Authors: : Jan-Erik Holmberg
                 Michael Knochenhauer

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Guidance for the Definition and Application of Probabilistic Safety Criteria

This report concerns a study which has been conducted for the Swedish Radiation Safety Authority, SSM. The conclusions and viewpoints presented in the report are those of the author/authors and do not necessarily coincide with those of the SSM.

SSM Perspective

Background
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 quality and realism of a risk assessment. On the other hand, strict use of probabilistic criteria is usually avoided, due to the large number of different uncertainties in a PSA model.

The aim of SSM and of the report
This report aims at providing general guidance concerning the formulation, application and interpretation of probabilistic criteria. The Nordic project "The Validity of Safety Goals" that was initiated in 2006 and finalised in 2010, had the aim to 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, as well as of experiences in Finland and Sweden. The project has also aimed at providing guidance related to the resolution of some of the problems identified, such as the problem of consistency in judgement, 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, a wide international overview was achieved by contributing to and benefiting from a survey on PSA safety criteria which was initiated in 2006 within the OECD/NEA Working Group Risk.

Results
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.

Possible continued activities within the area
Safety goals are currently widely discussed both nationally and internationally, e.g., in the OECD, the IAEA and in WENRA. The project results can be used in connection with these discussions.

Effect on SSM activities
The project results can be used by the SSM as a reference for risk-informed regulation and be a help in assessing PSA results in general. It can also be used as an input in international discussions on Safety Goals.

Project information
Project responsible at SSM: Ralph Nyman
Project number: 1465
Diary number: SSM 2009/2612

References to other similar research projects and reports:
Other reports issued within the project "The Validity of Safety Goals":
- Holmberg, J-E; Knochenhauer, M; Probabilistic Safety Goals. Phase 1 - Status and Experiences in Sweden and Finland; SKI Research Report 2007:06; 2007
- Holmberg, J.-E.; Knochenhauer, M; Probabilistic Safety Goals. Phase 2 - Status Report; Nordic Nuclear Safety Research report NKS-172, ISBN 978-87-7893-238-9; NKS; 2008
- Holmberg, J-E; Knochenhauer, M.; Probabilistic Safety Goals Phase 3 - Status Report; NKS-195 ISBN 978-87-7893-262-4; NKS; 2009
- Holmberg, J-E; Knochenhauer, M.; Probabilistic Safety Goals for Nuclear Power Plants; Phases 2-4 / Final Report; SSM Research Report 2010:35; 2011

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Acronyms and Abbreviations

ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
BWR	Boiling water reactor
CDF	Core damage frequency
CET	Containment event tree
CFF	Containment failure frequency
CLI	Criteria for limiting impact (in EUR)
CSNC	Canadian Nuclear Safety Commission
DBA	Design Basis Accident
DID	Defence-in-depth
DSA	Deterministic Safety Analysis
EOP	Emergency operating procedures
EPR	European Pressurized Reactor
ET	Event tree
EUR	European Utility Requirements
FKA	Forsmarks Kraftgrupp AB
FT	Fault Tree
HRA	Human reliability analysis
HSE	Health and Safety Executive (UK)
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IE	Initiating event
INES	International Nuclear Event Scale (IAEA)
JAEA	Japan Atomic Energy Agency
LERF	Large early release frequency
LOCA	Loss of coolant accident
LRF	Large release frequency
LWR	Light water reactor
NEA	Nuclear Energy Agency of OECD
NII	Nuclear Installations Inspectorate
NKS	Nordic nuclear safety research
NPP	Nuclear power plant
NPSAG	Nordic PSA Group
OECD	Organisation for Economic Co-operation and Development
PSA	Probabilistic safety assessment
PWR	Pressurised water reactor
RC	Release category
RPS	Reactor protection system
SAP	Safety assessment principle (UK HSE)
SAR	Safety Analysis Report
SG	Safety goal
SKI	Swedish Power Nuclear Inspectorate (Statens kärnkraftin-spektion); (until 2008 – now part of SSM)

SSC	Systems, structures and components (of a nuclear power plant)
SSI	The Swedish Radiation Protection Authority (Statens strålskyddsinstitut); (until 2008 – now part of SSM)
SSM	Swedish Radiation Protection Authority (Strålsäkerhetsmyndigheten)
STUK	Radiation and Nuclear Safety Authority of Finland (Säteilyturvakeskus)
TVO	Teollisuuden Voima Oy
U.S.NRC	United States Nuclear Regulatory Commission
VTT	Technical Research Centre of Finland
WG	Working Group (of OECD/NEA)

SUMMARY

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.

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 judgement, 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.

This guidance document aims at describing, on the basis of the work performed throughout the project, issues to consider when defining, applying and interpreting probabilistic safety criteria. Thus, the basic aim of the document is to serve as a checklist and toolbox for the definition and application of probabilistic safety criteria. The document describes the terminology and concepts involved, the levels of criteria and relations between these, how to define a probabilistic safety criterion, how to apply a probabilistic safety criterion, on what to apply the probabilistic safety criterion, and how to interpret the result of the application. The document specifically deals with what makes up a probabilistic safety criterion, i.e., the risk metric, the frequency criterion, the PSA used for assessing compliance and the application procedure for the criterion. It also discusses the concept of subsidiary criteria, i.e., different levels of safety goals.

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.

Acknowledgements

1. Introduction

1.1 Project overview

The project "The Validity of Safety Goals" has been financed jointly by NKS (Nordic Nuclear Safety Research), SSM (Swedish Radiation Safety Authority) and the Swedish and Finnish nuclear utilities. The national financing went through NPSAG, the Nordic PSA Group (Swedish contributions) and SAFIR2010, the Finnish research programme on NPP safety (Finnish contributions).

The project has been performed in four phases during 2006–2010. An overview of the entire project is given in
Figure 1.

Figure 1 Overview of the 4-year NKS project "The Validity of Safety Goals" (2006–2009).

The first phase of the project ("BASIS") was carried out with the aim to discuss and document current views, mainly in Finland and Sweden, on the use of safety goals, including both benefits and problems. The work has clarified the basis for the evolvement of safety goals for nuclear power plants in Sweden and Finland and of experiences gained. This was achieved by performing a rather extensive series of detailed interviews with persons who are or have been involved in the formulation and application of the safety goals. Results of phase 1 have been published in two parallel reports issued by NKS [NKS-153], and SSM [SKI_2007:06]. The report presents the project context and a background to safety goals, as well as a historical review describing reasons for defining safety goals, context of goals and experiences. A number of specific issues related to the definition, interpretation and use of probabilistic safety goals were also identified and discussed. Towards the end of project phase 1, the OECD/NEA Working Group RISK started preparations for carrying out a task aimed at mapping probabilistic safety criteria in use in the member countries, and at collecting experiences from application of probabilistic criteria. The OECD/NEA task was defined and carried out in co-operation with the NKS project.

The second, third and fourth project phases ("ELABORATION") increased the scope and level of detail of the project by addressing a number of specific issues related to the application and use of safety goals, i.e.: consistency in the usage of safety goals, usage of probabilistic analyses in support of deterministic safety analysis, criteria for assessment of results from PSA level 2 (criteria for off-site consequences), and the use of subsidiary criteria and relations between these. These phases also included the addition of a more systematic overview of international safety goals and experiences from their use, including participation in the OECD/NEA WGRISK Task 2006:2 "Probabilistic safety criteria" [NEA/CSNI/R(2009)16], and a concise review of safety goals related to other man-made risks in society, with focus on the railway and oil and gas industries. Separate reports were issued for project phases 3 and 4 [NKS-172 and NLS-195]; the present report covers project phases 2-4, i.e., it includes relevant part of these reports as well as project results from phase 4.

The fourth and final project phase has also resulted in a "Guidance for the formulation, application and interpretation of probabilistic safety criteria", which is issued as a separate report by NKS and SSM, [NKS-227 / SSM 2010:36].

Thus, the outcome of the project is covered by the following three project reports:

- BASIS: Probabilistic Safety Goals. Phase 1 – Status and Experiences in Sweden and Finland [NKS-153 / SKI 2007:06].

- ELABORATION: Probabilistic Safety Goals for Nuclear Power Plants. Phase 2-4 – Final Report [NKS-226 / SSM 2010:35].

- GUIDANCE: Guidance for the formulation, application and interpretation of probabilistic safety criteria [NKS-227 / SSM 2010:36].

1.2 Concepts involved

Figure 2 gives an overview of some (but not all) of the concepts that are involved when defining probabilistic safety criteria, using criteria for core damage frequency and large (early) release frequency as an example.
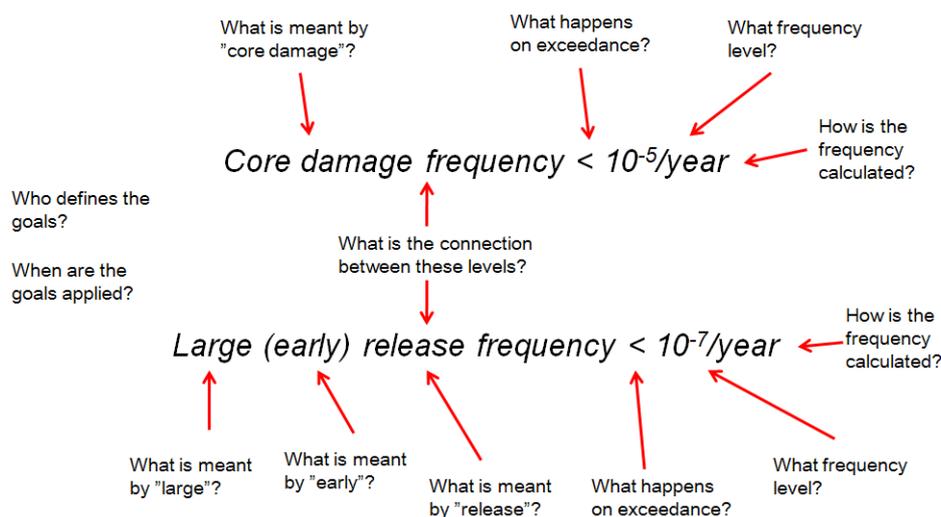
Figure 2 Some concepts involved when defining a probabilistic safety criterion.

As seen from the figure, some of the concepts are related to the definition of the safety criteria

- Who defines the goals?

- What is a core damage / large (early) release?

- What is the relation between criteria on different levels?

- What frequency level is used?

Other concepts relate to the application:

- When are the goals applied?

- How is the frequency calculated?

- Is the frequency a limit or an objective?

- What happens on exceedance of a criterion?

The guidance document will address these and other issues.

1.3 The guidance document

1.3.1 Aim and scope

The guidance document aims at describing, on the basis of the work performed throughout the project, issues to consider when defining, applying and interpreting probabilistic safety criteria. Thus, the basic aim of the document is to serve as a checklist and toolbox for the definition and application of probabilistic safety criteria. The guidance has been discussed at two project seminars, i.e., at the project phase 3 seminar in December 2008 to collect input on expectations [SG_Semin_2008], and at the final project seminar in January 2010 [SG_Semin_2010] where a draft version of the guidance document was presented and discussed.

The document describes the terminology and concepts involved, the levels of criteria and relations between these, how to define a probabilistic safety criterion, how to apply a probabilistic safety criterion, on what to apply the probabilistic safety criterion, and how to interpret the result of the application.

The document specifically deals with what makes up a probabilistic safety criterion, i.e., the risk metric, the frequency criterion, the PSA used for assessing compliance and the application procedure for the criterion. It also discusses the concept of subsidiary criteria, i.e., different levels of safety goals.

1.3.2 Limitations

Regarding the actual numerical values of probabilistic safety criteria, i.e., their frequency and magnitude in terms the risk metric chosen, no specific recommendations are given. However, values commonly used internationally and in the Nordic countries will be summarised for reference.

The focus in the guidance is on criteria for over-all assessment of PSA results. Therefore, although much of the contents are relevant also when considering criteria for risk informed (RI) decision making, some types of crite-

ria that are specific for RI applications are not discussed in the guidance, e.g., differential criteria and trade-off criteria.

Obviously, the relevance of the outcome of the application of probabilistic safety criteria is highly dependent on the over-all quality, completeness, and degree of realism in the PSA used for estimating the risk metric. Discussions of this aspect is not within the scope of the guidance, but have been indirectly addressed in the chapter on consistency in usage of safety criteria in the project phase 2-4 report [NKS-226 / SSM 2010:35].

1.3.3 OECD/NEA WGRISK Task 2006:2

As described in the background, an important sub-project within project phases 2-4 was the participation in the OECD/NEA WGRISK Task 2006:2 "Probabilistic safety criteria" [NEA/CSNI/R(2009)16]. The results from this work are used throughout the guidance to provide reference information. The following is a short summary of the scope of the task.

A questionnaire that was used as a basis for compiling information requested information on criteria defined on different levels, with added questions on the basis for the criteria, the way they are applied and experience on their use.

Answers were received from 13 nuclear safety organizations (Canada, Belgium, Chinese Taipei, Finland, France, Hungary, Japan, Korea, Slovakia, Sweden, Switzerland, UK and USA) and 6 utilities (Hydro-Québec, Fortum, OKG (E.ON), Ontario-Power-Generation, Ringhals AB (Vattenfall) and TVO). Two of the regulatory bodies (Belgium and Chinese Taipei) declared they have not set (and do not intend to set) any probabilistic safety criterion. The reported probabilistic safety criteria can be grouped into four categories:

- Core Damage Frequency (CDF) – Level 1 PSA – 16 respondents

- Releases Frequency (LERF, LRF) – Level 2 PSA – 14 respondents

- Frequency of Doses – Level 3 PSA – 4 respondents

- Criteria on Containment Failure – System level – 2 respondents

1.3.4 Overview of the Guidance

The guidance document includes three main sections. Chapter 2 describes in some detail the terminology and concepts needed to define and understand probabilistic safety criteria. The chapter also aims at clarifying concepts and making recommendations on how to use them. Chapter 3 deals with the definition of a probabilistic safety criterion, discussing what makes up a criterion and on what levels criteria can be defined. Specific descriptions are given for a number of criteria levels, including a summary of the international status related to the various types of criteria. Chapter 4 deals with the applica-

tions of probabilistic safety criteria, including a discussion of the users of criteria, and procedures for applying criteria and for acting on the outcome of the application.

2. Terminology and concepts

Table 1 lists and describes terms that are often used in the discussion of probabilistic safety criteria, and the interpretation given to them in this guidance. In some cases, recommendations are also given for the choice among alternative, more or less synonymous, concepts. If a description contains words in italics, this means that these are also explained in the table.

Table 1. Terminology used in connection with probabilistic safety criteria

Term	Description
Probabilistic	The use of the prefix *probabilistic* indicates that a criterion is expressed in terms of a frequency or probability. It is recommended to use the term *probabilistic* as a specification of a frequency/probability criterion in order to distinguish it from deterministic criteria.
Safety (Risk)	Somewhat paradoxically, these two concepts are often used more or less as synonyms, e.g., in PSA vs. PRA. Basically the choice of term is a question of the point of view, i.e., whether an analysis deals with *safety* (achieving or demonstrating absence of unacceptable risk) or with *risk* (more general in meaning, i.e., associated with achieving or demonstrating acceptably low risk only if used together with other concepts, e.g., criterion, objective or limit). In the present guidance, the word *safety* is given preference.

Table 1. Terminology used in connection with probabilistic safety criteria

Term	Description
Criterion *(Goal)* *(Target)*	When discussing probabilistic criteria, these terms are often used more or less as synonyms, in many cases without properly considering the implications of the choice. Thus, criterion is more static and objective in meaning, while *target* and *goal* indicate a process or aim. In the present guidance, the word *criterion* is given preference, and further specification is used in order to define the nature of a criterion. In order to make possible efficient interpretation of a criterion, it is recommended always to specify it, i.e., to define whether the criterion is mandatory or voluntary, whether it is a limit or an objective, etc.
Objective *(Goal)* *(Target)*	If a probabilistic safety criterion is an *objective*, it states a broadly acceptable level of safety. If the objective is achieved, further risk reduction is not required. An *objective* is usually defined together with a *limit*. If used in isolation, an *objective* is broadly equivalent with a goal or target.
Limit	If a probabilistic safety criterion is a *limit*, it states the lowest acceptable safety level. If not achieved, the probabilistic safety criterion is violated. If achieved, the safety level is acceptable, but further risk reduction is required. A *limit* is always defined together with an *objective*.
Band criterion	A *band criterion* consists of a limit and an objective, the band being the range of frequency or probability between these two values. Defining a band criterion is part of an *ALARP* approach.
Consequence or End state	This is the consequence considered for a specific probabilistic safety criterion. Example: ■ The end state may be "core damage" for a criterion related to PSA level 1.

Table 1. Terminology used in connection with probabilistic safety criteria

Term	Description
Metric	The definition of a *metric* requires a specific magnitude to be assigned to the consequence related to a probabilistic safety criterion. Example: ■ A "core damage" may be considered to have occurred if the local fuel temperature in any part of the core has exceeded 1204 ºC.
Risk metric (Risk measure)	The *risk metric* defines what constitutes a "risk" in the definition of a probabilistic safety criterion. For a specific criterion, "safety" means achieving an acceptable level of risk in terms of the risk metric defined for the criterion. In a situation with multiple criteria on different levels, where some of the criteria are subsidiary to a primary safety goal, the risk metric will be different on the different criteria levels, e.g., going from fatalities (PSA level 3), through the characterisation of an unacceptable radioactive release (PSA level 2) or of fuel damage (PSA level 1), to the reliability of safety systems or the frequency of PSA initiating events. The definition of a *risk metric* requires a frequency or probability to be assigned to the metric related to a probabilistic safety criterion. Example: ■ The risk from "core damage" is measured by calculating the "core damage frequency". ■ The terms risk metric and risk measure are basically synonyms, and in the present guidance the word risk metric is given preference.
Risk criteria	*Risk criteria* refer to any quantitative decision making criterion used when results of risk assessment are applied to support decision making. Various types of criteria can be used, such as: absolute criteria, relative criteria, differential criteria and trade-off criteria [RESS_36(1992)23].

Table 1. Terminology used in connection with probabilistic safety criteria

Term	Description
Primary safety goal	A *primary safety goal* is defined on the level that is ultimately to be protected from hazards. The risk may typically concern workers or individuals inside or around a site (criterion on individual level), groups of individuals (criterion on society level), or long-term ground contamination (ground contamination criterion). Primary safety goals are typically declared in high level regulatory documents or in utility safety policies. In most cases, primary safety goals are supplemented with subsidiary (lower-level) criteria.
Subsidiary criterion *(Surrogate criterion)*	A *subsidiary criterion* is any criterion that has been defined below the level of the primary safety goal. Thus, if the primary safety goal is on the level of fatalities (PSA level 3), subsidiary criteria may be defined, e.g., for unacceptable radioactive release (PSA level 2), fuel damage (PSA level 1), reliability of safety systems, or the frequency of PSA initiating events. The terms subsidiary or surrogate criteria are basically synonyms and work equally well. In the present guidance, the word *subsidiary criteria* is given preference.
Lower level criteria	In this guidance, *lower level criteria* is used for two types of criteria: ■ Criteria defined on a technical level below core damage, e.g., for safety functions or safety systems. ■ Barrier strength criteria, e.g., applied to containment integrity after a core damage has occurred.

Table 1. Terminology used in connection with probabilistic safety criteria

Term	Description
Scope (of probabilistic safety criterion)	The *scope* of a probabilistic safety criterion is related to the scope of the analysis required to demonstrate compliance. When a PSA is used in the demonstration, this relates to three parameters: 1. Sources of fuel release (inside core, outside core, fuel storage and transportation…) 2. Initiating events covered (internal events, area events, external events, etc.) 3. Operating states covered (power operation, shut-down and start-up, cold shut-down, etc.) For lower level criteria, e.g., related to system reliability, other scope definitions may be required.
Target (of probabilistic safety criterion)	The *target* of a probabilistic safety criterion defines what it is to be applied on, e.g., new plants, existing plants, specific plant, any nuclear facility, etc. It also states whether the criterion applies to a single reactor or to multiple reactors.
Mandatory *Informal (Voluntary) (Indicative)*	These terms relate to the formal status of the probabilistic safety criterion when being applied. Thus, they shall not be confused with the concepts limit/objective, which are used to characterise a criterion. It is important to specify as part of the definition of a probabilistic safety criterion whether and to what extent a criterion is mandatory. A *mandatory* criterion is required to be met under the application conditions specified as part of the definition of the probabilistic safety criterion. An *informal* criterion is not required to be met. The status of the criterion needs to be further defined as part of the definition of the probabilistic safety criterion.
Application (of probabilistic safety criterion)	As probabilistic safety criteria are typically not valid always and under all circumstances, there is a need to include in the definition of a criterion what is meant by an *application* of the criterion.

Table 1. Terminology used in connection with probabilistic safety criteria

Term	Description
Compliance (with probabilistic safety criterion)	*Compliance* with a probabilistic safety criterion means the criterion is met. If a band criterion is defined (ALARP), i.e., the compliance may be conditional, i.e., it may presuppose attempts for further risk reduction.
Violation (of probabilistic safety criterion)	*Violation* of a probabilistic safety criterion means the criterion is not met. Depending on the status of the criterion (*mandatory* or *informal*), the consequences of a violation can differ.
Individual risk	The *individual risk* is the risk faced by any specific individual as a result of an accidental event. Typically, in risk analysis this is calculated for an anonymous person in the most exposed position.
Societal risk Collective risk Group risk	The *collective, group* or *societal risk* is the expected total risk in the population exposed to risk, often expressed as the number of casualties per unit time.
F-N curve	Collective risk can be expressed by an *F-N curve*, e.g., as shown in the figure below. Probabilistic safety criteria can also be also defined with an F-N curve.
ALARP (ALARA)	Risk acceptance is often presented using the ALARP[1] (As Low As Reasonably Practicable) framework. ALARP divides levels of risk into three regions:
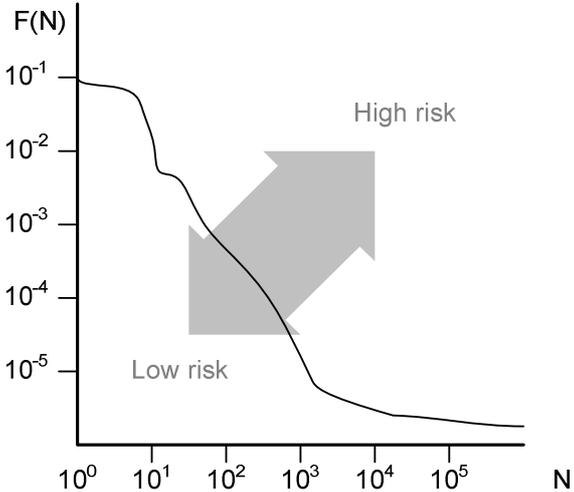
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[1] Sometimes also referred to as ALARA (As Low As Reasonably Achievable), with the same meaning.

Table 1. Terminology used in connection with probabilistic safety criteria

Term	Description
	1. Unacceptable (intolerable) region. Risk cannot be justified on any grounds. 2. The ALARP or tolerability region. Risk is tolerable if the benefit is desired. Trade-off analysis is made to evaluate the need for risk reductions. 3. Broadly acceptable region. Risk is negligible. No need for further risk reduction. The figure below presents the risk acceptance criteria for major industrial accidents defined by the Dutch safety authority [VROM-1988], an ALARP approach with $F(N) = 10^{-3} \cdot N^{-2}$. ALARP is often used when defining *F(N) criteria*, but can also be applied to a single risk metric, e.g., by defining a limit and objective for a probabilistic safety criterion related to core damage frequency.
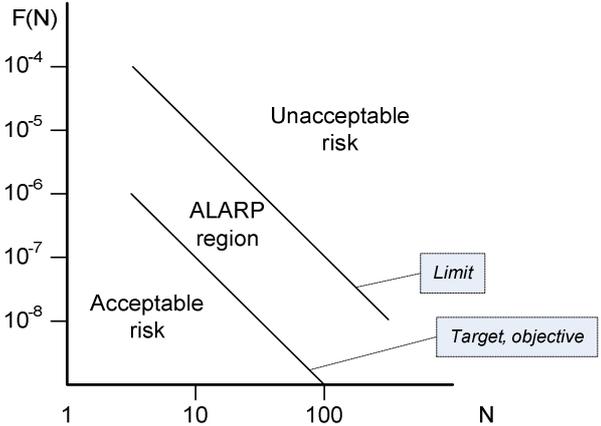
3. Defining probabilistic safety criteria

3.1 Introduction

This chapter deals with the definition of a probabilistic safety criterion, discussing what makes up a criterion and on what levels criteria can be defined. Specific descriptions are given for a number of criteria levels, including a summary of the international status related to the various types of criteria.

3.2 Levels of probabilistic safety criteria

Risk criteria related to the operation of nuclear power plants are defined on three levels:

- Society level

- Intermediate level

- Technical level

3.2.1 Society and intermediate level criteria

In many countries, nuclear safety is ultimately governed by qualitative criteria on *society level*, which are defined in nuclear legislation or issued by regulatory authorities. These criteria differ in wording between countries, but generally presuppose the "prevention of unreasonable risk to the public and the environment". Society level criteria are important as high-level statements, but cannot in themselves be used as a basis for defining numerical criteria.

Intermediate level criteria are more precise and can be both qualitative and quantitative. They typically define "unreasonable" risk by comparison with the levels of risks coming from other involuntary sources of risk, e.g., with fatality risks from other sources of energy production or cancer fatality risks from other unnatural causes to which an individual is generally exposed. Generally they express the requirement that "risks from use of nuclear energy shall or should be low compared to other risks to which the public is normally exposed". Thus, intermediate level criteria are the implicit basis for defining the primary safety goal, which requires an interpretation in numerical terms of what constitutes an unreasonable risk to an individual or to society.

The Guidance will deal with criteria on the technical level, i.e., no further comments will be given to these high level criteria.

3.2.2 Technical level criteria – introduction

Criteria on *technical level* are quantitative, and always in some way or other aim at deciding whether a risk is acceptable or not. Acceptability can be judged using criteria which are based on three basically different approaches:

■ criteria which define acceptable risks,

■ criteria which focus on controlling the risk increase, or

■ criteria which define a negligible risk.

Criteria may be of four kinds, i.e., absolute, relative, differential or involving trade-off:

■ Absolute Criteria
  Risk is expressed in absolute terms and judged against absolute risk criteria.

■ Relative Criteria
  Risk is expressed in relative terms, e.g., in terms of the relative difference between absolute risks on two different levels.

■ Differential Criteria
  With this type of criterion, the focus is on the absolute risk increase. Thus, a differential criterion may define the maximal allowed risk increase, e.g., $\Delta f(\text{core melt}) < 10^{-7}$./year.

■ Trade-off Criteria
  This approach assumes a constant risk level, meaning that any changes resulting in additional risk must be compensated by changes reducing the risk back to the original level.

The focus in the guidance is on criteria for over-all assessment of PSA results. Therefore, criteria that are specific for RI applications, e.g., differential criteria and trade-off criteria are not further discussed.

3.2.3 Technical level criteria – introduction

Criteria on *technical level* are typically defined on one or more of the following levels:

■ Off-site consequence level (corresponding to PSA level 3)

■ Radioactive release from plant level (corresponding to PSA level 2)

■ Core or fuel damage level (corresponding to PSA level 1)

■ Lower technical level (barrier strength, safety function, safety system)

Each of the criteria levels listed above is described in detail in separate sections. This is preceded by a section dealing with considerations common to all types of criteria.

3.3 Considerations common to all types of criteria

3.3.1 Main constituents of a probabilistic safety criterion

A properly defined probabilistic safety criterion consists of four parts, which are all further described in separate sections:

- The definition of the criterion
  This defines the criterion, e.g., "the core damage frequency of a nuclear power plant shall be $< 10^{-5}$/year". In order for the criterion to be relevant, further definition are required, e.g., of "core damage", and of "$< 10^{-5}$/year".

- The scope of the criterion
  This defines what the criterion is to be applied on, e.g., "a full scope PSA for the power operation mode".

- The target of the criterion
  This defines the plants to which the criterion applies, e.g., "the criterion applies to new plants only".

- The application procedure
  This defines how the criterion is to be applied, including when to apply, how to apply and the consequences of a violation, e.g., "The criterion is to be applied in connection with every major PSA update. In case the criterion is violated, the reason shall be identified and, if needed, corrective actions related to the PSA model, or plant design or procedures, shall be initiated".

3.3.2 Definition of a probabilistic safety criterion

Concepts involved

A probabilistic safety criterion is generally defined by a *consequence*, a *metric* for the consequence, a *risk metric,* and a *frequency* or *probability*.

The *consequence* is the end state considered for a specific probabilistic safety criterion, e.g., the consequence may be "core damage" for a criterion related to PSA level 1.

The *metric* is needed in order to define the consequence further, e.g., by defining "core damage" to have occurred if the local fuel temperature in any part of the core has exceeded 1204 ℃.

The *risk metric* is defined by assigning a frequency or probability to the metric, e.g., by measuring the risk from "core damage" in terms of the "core damage frequency".

The *frequency* or *probability* define the acceptance level for the risk metric, e.g., by stating that the "core damage frequency shall be shown to be $< 10^{-5}$/year".

Some further definitions relate to the presentation and interpretation of the risk metric, i.e.:

■ Consideration of uncertainties
  The criterion should state whether the application relates to the best estimate or mean value of the frequency or probability, or if it shall be related to some level of confidence. The definitions for "best estimate", "mean value", "confidence level", etc., requested in the application should be provided.

■ Justification of the definitions made
  Reference documents or supporting analyses are needed to justify the selected definitions, e.g., why the metric "core damage" is interpreted as "fuel cladding temperature > 1204 °C".

Reference information
The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below. There was complete agreement among the respondees that the comparison with probabilistic risk criteria should use the best estimate of the PSA results. Uncertainty analysis was noted to be an integral part of a PSA, with its results being considered in the decision-making process. Sensitivity analysis was also noted to be an integral part of the PSA and one of the components of the decision-making process when assessing compliance with the criteria.

Recommendation
The definition of a probabilistic safety criterion shall explicitly address the following concepts:

■ Consequence

■ Risk metric

■ Associated frequency or probability

References shall be given justifying the definition.

It is further recommended to use the best estimate of the frequency or probability when applying the criterion[2].

3.3.3 The scope of a probabilistic safety criterion
Concepts involved
The scope of a probabilistic safety criterion is defined by the scope of the PSA used to calculate the frequency or probability defining the criterion acceptance level.

Reference information
The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below.

All countries contributing to the task report aim at using full scope (internal events, area events, and external events, full power and shutdown operating modes) PSA. In some cases, comments were given on the degree of maturity for some parts of the analysis, and the degree of uncertainty associated with some initiating event categories. The WGRISK overview did not consider outside-core sources of radiation.

The scope of probabilistic safety criteria was also discussed at a workshop during the phase 3 project seminar [SG_Semin_2008]. The workshop did not aim at reaching consensus about the issues discussed and workshop recommendations have not been formally adopted by any of the stakeholders. However, the following views were expressed and are useful for reference:

- Basically, every source of radioactive release needs to be included, but simplified screening should be acceptable for outside core events.

- All initiating events need to be included, but simplified screening should be acceptable in some cases.

- Every operational state challenging a safety function should be included, but some simplification may be acceptable.

- Regarding status during different life cycle phases, the focus should be on the operating phase, but the criteria need to be known and considered during design.

WENRA [WENRA-2010] states that for new reactors, the scope of the defence-in-depth has to cover all risks induced by the nuclear fuel, even when

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[2] Possibly, the best estimate may not be sufficient for level 2 PSA criteria, where the consequence part has more dimensions and the approaches for calculating the release frequencies vary.

stored in the fuel pool. Hence, core melt accidents (severe accidents) have to be considered when the core is in the reactor, but also when the whole core or a large part of the core is unloaded and stored in the fuel pool.

Recommendation
The probabilistic safety criterion should apply to a full scope PSA, i.e.,

- All initiating events
- All plant operating modes

If the PSA is not full scope, a justification is required and it is recommended to perform simplified screening analyses for parts missing.
In addition to fuel damage accidents in the reactor pressure vessel also fuel damage when fuel is stored in the fuel pool should be considered. Qualitative screening of fuel damage risk can be applied if well justified. Fuel damage in the interim spent fuel storage facility can be excluded, since the interim spent fuel storage facility can be regarded as a separate facility for which risk criteria shall be applied separately.

3.3.4 The target of a probabilistic safety criterion
Concepts involved
The target of a probabilistic safety criterion is defined by the plants the criterion is applicable to.

Reference information
The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below.

Although there are exceptions to this, several countries define different criteria for existing plants and new plants, or give the criteria different status. In many cases, probabilistic safety criteria use the same metric for existing and future plants, whereas the numerical values for the frequencies are a factor (typically 10) lower for future plants. In other cases, the criteria involve the same numerical values for the frequencies, but with status as limits for future plants and targets for existing plants. For modernisation and life extension, generally the same criteria are applied as for operating plants.

In all countries, criteria are applicable at reactor level, even if there are several reactors on one site. One justification for this is the aim to be able to evaluate the safety of each individual reactor.

Recommendation
The target of a probabilistic safety criterion is defined by explicitly addressing the following:

- Status relative to existing plants

- Status relative to new plants

- Status in case of modernization and life extension of existing plants

Obviously, the definition of the target is related to the usage of the criterion. This implies a further need to check the consistency between different usages, e.g., a balance in treatment between new and existing plants, consistency between overall criteria and criteria used in RI applications.

3.3.5 The application of a probabilistic safety criterion
All aspects related to application are discussed in chapter 4.

3.4 Off-site consequence criteria
Description
Off-site consequence criteria are most closely related to the primary safety goal, related to off-site health, societal and environmental effects. In terms of application, a PSA level 3 is required to address off-site consequence criteria.

Health risks are divided into fatal acute or fatal late health risks and these can be calculated for an individual or a group. In both cases, risk is defined as the risk to the member of a critical group that receives maximum exposure from an accident. Typically acute health effects have a threshold dose value under which the probability of health effect is zero, but above which the probability of acute health effect is increased with increasing dose. Most late health effects do not have threshold values for dose. Based on these assumptions acute health effects can be expected in the vicinity of the release point, whereas late health effects appear in the public exposed to radiation over larger areas.

The societal and environmental effects of a severe reactor accident include evacuation of population, restrictions to the land use and effects on biosphere. The qualitative safety objective is to eliminate the risk for permanent relocation, the need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, and long term restrictions in food consumption. Quantitative criteria controlling these risks are defined as release criteria (see next chapter).

Frequency of doses criteria are expressed as rate of exposure in Sv/yr to the individual and/or probability of latent health effects.

As off-site consequence criteria are defined for individuals and groups (sometimes differing between on-site personnel and public), and cover both acute and late effects, multiple criteria need to be defined.

As seen from the reference information, only few countries define technical level criteria for off-site consequences.

Concepts involved
The concepts involved in defining a criterion for off-site consequences are shown and described in Table 2, using as an example a set of criteria defined by the UK HSE [HSE_SAP_2006]

Table 2. Concepts involved in defining an off-site consequence criterion

Concept	Definition	Example
Consequence	Defines the health effects and the individual/group to which the criterion applies.	Accident resulting in a dose to individuals off-site.
Metric	Qualifies the consequence (in this case "health effect") in terms of a measurable magnitude.	Dose received in the interval 10 to 100 mSv
Risk metric	Defines how the risk is to be expressed.	Frequency of achieving a dose rate in the interval defined.
Frequency/ probability	Defines specific levels related to the frequency/probability.	ALARP approach involving the definition of a basic safety limit (BSL) not to be exceeded, and a basic safety objective (BSO), under which the risk is considered to be broadly acceptable. BSL: 1 x E-4 / year BSO: 1 x E-6 / year

Reference Information
The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below.

While being generally the basis for the criteria on technical level, only one of the responding authorities (UK HSE)[3] has actually defined frequency of doses as a technical level criterion, including the following types of targets:

- Individual risk of death from on-site accidents – any person on the site

- Frequency dose targets for any single accident – any person on the site

- Individual risk to people off the site from accidents

- Frequency dose targets for accidents on an individual facility – any person off the site

- Total risk of 100 or more fatalities.

WENRA [WENRA-2010] states that most countries use Caesium release based criteria in case of severe accident, but acknowledges that it is difficult to make a link between a relevant numerical value for Cs releases and the higher level safety objective.
Regarding dose criteria, the publications of ICRP (International Commission on Radiological Protection) provide a comprehensive discussion; see e.g. [ICRP-103].

Regarding criteria used in other industries [SSM 2010:35], it is worth noticing that criteria on this level, i.e., fatalities/injuries to the individuals or groups, have defined in many countries, e.g., in railway transportation, off-shore oil and gas industry, chemical and process industry and many others. The definitions of these criteria are usually based on allowing a very small increase of risks the individual/group is already exposed to.

Recommendation
The following recommendations are given for probabilistic safety criteria related to releases:

- Criteria defined on this level deal with risk to individuals or groups of the population or workers as well as with risks to the environment. Corresponding criteria have been defined within other industries (chemical, railway, etc.) with the same basic aim, i.e., not to increase more than marginally the risk to individuals or groups compared to other risks they are exposed to. Any criteria defined on off-site consequence level should be consistent with corresponding criteria defined in other industries.

- The focus within the project has been on technical level criteria currently in use in the Nordic countries. Since level 3 PSAs are not performed, no further recommendations are given for off-site consequence criteria.

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[3] Some other countries (not participating in the WGRISK task) have also defined criteria on off-site consequence level, e.g., Australia and the Netherlands.

3.5 Release criteria

Description

Release criteria are related to radioactive release from plant. In terms of application, a PSA level 2 is required to address release criteria.

As seen from the reference information, the definition of what constitutes an unacceptable release differs a lot. Part of the reason for the complexity of the release definition, is the fact that it constitutes the link between the PSA level 2 results and an indirect attempt to assess health effects from the release. However, such consequence issues are basically addressed in PSA level 3, and cannot be fully addressed in a PSA level 2.

The definition of release criteria involves many parameters, the most important ones being the time, the amount, and the composition of the release. Additionally, other aspects may be of interest, such as the height above ground of the point of release. This means that multiple criteria may be defined, which is however unusual.

As seen from the reference information, many countries define technical level criteria for releases.

Concepts involved

The concepts involved in defining release criteria are shown and described in Table 3, using as an example the release criterion defined by the SSM in Sweden [SKI_SSI_1985] and by STUK in Finland [STUK_YVL-2.8]

Table 3 Concepts involved in defining a release criterion

Concept	Definition	Example
Consequence	Defines the consequence related to the release.	Unacceptable release with respect to long-term ground contamination.
Metric	Qualifies the consequence (in this case "release causing long-term ground contamination") in terms of a measurable magnitude.	**Sweden:** Release of Cs-137 in excess of an amount corresponding to 0,1 % of the core inventory in a 1800 MWt reactor (equivalent to about 103 TBq of Cs-137). **Finland:** Release of > 100 TBq of Cs-137.

Concept	Definition	Example
Risk metric	Defines how the risk is to be expressed.	**Sweden:** No risk metric has been defined by SSM. However, it is stated that a release exceeding the limit shall be "extremely unlikely", indicating consideration of an occurrence frequency. **Finland:** Frequency of exceeding the release limit.
Frequency/ probability	Defines specific levels related to the frequency/probability.	**Sweden:** "Extremely unlikely" has been interpreted to indicate a limit between 10^{-6} and 10^{-7} per year. **Finland:** The criterion is defined as a frequency limit, which is set to $5 \cdot 10^{-7}$ per year.

Reference Information
The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below.

Relative to criteria related to core damage, there is both a considerably larger variation in the frequency limits, and in the definition of the risk metric, i.e., what constitutes an unacceptable release.

The releases for which criteria have been defined are defined in several different ways:

- Large release
  Expressed in terms of an absolute magnitude of activity and isotopes released

- Large early release
  Usually defined more qualitatively, e.g., "Large off-site releases requiring short term off-site response" or "Significant, or large release of Cs-137, fission products before applying the offside protective measures".

- Small release
  Only defined by CNSC (Canada)

- Unacceptable consequence
  Only defined by one country (France), and not related to comparison with level 2 PSA results.

- Containment failure
  Defined in two countries (US and Japan) and related to robustness of the defence-in-depth. This type of criterion is discussed as part of lower level criteria in chapter 0.

Figure 3 summarises the numerical criteria defined for large (early) releases. As explained above, the definitions for "large release" is not the same for all organisations. However, it can be seen that objectives vary between $1 \cdot 10^{-7}$ and $1 \cdot 10^{-5}$ per year, which is a rather large spread. As with the CDF, the magnitudes are sometimes based on IAEA safety goals suggested for existing plants, i.e., on the level of $1 \cdot 10^{-5}$ per year [IAEA_INSAG-12]. However, many countries seem to define stricter limits, between $1 \cdot 10^{-6}$ per year and $1 \cdot 10^{-7}$ per year. Requirements for new plants are typically stricter (in terms of frequency) than for existing ones, and are mandatory as opposed to indicative.
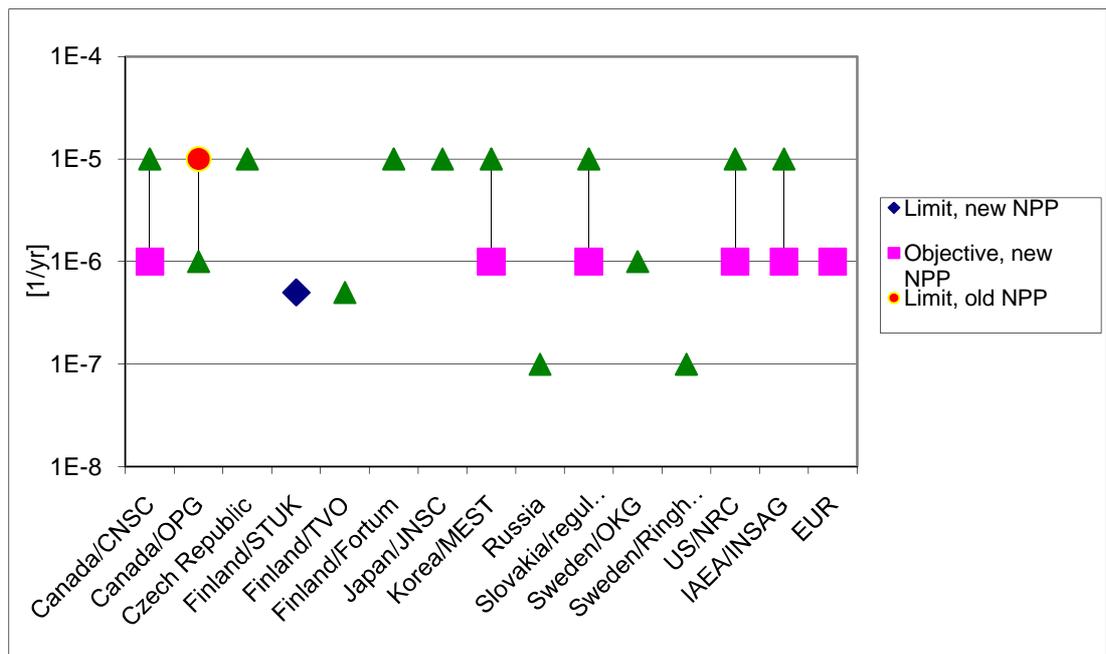
Figure 3 Numerical criteria defined for large release. Definition and timing of "large release" varies.

The issue of defining justifiable target values for level 2 PSA is also discussed in the EU 7th framework programme research project ASAMPSA2 (Advanced Safety Assessment Methodologies: Level 2 PSA).[4] At the stage of writing this report, the work of ASAMPSA2 is not yet finalized and it is

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[4] Only draft documents of the project work are presently available

open what the recommendation, if any, there will be on this topic. One proposal is to define target values which have a link to the IAEA INES-scale [IAEA_INES].

Recommendation
The following recommendations are given for probabilistic safety criteria related to releases:

- Probabilistic safety criteria should always be defined for unacceptable release.

- It may be considered to define more than one release criterion, related to at least acute health effects and long-time effects[5].

- The criterion/criteria should directly or indirectly relate to off-site consequences (see chapter **Fel! Hittar inte referenskälla.**).

- If the over-all scope of the probabilistic safety criteria also includes outside core events, sources of radioactivity outside the core will also need to be addressed, at least in a simplified conservative manner.

- An ALARP approach is used in many countries, and has some advantages from the risk management point of view. It is therefore recommended to consider introducing ALARP type criteria with a limit and an objective.

- Regarding the frequency criterion, no specific recommendations are given. It is however evident from the reference information, that a limit on the level of $1 \cdot 10^{-7}$ per year for an unacceptable release is unusually strict both for new and existing plants. For existing plants, the typical values for a frequency limit is about $1 \cdot 10^{-5}$ per year, with the objective one order of magnitude lower, i.e., at $1 \cdot 10^{-6}$ per year[6].

- The definition of the consequence and risk metric needs to be done and documented with care, including proper justification and references.

3.6 Core damage criteria

Description
Core damage criteria are related to damage to the fuel in the core. In terms of application, a PSA level 1 is required to address core damage criteria. It is worth noting, that there is some vagueness in the use of the concept "core damage", as fuel may be damaged or overheat in other locations than the core.

The definition of what constitutes an core damage is rather homogenous among countries using the criterion, usually defined as local fuel temperature

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[5] It is a general experience that level 2 PSA:s can provide more detailed information about the spectrum of releases than is made use of in existing criteria.
[6] Looking at the span of criteria included in the OECD/NEA WGRISK task, this applies in spite of the wide variety in the definition and timing of what constitutes a large or "unacceptable" release.

above 1204 ºC[7], i.e., the limit defined in section 1b of 10 CFR 50.46, Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors [10 CFR 50.46].

In success criteria analysis for PSA, it can be more practical in some scenarios to use other criteria than local fuel temperature, having, however, the same intention to define a criterion when core cooling is considered lost resulting in fuel damage.

Another question is whether mechanical damage of fuel due to dropped load or fuel handling error should be defined as fuel damage. Such events are relevant to the refuelling outage PSA, and there is a variation regarding the way mechanical fuel damage is accounted.

As seen from the reference information, all responding countries define technical level criteria for core damage.

Concepts involved
The concepts involved in defining a criterion for core damage are shown and described in Table 4, using as an example criteria defined for the OKG by E.ON Nordic [EON_2005_Larsson]

Table 4. Concepts involved in defining core damage criteria

Concept	Definition	Example
Consequence	Defines the consequence related to the fuel overheating.	Severe core damage
Metric	Qualifies the consequence (in this case "severe core damage") in terms of a measurable magnitude.	"Severe" is not qualified, but previous versions of the safety policy have referred to 10 CFR 50.46 (local fuel temperature above 1204 ºC).
Risk metric	Defines how the risk is to be expressed.	Frequency of exceeding the limit. As long as "severe" is not defined, there is some vagueness in the definition of the risk metric.
Frequency/ probability	Defines specific levels related to the frequency/probability.	The criterion is defined as a frequency limit, which is set to $1 \cdot 10^{-5}$ per year.

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[7] 1204 ºC is an accurate conversion of the approximative criterion 2200 ºF.

Reference Information
The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below.

The criterion core damage frequency is used by 14 of the respondents, but the definition of the criterion differs with the reactors technology. Some countries have very precise technical definitions of CDF, e.g. defining core damage as local fuel temperature above 1204 ºC, i.e., the limit defined in section 1b of 10 CFR 50.46 (Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors). Other countries have more general definitions referring, for instance to prolonged core uncovery or loss of long-term cooling.

Figure 4 summarises numerical criteria defined for core damage. The frequency limits for core damage vary between $1 \cdot 10^{-4}$ and $1 \cdot 10^{-6}$ per year. The criterion is usually justified by reference to USNRC and/or IAEA documents, or by comparison with international practice. The IAEA core damage criteria suggested for existing plants are on the level of $1 \cdot 10^{-4}$ per year [IAEA-INSAG-12]. Requirements for new plants are typically stricter (in terms of frequency) than for existing ones, and are mandatory as opposed to indicative.
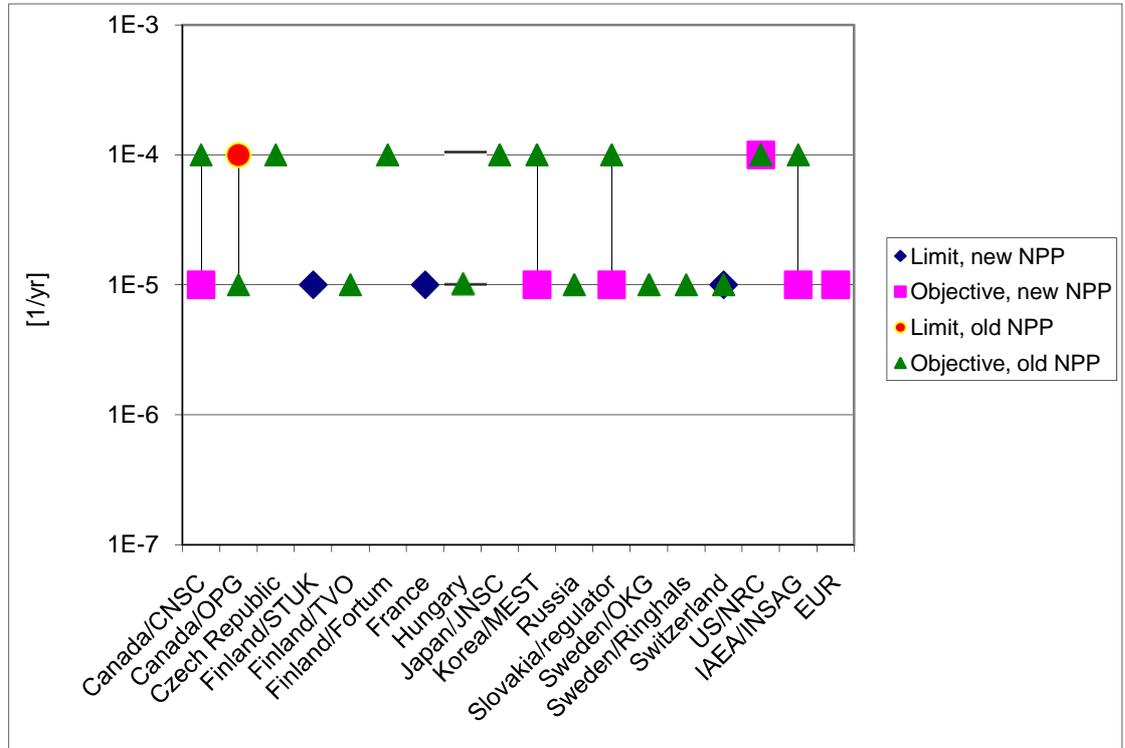
Figure 4   Numerical criteria defined for core damage.

[WENRA-2010] does not provide a common numerical target, but mentions target values of INSAG-12 and the CDF target $1 \cdot 10^{-5}$ per year for new reactors used by some WENRA countries. Two arguments were put forward not to adopt a common target: 1) in some counties, this value is considered as being already reached by some existing reactors, 2) the methodologies to calculate the CDF may differ from one country to another.

Recommendation
The following recommendations are given for probabilistic safety criteria related to releases:

■ Probabilistic safety criteria should always be defined for core damage.

■ It might be considered to use a more general wording in order to include fuel damage in other locations than the core, e.g., the fuel pool. On possibility would be to use the term "Fuel damage" or "Fuel over-heating".

■ If the over-all scope of the probabilistic safety criteria also includes outside core events, sources of radioactivity outside the core will also need to be addressed, at least in a simplified conservative manner.

- An ALARP approach is used in many countries, and has some advantages from the risk management point of view. It is therefore recommended to consider introducing ALARP type criteria with a limit and an objective.

- Regarding the frequency criterion, no specific recommendations are given. The typical values for a frequency limit is about $1 \cdot 10^{-4}$ per year, with the objective one order of magnitude lower, i.e., at $1 \cdot 10^{-5}$ per year. In most cases, the difference to criteria for unacceptable release is one order of magnitude.

- The definition of the consequence and risk metric needs to be done and documented with care, including proper justification and references.

3.7 Lower level criteria

Description

Criteria on the level of safety system reliability were defined quite early, e.g., by authorities in Finland and Canada. However, at the time they were meant to be an aid in system design, rather than to be surrogates of higher level criteria.

In this guidance, the term lower level criteria applies to criteria that are defined on a lower technical level than core damage, as well as to criteria on any level related to barrier strength. In all of these cases, criteria aid in assessing the strength of the defence in depth.

As part of the mapping of current practice made during the first project phase [NKS-153 / SKI_2007:06], a number of cases were identified, where lower level criteria are used:

- Westinghouse uses complementary probabilistic goals, defined on the basis of classes of initiating events (H1–H5), where the related frequencies define the probabilistic target values.

- OKG is using acceptance criteria related to barrier strength for events with major uncertainties in the initiating event frequency, e.g., internal fires.

In the WGRISK task, another important example was identified, i.e., a separate containment integrity criterion (conditional probability) defined in addition to frequency criteria on the levels of core damage and release.

Concepts involved

The concepts involved in defining a lower level criterion are the same as on higher levels, but the definitions may obviously differ considerably from case to case. In Table 5, an example is given for a containment integrity criterion.

Table 5. Concepts involved in defining lower level criteria (example for containment integrity criterion)

Concept	Definition	Example
Consequence	Defines the consequence related to the fuel overheating.	Loss of containment integrity (resulting in an unacceptable release) after core damage has occurred.
Metric	Qualifies the consequence (in this case "loss of containment integrity") in terms of a measurable magnitude.	Must be based on the metric already defined for the criteria on the levels of core damage and release.
Risk metric	Defines how the risk is to be expressed.	Probability of exceeding the metric related to the release criterion, after the metric related to the core damage criterion has been exceeded.
Frequency/ probability	Defines specific levels related to the frequency/probability.	The criterion is defined as a conditional probability, with a limit set to 0,1. *Note: This criterion can be used both if the higher level criteria are defined as single criteria and if they are ALARP criteria with a limit and an objective.*

Reference Information

The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below.

The WGRISK task did not explicitly address lower level criteria, but identified two cases, where containment integrity criteria have been defined along with criteria on other levels. Thus, a criterion for a containment failure frequency (CFF) has been defined by the Japanese Nuclear Safety Commission (NSC). In addition, for new or advanced nuclear power plants, the US NRC has set a target for conditional containment failure probability. In both cases, the criterion is defined as a conditional failure probability after occurrence of core damage on the level of 0,1.

In the context of I&C systems, it is common practice to define target reliability values depending on the safety class of the system. For instance, [IEC_61508] and the EUR requirements [EUR_2002] define the failure per demand requirements similarly:

IEC-61508	EUR	Criterion (failure probability per demand)
SIL-4	F1A/L1A	$< 10^{-4}$
SIL-3	F1B/L1B	$< 10^{-3}$
SIL-2	F2-NS/L2-NS	$< 10^{-2}$

Recommendation

The following recommendations are given for lower level criteria:

- Lower level criteria can be useful for assessing barrier strength, especially in a defence in depth context. In order to create a connection with defence in depth, it is recommended to consider defining barrier strength criteria for higher technical levels.

- Lower level criteria can be useful as design guidance on lower technical levels, which would considerably broaden the usefulness of probabilistic safety criteria. However, few such applications have been made to date, and in order to assure relevance in the definition of lower level criteria, it is recommended to investigate this issue further. This also applies when attempting to define criteria for defence in depth levels lower than 3 (according to the definitions in [IAEA_INSAG-10]).

- In case barrier strength criteria are defined for higher technical levels, the definition of consequence and risk metric must be based on the consequences and metrics already defined for the criteria on the higher technical levels.

- The definition of the consequence and risk metric needs to be done and documented with care, including proper justification and references.

4. Applying probabilistic safety criteria

4.1 Introduction

This chapter deals with the applications of probabilistic safety criteria, including a discussion of the uses and users of criteria, procedures for applying criteria, and procedures for acting on the outcome of the application.

Compared to the rather strict definitions in the previous chapter on definition of safety criteria, the descriptions and recommendations regarding the application of criteria will necessarily be more open-ended. The aim is mainly to present relevant background information on current practices and give some recommendations.

4.2 Uses and users of probabilistic safety criteria

Concepts involved

Uses and users of probabilistic safety criteria are largely the same as for the PSA as such. In a research project on interpretation and presentation of results from PSA:s [SKI_1997:49], the users and uses were defined. Information from this project has been used as a basis for the listing of users presented in Table 6 and of uses presented in Table 7. Some specific thoughts regarding uses of probabilistic safety criteria are presented in Table 8 [Flodin_2008].

Table 6. Users of PSA results [SKI_1997:49]

User category	Specific examples
Utilities	▪ Top level users (strategic level)
Plant units	▪ Safety department ▪ Operation department ▪ Maintenance department ▪ Technical department, including R&D ▪ Training department ▪ Information department
Most important authorities	▪ SSM ▪ STUK
Other authorities	▪ Government, parliament ▪ Civil contingency agency ▪ County administrative board ▪ Fire fighting and rescue services
Research and development	▪ TSO:s ▪ Specific research programmes, e.g., EU programmes, NPSAG, NKS, and SAFIR ▪ Universities
Third party users	▪ The public ▪ Journalists ▪ External organisations

Table 7. Uses of PSA results [SKI_1997:49]

	Total risk	Quantitative uses	Qualitative uses
Description	Assessment of basic PSA results.	Uses based on analysis and processing of the PSA model and results.	Use of the Boolean structure of the PSA to present, verify and analyse complex qualitative information.
Areas of use	■ Identification and prioritisation of safety improvement actions. ■ Presentation of risks to third party users ■ Risk comparison to probabilistic safety criteria. ■ Inspection guidance for authorities ■ Guidance of training (focus on dominating risks) ■ Comparison of plants with respect to risk	■ Planning of testing and maintenance. ■ Evaluation of existing TechSpecs. ■ Assessment of permanent TechSpec changes. ■ Assessment of temporary TechSpec changes (exemptions) ■ Evaluation of suggested plant changes. ■ Evaluation of events. ■ Risk follow-up	■ Verification of deterministic design criteria, e.g., regarding redundancy and diversification. ■ Development of operating instructions, EOP:s and SAMG:s
		■ Use within R&D	
	■ Prioritisation of R&D		

Table 8. Uses of probabilistic safety criteria as presented by Vattenfall [Flodin_2008]

Use	Objective	Comment
Compliance with Nuclear Acts & regulatory requirements – Interpreted into SAR and Tech-Specs	To protect employees, public and environment, <u>and</u> to secure operations (with sufficient and quantified margins)	■ The starting point is normally doses to a critical person/group, broken down into lower levels, i.e. PSA levels 2 & 3
Assessment of Severe Business Risks	To secure company assets	■ Normally a PSA level 1 would be sufficient ■ End state could be other than core damage, i.e. dry-out or other interesting sequences that can be derived from the PSA model (event/fault tree structure) i.e. loss of complete safety system/safety function ■ Consequences expressed in monetary terms ■ Current business risk analyses make little use of the PSA models, there should be a potential for development in this area.
Assessment of "Continuous safety improvement"	Optimization of allocation of resources (Cost/Benefit)	■ The idea of continuous safety improvement is today quite firmly established within Europe (ref. WENRA) ■ The idea should still be balanced in order not to waste limited resources ■ Would require PSA level 1 (and sometimes level 2)

Reference information
The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below. Thus, the information obtained from the application of probabilistic risk criteria was stated often to be used for:

- general safety improvements

- plant modifications (including procedures)

- system upgrades

- decision making

- temporary configurations

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- identification of functional dependencies

The general experience from the implementation of risk criteria is positive. Respondents who have implemented criteria have experienced various benefits. In a number of cases, design or procedural weaknesses in NPPs have been identified using PSA and PSA criteria, resulting in the introduction of safety improvements. More than half of the respondents describe how the implementation of risk criteria and safety goals have lead to plant modifications in order to meet probabilistic risk criteria. One of the respondents also described how, using PSA, changes suggested on a deterministic basis have been avoided.

Furthermore, the implementation of probabilistic risk criteria often emphasizes the need for more detailed and realistic PSA models, since conservative assumptions in the PSA often make the calculated risk unnecessarily high. It appears that the use of probabilistic risk criteria has increased the focus on the correctness and quality of PSA models. One problem that was highlighted, is the scope of the PSAs, i.e., results from limited scope PSAs may be harder to assess and difficult to compare to probabilistic risk criteria.

Some respondents emphasize the importance of using PSA as an integrated part of the total safety analysis concept, i.e. as a complement to other relevant information such as deterministic analyses, human reliability analysis and operating experience.

Some respondents pointed out a general concern about using probabilistic risk criteria and defined safety goals as absolute limits, as this might indirectly have a negative impact on the quality and relevance of the PSA models. According to these respondents, the defined goals should rather be used as triggers for identifying potential deficiencies, and as indicators showing that changes made have a positive effect.

Recommendations
The following recommendations are given regarding the use of probabilistic safety criteria:

- Uses differ between levels of criteria, with criteria on higher levels (closer to the primary risk) being more related to basic risk acceptance issues, and criteria on lower levels are more technical and are more useful for evaluation of design and procedures.

- Uses of criteria will differ between users, and will be more related to basic risk acceptance for authorities and to strategic issues related to risk exposure and relations to economical for utility management. Detailed uses by various plant departments and in day-to-day PSA work will be more related to assessment and improvement of design and procedures.

- As part of the definition of a probabilistic safety criterion, known uses and potentially relevant future uses should be described, and their impact on the formulation of the criterion considered.

4.3 Procedures for applying probabilistic safety criteria

Concepts involved

Generally, issues of interest in the application of probabilistic safety criteria is when they are applied and what are they applied for. Basically, application of probabilistic safety criteria can be relevant in several situations, e.g.:

- Application in licensing

- Application in connection with periodic safety reviews

- Application in connection with plant changes

- Application after PSA updates

- Use for specific PSA applications

Reference information

The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below.

The question on when evaluation of plant performance against Probabilistic Risk Criteria is required, received very different answers. In many cases, criteria are applied quite infrequently, being made in connection with Periodic Safety Review, typically generally every 10 years. In a few cases, shorter intervals are specified (one to three years).

However, all countries/utilities also require the usage of the criteria to evaluate significant plant changes, and some also require usage of the criteria for assessing the impact on risk (and the appropriate response) from incidents and/or on discovery of new information.

Recommendations

The following recommendations are given regarding the application of probabilistic safety criteria:

- Active usage of the criteria is recommended. Thus, the application of probabilistic criteria on CDF and unacceptable release is recommended to be done as part of the analysis of results in connection with the issuing of a new PSA version, i.e., usually yearly.

- Application of lower level criteria (if defined) is assumed usually to be done in connection with detailed evaluation of propose plant changes.

- The procedure for applying probabilistic safety criteria should be developed in parallel with the definition of the criteria.

4.4 Procedures for acting on the outcome of an application

Concepts involved

The procedures for acting on the outcome of the application are related to the general status of the criteria and on the context within which the criteria are applied.

Reference information

The international overview performed within the task initiated by the OECD/NEA WGRISK [NEA/CSNI/R(2009)16] has provided reference information as described below. The status of risk criteria varies widely, ranging from legally strict values to be fulfilled to target values. However, the overview shows that most respondents probabilistic risk criteria are applied as target values, orientation values or safety indicators.

The type of action if a probabilistic risk criterion is exceeded also differs considerably between the different countries. As the criteria are generally considered as indicators or orientation values, mostly no hard regulatory actions are expected on non-compliance with a criterion. Practically, there is a consensus on finding the reasons for the non-compliance and identification on the way to overcome it.

For new builds the picture is different, and it is mostly stated in countries having specific criteria for new plants, that not meeting the probabilistic risk criteria would prevent the regulatory body granting an operating license.

In some cases, among Swedish utilities, rules and action levels have been defined for use in case of non-compliance with the CDF criterion. An example of such a CDF action levels is:

$$\text{PSA results} \quad > 10^{-3} \text{ /year immediate shutdown}$$

$$10^{-3} \text{ /year} > \quad \text{PSA results} \quad > 10^{-4} \text{ /year correction at next planned}$$
$$\text{yearly shutdown}$$

$$10^{-4} \text{/year} \quad > \quad \text{PSA results} \quad > 10^{-5} \text{ /year long-term planning of actions}$$

A number of the respondents express scepticism towards a strict application of quantified safety criteria, and the use of criteria does not appear to be

prioritized within the over-all PSA activities of these respondents. 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.

Regulatory Guide 1-174 [RG_1.174] includes a section with acceptance guidelines. The guidelines are intended for use when assessing the acceptability of proposed changes in the plant. Depending on the risk increase ΔCDF or ΔLERF caused by the plant change, acceptability regions are established. Detailed interpretation and application guidance is given in the reference. In short, regions are established in the two planes generated by a measure of the baseline risk metric (CDF or LERF) along the x-axis, and the change in those metrics (ΔCDF or ΔLERF) along the y-axis; see Figure 5 for the acceptance criteria relating to LERF/ΔLERF.
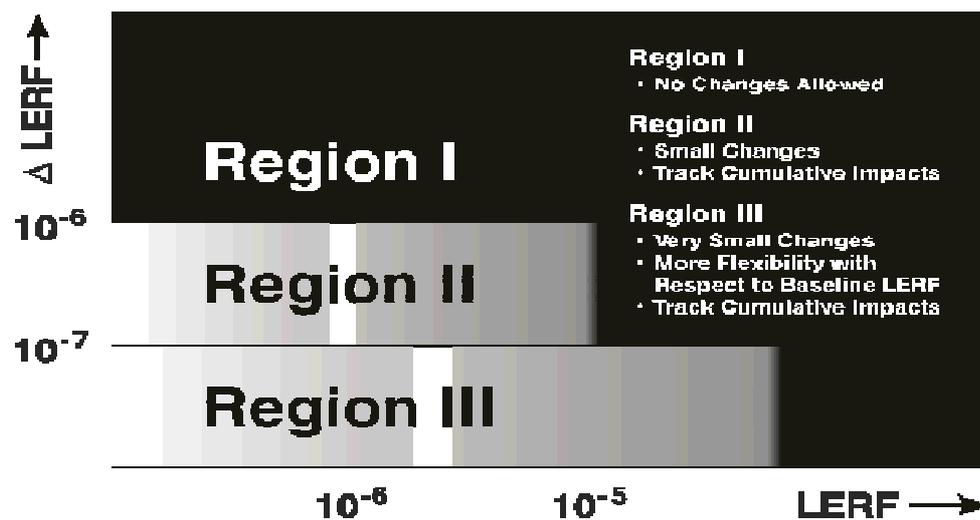
Figure 5 RG 1.174 Acceptance Guidelines for Large Early Release Frequency (LERF).

Recommendations
The following recommendations are given regarding the application of probabilistic safety criteria:

- It is important to define the status of the probabilistic risk criteria defined within an organisation.

- There seems to be a consensus among many of the stakeholders that strict application of safety criteria may is not beneficial. It is recommended to take account of this fact when defining the criteria and associated application and interpretation procedures.

- Additional interpretation rules, similar to the graded approach defined by some Swedish utilities may be useful.

The procedure for acting on the outcome of application of probabilistic safety criteria should be developed in parallel with the definition of the criteria.

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The Swedish Radiation Safety Authority has a compre-
hensive responsibility to ensure that society is safe
from the effects of radiation. The Authority works to
achieve radiation safety in a number of areas: nuclear
power, medical care as well as commercial products and
services. The Authority also works to achieve protec-
tion from natural radiation and to increase the level of
radiation safety internationally.

The Swedish Radiation Safety Authority works pro-
actively and preventively to protect people and the
environment from the harmful effects of radiation, now
and in the future. The Authority issues regulations and
supervises compliance, while also supporting research,
providing training and information, and issuing advice.
Often, activities involving radiation require licences is-
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thority maintains emergency preparedness around the
clock with the aim of limiting the aftermath of radiation
accidents and the unintentional spreading of radioactive
substances. The Authority participates in international
co-operation in order to promote radiation safety and
finances projects aiming to raise the level of radiation
safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environ-
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sciences, law, economics and communications. We have
received quality, environmental and working environ-
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