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Probabilistic safety goals for nuclear power plants – status in Sweden and Finland

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ABSTRACT: The paper describes the results from the first phase of an ongoing Nordic research project titled "The Validity of Safety Goals". The focus in this phase is on describing the status and experiences of safety goals in Sweden and Finland. The work has clarified the basis for the evolvement of safety goals for nuclear power plants in Sweden and Finland and of experiences gained, and resulted in a multi-faceted picture of the interpretation of existing safety goals, and of views regarding the usage of the goals and of perceived development needs. To provide further perspective, crucial references related to the formulation and use of safety goals were identified and reviewed. The second phase will be carried out during 2007, and is planned to include a more general international overview, including a comparison with safety goals used in other industries as well as detailed studies of specific issues, e.g., the relationship between probabilistic and deterministic acceptance criteria.

1 INTRODUCTION

1.1 *Background*

The outcome of a probabilistic safety assessment (PSA) for a nuclear power plant (NPP) is a combination of qualitative and quantitative results. Quantitative results are typically presented as the Core Damage Frequency (CDF) or as the frequency of an unacceptable radioactive release, often associated with the Large Early Release Frequency (LERF). 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.

Target values for PSA results are in use in most countries having nuclear power plants. In some countries, the safety authorities define these target values or higher level safety goals. In other countries, they have been defined by the nuclear utilities. Ultimately, the goals are intended to define an acceptable level of risk from the operation of a nuclear facility. There are usually also important secondary objectives, such as providing a tool for identifying and ranking issues with safety impact, which includes both procedural and design related issues. Thus, safety goals usually have a dual function, i.e., they define an acceptable safety level, but they also have a wider and more general use as decision criteria.

The exact levels of the safety goals differ between organisations and between different countries. There are also differences in the definition of the safety goal, and in the formal status of the goals, i.e., whether or not they are mandatory. Defining quantitative goals for reactor safety may have a large impact on both the analysis burden and on requirements for safety improvements at nuclear power plants. It is therefore of great importance that safety goals are soundly based, that they can be effectively and unambiguously applied, and that they can be accepted and understood by all parties concerned.

In most countries, the history of PSA safety goals starts in the 1980s, e.g., USNRC (1982) or IAEA (1988). At that time, PSA models were rather limited in scope. For various reasons, including limitations in analysis scope and capacity problems with the computer codes used for the analysis, the level of detail of the PSA models was also rather limited. In addition, the focus was on level 1 PSA, i.e., on calculation of CDF. Furthermore, the actual use of early PSA:s was generally rather limited, even if the issue of Living PSA received considerable attention during the 1980s.

During the 1990s, PSA models expanded considerably, both regarding operating states and classes of initiating events. The level of detail of the analyses also increased. In parallel, PSA:s were expanded to level 2, making it possible to calculate the frequency of radioactive releases. Thus, the scope, level of detail and areas of use of PSA have changed considerably since the time the safety goals were originally defined. At the same time, there is a growing interest in PSA applications. This has lead to an increased interest and need to make judgments concerning the acceptability of risk contributions calculated with PSA.

1.2 *Aim and scope*

The paper deals with the first phase of the project "The Validity of Safety Goals", see Holmberg and Knochenhauer (2007). The overall aim in this phase has been to discuss and document current views, mainly in Finland and Sweden, on the use of safety goals, including both benefits and problems. Another important aim has been to identify and clearly define the concepts involved in the definition, interpretation and use of safety goals.

The main objective has been to clarify the basis for the evolvement of safety goals for nuclear power plants and to describe the experiences gained. This was achieved by performing a series of rather detailed interviews with people who are or have been involved in the formulation and application of the safety goals, putting the focus on the question of where the safety goals came from, what they are perceived to stand for, and how they are interpreted. The experiences from their use was also discussed, as well as development needs. To provide further perspective, crucial references related to the formulation and use of safety goals were identified and reviewed. In addition, a limited review of the state-of-the-art internationally was performed by letting a number of people and organisations outside the Nordic countries answer a revised version of the questionnaire used for the Nordic interviews.

2 CONTEXT OF SAFETY GOALS

There are different reasons for defining safety goals, and the reasons may differ between different types of organizations. One aim may be to provide a tool to control the risk posed to society by the operation of nuclear power plants by defining a maximum acceptable risk. This risk may be related to the population potentially exposed to the risk, which is the most common case, but may also be related to some other entities, e.g., land contamination. Third party protection aim is always valid to some extent, even if it is not explicitly stated. When relating calculated risks to such a safety goal, the goal can in principle be used in an absolute manner giving the answer "Yes" or "No" to the question of whether the risk is acceptable or not.

The actual definition of a safety goal involves two elements, the definition of the risk metric and of the maximum frequency allowed in terms of the risk metric chosen. The frequency part is quite simple (but not necessarily uncontroversial), and is done by stating one or more frequency levels, e.g., a maximum CDF of 10^{-5} per year. The process used to derive the frequency may be more or less complex and sometimes relates to higher level safety goals, e.g., to overall safety goals on a national level.

The choice of the risk metrics can be a more complex activity, as it should be possible to relate to the degree of harm experienced by the population exposed to the risk (or other risk metrics). As an example, there is no simple connection between the core damage frequency for a nuclear power plant and the degree of risk experienced by the public. For level 2 PSA criteria (radioactive release), the connection is more evident, but not necessarily straight-forward and easily interpreted. In contrast, safety goals for other man-made risks are often expressed in terms of frequency and number of fatalities (F-N curves). Such safety goals are usually easier both to interpret and to apply. The F-N curve approach may also be chosen for criteria related to the results of a level 3 PSA (consequences of a radioactive release).

A related question is the definition of the target PSA of the safety goal, i.e., the probabilistic plant model and calculation procedure that are used to calculate the risk level which is to be compared to the safety goal. Thus, the scope of the analysis leading up to the quantitative assessment of the risk metric needs to be clearly stated. The precise and unambiguous definition of the target PSA should be part of the statement of the safety goal.

Once a safety goal has been defined, there is a need for an accepted procedure for carrying out the quantitative risk assessment, for applying the goal to the relevant risk metric, and for acting on the outcome of the application. In this context, a number of issues must be considered including handling of violations, handling of uncertainties of the quantitative risk assessment and use of safety goals in a *living* safety management context. Safety goals are typically quite stable, while PSA results may vary considerably over time. This may be due to changes in the actual plant, changes in the scope of the PSA, and changes in analysis methods or data used.

3 PROBABILISTIC SAFETY GOALS IN FINLAND

The first PSA projects were initiated for the Loviisa and Olkiluoto NPP:s in the early 1980s and the first level 1 PSA:s, including analysis of internal initiating events, were submitted in 1989 to STUK, the Radiation and Nuclear Safety Authority of Finland. In the 1990s, the PSA:s were complemented with analyses of area events, low power and shutdown operating modes, external events and level 2 PSA.

A special aspect in the Finnish history of PSA and safety goals is the long lasting planning of the fifth unit. The STUK's regulatory guide on PSA, YVL-2.8, was formulated from the very beginning to be used in the licensing of a new NPP. Olkiluoto 3 NPP, which is now under construction, is the only Finnish plant that has gone through a regulatory review including a comparison with quantitative probabilistic objectives.

3.1 *Requirements from authorities*

In the late 1980s, the plan to build a new plant caused a need to develop regulatory guides for licensing a new NPP. The first version of the regulatory guide for PSA, YVL guide 2.8 was issued in 1987, and included numerical design objectives for important safety functions. At this time, the PSA methodology was not regarded as mature enough for use of CDF- and LERF-level criteria.

The YVL guide 2.8 was revised in 1996 and again in 2003, see STUK (2003). These versions include safety goals for core damage frequency and for the frequency of an unacceptable radioactive release. The latest version has excluded the numerical design objectives for safety functions, because the safety functions included presumed a certain reactor type, which could make the guide inapplicable for other conceivable reactor types.

The numerical objectives 10^{-5} per year for core damage and $5 \cdot 10^{-7}$ per year for a large release were derived by comparing results from existing PSA:s in the 1980s and early 1990s and criteria presented in international guidelines, above all the IAEA INSAG-3, see IAEA (1988). The frequency 10^{-5} per year was considered a challenging but possible objective for a new NPP. The release criterion $5 \cdot 10^{-7}$ per year corresponds to a conditional probability of 0,05 for a containment failure. The limit for a severe accident, 100 TBq release of Cs-137 was taken from Swedish studies performed in the context of designing filtered venting systems in the 1980s, see VnP (1991). This corresponds to a rather small release, which makes the level 2 PSA objective very tight.

3.2 *Use of safety goals at the utilities*

The five Finnish nuclear power units are operated by TVO (Olkiluoto 1 and 2 BWR:s and Olkiluoto 3 PWR, which is under construction) and Fortum (Loviisa 1 and 2 PWR:s). The YVL 2.8 requirements only apply to new plants, i.e., they are mandatory only for the Olkiluoto 3 plant. To some extent, this criterion is also used as a reference or target value by the utilities. However, both utilities have defined informal safety goals for internal safety assessment.

TVO started development of numerical criteria while developing PSA applications in the early 1990s. The first applications were planning of preventive maintenance during power operation, optimisation of allowed outage times, and test interval optimisations. The criteria were based on results from PSA, YVL 2.8 and the U.S.NRC's regulatory guides 1.174–1.178. They are formulated in an internal PSA guide.

According to the TVO PSA guide, a permanent design change is not allowed to increase the CDF or frequency for unacceptable radioactive release by more than 1% of the target values in YVL 2.8. A higher risk increase must be justified. For temporary exemptions from Technical Specifications, STUK requires a PSA evaluation. In this case as well, TVO applies the 1% risk increase criterion, as well as the requirement, that higher risk increases must be justified.

In the Loviisa NPP, early PSA results indicated relatively high core damage frequency. PSA was used in the prioritisation of changes and comparison of alternatives. In this decision making, criteria are needed and therefore goals have been developed. The PSA goals are formulated in a bulletin, which is an unofficial procedure for PSA applications. The goal regarding core damage frequency is 10^{-4} per year and regarding frequency of large release 10^{-5} per year. These values correspond to recommendations in IAEA documents regarding plants built to earlier standards, IAEA (1998).

Loviisa has also developed economic criteria for justification of safety improvements, which could be used also for justification of plant modifications that can increase core damage risk. In practice, compensating measures are often applied. Criteria have been defined based on an estimation of the monetary value of core damage and large release.

3.3 *Summary of experiences*

The overall Finnish experience on the use of PSA safety goals is positive. Attention is paid to the comparison of numerical results. Safety goals also affect the quality of PSA by requiring more detailed modelling of some issues, and make it clear that excessively conservative assumptions need to be avoided since they can make the numbers look too bad. Safety goals thus are an incentive to make better analyses. In some cases, PSA has helped to avoid unnecessary changes suggested on a deterministic basis.

Concerning needs for improvements, the most discussed issue in Finland is the current definition for a large release, which is considered to be very stringent. The performance of level 3 PSA could be needed to judge the feasibility of the 100 TBq limit.

4 PROBABILISTIC SAFETY GOALS IN SWEDEN

The first PSA projects were initiated for all Swedish NPP:s in the early 1980s. The first level 1 PSA:s, including analysis of internal initiating events, were submitted in the mid-1980s, and followed by the first level 2 PSA a few years later. During the 1990s and up to today, the PSA:s have been complemented with analyses of area events, low power and shutdown operating modes, and external events.

4.1 *Requirements from authorities*

The Swedish regulatory tradition is mainly non-prescriptive, meaning that often high-level requirements are given, while the exact ways to fulfil the requirements is left to the licensees to decide. The focus of SKI, the Swedish Nuclear Power Inspectorate is on avoidance of radiological accidents, i.e., safety goals are directed towards protection of the public rather than towards avoidance of core damage.

This became evident in the discussions related to the introduction of procedures and systems for severe accident mitigation during the 1980s. The document which served as a basis for the design, SKI (1985), included a number of acceptance criteria for the mitigating systems after a severe accident, indirectly stating a frequency acceptance criterion ("extremely low probability") and a release criterion related to short-term health effects and long-term land contamination. A simplified interpretation of the criterion is that the requirements are fulfilled if the radioactive release after a severe accident is limited to below 0,1% of the inventory of the caesium isotopes Cs-134 and Cs-137 in a core of 1800 MWt. This corresponds to a release of 160 TBq of Cs-134 and of 103 TBq of Cs-137.

The interpretation of the frequency requirement, i.e., converting "extremely low probabilities" into a frequency of occurrence, was done by relating to the concept of *residual risk*, which has been interpreted by both the SKI and the licensees to correspond to an event with a frequency of about 10^{-7} per year. However, this is not spelled out in any of the government decisions, neither in SKI (1985). Except for this implicit numerical safety goal, the SKI has not defined any numerical safety goals.

4.2 *Use of safety goals at the utilities*

The twelve Swedish nuclear power units are operated by companies belonging mainly to the Vattenfall group (Ringhals 1 BWR, Ringhals 2–4 PWR, and Forsmark 1–3 BWR:s) and to the EON group (Oskarshamn 1–3 BWR:s and the decommissioned Barsebäck 1–2 BWR:s).

At Vattenfall, safety goals were first discussed at the end of the 1980s, resulting in the publication of a company policy for reactor safety in 1990. PSA related issues in the safety policy have been continuously discussed through the years, and minor revisions of the policy, not affecting the PSA related safety goals, were made from time to time, the most recent version being from 2006. The policy states that high priority is given to safety enhancing measures if probabilistic analyses indicate that the core damage frequency is above 10^{-5} per year with a high degree of confidence or above 10^{-7} per year for an unacceptable release (i.e. the SKI criterion).

The Vattenfall safety policy stresses the integrated aspects of safety assessment, stating that the planning of safety improvements shall be based on a combination of deterministic criteria, probabilistic methods, human factors analysis and utilisation of experience feedback. The safety policy on company level has been converted to site specific policies at the Ringhals and Forsmark plants, with more specific evaluation criteria including a graded approach similar to the one outlined in the IAEA Safety Report 12, IAEA (1998).

The Sydkraft group (now part of EON Nordic) issued a safety policy in 1995, which included safety goals for the frequency of core damage and large releases. The levels defined were 10^{-5} per year for core damage and 10^{-7} per year for an unacceptable release (i.e. the SKI criterion). The safety goals were not mandatory, but in case of PSA results above these levels, safety enhancing measures were to be prioritised. The policy was effective until 2004 when it was updated and re-issued as the EON Nordic safety policy. As part of the update, the quantitative safety goals were slightly revised; the core damage criterion is still at 10^{-5} per year but applies to *severe* core damage and the criterion for unacceptable releases now states that the frequency shall be considerably lower than the core damage criterion of 10^{-5} per year, which could be interpreted as at least a factor of 10 (the factor is not defined).

The EON group policy is the basis for the local policy applied by the OKG utility at the Oskarshamn plants. Detailed local criteria for interpretation and judgement of PSA results have been developed, including a graded approach similar to the one outlined in the IAEA Safety Report 12, IAEA (1998). In addition, probabilistic criteria have been defined with a focus on assessment of the remaining system barrier after an initiating event. These are typically applied for rare initiating events with large uncertainties in the event frequency, such as internal fires or external events.

4.3 *Summary of experiences*

PSA results and fulfilment of safety goals has been important in some applications and influenced the decision taken by the SKI, e.g., in the FENIX project for restart of Oskarshamn 1 after a major upgrade including considerable improvements of some safety related systems and functions.

At the utilities, the use of probabilistic safety goals is felt to have triggered a number of important safety improvements. PSA has generally provided an aspect on safety that has been valuable for the total activities at the plants, but this has largely been achieved independently of the safety goals. A general concern with probabilistic safety goals is the risk of the goals being seen as absolute limits, as this might indirectly have an impact on the quality and relevance of the PSA models.

At some utilities the development has been a move from a rather negative impression of PSA to a more positive one. The current view is that PSA in the right context and accompanied by other relevant information gives a very valuable contribution to safety analysis, and PSA has become an integrated part of the total safety analysis concept.

Safety goals have contributed to an increased awareness of the usefulness of PSA. They have also increased the focus on the correctness of the PSA models. Another experience is that the quality requirements on PSA increase in risk-informed applications. At an earlier stage, they are also believed to have had a slightly repellent effect, mainly because of a fear that exceedances might lead to unreasonable requirements on implementation of safety improvements, and that such actions might then be based on crude assumptions and prerequisites. An important background to this concern is that previous updates and extensions of PSA:s have resulted in large variations of results. For this reason, the view is that safety goals are mainly to be used as checkpoints showing that changes made point in the right direction, and that they can be useful as guiding lines in the safety work.

5 RESULTS AND CONCLUSIONS

5.1 *Use in decision making*

A numerical safety goal can be a mandatory criterion (limit), a desired target (an objective), a compensatory criterion, or an informal goal. In mandatory use, the value must be strictly met. This is typically the situation when numerical objectives are used for new NPP:s.

An objective is a desired target that should be aimed at, but where violations can be accepted and justified. Many licensees have defined safety goals for their plants as objectives, e.g., CDF $< 10^{-5}$ per year. In this usage, the safety goal is part of the long-term strategy to improve the safety of the plant. Some utilities include the PSA safety goals in their formal safety policy (Swedish utilities), while others keep them informal (Finnish utilities).

All of the organisations interviewed seem to favour an informal use of safety goals, due both to the uncertainties in the methodology and to the possibility for flexible handling of risk. It is feared that strict safety goal may switch the attention from an open-minded assessment of safety to the strict fulfilment of safety goals.

The use of safety goals implies a need for rules to handle violations. In Sweden, rather formal procedures for applying PSA safety goals are in place, but are not strictly enforced. This is probably due to the fact that PSA results have exceeded the safety goals ever since they were defined. Implicitly, a graded ALARP-like (As Low As Reasonably Practicable) approach has been applied, i.e.,:

- CDF $< 10^{-4}$ per year, i.e. the IAEA goal is a *limit*,
- CDF $< 10^{-5}$ per year, i.e., the own goal is a *target*.

In Finland, the companies' own safety goals for operating plants are informal and are interpreted as targets, not as limits. For this reason, discussion on handling of violations has not yet been necessary.

Although there has been a continuous progress in the use of PSA in decision making, there has also been variation in the enthusiasm for PSA. This depends on experience gained from the use of PSA. Positive experiences are the complementary view on safety provided by PSA and the possibilities to relax stringent deterministic rules. Resistance to the use of PSA can arise if PSA is felt to be an extra burden in addition to deterministic rules. Also, large variations in PSA results when updated can weaken the credibility of the method, especially among decision makers with a limited knowledge of the technique.

5.2 *Ambiguities in definitions*

There is quite good consensus about the definition of a core damage. For the frequency, most organisations have chosen either the levels 10^{-4} per year or 10^{-5} per year, usually referring to IAEA safety goals suggested for existing plants and future plants, respectively. The actual definition of what constitutes a "core damage" shows a larger variation, spanning from the 10 CFR 50.46 limit for local fuel temperature of 1204°C, which is a conservative definition, to "severe core damage" which is more realistic but less stringently defined. Obviously, other reactor types may require differently defined criteria.

The definitions of a large release vary considerably. There is both a larger variation in the frequency limits, and very different answers to the question of what constitutes an unacceptable release. As with the CDF, the magnitudes are sometimes based on IAEA safety goals suggested for existing plants, i.e., on the level of 10^{-5} per year. However, most countries have defined much stricter limits, between 10^{-6} and 10^{-7} per year. Definitions of an unacceptable release vary a lot, and there are many parameters involved, e.g., the time, amount, and composition of the release. The underlying reason for the complexity of the release definition is largely the fact that the release definition constitutes the link between the level 2 PSA results and an indirect attempt to assess health effects from the release. However, the consequence issue is basically a level 3 PSA issue.

5.3 *Treatment of uncertainties*

Uncertainties of PSA should be accounted for in decision making but there is no formal method, within PSA methodology, how to do it. As long as safety goals have an informal role, uncertainties can be handled by discussion. However, a mandatory goal requires strict comparison of two numbers.

One approach is to make a quantitative uncertainty analysis and to apply a numeric goal for uncertainties, too. There is, however, no theoretical framework to justify the use of the median, the mean or some other characteristics of an uncertainty distribution for this type of evaluation. A typical approach to handle uncertainties, is to perform combinations of qualitative and quantitative uncertainty analyses in parallel with sensitivity analyses. No numerical acceptance criterion is applied, but results are discussed qualitatively.

The problem of uncertainties can be turned around by focussing on the demonstration of safety goals instead of aiming at a realistic assessment of risk. Another approach to account for uncertainties is to make the necessary complementary assessments to PSA, e.g., simplified judgements regarding missing parts in the "original" PSA.

5.4 *Ambiguities in scope*

The status of PSA:s in the late 1980s, i.e., at the time of discussing and issuing the first safety goals, was less mature than today and PSA:s at the time were very incomplete compared to today's full scope PSA:s. It seems to have been implicitly assumed that the safety goals issued were applicable to a "typical PSA", which at that time was limited to power operation and included mainly internal events. Based on results from PSA:s performed at that time it was also assumed that the safety goals defined could be reasonably expected to be fulfilled. The gradual extension of the PSA:s and the inclusion of new initiating event categories and operating modes has lead to a situation where safety goals defined are frequently violated.

A reasonable position, is that the high level criteria (health effects for people or contamination of surrounding land and sea areas), i.e., the criteria which are closest to the subject at risk, should remain unaffected by the scope of a PSA. An example is the requirements regarding unacceptable releases to the surroundings (0,1%/1800 MWt). Thus, the safety goals shall in principle be applied to a full scope PSA, i.e., to the total risk of the plant. This is also a prerequisite when aiming at rational risk-based decision making.

Another problem arises for certain initiating event classes which include much larger uncertainties than the basic PSA, e.g., area events and external events. The uncertainty usually relates both to the frequency of occurrence of the events and to their characteristics (strength, duration, etc.). The analysis approaches for such event categories include both conservative and non-conservative assumptions to simplify the analysis of complex scenarios. In this case, there may be reason to consider alternative approaches, such as the introduction of lower level criteria for analysis of crucial parts of the scenarios. As an example, criteria can be defined for barrier strength after the postulated occurrence of an initiating event with high uncertainty, e.g., a certain fire scenario. Such an approach can be efficient as a decision tool, but has the drawback, that no integrated risk picture can be created.

5.5 *Relationship between safety goals on different levels*

In attempting to rank safety goals on different levels, high level criteria, which are closest to the subject at risk, can be considered most important. With such a view, lower level safety goals are seen as subsidiary goals, which are used in order to gain confidence, based on lower level results, in the ability of plant systems and functions to contribute to the fulfilment of the high-level goal. There may be an added advantage of reduced uncertainties on lower levels, leading to less ambiguity in decision making.

If multiple criteria are defined, it is natural to require consistency between safety goals on different levels. This will usually be fulfilled as the goals address different aspects of plant safety, by relating to different defence-in-depth levels. A reasonable position is that both the CDF and release goals should be fulfilled. However, they are not equally important, as the level 2 goal is closer to the subject of the risk (people or plant surroundings) and therefore should have priority over the level 1 goal. On the other hand, it is easier to compare results in a level 1 PSA where the methodology is more stable and uncertainties smaller than in a level 2 PSA. This aspect prioritises the use of level 1 goal. In practice, both these considerations will need to be kept in mind in the use of safety goals.

To validate goals related to CDF and large releases as surrogates of societal risk calls for assessments of the environmental consequences of event sequences resulting in radioactive releases. The results of a level 3 PSA consider this aspect. Level 3 PSA is only required in few countries, typically those with safety goals defined on the level of population risk, e.g., the UK and the Netherlands. In Finland and Sweden, there are not yet plans to perform level 3 PSA:s.

5.6 *Use for new plants vs. for operating plants*

New plants and old plants are not in the same position in the use of safety goals. For the oldest plants, the design basis is solely deterministic and PSA was not used at all during the design and licensing phase.

A design phase PSA is also different from an as-operated PSA with regard to level of details and quality of data.

In the case of new plants, safety goals are used by the utility both in relation to the vendor and to the safety authority. In the regulatory use, the role of safety goals is principally clear, i.e., PSA results are compared with numerical objectives and no violations are accepted in this situation.

The role of safety goals for operating plants is less clear. In Sweden and Finland, the regulatory guides only require performance of PSA and use of PSA in safety management. It is mainly up to utilities to define the goals and the way of applying them. Therefore great variations exist between utilities, even if the safety goals defined for new plants reference, IAEA (1998). The U.S.NRC's guides for risk-informed applications are also widely used standards.

A frequently encountered regulatory requirement for operating plants calls for continuous safety improvement. It is not clear, if this should always be understood in such a way, that risk increasing modifications are never acceptable, regardless of the absolute level of the frequency of core damage or large release.

5.7 *Comparison of safety goals defined in different contexts*

There is a need to compare safety goals defined in different contexts, e.g., for different industries. In this way a better basis could be gained for justifying that the safety goals are such that compliance warrants a "safe enough" plant. In the next phase of the project, one aim is to make a compilation of high level safety goals used in some other contexts (offshore industry, transportation, etc.).

The societal level criteria (F-N-curves) and individual risk criteria used in other areas are applicable references for high level safety goals. A variety of criteria can be found. The numerical societal criteria defined in the UK and the Netherlands define the limit 10^{-5} per year (UK) or 10^{-7} per year (the Netherlands) for an accident with more than 100 deaths. In the USA, the societal risk criterion is comparative and qualitative, so that the risk to society from generating electricity using nuclear power should be comparable with that from generating electricity by other techniques. It should not make a significant addition to other societal risks, and the quantitative criterion is that the risk of death should be $< 0{,}1\%$ of the sum of cancer fatalities from other sources. Individual risk criteria vary between 10^{-4} per year (limit in the UK and Canada) to 10^{-6} per year (objective in the UK, Japan and Canada, limit in the Netherlands for a single source). Cost-benefit ratios for saving a human life may be also used as references, if a comparison of the risks with nuclear accident risks is considered reasonable.

6 CONCLUSIONS

In Sweden and Finland there are more than 20 years of experience of performing PSA, which includes several revisions of the studies, a gradual increase in scope and level of detail, as well as steadily increasing use of PSA for decision making. In spite of the many safety improvements made through the years based on PSA results, a current view is that the safety goals outlined in the 1980s, i.e., 10^{-5} per year for CDF and 10^{-7} per year for unacceptable release, are hard to achieve for operating NPP:s. This experience arouses confusion that should be resolved in order to further strengthen the confidence in the PSA methodology. Questions aroused include what safety goals should be applied to operating plants, whether the risk level of the plants is too high, whether PSA:s are too conservative, and if safety goals are being applied in an incorrect way. The situation can be somewhat different for a new plant, for which risk insights have been utilised already from the design phase. Therefore, it will be interesting to see to what extent the Olkiluoto 3 NPP currently being built in Finland will fulfil existing safety goals, and what influence the they will have on the final design of the plant.

The use of safety goals is mostly understood to have had a positive impact from a PSA quality point of view. It seems that informal use of safety goals and cost-benefit evaluations is preferred by most in comparison to a situation with strictly enforced acceptance criteria. One perceived reason to avoid strict use of safety goals is that this might switch the attention from an open-minded assessment of plant safety to the mere fulfilment of safety goals. In order to fulfil safety goals, unnecessary conservatism needs to be avoided in the modelling, i.e., the basic aim should be to have realistic PSA models.

The use of safety goals implies a need for rules to handle violations. In Sweden, formal procedures for handling PSA safety goals are in place, but are not strictly enforced, which is probably due to the fact that PSA results have exceeded the safety goals during most of the time since they were defined. In consequence, a graded approach similar to ALARP has been implicitly applied.

From the regulatory perspective, quantitative safety goals are not strictly applied for operating plants. Utilities may define safety goals and the way they are applied. In regulatory decision making, i.e., in risk-informed applications and plant modifications, decisions are made case by case. There is, however, a general regulatory requirement on continuous improvement of safety. There is a need to clarify the role of this requirement relative to the role of numerical safety goals.

Goals related to CDF and LERF are surrogates to societal risk level criteria. To fully validate these goals, calculations of environmental consequences of release sequences would need to be made. In a few countries, the performance of level 3 PSA:s is required, which includes this aspect. In Finland and Sweden, there are not yet plans to perform level 3 PSA:s. However, there is a need to discuss and define more precisely the safety goals related to radioactive release, as they are understood differently in different organisations.

Integration of deterministic and probabilistic criteria is still a problematic issue. The concepts seem to be difficult to integrate in practice and people are often inclined to be tuned to one or the other. Finding the correct balance between deterministic and probabilistic safety thinking has to do with the fundamental questions of "how safe is safe enough?" and of how to prove this safety level. It would be beneficial to discuss relationships between deterministic and probabilistic criteria, and their interpretation in illustrative cases. Fulfilment of the defence-in-depth principle as well as of redundancy, diversity and separation criteria for various initiating event categories are examples of open questions.

The final underlying obstacle in the use of safety goals are the uncertainties of PSA. Differences in the scope of PSA, and different methods used in different parts of PSA make consistent comparisons of risks difficult. The only way to resolve the problem of uncertainties is to put emphasis on justification of the results and conclusions. This implies explicit presentation of claims, arguments and the underlying evidence, in order to convince the reviewer of the conclusions that the plant is safe enough. This is the so called safety case approach.

The results from the project can be used at the utilities as a platform for discussions 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 are expected to support on-going activities concerning risk-informed applications.

The second project phase, during 2007, aims at providing guidance for some of the problems identified in the project. Additional information will be provided by extending the international overview and including experiences from other industries. This is partly achieved by participation in the Safety Goals project in the OECD/NEA Working Group on Risk Assessment. Insights from other on-going research projects will be considered, e.g., a planned SKI project on using PSA in the assessment of defence-in-depth and the ongoing EU programme SARNET (Severe accident research network).

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