€=10^9€$)	Comment ~ Estimated or Comparable cost
INES 4	Property damage D1-D3, Release damage R1	None	<1 G€	Partial or complete loss of reactor ~ Losses 2020 due to Ringhals 1-2 phase out, ~0,5 G€
INES 5	Property damage D1-D3, Release damage R2	Possible in personnel	1-10 G€	Loss of reactor and unacceptable release. ~ Windscale 2 G€, TMI 10 G€ ~ 0,25-2,5% of Swedish GNP ~ Nuon losses 2013, ~1,5 G€
INES 6	Property damage D2-D4, Release damage R3	Possible in personnel and public	10-100 G€	Large release ~ 2,5-25% of Swedish GNP ~ Volkswagen crash 2015, ~10 G€
INES 7	Property damage D4, Release damage R4	Probable in personnel and public	100-1000 G€	Severe release, ~ Chernobyl 300 G€, Fukushima 270 G€ (3 units) ~ 25-250% of Swedish GNP (2014 ≈ 415 G€) ~ Swedish national debt 140G€, 37% of GNP

II.D. Understanding uncertainties

In presenting the result from a Level 3 PSA study it is important to include the uncertainty of the result. The uncertainty stems from data and modelling uncertainties in all three levels of PSA. There are modelling and parameter uncertainties. Parameter uncertainty is usually categorized as either aleatory or epistemic uncertainty. The distinction is that aleatory uncertainties characterize stochastic variability, for example weather variability. In Level 3 PSA, weather variability is the major form of aleatory uncertainty considered in most consequence analyses and it is generally quantified even when other input parameters are chosen as point estimates. Epistemic parameter uncertainty is associated with lack of knowledge and can be reduced by further study. An example in Level 3 analysis is the uncertainty associated with health effects. In addition there are incompleteness uncertainties, i.e. lack of completeness in treating all aspects of an accident scenario. This is usually difficult to study and resource intensive, it requires development of a model describing a previously not included phenomena. A best estimate approach is generally recommended because of the difficulty in determining uncertainties and difficulty in determining “conservative” assumptions. This arises because seemingly “conservative” assumptions may lead to non-conservative results in downstream considerations, which was briefly discussed with respect to countermeasures in section II.B.

II.E. Presentations of results

The results that can be presented vary significantly for Level 3 PSA studies; the ways these results can be presented vary still further. Level 3 consequences results are usually presented through various risk metrics, which are discussed in previous sections. In the case of health effects, these are the estimated number of acute radiation sicknesses in the short term and cancer deaths in the long term. Studies may also choose to convey results in terms of individual doses, collective doses, or Environmental metrics such as land areas exceeding certain contamination thresholds. In the case of economic consequences, these may be the amount of electricity production lost at the site, the amount of production lost in the fallout area due to evacuations, the value depreciation of the real estate in the affected area, and the costs of evacuation and other countermeasures.

A common way of presenting Level 3 PSA consequence magnitudes and frequencies simultaneously are with so called “Farmer’s curve”. Farmer’s curves also have a list of aliases including, exceedance curves, Complementary Cumulative Distribution Functions (CCDF). These curves show the probability or frequency (x-axis) that a certain event occurs or is exceeded (y-axis). Therefore, as one travels from left to right the trend of a CCDF curve is to strictly decrease. An example of a Farmer’s curve for the probability of cancer cases, as calculated in the Finnish Pilot study, is shown in Fig. 1. Farmer’s curves are also presented in the Swedish pilot study as also shown in Fig. 1, which shows the exceedance frequencies of collective doses for three different release categories is shown.

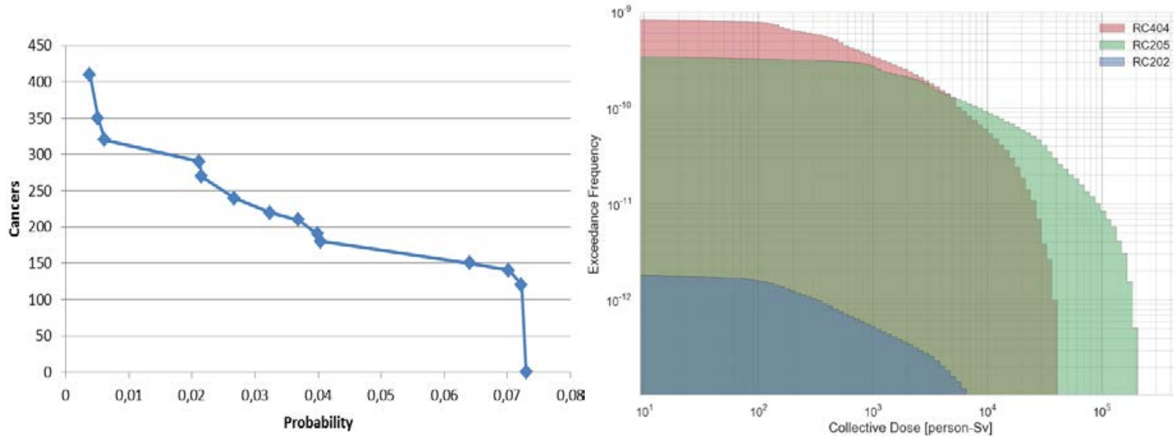

Fig. 1. Left: Farmer's curve plotting the number of cancer deaths against the conditional probability given an imaginary Fukushima-like nuclear accident (see Finnish Pilot Study [7]).
Right: Another representation of a "Farmer's curve" depicting the exceedance frequency of different collective doses for three different release categories (see Swedish Pilot Study [8]).

Since Level 3 PSA analyses vary significantly in scope and purpose the important results and metrics will depend on the scope of the particular analysis. Likewise, the best way to present the data will also vary. What can be stated is that when presenting Level 3 PSA results, the emphasis should be on representing and describing the consequences. When countermeasures are assessed, their effectiveness should be presented through a comparison of a metric both without any countermeasures and with each countermeasure applied (or all that would be applied in each situation).

Above all, it is important that the results are presented clearly. Results do not need to be presented in overly complicated ways. Often these studies present the end of a long line of probabilistic safety analyses (Level 1, 2 and 3 PSA). These studies have huge numbers of assumptions and considerations that one must incorporate into a results discussion. It is not likely that those reading the results of a Level 3 PSA study will be familiar with all of these assumptions and their implications. Therefore, it is important when presenting the results to be clear, concise and direct. One should point out many of these considerations to the reader, highlighting those of greatest relevance. The SOARCA study, which was a very large research project, has a very modest set of simple bar charts and tables used to show the results of the study, but it also includes substantial discussion that easily breaks down the results and the implications of these results [5].

III. CONCLUSIONS

The discussion and conclusions presented in this guidance document are based on the multi-year project that started in January 2012 and is sponsored by the Nordic PSA Group (NPSAG) and the Nordic Nuclear Safety Research (NKS). Specific insights were developed from the several activities initiated during this project. These activities were:

- The development of an industrial survey completed by Nordic utilities, Nordic Nuclear Safety Authorities, and Nuclear PSA experts.
- A study of Risk Metrics
- Involvement in IAEA and ASME/ANS Level 3 PSA activities.
- Two Parallel Level 3 PSA pilot studies (conducted using Swedish and Finnish probabilistic consequence analysis tools).
- The conclusions from three project seminar/workshops.

The objective of today's Level 3 PSA studies is to assess the off-site radiological consequences of a radioactive release caused by an accident at a nuclear facility. The consequences of interest can be separated in to several general categories:

1. Health effects,
2. Environmental effects,
3. Economic effects.

Since Level 3 PSA is performed relatively infrequently, it is not currently standardised. Many different types of analyses can be performed and may fit different situations for different stakeholders. Some examples of studies where Level 3 PSA may be very applicable are: Siting, emergency planning/ mitigation strategies, and risk characterization (e.g. risk to society, financial liabilities/ insurance).

Much of the benefit of Level 3 PSA is quite apparent; as Level 3 PSA provides direct assessment of off-site consequences which are of significant interest for the assessment of public safety, whereas, the primary impediment to Level 3 PSA is the question of uncertainty.

Level 3 PSA can provide further understanding of consequences for a spectrum of source terms. Level 3 PSA provides a framework to analyse types of accidents that are not specifically discussed in deterministic analyses, potentially filling in gaps where deterministic analyses are not performed. Likewise, current Probabilistic Safety Analysis is largely focused on reactor core damage sequences. Since there is potential for radiological releases even when core damage may not occur, Level 3 PSA may give motivation to expand the scope to Level 1 and Level 2 PSA to account these deficiencies. Perhaps the simplest argument for regular probabilistic analysis of off-site consequences would be the additional scrutiny to Level 2 PSA source terms and focus of Level 1 and Level 2 PSA on relevant consequence metrics.

The discussion on the elements of Level 3 PSA, as described in chapter 4, is based on three cases which aim at covering a spectrum of Level 3 PSA consequences. The delineation between cases A, B and C has been made, as the intended use of the study has a great impact upon the necessary input and resources. The three cases are the following:

- Environmental risk – Case A: Size of land area with significant Cs contamination
- Individual risk – Case B: Risk of (early) death to maximum exposed individual (individual risk)
- Population Risk – Case C: Number of lethal cancers (late effects)

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