European Nuclear Installation Safety Standards

POSITION PAPER

Application of the concept of Practical Elimination of scenarios

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Summary

The amended (2014) EU Nuclear Safety Directive in its article 8a, and the Principle 1 in the Vienna Declaration for Nuclear Safety introduce an objective implying the need to demonstrate the avoidance of early radioactive releases and large radioactive releases.

This position paper provides the ENISS views on the demonstration expected to meet the EU Nuclear Safety Directive requirements in its article 8a and on how it can be supported by the application of the concept of Practical Elimination of scenarios. This is summarised through the following key definitions and general principles which are recommended to be used as a basis for a widely shared understanding.

Key definitions:

Two distinct categories of radioactive releases should be defined to clarify the terminology:

- Large and Early radioactive Releases (LER),
- Large and Late radioactive Releases (LLR).

The term “Practically Eliminated” is used to mean “physically impossible or extremely unlikely to occur with a high degree of confidence”.

The concept of “Practical Elimination” applies to scenarios (groups of sequences characterised by a specific containment failure mode).

The term “avoidance” applies to the overall risks of early radioactive releases and large radioactive releases.

General Principles:

1. Demonstration of avoidance of LER and LLR can rely on different approaches commensurate to the risks to be discarded, including the application of the concept of Practical Elimination of scenarios.

2. Practical Elimination of scenarios is a concept for new nuclear power plants applied from the onset of the design process to support the safety goal of avoidance of LER and LLR.

3. For existing plants, the notion of Practical Elimination of scenarios is not mandatory, but it could be used to help identify reasonably practicable safety improvements intended to avoid LER and LLR through the processes for continuous improvement or Periodic Safety Review.

4. Demonstration of avoidance of LER and LLR credits all the relevant lines of defence as well as the analyses of the Design Basis and Design Extension Conditions, and the Probabilistic Safety Analysis.

5. Practically eliminated scenarios are excluded from DBC and DEC analyses, i.e. their consequences are not required to be mitigated because their occurrence is prevented.

6. The demonstration of avoidance of LER and LLR should be based on a balanced use of deterministic and/or probabilistic studies, including sensitivity analyses – associated methodologies are developed on a case-by-case basis.

7. Early dialog with the Regulator is recommended to discuss and agree on a structured and detailed approach to avoid LER and LLR, including the application of the concept of Practical Elimination of scenarios.

1. Introduction

The amended (2014) EU Nuclear Safety Directive (ref. /1/) establishes a framework for nuclear safety of nuclear installations, where the article 8a requires:

> *“1. Member States shall ensure that the national nuclear safety framework requires that nuclear installations are designed, sited, constructed, commissioned, operated and decommissioned with the objective of preventing accidents and, should an accident occur, mitigating its consequences and avoiding:*
>
> *a) early radioactive releases that would require off-site emergency measures but with insufficient time to implement them;*
>
> *b) large radioactive releases that would require protective measures that could not be limited in area or time.“*

This requirement was reiterated in the Principle 1 of the 2015 Vienna Declaration for Nuclear Safety (ref. /2/):

> *“1. New nuclear power plants are to be designed, sited, and constructed, consistent with the objective of preventing accidents in the commissioning and operation and, should an accident occur, mitigating possible releases of radionuclides causing long-term off site contamination and avoiding early radioactive releases or radioactive releases large enough to require long-term protective measures and actions.”*

The WENRA report (ref. /3/) discusses the practical elimination concept and the means to achieve it, with the aim to meet WENRA safety objective O3:

> *“reducing potential radioactive releases to the environment from accidents with core melt, also in the long term, by following the qualitative criteria below:*
>
> - *accidents with core melt which would lead to early or large releases have to be practically eliminated;*
> - *[…].”*

This has been recently detailed in the additional WENRA report (ref. /4/), specifically discussing Practical Elimination applied to New NPP designs.

This position paper provides the ENISS views on the demonstration expected to meet the EU Nuclear Safety Directive requirements in its article 8a and on how it can be supported by the application of the concept of Practical Elimination of scenarios which has been introduced in several international and national standards, guidance and reports for more than 20 years.

Section 2 focuses on key definitions related to the concept of Practical Elimination.

Section 3 draws key elements from observations and experiences regarding the notion of Practical Elimination, on the basis of international standards and national practices.

Section 4 presents the ENISS position through seven general principles.

Appendix 1 presents a summary of the history of the definitions, interpretations and applications of the concept of Practical Elimination.

Appendix 2 gathers the detailed quotations used to support this position paper.

2. Key definitions relating to the concept of Practical Elimination (PE)

2.1 Observations

The historical summary presented in Appendix 1 shows a series of evolutions of the multiple ways to present the concept of Practical Elimination, as well as various interpretations.

Factually, the descriptions of the concept of Practical Elimination have largely evolved in the last 20 years. Despite more or less following the IAEA safety standard SSR-2/1 (ref. /5/), the international and national standards, guidance, reports, papers discussing Practical Elimination may diverge on:

- the terminology,
- the existing approaches to be considered,
- the need or not to define specific Practical Elimination approaches,
- the consideration as part or not of severe accident development, or
- the reference to updated or older standards.

As a consequence, ENISS Licensees observe that there is a variation in the terminology and possible interpretation of the concept (also considered as “the notion”) of Practical Elimination (PE).

ENISS Licensees observe that the actual application of the Practical Elimination concept is limited to a few Regulatory and Licensee documents. This application relies on design provisions defined following existing processes (i.e. application of the Defence in Depth concept) rather than a specific Practical Elimination approach, or a specific categorisation/classification for Practical Elimination purpose. Such examples are not forming a consistent and shared approach and may not be considered as fully aligned to SSR-2/1 rev.1, with a noticeable open point on the consideration of either:

- Large and early releases, (INSAG 10 and 12 (ref. /6/ and /8/), Technical Guidelines (ref. /9/), FA3 (ref. /10/), YVL B.1 (ref. /11/), IRSN approach (ref. /12/)).
- Early releases or large releases, (IAEA SSR-2/1 (ref. /5/), WENRA (ref. /13/), FANC (ref. /14/)).

From these observations, ENISS Licensees draw the following key elements:

- Application of the concept of Practical Elimination requires Licensees and their Regulator to share the same understanding.
- The terminology relating to the concept of Practical Elimination should be clarified for a better understanding.

2.2 Key Definitions

ENISS Licensees share the view that the following set of definitions clarifies the Practical Elimination terminology and helps in providing a clearer picture of the European Nuclear safety Directive (ref. /1/) expectations, with respect to article 8a.

- **The term “avoidance”, as in the EU Nuclear Safety Directive applies to the overall risks of early radioactive releases and large radioactive releases.**
- **The term “Practically Eliminated” is used to mean “physically impossible or extremely unlikely with a high degree of confidence” and applies to scenarios (groups of sequences characterised by a specific containment failure mode).**

Besides, in order to facilitate the safety analysis which aims at demonstrating the avoidance of large or early releases it is strongly suggested to define **two distinct categories of radioactive releases which have to be avoided:**

- **Large and Early radioactive Releases (LER)**: releases that would require off-site emergency measures, but with insufficient time to implement them.
- **Large and Late radioactive Releases (LLR)**: releases that would require protective measures which are not limited in area or time, but late enough for these measures to be fully effective in due time.

Understandably, where LER and LLR are avoided, the early radioactive releases and the large radioactive releases, as defined in the EU NSD (ref. /1/), are avoided.

Accident scenarios (groups of accident sequences) with severe fuel degradation and loss of the confinement function which potential consequences are LER or LLR can be grouped into 3 types:

Type 1: **Scenarios of severe fuel degradation with, or quickly followed by, a failure of the confinement function** (ex: reactor pressure vessel rupture and large reactivity insertion as initiating events, accidents sequences of core melt accident with a containment open or a by-pass of it).

Type 1 scenarios lead to LER.

Type 2: **Scenarios of severe accident (e.g. core melt) resulting in an early failure of the confinement function** (ex: core melt with high energetic phenomena like direct containment heating or hydrogen detonation).

Type 2 scenarios lead to LER.

Type 3: **Scenarios of severe accident resulting in a late failure of the confinement function** (typically core melt with loss of containment heat removal systems leading to slow containment over-pressurization or basemat melt-through for instance).

Type 3 scenarios lead to LLR.

In comparison to the types defined by the IAEA safety guide SSG-2 (ref. /15/) (section 3.56) type 1 are type a, d and e, type 2 are type b and type 3 are type c.

3. Key elements drawn from observations and experiences of application

The following key elements are drawn from ENISS members' observations and experiences – cf. appendix 1.

3.1 The concept of Practical Elimination and Defence in Depth

As stated in the IAEA Fundamental Safety Principles (ref. /16/):

> *"The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation."*

In addition, paragraph 3.31 of IAEA Fundamental Safety Principles states that:

> *"Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection that would have to fail before harmful effects could be caused to people or to the environment."*

Practically the IAEA Safety Standard SSR-2/1 (ref. /5/) defines a series of five levels of Defence in Depth (DiD) to achieve this fundamental safety objective. Overall, DiD levels 1 to 4 aim at preventing and mitigating radioactive releases. As a result of all these four lines of defence, a severe accident or any accident leading to large radioactive releases is very unlikely to occur. Level 4 aims particularly at avoiding off-site contamination from severe accidents or at least limiting their consequences such that only protective actions limited in terms of time and area of application would be necessary.

The additional emphasis put on reducing the risks from large radiological releases, via the concept of Practical Elimination of scenarios, raises the question of how it fits with the DiD levels.

On one hand the DEC-B analysis and the associated severe accident mitigation provisions[1] which form part of the 4th DiD level contribute to the demonstration of the Practical Elimination of core melt scenarios which would lead to large radioactive releases.

> This is consistent with IAEA SSR-2/1 (ref. /5/), cf. paragraph 2.13 fully quoted in Appendix 2:
>
> > *"(4) The purpose of the fourth level of defence is to mitigate the consequences of accidents that result from failure of the third level of defence in depth. […] Event sequences that would lead to an early radioactive release or a large radioactive release[3] are required to be 'practically eliminated'[4]. "*
>
> This is also the case in the German and French Technical Guidelines (ref. /9/), where Practical Elimination is introduced in section A.1.3, related to severe accident and Practical Elimination is introduced as the first item.

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[1] Severe Accident Mitigation provisions include means which aim at preventing phenomena which could lead to containment failure and means which contribute to the limitation of radioactive releases.

The ONR SAPs (ref. /17/) introduce Practical Elimination as part of the severe accident section.

The FANC guidance (ref. /14/) for new plants also introduces Practical Elimination as part of the 4th DiD level:

> *"5.2.4 Severe accidents […]*
>
> *Severe accidents which would lead to an early or large release or unacceptable direct irradiation (see section 6.2.3) should be practically eliminated"*

On the other hand, the 1st to 3rd DiD levels, including all provisions to prevent core melt, also contribute to the demonstration of the Practical Elimination of scenarios which would lead to large radioactive releases.

This is for example stated in INSAG 12 (ref. /8/):

> *"129 For future nuclear power plants, the design features related to the prevention and mitigation of accidents, including severe accidents, […] Notably, the practical elimination of accident sequences"*

This has been developed in a similar meaning within the EUR section 2.1 (ref. /26/):

> *Accident sequences that have the potential to cause a Large Release* or Early Release* shall be Practically Eliminated*. […] bringing the appropriate justification that those accident sequences do not need to be considered in the plant design under the Defence-in-Depth* concept.*

And also in the OECD report (ref. /18/) about application of Defence in Depth:

> *"The practical elimination concept is an approach that sets improved safety goals (or expectations) for nuclear installations by incorporating additional design features or, more rarely, operating provisions. These features or provisions can be associated with level 1, 2, 3 or 4, or any combination of these."*

Both interpretations can also be seen in the Finnish Regulator STUK assessment of Practical Elimination application in Finland, as presented at the International Conference in June 2017 (ref. /19/):

> *"Practical elimination of early or large releases consist of two aspects:[…] As shown in Fig. 1. at Defence-in-Depth Level 1, the rupture of the pressure vessel and severe criticality accidents are "practically eliminated", and at Level 4 the severe accident sequences leading to the loss of containment are to be identified and "practically eliminated".*

ENISS Licensees support the need to clarify the position of Practical Elimination in the Defence in Depth (DiD) approach.

ENISS Licensees draw the following key elements for the application of the Practical Elimination concept in a NPP safety case and observe that existing examples of application are consistent with this approach:

- All existing lines of defence provided by 1st to 4th DiD levels can be considered in the demonstration of the Practical Elimination of scenarios.
- The evaluation of the Practical Elimination of scenarios is a verification of the capability of the 1st to 4th DiD levels to sufficiently reduce the likelihood of LER or LLR with a high degree of confidence. In a NPP design process this evaluation may lead to identify additional design provisions at all levels of DiD.

- Implementation of those additional design provisions would then rely upon existing licensee/designer processes for selecting the reasonably practicable option, and for the associated SSC classification and assignment of requirements.
- A minimum number of the design provisions necessary to demonstrate the practical elimination should remain effective during and after internal or external hazard events. In addition the whole set of provisions should have a limited sensitivity to a human error.

3.2 Identification of the scenarios to be Practically Eliminated

The German and French Technical Guidelines (ref. /9/) made a link between Practical Elimination demonstration and the justification for screening out some initiating events:

> *“Single initiating events can be ‘excluded’ only if sufficient design and operation provisions are taken so that it can be clearly demonstrated that it is possible to ‘practically eliminate’ this type of accident situations.”*

This is also proposed in the IRSN Practical Elimination approach (ref. /12/), where the accident scenarios to be identified are also referring to the screened out initiating events:

> *“[…] applicants identify the operating and accident conditions, which are classified into categories […] At this stage, a number of single initiating events and multiple failures are “excluded” since considered as not plausible; thus, their consequences are not studied […]. In order to consider situations likely to lead to large early releases as “excluded”, the applicant shall use the ‘practical elimination’ approach.“*

The accident scenarios to be practically eliminated, and therefore excluded from the design with appropriate justification, have to be identified in the comprehensive list of PIE and their subsequent developments in sequences. It requires:

- further analysis and justification of the discarded Initiating Events in a systematic approach,
- further analysis of failure modes of some safety systems used to prevent releases.

Indeed, based on the above quotations and examples of application, it appears as a key step in the application of the concept of Practical Elimination of scenarios, to identify the accident scenarios with severe fuel degradation and loss of the confinement function.

<u>As an example, the following scenarios were identified in the course of the Flamanville 3 EPR design (ref. /10/):</u>

Scenario to be practically eliminated	Design provision
Fast uncontrolled increase of reactivity	Isolation of sources of dilution, automatically (isolation signal or use of non-return valves) Operational rules for enhanced isolation, control of boron concentration
High pressure core melt and direct containment heating (DCH)	Ultimate discharge valve
Steam explosions likely to lead to failure of the containment	Leak tightness of the area around the vessel ensuring that the core-catcher is dry (physical impossibility of a molten core and coolant interaction) (design provision in DEC-B – part of the overall core-catcher design)

Scenario to be practically eliminated	Design provision
Hydrogen detonation endangering the containment integrity	Passive Autocatalytic Recombiners (design provision in DEC-B)
Core melt with containment by-passes	Passive provision and active provision for enhanced isolation as well as enhanced operational rules after identification of all by-passes sources
Fuel melting within the Spent fuel pool in the spent fuel building	Control of cooling systems and water inventory of the spent fuel pool ensuring that there is always a cover of water and cooling of the fuel assemblies

ENISS licensees share the view that the identification of the scenarios to be practically eliminated should be part of the design process and be completed as early as possible.

For example, a process for identifying the scenarios to be practically eliminated could follow these steps:

- Screen-in only credible events and accident sequences with the potential for unacceptable consequences.
- Check previously discarded events (double check the process followed to define the PIEs and PSA initiating events).
- Further analyse the list of events and use an event tree approach (or Level 2 PSA) to identify sequences of failures.
- Focus on the potential for confinement threat: Analytical approach to define scenarios of severe accident with confinement threat. Use of Level 2 PSA or equivalent process if not available to define sequences giving rise to these scenarios.
- Identify the existing lines of defence and discuss the likelihood of their failure modes.
- Confirm the threat on the confinement or discard the event/accident sequence.
- Confirm the credibility or discard the event/accident sequence.

3.3 Demonstration of avoidance of LER and LLR: use of deterministic and probabilistic analyses

The focus is here about the methods to be applied to demonstrate the avoidance of LER and LLR.

There is general agreement on the need for applying both deterministic and probabilistic analyses.

The German and French Technical Guidelines (ref. /9/) require:

> *"A.1.4 [...] Their Practical Elimination can be demonstrated by deterministic and/or probabilistic considerations, taking into account the uncertainties due to the limited knowledge on some physical phenomena. It is stressed that the Practical Elimination cannot be demonstrated by the compliance with a general "cut-off" probabilistic value".*

In the UK, the ONR SAPs (ref. /17/), recommend:

> *"6.11 [..] Each instance where practical elimination is claimed should be assessed separately, taking into account relevant uncertainties, particularly those due to limited knowledge of extreme physical phenomena […] an accident state should not be considered to have been practically eliminated simply on the basis of meeting probabilistic criteria. "*

In Belgium, the Regulator FANC guidance (ref. /14/) makes a difference between initiators and accident sequences:

> *"5.3 […] if the demonstration applies to the initiator then it is sufficient to agree with the regulatory authority on a cut-off probabilistic value. If the demonstration applies to the accident sequence then the demonstration cannot be claimed successful solely based on compliance with a general cut-off probabilistic value:"*

In addition it has to be pointed out that the choice of the method for the demonstration of practical elimination should generally be devised on a case-by-case basis. There is no expectation of a single method to be applied to all situations. This view is widely shared:

- The IRSN Practical Elimination approach (ref. /12/) concludes on the need for a case-by-case evaluation:

  "The situations for which the Practical Elimination approach can be applied are very diverse and proof that they are physically impossible or, […], extremely unlikely […] can only be achieved through analysis on a case-by-case basis."

- In the UK, the ONR SAPs (ref. /17/) recommend also to be specific:

  "611 Each instance where practical elimination is claimed should be assessed separately".

- This is aligned with the German and French Technical Guidelines (ref. /9/):

  "A.1.4 [...] However, the Practical Elimination of accident situations which could lead to large early releases is a matter of judgement and each type of sequences has to be assessed separately".

- This has been highlighted by the Finnish Regulator at the International Conference in June 2017 (ref. /19/):

  "The overall methodology of Practical Elimination cannot be the same for large amount of sequences".

ENISS Licensees draw the following key elements:

- The methodology which supports the demonstration of avoidance of LER and LLR should be based on both deterministic and probabilistic analyses.
- Each methodology is devised on a case-by-case basis as a function of the scenario to be practically eliminated.

3.4 Demonstration of avoidance of LER and LLR on existing plants

The Article 8a of the Nuclear Safety Directive (ref. /1/) stipulates:

> *Member States shall ensure that the national framework requires that the objective set in paragraph 1* [i.e. objective of avoidance of early radioactive releases and large radioactive releases]*:*
>
> *(b) is used as a reference for the timely implementation of reasonably practicable safety improvements to existing nuclear installations, including in the framework of the periodic safety reviews as defined in Article 8c(b).”*

The concept of Practical Elimination was introduced in international standards targeting the design of new nuclear plants. For instance IAEA SSR-2/1 rev.1 (ref. /5/) states in its introductory section:

> *“1.3 It might not be practicable to apply all the requirements of this Safety Requirements publication to nuclear power plants that are already in operation or under construction.”*

The WENRA guidance (ref. /21/) on this part b of article 8a of the NSD states:

> *“In comparing safety of an existing NPP with new reactor standards it is important to look at the safety outcome not just the specific technology used to achieve that outcome. The objective is to implement reasonably practicable improvements to prevent and mitigate radioactive releases. […]”*
>
> *“certain safety improvements that may be reasonable at one reactor may not be necessary at another or conversely may be insufficient so better or more measures might be called for. Being proportionate should also take account of the individual circumstances of a facility and its future lifetime.”*

In the UK, the ONR guidance on the application of the ALARP principle (ref. /22/) reinforces the approach to be followed for existing plants:

> *“6.2 For an existing facility, relevant good practice is established by using the standards that would be applied to a new design as a benchmark and then subjecting any shortfalls to the test of reasonable practicability.”*

The ASN guide 22 (ref. /23/), follows this trend:

> *[The present guide applies to PWRs. […]*
>
> *Having the design of new reactors for primary scope of application, the recommendations from this guide would also be used, as being a reference, when looking for improvements to be added to existing reactors […]”*

As well as the Finnish Regulation YVL B.1 (ref. /11/):

> *“The Guide shall apply as it stands to new nuclear facilities.*

> *When considering how the new safety requirements presented in the YVL Guides shall be applied to the operating nuclear facilities, or to those under construction, STUK will take due account of the principles laid down in Section 7 a of the Nuclear Energy Act (990/1987): The safety of nuclear energy use shall be maintained at as high a level as practically possible."*

The NEA report on the Implementation of Defence in Depth (ref. /18/) fully recognises the challenge posed to existing plants:

> *"For operating reactors, there are likely to be fewer practical opportunities for enhancing safety. These have to be considered on a case-by-case basis."*

ENISS licensees observe that continuous improvement or Periodic Safety Review processes for existing NPPs may use the concept of Practical Elimination of scenarios as a guideline but only reasonably practicable safety improvements may be identified as potential candidates to reinforce the avoidance of early releases and large releases.

4. General principles

The ENISS position on the demonstration of avoidance of early radioactive releases and large radioactive releases and the application of the concept of Practical Elimination of scenarios is presented through the following principles, accounting for the definitions, observations and arguments presented in the above sections 2 and 3.

Principle 1: Demonstration of avoidance of LER and LLR can rely on different approaches commensurate to the risks to be discarded, including the application of the concept of Practical Elimination of scenarios.

In the design of a new nuclear power plant, as part of the risk analysis, the situations likely to lead to large early or large late releases (LER and LLR) are considered. The higher the risk, expressed in terms of the product of frequency and consequences, the higher should be the confidence in its extremely low probability of occurrence.

The demonstration of avoidance of LER and LLR may therefore rely on a methodology to be adapted accordingly, with for example the application of the concept of Practical Elimination of scenarios which may lead to large releases which must be avoided (for instance when protecting the public would be necessary but unlikely to be fully effective in a timely manner). In this latter case the demonstration would rely on practical means, design and operational provisions, to achieve practical elimination, preferably on the basis of physical impossibility, if reasonably practicable.

Principle 2: Practical Elimination of scenarios is a concept for new nuclear plants, applied from the onset of the design process to support the safety goal of avoidance of LER and LLR

The design of a new nuclear power plant is an iterative process following different stages progressively entering in deeper level of details: feasibility studies, conceptual design, basic design, detailed studies… The application of the DiD concept, providing a combination of consecutive levels of protection, is therefore progressively refined, but is also subject to the concept of reasonable practicability. Indeed, where several design options may be implemented, they are assessed by the licensee/designer decision making process for their safety benefits in regards to their cost effectiveness.

In order to support the demonstration of avoidance of LER and LLR as required in the Nuclear Safety Directive (ref. /1/), the application of the concept of Practical Elimination of scenarios should be part of the design process from the beginning, and therefore apply to new nuclear power plants.

Principle 3: For existing plants, the notion of Practical Elimination of scenarios is not mandatory, but it could be used to help identify reasonably practicable safety improvements intended to avoid LER and LLR through the processes for continuous improvement or Periodic Safety Review.

In the large majority of existing plants (e.g. Generation II ones), core melt accidents had not been taken into account at the design stage. However from the 70’s and the WASH-1400 NRC report (also called the Rassmussen report) and especially after the accident of Three Mile Island in 1979, designers and operators initiated new studies and the design of mitigation means to deal with the occurrence of core melt accidents. A large number of design and operations changes have been implemented since then allowing a significant decrease of the risks of LER and LLR.

In practice the concept of Practical Elimination of scenarios, despite using a different terminology, has already been practically considered for existing plants – for example:

- Hydrogen control systems have been installed in LWRs with design criteria aiming at avoiding any hydrogen detonation events.
- Supplementary emergency power supply systems have been installed and contribute to reduce with a high level of confidence the probability of LER and LLR.

For existing plants, the objective of avoidance of LER and LLR is used as a reference. However, the concept of Practical Elimination can be used, where appropriate, in the overall plant capability verification, in the frame of the processes for continuous improvement or Periodic Safety Reviews. Where relevant, and as an outcome of this verification of the plant capability to avoid LER and LLR, existing reactors should consider the concept of “reasonably practicable” safety improvements, as already discussed in a separate ENISS position paper (ref. /34/).

Principle 4: Demonstration of avoidance of LER and LLR credits all the relevant lines of defence as well as the analyses of the Design Basis and Design Extension Conditions, and the Probabilistic Safety Analysis.

The scenarios that could lead to LER and LLR are severe accidents with failure of the confinement function, as defined in section 2.2 above.

The demonstration of avoidance of LER and LLR does not require another set of design conditions (i.e. a set coming in addition to NO, AOO, DBC and DEC forming the design envelope). This is a demonstration of the plant capability to ensure either the physical impossibility or the extremely low likelihood of occurrence of scenarios that may lead to LER and LLR, with a high degree of confidence.

The Design Basis Analysis, and the Design Extension Analyses without significant fuel degradation (DEC-A) or with core melt (DEC-B), and the Level 1 and level 2 PSA provide the basis for demonstrating the avoidance of LER and LLR.

This demonstration should credit all lines of defence provided by the application of the DiD concept. For a given scenario, the overall robustness of the relevant lines of defence is assessed (e.g. adequate margins, adequate reliability, qualification against operation conditions …). This includes appropriate independence between these lines (i.e. sufficient combination of redundancy and physical separation, diversity, functional isolation) and low sensitivity to human errors. A minimum number of the design provisions necessary to demonstrate the practical elimination should remain effective during and after internal or external hazard events.

The set of design provisions, that may be part of any level of DiD, contributing to the demonstration of avoidance of LLR and LER, are classified according to their safety role through the existing categorisation/classification approach. This level of classification is then reflected into the operating documentation such as the periodic test schedule, the maintenance schedule and where necessary the operating technical specification.

Principle 5: Practically eliminated scenarios are excluded from DBC and DEC analyses, i.e. their consequences are not required to be mitigated because their occurrence is prevented.

As defined in section 2.2 above, the term “Practically Eliminated” means “physically impossible or extremely unlikely with a high degree of confidence” and applies to scenarios, defined as groups of accident sequences with severe fuel degradation and loss of the confinement function which potential consequences are LER or LLR.

When they are practically eliminated, such accident scenarios with severe fuel degradation and loss of the confinement function are not studied as part of the Design Extension Analyses (DEC-B).

Principle 6: The demonstration of avoidance of LER and LLR should be based on a balanced use of deterministic and/or probabilistic studies, including sensitivity analyses – associate methodologies are developed on a case-by-case basis.

The demonstration of avoidance of LER and LLR should commonly rely on the usual deterministic (design basis, design extensions), probabilistic (PSA) safety analyses and engineering/expert judgment. When applying the concept of Practical Elimination of scenarios a balanced use of deterministic and/or probabilistic studies should be the general rule to avoid relying only on PSA results. This is especially the case when complex and dynamic phenomena would lead to the containment failure mode. However in some instances the use of PSA may provide a robust and appropriate demonstration, given that the associated models and supporting assumptions provide a high level of confidence.

Practically, the detailed methodology should be devised on a case-by-case basis as the most appropriate for a given scenario to be practically eliminated.

Sensitivity analyses should be developed to account for uncertainties, namely relating to some severe accident physical phenomena.

Principle 7: Early dialog with the Regulator is recommended to discuss and agree on a structured detailed approach to avoid LER and LLR, including the application of the concept of Practical Elimination of scenarios.

Design approaches follow international standards and National Regulation. Before entering a detailed design phase for a new nuclear power plant, a stable design basis built up on these international standards and National Regulation is required, in order to keep control of schedule and costs. This stability reduces the risks of major design changes or the risks of major development of supporting studies that may be required in the course of the design development or in the course of the regulatory assessment. Thus, Regulator and Licensee need a shared terminology and interpretation on the way to implement the concepts of Practical Elimination and avoidance of LER and LLR, at an early stage.

Besides, there is not a single way to present the demonstration of avoidance of LER and LLR in the NPP safety report. A common goal should be to focus on the clarity of the demonstration, including the Practical Elimination of scenarios, with flexibility on its format and where it stands in the safety report.

Abbreviations

Abbreviations	Definitions
AOO	Anticipated Operational Occurence
ALARP	As Low As Reasonably Practicable
ASN	Autorité de Sûreté Nucléaire (France) – The French Regulator - Safety Nuclear Authority
CEGB	Central Electricity Generating Board (England and Wales historic operator)
DBA / DBC	Design Basis Analysis / Design Basis Conditions
DEC	Design Extension Conditions
DEC-A	Design Extension Conditions without significant fuel degradation
DEC-B	Design Extension Conditions with core melt
DCH	Direct Containment Heating
DiD	Defence in Depth
ENISS	European Nuclear Installations Safety Standards initiative
ENS	European Nuclear Society
EPR	European Pressurised Reactor
EUR	European Utility Directives
EURATOM	European Atomic Energy Community
FA3	Flamanville 3 EPR - France
FANC	Federal Agency for Nuclear Control (Belgium)
INB	Installation Nucléaire de Base (Basic Nuclear Unit – basic definition of nuclear plant where French Nuclear Regulation applies)
IRSN	Institut de Radioprotection et de Sûreté Nucléaire - French Institute for Radioprotection and Nuclear Safety
IAEA	International Atomic Energy Agency
LER	Large and Early radioactive Releases
LLR	Large and Late radioactive Releases
OECD	Organisation for Economic Cooperation and Development
OL3	Olkiluoto 3 EPR - Finland
ONR	Office for Nuclear Regulation (UK)
NEA	OECD Nuclear Energy Agency
NO	Normal Operation
NPP	Nuclear Power Plant
NSD	Nuclear Safety Directive 2014/87/EURATOM 2014
PE	Practical Elimination
PIE	Postulated initiating Event
PSA	Probabilistic Safety Analysis
PSR	Periodic Safety Review
RHWG	WENRA Reactor Harmonisation Working Group
SAPs	ONR Safety Assessment Principles for the UK
SSM	Swedish Radiation Safety Authority (Sweden)
SSR	Specific Safety Requirements – type of IAEA document
STUK	Radiation and Nuclear Safety Authority (Finland)
TAG	ONR Technical Assessment Guide
WENRA	Western Europe Nuclear Regulators Association

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/2/ Declaration - Contracting Parties meeting at the Diplomatic Conference of the Convention on Nuclear Safety - Vienna, Austria 9 February 2015 - Vienna Declaration on Nuclear Safety, On principles for the implementation of the objective of the Convention on Nuclear Safety to prevent accidents and mitigate radiological consequences

/3/ WENRA RHWG – August 2013 – Report on Safety of new NPP designs

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/6/ IAEA - INSAG-10 1996 - Defence in Depth in nuclear safety

/7/ IAEA - INSAG-3 1988 - Basic safety principles for nuclear power plants

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/26/ EUR Revision E July 2017 - European Utility Requirements for LWR nuclear power plant

/27/ France - JORF No. 0033 of 8 February 2012, page 2231 Text No. 12 - consolidated version 09th September 2014 - French Order of 7th February 2012 setting the general rules relative to basic nuclear installations

Note that the English version is not accounting for the latest French consolidated version of 24th September 2018, where only article 5.1 is modified. But this has no impact on this document.

/28/ CEGB Closing Statement to the Sizewell B Public Inquiry 1982-1985, Volume 1

/29/ Report - EDF Energy NNB GenCo - HPC PCSR3 2016 - HPC Pre-Construction Safety Report 3

/30/ German Regulation - Safety Requirements for Nuclear Power Plants 03rd March 2015 (translation from the document Sicherheitsanforderungen an Kernkraftwerke)

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Appendix 1 – Summary of definitions, interpretations, applications of Practical Elimination (PE)

A1.1 Latest international development of the Practical Elimination concept

When referring to Practical Elimination, IAEA safety standard SSR-2/1 rev. 1 (ref. /5/) is the international reference. PE is introduced as a concept at the very beginning, when discussing high level safety objectives for Nuclear Power Plants (NPPs), part of section 2 "*applying the safety principles and concepts*". Para 2.11 states:

> *"2.11. […] Plant event sequences that could result in high radiation doses or in a large radioactive release have to be 'practically eliminated'."*

SSR-2/1 introduces Practical Elimination as key to achieve principle 8 of IAEA Fundamental Safety SF-1 (ref. /16/), which is at the top of the IAEA pyramid of documents. However, details about Practical Elimination demonstration are deferred to footnote 2 as:

> *"The possibility of certain conditions arising may be considered to have been 'practically eliminated' if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise".*

Hence, there is no formal definition for Practical Elimination. The IAEA glossary (ref. /24/) is in the same position, referring to SSR-2/1, but concluding that:

> *"The phrase 'practically eliminated' was used in requirements for the design of nuclear power plants to convey the notion that, for a nuclear power plant, the possibility of the potential occurrence of certain hypothetical event sequences in scenarios could be considered to be excluded ("practically eliminated") provided that (1) it would be physically impossible for the relevant event sequences to occur or that (2) these sequences "could be considered with a high level of confidence to be extremely unlikely to arise"].*

but with the following caution:

> *"The phrase 'practically eliminated' is misleading as it actually concerns the possible exclusion of event sequences from hypothetical scenarios rather than practicalities of safety. The phrase can also all too readily be misinterpreted, misrepresented or mistranslated as referring to the 'elimination' of 'accidents' by practical measures (or else 'practically' in the sense of 'almost'). Clear drafting in natural language would be preferable."*

A1.2 History of the introduction of the concept of Practical Elimination

As highlighted in the IRSN report on Practical Elimination approach (ref. /12/), PE terminology was probably first used in the 90's and introduced as part of the first German and French Regulator discussions to establish safety objectives for a new generation of nuclear reactors. This was finally included in the resulting German and French Technical Guidelines (ref. /9/):

> *"A.1.1.d) Accident situations with core melt which would lead to large early releases have to be "practically eliminated": if they cannot be considered as physically impossible, design provisions have to be taken to design them out."*

Other approaches, already implemented in the design of operating Nuclear Power Plants, may be seen as Practical Elimination despite not using the PE terminology, but this is still under debate internationally, at least between ENISS Licensees. Some of these approaches are related to the design of large pressurised components, where design provisions allow to consider their failure very unlikely such as: "Non-breakable components" or Incredibility of

Failure. This was discussed as part of an international conference on safety topical issues regarding Practical Elimination approach in Finland (ref. /19/).

> *"The idea of practically eliminate rupture of the reactor pressure vessel and fast increase of reactivity threatening the integrity of the containment and causing early or large releases have been in the design of nuclear power plants from the 1970s."*

In terms of international standards, the terminology Practical Elimination was first introduced via IAEA INSAG 12 (ref. /8/) in 1999, but the concept was referenced in earlier standards using different terminology. It is referred to in the "Technical Safety Objective" set down in IAEA INSAG-3 (ref. /7/):

> *"19. Objective: To prevent with high confidence accidents in nuclear plants; to ensure that, for all accidents taken into account in the design of the plant, even those of very low probability, radiological consequences, if any, would be minor; and to ensure that the likelihood of severe accidents with serious radiological consequences is extremely small."*

This was incorporated in the IAEA INSAG 10 (ref. /6/):

> *"124. For advanced designs, it would be demonstrated, […], that hypothetical severe accident sequences that could lead to large radioactive releases due to early containment failure are essentially eliminated with a high degree of confidence".*

This was incorporated in the revision of INSAG-3 renamed as INSAG 12 (ref. /8/), under the discussion of the Technical Safety Objective as:

> *"27 […] Another objective for these future plants is the practical elimination of accident sequences that could lead to large early radioactive releases, whereas severe accidents that could imply late containment failure would be considered in the design process with realistic assumptions and best estimate analyses so that their consequences would necessitate only protective measures limited in area and in time.".*
> *"129 For future nuclear power plants […]. Notably, the practical elimination of accident sequences which could lead to large early radioactive releases"*

Based on these documents (ref. /12/, /9/, /8/ and /6/), PE was historically defined as an objective to reduce the risks of large and early radioactive releases (LER), potentially raised by severe accident scenarios. The need to include design provisions to prevent and mitigate severe accidents leading to late containment failures was also included in the objectives as an additional item.

However, the term Practical Elimination has been revised in recently issued IAEA publications. In 2004, the IAEA safety guide NS-G-1.10 (ref. /25/) extended PE by the provision of a list of scenarios to be considered, a first step going further than the initial "large and early releases" (LER) via the introduction of LLR:

> *"6.5 For new plants, […] The consideration of severe accidents should be aimed at practically eliminating the following conditions:*
> - *Severe accident conditions that could damage the containment in an early phase […];*
> - *Severe accident conditions that could damage the containment in a late phase […];".*

Where the details about demonstration of PE is also in a footnote (Footnote 14).

Then in 2012 the IAEA safety standard SSR-2/1 came into force. The 2012 version introduces Practical Elimination in relation to:

> *"2.11. [...] plant event sequences that could result in high radiation doses or radioactive releases must be practically eliminated"*

This was probably seen as a broad definition (you could read it as "all radioactive releases") going above the intent and all instances were corrected in 2016 (revision 1 - ref. /5/). But this revision 1 does not come back to the "large and early releases" (LER) of INSAG 10, while introducing further details about Practical Elimination, but rather extend it to LLR. The main addition is a sentence, making PE part of the 4th level of Defence in Depth (DiD), closely linked to accident with significant fuel degradation, and two new footnotes:

> *"2.11. […] Plant event sequences that could result in high radiation doses or in a large radioactive release have to be 'practically eliminated […]*
> *"2.13. […]*
> *(4) The purpose of the fourth level of defence is […] Event sequences that would lead to an early radioactive release or a large radioactive release[3] are required to be 'practically eliminated'[4]."*
>
> *"Footnote 3: An 'early radioactive release' in this context is a radioactive release for which off-site protective actions would be necessary but would be unlikely to be fully effective in due time. A 'large radioactive release' is a radioactive release for which off-site protective actions that are limited in terms of lengths of time and areas of application would be insufficient for the protection of people and of the environment."*
> *"Footnote 4: The possibility of certain conditions arising may be considered to have been 'practically eliminated' if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise."*

It should be highlighted that Footnote 3 is introducing a distinction between LER and LLR and is using a terminology very similar to the one used for Design Extension Conditions (DEC with or without core melt) in IAEA safety standard SSR-2/1:

> *"5.31A. The design shall be such that for design extension conditions, protective actions that are limited in terms of lengths of time and areas of application shall be sufficient for the protection of the public, and sufficient time shall be available to take such measures."*

The IAEA safety standard SSR-2/1 is also referring to Practical Elimination in several requirements, this being new parts from revision 1 or amendments, in areas such as: Requirement 5: Radiation protection in design (para 4.3), Requirement 20: Design extension conditions (para 5.27), Requirement 58: Control of containment conditions (para 6.28), Fuel handling and storage systems (para 6.68), External hazards (para 5.21A).

In addition to IAEA SSR-2/1, some international regulations, standards, guides are also discussing Practical Elimination:

- The European Utility Requirements (EUR) for LWR NPPs Revision E (ref. /26/) section 2.1 closely considers IAEA SSR-2/1. The EURs raise the SSR-2/1 footnotes as definitions for Practical Elimination, "early releases" (LER) and "large releases" (LLR) (note that all terms followed by a "*" are in the EUR list of definitions):

> *"Accident sequences that have the potential to cause a Large Release* or Early Release* shall be Practically Eliminated*."*

- WENRA also introduces Practical Elimination in the safety objectives for New Power Reactors (ref. /13/) through Objective O3 "Accidents with core melt", with the same definition as IAEA SSR-2/1 for "early releases" (LER) and for "large releases" (LLR) :

> *"accidents with core melt which would lead to early or large releases have to be practically eliminated;"*

- The OECD NEA report on the Implementation of Defence in Depth following the Fukushima Daichi Accident (ref. /18/) also refers to IAEA SSR-2/1 in these terms:

> *"The goal of level 4 is to prevent or mitigate any significant radioactive releases from such accidents. In some cases, prevention and mitigation through the implementation of DiD should be reinforced, and those sequences leading to significant radioactive releases have to be "practically eliminated".*

- Finally, the recently published IAEA safety glossary (ref. /24/) takes the definition as given in SSR-2/1, but states the following:

> ***"****The phrase 'practically eliminated' is misleading as it actually concerns the possible exclusion of event sequences from hypothetical scenarios rather than practicalities of safety. The phrase can also all too readily be misinterpreted, misrepresented or mistranslated as referring to the 'elimination' of 'accidents' by practical measures (or else 'practically' in the sense of 'almost'). Clear drafting in natural language would be preferable."*

A1.3 A large variety of interpretations of Practical Elimination application

Practical Elimination has been introduced in France through the French and German Technical Guidelines (ref. /9/). Despite an early appearance of the concept in the 90s, further discussions and recent development took place. Article 3.9 of the Order of 7th February 2012 (ref. /27/) gave a high level description of principles similar to Practical Elimination:

> *"accidents that could lead to large releases of hazardous substances or to hazardous effects off the site that develop too rapidly to allow timely deployment of the necessary population protection measures are physically impossible or, if physical impossibility cannot be demonstrated, that the measures taken on or for the installation render such accidents extremely improbable with a high level of confidence."*

The ASN guide 22 (ref. /23/), issued in 2017 explains this further (translated for this paper, as the English version is not available yet) but, again, without referring to "Practical Elimination" nor "practically eliminated" terminology:

> *"[Core melt accidents with the potential to lead to large releases, for which it would be unlikely that the required protective measures for people off-site will be effective in time, are made physically impossible; or, if not possible, provisions are implemented to make them extremely unlikely to arise with a high level of confidence.]"*

Additionally, IRSN issued in 2017 an approach to Practical Elimination (ref. /12/):

> *"[...] situations likely to lead to large releases, because of the simultaneous or successive loss of integrity of all the containment barriers or because of the bypass of these barriers (containment bypass situations):*
> - *either lead to define provisions allowing to significantly limit their consequences;*
> - *or shall be "practically eliminated" […]."*
>
> *"[…] This highlights how important the discussions between applicants and safety authorities in the early stages of a new design are […]."*

The conclusion of the report includes the following statement:

> *"The situations for which this approach [(Practical Elimination)] can be used shall be discussed by applicants and safety authorities from the initial design stages of a new reactor type."*

In the UK, the ONR SAPs (ref. /17/), inspired by IAEA safety standard SSR-2/1, have incorporated Practical Elimination as part of the severe accident topic:

> *"6.11 […] the SAA [Severe Accident Analysis] should form part of a demonstration that potential severe accident states have been 'practically eliminated'. To demonstrate practical elimination, the safety case should show either that it is physically impossible for the accident state to occur or that design provisions mean that the state can be considered to be extremely unlikely with a high degree of confidence. "*

In Belgium, the Federal Agency for Nuclear Control (FANC) introduced Practical Elimination in the recent issue of a guidance (ref. /14/) for new reactors:

- *"severe accidents which would lead to early or large releases should be practically eliminated (See section 5.3);*
- *severe accidents which would lead to unacceptable direct irradiation (e.g. in case of criticality accidents without release) should be practically eliminated (see section 5.3) […] "*

"5.3 […] The demonstration of practical elimination is considered successful if [7]:

- *The sequence (initiator) can be proven to be physically impossible;*
- *The sequence (initiator) is extremely unlikely to arise with a high level of confidence."*

In Finland, Practical Elimination has been recently introduced in the updated Finnish Regulation through YVL B.1 (ref. /11/) as follows:

> *"423. Events that may result in a release requiring measures to protect the population in the early stages of the accident shall be practically eliminated.*
> *424. Events to be practically eliminated shall be identified and analysed using methods based on deterministic analyses complemented by probabilistic risk assessments and expert assessments.…]"*

In addition at the June 2017 international conference on safety topical issues, regarding Practical Elimination approach in Finland, the Finnish Regulator STUK (ref. /19/) stated that:

> *"[…] This overall approach for Practical Elimination of large and early releases is supported by the approach of "practically eliminating" specific sequences and conditions threatening the containment integrity in severe accidents."*

In Sweden, the National Regulation SSMFS 2018:17 (ref. /31/) is in some way discussing Practical Elimination or at least the events that should be considered:

> *"a safety evaluation should be performed of events and phenomena which may be of importance for containment integrity in highly improbable events. Examples of such events and phenomena which can result in the need to take measures include high pressure melt-through of the reactor pressure vessel, steam explosion, recriticality, hydrogen fire and containment underpressure."*

Based on the Technical Guidelines (ref. /9/), Flamanville 3 EPR project has considered Practical Elimination from early stages. This is now reflected in the FA3 Pre-Commissioning Safety Report (Translated from ref. /10/):

> *"Situations to be specifically handled to practically eliminate them are those liable to yield large early releases. The situations to be considered are […]*
> *"Regarding situations to be practically eliminated, this deterministic approach aims at identifying phenomena that could give rise to early failure of the containment in severe accident situation."*

The Olkiluoto 3 project has followed a similar route, although, the French and German Technical Guidelines (ref. /9/) are not a formal design reference, in Finland. In addition, the Finnish Regulator STUK has required additional severe accident management measures that are not part of other EPR projects. It is worth underlining the following part of their assessment of PE application in Finland, as presented at an International Conference in June 2017 (ref. /19/):

> *"Practical elimination of early or large releases consist of two aspects: for the first consideration of Defence-in-Depth effectively in design and operation of a reactor […]*

> *<u>at Level 4</u> the severe accident <u>sequences leading to the loss of containment are to be identified and "practically eliminated"</u>. These sequences are specific to the reactor type and design. The general goal for "practically eliminating" large or early releases is driven by the probabilistic limit for large and early releases above."*

Knowing that IAEA safety standard SSR-2/1 was still new and may be interpreted in different ways, IAEA initiated TECDOC 1791 (ref. /20/) to collate insights and approaches in support to the application of IAEA SSR-2/1. This TECDOC recognises that:

> *"There is still discussion in several Member States on the actual conditions for which the practical elimination needs to be pursued." […]"*
> *"The concept of 'practical elimination' must not be misinterpreted or misused. It is to be considered as part of a general approach to safety and its appropriate application <u>as an enhancement of defence in depth</u>."*
> *"It is a decision of the regulatory body to establish or not what are acceptable targets to support the demonstration of practical elimination."*

At the same time in 2016, OECD report (ref. /18/) about application of Defence in depth following Fukushima Daichi Accident included discussions on Practical Elimination:

> *"be ensured that accident sequences that lead to significant radioactive releases are "practically eliminated". There has been some debate about what this means in practice."*
> *"To date, <u>there does not seem to be a common understanding</u> of what that implies for reactor safety systems."*

In addition, the European Nuclear Society held a meeting in Vienna to share about NPPs safety, this included a session on Practical Elimination (ref. /33/) where IAEA SSR-2/1 and IAEA TECDOC 1791 were discussed. It was noted that:

> *"The practical elimination of large or early radioactive releases during nuclear power plant accidents is desired. However, the demonstration of the Practical Elimination is a complex process for which no specific guidance and criteria are available and not sufficient experience is so far generated."*

Based on all that, ENISS Licensees observe a large variety in the terminology and that the current definition of PE or ways of implementing the concept of PE have evolved and are not consistently shared. Therefore, the PE safety objective, PE relation to DiD concept and methods of demonstration differ, opening the door to differing interpretations that may be used by Licensees and Regulators.

A1.4 Observations and examples of applications

In Belgium:

The Federal Agency for Nuclear Control (FANC) introduced Practical Elimination in the recent issue of the Guideline for Safety demonstration of new class I nuclear installation (ref. /14/). As per the title, this new guideline is intended to apply to new plants and hence have not been used so far in Belgium.

However, recent and current safety improvements performed on Belgian NPPs could be seen as Practical Elimination application. For example, the Filtered Containment Venting System (FCVS) installed on Belgian units can be seen as a means to practically eliminate scenarios leading to containment failure due to slow pressurisation. Such late containment failure could lead to releases for which limited off-site protective actions would be insufficient. Furthermore, the installation and design of this system is supported by probabilistic considerations which falls in line with the Practical Elimination concept, although the concept has not been formally considered. Another example is the establishment of the list of sequences for Design Extension Conditions (DEC) studies that has been supported by both deterministic and probabilistic arguments. A probabilistic approach supported the definition of lower bounds in terms of frequencies issued from both level 1 and level 2 Probabilistic Safety Analysis (PSA) studies (i.e. frequencies of core damage and release categories levels). Sequences with frequencies falling under these lower bounds and under additional deterministic considerations, have been excluded from the list of DEC sequences. Therefore the consequential severe accident scenarios can be seen as practically eliminated.

In France:

Practical Elimination has been introduced in France and Germany as a regulatory expectation, in the 1990's, through the French and German Technical Guidelines (ref. /9/).

Based on this French Regulation, Flamanville 3 (FA3) EPR project has considered Practical Elimination of large and early releases (LER) from early stages, whereas LLR avoidance is part of severe accident studies (DEC-B). This is now reflected in the FA3 Pre-Commissioning Safety Report (ref. /10/) with dedicated sections. Future designs under development in France, such as EPR 2, are also considering Practical Elimination.

Practical Elimination is also part of the French Article 3.9 of the Order of 7th February 2012 (ref. /27/). The general description in this Order is further detailed by the ASN guide 22 (ref. /23/), issued in 2017 with the aim to provide additional recommendations on the interpretation of the French legal framework for the design of NPPs. Neither document uses the Practical Elimination terminology.

In Finland:

The recently updated Finnish Regulation YVL B.1 (ref. /11/) has introduced Practical Elimination. In essence, the Practical Elimination means a very low frequency of occurrence for large or early releases, and the satisfaction of the authority that there are no further reasonably achievable means to further decrease the likelihood of such accident sequences.

The NPP unit Olkiluoto 3 has, in practice, the Practical Elimination in its design basis, although the wording in the safety case does not use this concept. At older units, such as Olkiluoto 1 and 2, the Practical Elimination is considered as a design goal towards which all reasonable actions need to be made.

When the severe accident management approach was developed and implemented at the Loviisa power plant starting from 1988 until 2002, the guiding principle was to avoid any containment failure that could lead to early and large releases. The Risk-Oriented Accident Analysis Methodology (ROAAM) was extensively applied to demonstrate that "Containment failure is a physically unreasonable event for any accident sequence that is not remote and speculative". Although the wording in the safety case does not use the Practical Elimination concept, this approach is equivalent to demonstrating Practical Elimination.

In Germany:

There is consideration of Practical Elimination in the French and German Technical Guidelines (ref. /9/) developed in the 1990s. Practical Elimination may be regarded as already being considered, where initiating events or accident sequences have been discarded from the design with justification. Practical Elimination is more seen as a practical means to demonstrate the completeness of a safety evaluation.

Furthermore, Practical Elimination is mentioned in the “Safety Requirements for Nuclear Power Plants” (ref. /30/), where it is defined similar to IAEA safety standard SSR-2/1. When issuing nuclear licenses German authorities are bound by a fundamental decision of the German Supreme Court, ruling that a license may only be granted if any harm resulting from a nuclear activity is practically eliminated.

In Spain:

The explicit term of Practical Elimination is not used in the Spanish nuclear regulation, however, the concept is considered as part of the application of the “Defense in Depth” concept, requiring that the design should prevent as far as possible the failure of the successive barriers that prevent the release of radioactive material to the environment.

The application of the Defense in Depth is required by specific regulation, issued by the government (Nuclear Safety Royal Decree, article 16) and by the Spanish Regulator (Safety Instruction IS-26 “Basic safety requirements about nuclear safety at nuclear installations” and Safety Instruction IS-37 “Design basis accidents at nuclear power plants”). Therefore practical elimination of events that could result in large or early releases is taken into consideration by addressing these regulations.

In Sweden:

The explicit term Practical Elimination is not used in the nuclear Regulations and there has not been much discussions as regard the implementation of the concept. Swedish nuclear safety Regulations (SSMFS 2008:17 - ref. /31/) applies the concept of “Residual Risk”, a concept introduced in 1986.

Practical Elimination is considered to be part of the nuclear safety objective (Article 8a) established under the revised Nuclear Safety Directive (2009/71EURATOM – ref. /1/), which has been implemented into national Regulations (Swedish Nuclear Law 4§). For existing plants, Practical Elimination of events that could result in large or early releases is taken into consideration by addressing specific severe accident scenarios (part of “highly improbable events”) and by means of reasonably practicable safety improvements. It is not expected that Practical Elimination will lead to further plant improvements, but rather confirm the justification that effective mitigation measures are in place. Practical Elimination of events that could result in large or early releases is regarded as already fulfilled for existing plants through back-fitting measures, such as installation of filtered containment venting systems in the mid 80's.

Practical Elimination is considered as an expectation for new installations, in line with IAEA SSR-2/1, although the explicit terminology is not included in the Swedish Regulation yet. Practical Elimination is applied in the design of a new spent fuel storage and encapsulation plant. Practical Elimination is applied to demonstrate that severe fuel damage is extremely unlikely with a high degree of confidence.

In the UK:

The CEGB Design Safety Criteria and Guidelines were developed so as to achieve two fundamental aims so far as risks to the public are concerned. One is to ensure that accidents, which in practical terms could conceivably happen have consequences which can be accepted. The other is to ensure that accidents which would have unacceptable consequences, in practical terms will not occur. These aims are achieved by setting reliability targets related to design basis accidents and to uncontrolled releases (ref. /28/). The approach includes what is now termed Practical Elimination and dates back to the 1970s. The use of PSA techniques to ensure that a systematic approach is followed, and a balanced design is achieved is also required.

Although there is no explicit expectations to consider Practical Elimination for existing plants, there is a requirement to demonstrate that the risk posed by the plant remains as low as is reasonably practicable taking into account current standards.

The ONR SAPs (ref. /17/) revised in 2014, have simply incorporated Practical Elimination as part of the severe accident topic, consistent with the IAEA safety standard SSR-2/1 (i.e. there are few instances of PE and no specific section discussing PE terminology).

HPC EPR, despite including Practical Elimination in its initial design inherited from FA3, is following the move, with no explicit reference to Practical Elimination in HPC PCSR3 (ref. /29/). Practical Elimination relies upon the overall deterministic and probabilistic results justifying that the lines of defence (1st to 4th DiD levels) achieve HPC Safety Design Objectives (SDOs) on releases targets, in line with the ONR views expressed in the ONR SAPs (ref. /17/).

Appendix 2 – full quotations

A2.1 Quotations of section 1

European Nuclear Safety Directive (ref. /1/):

> *"Article 8a - Nuclear safety objective for nuclear installations*
>
> 1. *Member States shall ensure that the national nuclear safety framework requires that nuclear installations are designed, sited, constructed, commissioned, operated and decommissioned with the objective of preventing accidents and, should an accident occur, mitigating its consequences and avoiding:*
>   - *(a) early radioactive releases that would require off-site emergency measures but with insufficient time to implement them;*
>   - *(b) large radioactive releases that would require protective measures that could not be limited in area or time.*
> 2. *Member States shall ensure that the national framework requires that the objective set out in paragraph 1:*
>   - *(a) applies to nuclear installations for which a construction licence is granted for the first time after 14 August 2014;*
>   - *(b) is used as a reference for the timely implementation of reasonably practicable safety improvements to existing nuclear installations, including in the framework of the periodic safety reviews as defined in Article 8c(b)."*

Vienna Declaration for Nuclear Safety (ref. /2/):

> *"the contracting parties to the convention on nuclear safety have adopted the following principles to guide them, as appropriate, in the implementation of the objective of the CNS to prevent accidents with radiological consequences and mitigate such consequences should they occur:*
>
> 1. *New nuclear power plants are to be designed, sited, and constructed, consistent with the objective of preventing accidents in the commissioning and operation and, should an accident occur, mitigating possible releases of radionuclides causing long-term off site contamination and avoiding early radioactive releases or radioactive releases large enough to require long-term protective measures and actions."*

WENRA RHWG report (ref. /3/) - safety objective O3:

> *"reducing potential radioactive releases to the environment from accidents with core melt, also in the long term, by following the qualitative criteria below:*
>
> - *accidents with core melt which would lead to early or large releases have to be practically eliminated;*
> - *for accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited protective measures in area and time are needed for the public (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in food consumption) and that sufficient time is available to implement these measures."*

IAEA safety guide SSG-2 (ref. /15/) (section 3.56)

> *"3.56. The event sequences for which specific demonstration of their 'practical elimination' is required should be classified as follows:*
>
> - *a) Events that could lead to prompt reactor core damage and consequent early containment failure, such as:*
>   - *(i) Failure of a large pressure-retaining component in the reactor coolant system;*
>   - *(ii) Uncontrolled reactivity accidents.*
> - *b) Severe accident sequences that could lead to early containment failure, such as:*
>   - *(i) Highly energetic direct containment heating;*
>   - *(ii) Large steam explosion;*

(iii) Explosion of combustible gases, including hydrogen and carbon monoxide.

c) *Severe accident sequences that could lead to late containment failure 8 :*
    (i) Basemat penetration or containment bypass during molten core concrete interaction;
    (ii) Long term loss of containment heat removal;
    (iii) Explosion of combustible gases, including hydrogen and carbon monoxide.

d) *Severe accident with containment bypass.*

e) *Significant fuel degradation in a storage fuel pool and uncontrolled releases. "*

A2.2 Quotations of section 3.1

IAEA Fundamental Safety Principles SF-1 (ref. /16/):

> *"2. SAFETY OBJECTIVE*
> *The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation.*
> *2.1. This fundamental safety objective of protecting people — individually and collectively — and the environment has to be achieved without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks. To ensure that facilities are operated and activities conducted so as to achieve the highest standards of safety that can reasonably be achieved, measures have to be taken:*
> - *(a) To control the radiation exposure of people and the release of radioactive material to the environment;*
> - *(b) To restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation;*
> - *(c) To mitigate the consequences of such events if they were to occur.*
>
> *2.2. The fundamental safety objective applies for all facilities and activities, and for all stages over the lifetime of a facility or radiation source, including planning, siting, design, manufacturing, construction, commissioning and operation, as well as decommissioning and closure. This includes the associated transport of radioactive material and management of radioactive waste.*
> *2.3. Ten safety principles have been formulated, on the basis of which safety requirements are developed and safety measures are to be implemented in order to achieve the fundamental safety objective. The safety principles form a set that is applicable in its entirety; although in practice different principles may be more or less important in relation to particular circumstances, the appropriate application of all relevant principles is required."*
>
> *"Principle 8: Prevention of accidents: All practical efforts must be made to prevent and mitigate nuclear or radiation accidents."*
> *"3.31. The primary means of preventing and mitigating the consequences of accidents is 'defence in depth'. Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection that would have to fail before harmful effects could be caused to people or to the environment. If one level of protection or barrier were to fail, he subsequent level or barrier would be available. When properly implemented, defence in depth ensures that no single technical, human or organizational failure could lead to harmful effects, and that the combinations of failures that could give rise to significant harmful effects are of very low probability. The independent effectiveness of the different levels of defence is a necessary element of defence in depth."*

IAEA safety standard SSR-2/1 rev.1 (ref. /5/) - section 2 "*applying the safety principles and concepts*":

> *"2.11. The design for safety of a nuclear power plant applies the safety principle that practical measures must be taken to mitigate the consequences for human life and health and for the environment of nuclear or radiation accidents (Principle 8 of the Fundamental Safety Principles [1]). Plant event sequences that could result in high radiation doses or in a large radioactive release have to be 'practically eliminated' and plant event sequences with a significant frequency of occurrence have to have no, or only minor, potential radiological consequences. An essential objective is that*

the necessity for off-site protective actions to mitigate radiological consequences be limited or even eliminated in technical terms, although such measures might still be required by the responsible authorities."
"Footnote 2: The possibility of certain conditions arising may be considered to have been 'practically eliminated' if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise".

"2.13. […] Paragraph 3.31 of the Fundamental Safety Principles [1] states that: "Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection that […]
(4) The purpose of the fourth level of defence is to mitigate the consequences of accidents that result from failure of the third level of defence in depth. This is achieved by preventing the progression of such accidents and mitigating the consequences of a severe accident. The safety objective in the case of a severe accident is that only protective actions that are limited in terms of lengths of time and areas of application would be necessary and that off-site contamination would be avoided or minimized. Event sequences that would lead to <u>an early radioactive release or a large radioactive release</u>[3] are required to be 'practically eliminated'[4]."

"Footnote 3: An 'early radioactive release' in this context is a radioactive release for which off-site protective actions would be necessary but would be unlikely to be fully effective in due time. A 'large radioactive release' is a radioactive release for which off-site protective actions that are limited in terms of lengths of time and areas of application would be insufficient for the protection of people and of the environment."
"Footnote 4: The possibility of certain conditions arising may be considered to have been 'practically eliminated' if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise."

Technical Guidelines (ref. /9/).

"A.1.3 - General strategy related to severe accidents
The general objectives set in section A.1.1 have the following general implications concerning severe accidents.
a) Practical Elimination of accident situations which would lead to large early releases
- *Accident sequences involving containment bypassing (via the steam generators or via circuits connected to the primary system which exit the containment) have to be "practically eliminated" by design provisions (such as adequate piping design pressure) and operating provisions, aimed at ensuring reliable isolation and also preventing failures.*
- *Special attention shall be given to shutdown states and open containment building.*
- *Reactivity accidents resulting from fast introduction of cold or deborated water must be prevented by design provisions so that they can be "excluded".*
- *Overpressurization of the primary circuit must also be prevented as far as necessary by design provisions and operating procedures so as to contribute in particular to the "exclusion" of the reactor pressure vessel rupture.*
- *High pressure core melt situations must be prevented by design provisions (such as diversity and automatic actuation) for the secondary side safety systems and if necessary for the reactivity control and primary feed and bleed systems. It must be a design objective to transfer high pressure core melt to low pressure core melt sequences with a high reliability so that high pressure core melt situations can be "excluded". The depressurization must be such that loads from ejected melt into the containment atmosphere ("direct containment heating") and loads on the reactor pressure vessel support and cavity structures can be coped with.*
- *Global hydrogen detonations and in-vessel and ex-vessel steam explosions threatening the containment integrity must be "practically eliminated"."*

ONR SAPs (ref. /17/):

"611 In line with wider international guidance, the SAA [Severe Accident Analysis] should form part of a demonstration that potential severe accident states have been 'practically eliminated'. To demonstrate practical elimination, the safety case should show either that it is physically impossible

> *for the accident state to occur or that design provisions mean that the state can be considered to be extremely unlikely with a high degree of confidence. Each instance where practical elimination is claimed should be assessed separately, taking into account relevant uncertainties, particularly those due to limited knowledge of extreme physical phenomena (e.g. the behaviour of molten reactor cores). Moreover, an accident state should not be considered to have been practically eliminated simply on the basis of meeting probabilistic criteria. Instead, any claims made on SSCs in relation to practical elimination need to be substantiated.“*

Federal Agency for Nuclear Control (FANC) guidance (ref. /14/) for new nuclear installations:

> *“5.2.4. C4 “Severe Accidents”*
>
> *Severe accidents (SA) are a specific set of rare accidents for which the consequences are beyond those of C3b accidents.*
>
> *Although C3b aims at preventing severe accidents as far as reasonably practicable, severe accidents should nevertheless be considered as part of the DiD approach. Severe accidents which would lead to an early or large release or unacceptable direct irradiation (see section 6.2.3) should be practically eliminated (see section 5.3).*
>
> *C4a accidents 9 are severe accidents (e.g. core melt, large releases of radioactive material from the installation…) that have not been practically eliminated (see section 5.3).*
>
> *For these accidents, design measures should be implemented in order to meet safety objective SO3. In addition, the applicant should demonstrate to the regulatory authority that there are no reasonably practicable design measures that could be implemented to meet safety objective SO2.*
>
> *Quantitative safety objectives are presented in section 6.2.3 and section 6.3 and should be met with an approach which could be less conservative than the one used for the analysis of C3a events.*
>
> *For SA practically eliminated there are no quantitative safety objectives defined. Any additional reasonably practicable mitigating provisions should be implemented to address SA phenomena that arise in the practically eliminated SA situations and which are not covered under C4a with the aim to reduce the risk further. To meet this objective, “severe accidents” should be postulated (i.e. hypothetical accidents) under C4b. The intention in addressing these additional SA phenomena is to ensure that the DiD Level 4 analysis covers a wide set of severe accident phenomena. The mitigation means for these situations belong to level 4 of the Defence in Depth (DiD).”*

IAEA INSAG 12 (ref. /8/):

> *“129 For future nuclear power plants, the design features related to the prevention and mitigation of accidents, including severe accidents, will be determined on the basis of deterministic analysis, best estimate probabilistic considerations, the application of numerical safety targets and engineering judgment. Notably, the practical elimination of accident sequences which could lead to large early radioactive releases will be based, as far as necessary, on detailed deterministic and/or probabilistic studies. PSAs will be used from the design stage as a useful tool for in-depth analysis of the contribution of the different accident sequences to the risk. Reaching a final decision about features to be incorporated in future nuclear power plants will be an iterative process, with initial judgements made by the designers, based on experience and research results and with the help of PSAs. This is followed by review by plant owners/operators and regulators to confirm that an appropriate decision has been made. This process of careful evaluation and decision making will lead to a consistent and stable set of design features.”*

EUR section 2.1: (ref. /26/)

> *Accident sequences that have the potential to cause a Large Release* or Early Release* shall be Practically Eliminated*. The relevant safety demonstration requires identifying accident sequences potentially leading to such unacceptable releases and then bringing the appropriate justification that those accident sequences do not need to be considered in the plant design under the Defence-in-Depth* concept.*

OECD NEA report on the Implementation of Defence in Depth following Fukushima Daichi Accident (ref. /18/:

> *“The Practical Elimination concept is an approach that sets improved safety goals (or expectations) for nuclear installations by incorporating additional design features or, more rarely, operating*

> *provisions. These features or provisions can be associated with level 1, 2, 3 or 4, or any combination of these.*
> *It is important that practical elimination is not used to justify a lack of severe accident management arrangements and capabilities, or the absence of fully effective emergency arrangements both on-site and off-site. Such an approach would go against the concept of DiD and the independent effectiveness of the various levels of DiD.“*

International Conference in June 2017 (ref. /19/):

> *“The Finnish approach for practical elimination of large or early releases is driven by limiting the overall frequency of initiating events that could lead to such a situation. Specific approach for Practical elimination is addressing sequences, for which mitigation is not feasible due to the nature of the phenomena resulting from some specific initiating events. The possibility of occurrence of such sequences has to remain extremely low, which supports also achieving the probabilistic overall safety goal.”*
> *Practical Elimination of early or large releases consist of two aspects: for the first consideration of Defence-in-Depth effectively in design and operation of a reactor and for the second accident sequences for which provisions ensure that they are extremely unlikely to arise so that the mitigation of their consequences does not need to be included in the design.*
> *As shown in Fig. 1. at Defence-in-Depth Level 1, the rupture of the pressure vessel and severe criticality accidents are “practically eliminated”, and at Level 4 the severe accident sequences leading to the loss of containment are to be identified and “practically eliminated”. These sequences are specific to the reactor type and design. The general goal for “practically eliminate” large or early releases is driven by the probabilistic limit for large and early releases above. The overall methodology of Practical Elimination cannot be the same for large amount of sequences, but the reactor unit is to be considered as a whole including all relevant combinations of events. This overall approach for Practical Elimination of large and early releases is supported by the approach of “practically eliminating” specific sequences and conditions threatening the containment integrity in severe accidents.”*

A2.3 Quotations of section 3.2

Technical Guidelines (ref. /9/):

> *“In this [safety] demonstration, single initiating events have to be "excluded" or "dealt with" -that is to say that their consequences are examined in a deterministic way. Single initiating events can be ‘excluded’ only if sufficient design and operation provisions are taken so that it can be clearly demonstrated that it is possible to ‘practically eliminate’ this type of accident situations ; for example, the reactor pressure vessel rupture and other large components (as steam generator secondary side or pressurizer) rupture can be examined in that way.”*

IRSN PE approach (ref. /12/):

> *“Situations for which a ‘practical elimination’ approach can be used: In the general design approach, applicants identify the operating and accident conditions, which are classified into categories associated with objectives for limiting off-site consequences, depending on the estimated frequency of occurrence of the conditions. At this stage, a number of single initiating events and multiple failures are “excluded” since considered as not plausible; thus, their consequences are not studied deterministically in the safety demonstration and no mitigation provisions are defined. In order to consider situations likely to lead to large early releases as “excluded”, the applicant shall use the ‘practical elimination’ approach. These situations are identified on the basis of the analysis of the third barrier (or its extension) possible failure modes“.*

A2.3 Quotations of section 3.3

IAEA-TECDOC-1791 (ref. /20/):

> *“The definition above [(i.e. SSR-2/1 footnote 4)] is based on two concepts of different nature. The first concept is of deterministic nature on the consideration of the physical impossibility (in practice*

> *limited to very specific cases), and the second concept is of probabilistic nature and implies the use of probabilistic methods to assess that the probability of a condition is very low (extremely unlikely), and the degree of confidence of the probability estimate is very high."*
>
> *"The concept of 'practical elimination' must not be misinterpreted or misused. It is to be considered as part of a general approach to safety and its appropriate application as an enhancement of defence in depth. The 'practical elimination' is achieved by prevention of the conditions that could lead to an early radioactive release or a large radioactive release.*
> *As a first step for the implementation of design provisions for the practical elimination of undesired conditions it is necessary to identify what are these conditions and then for each of them specify the design provisions."*
>
> *"There is a quite wide consensus on the view that the 'practical elimination', even involving probabilistic considerations, always needs to be based on solid design provisions and supported by deterministic assessment and engineering judgement."*
>
> *"The concept of 'practical elimination' must not be misinterpreted or misused. It is to be considered as part of a general approach to safety and its appropriate application as an enhancement of defence in depth. The 'practical elimination' is achieved by prevention of the conditions that could lead to an early radioactive release or a large radioactive release.*
> *As a first step for the implementation of design provisions for the practical elimination of undesired conditions it is necessary to identify what are these conditions and then for each of them specify the design provisions."*
>
> *"The 'Practical Elimination' from consideration of accident situations that could lead to large or early releases has to be demonstrated by deterministic considerations supported by probabilistic considerations, taking into account the uncertainties due to the limited knowledge of some physical phenomena."*

German and French Technical Guidelines (ref. /9/):

> *"A.1.4 [...]*
> *However, the Practical Elimination of accident situations which could lead to large early releases is a matter of judgement and each type of sequences has to be assessed separately. Their Practical Elimination can be demonstrated by deterministic and/or probabilistic considerations, taking into account the uncertainties due to the limited knowledge on some physical phenomena. It is stressed that the Practical Elimination cannot be demonstrated by the compliance with a general "cut-off" probabilistic value".*

ONR SAPs (ref. /17/):

> *6.11 - See text already quoted above.*

Federal Agency for Nuclear Control (FANC) guidance (ref. /14/) for new nuclear installations:

> *"Safety objective SO3 aims at reducing potential releases to the environment from severe accidents, also in the long term, by following the qualitative criteria below:*
>
> - *severe accidents which would lead to early or large releases should be practically eliminated (See section 5.3);*
> - *severe accidents which would lead to unacceptable direct irradiation (e.g. in case of criticality accidents without release) should be practically eliminated (see section 5.3);*
> - *for severe accidents that have not been practically eliminated, design provisions should be taken so that only limited protective measures in area and time are needed for the public (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in food consumption) and that sufficient time is available to implement these measures."*
>
> *"5.3 demonstration of practical elimination […]*
> *This section addresses the demonstration of practical elimination of a sequence (initiator) which could lead to early or large releases.*

The demonstration of practical elimination is considered successful if [7]:

- *The sequence (initiator) can be proven to be physically impossible;*
- *The sequence (initiator) is extremely unlikely to arise with a high level of confidence.*

Steps to demonstrate that the sequence (initiator) is extremely unlikely to arise with a high level of confidence are:

- *Identify the initiator or the accident sequence that would lead to radiological consequences beyond SO3 11 ;*
- *The probability of this initiator or accident sequence should be pushed to very low probabilities. If the demonstration applies to the initiator then it is sufficient to agree with the regulatory authority on a cut-off probabilistic value. If the demonstration applies to the accident sequence then the demonstration cannot be claimed successful solely based on compliance with a general cut-off probabilistic value: the demonstration should be robust noting that:*
  - *If the demonstration of practical elimination relies on the demonstration that the event is "extremely unlikely with a high level of confidence" then, in order to quantify the notion of "extremely unlikely", it is important to provide an order of magnitude of acceptable reliability for the upstream credited layer(s) of provision(s) 12 (also referred to as "line of defence" or "line of protection") used in the safety demonstration;*
  - *because of the existence of unforeseen/unexplained common cause failures there is a limit to the reliability that can be allocated to a single layer of provision. It is important to include arguments on reliability of the relevant structures, systems and components;*
  - *when relevant in the demonstration, the probability of the common cause failure is taken into account;*
  - *the simplicity of the safety architecture or the demonstrated degree of knowledge for the phenomena involved in the accident will contribute to a robust demonstration of the practical elimination."*

IRSN Practical Elimination approach (ref. /12/):

"The situations for which the Practical Elimination approach can be applied are very diverse and proof that they are physically impossible or, failing that, extremely unlikely with a high degree of confidence, can only be achieved through analysis on a case-by-case basis.
The justification of Practical Elimination shall preferably rely on the physical impossibility of the situation (see Section 4.1 below). Where this is not possible, the applicant shall demonstrate with a high degree of confidence that the situation is extremely unlikely."

ONR SAPs (ref. /17/):

6.11 - See text already quoted above.

German and French Technical Guidelines (ref. /9/):

A.1.4 - See text already quoted above.

Approach to Practical Elimination in Finland presented at June 2017 international conference on safety topical issues (ref. /19/):

"The idea of practically eliminate rupture of the reactor pressure vessel and fast increase of reactivity threatening the integrity of the containment and causing early or large releases have been in the design of nuclear power plants from the 1970s. Operating experience, research and development have shown the complexity of safety issues to be considered at different Defence-in-Depth levels in this context."

A2.4 Quotations of section 3.4

European Nuclear Safety (ref. /1/):

Article 8a - See text already quoted above.

IAEA SSR-2/1 rev.1 (ref. /5/):

"1.3 It might not be practicable to apply all the requirements of this Safety Requirements publication to nuclear power plants that are already in operation or under construction. In addition, it might not be feasible to modify designs that have already been approved by regulatory bodies. For the safety analysis of such designs, it is expected that a comparison will be made with the current standards, for example as part of the periodic safety review for the plant, to determine whether the safe operation of the plant could be further enhanced by means of reasonably practicable safety improvements."

OECD NEA report on the Implementation of Defence in Depth (ref. /18/):

"The implementation of the practical elimination concept is most effective through design features, and thus it is easier to implement in new reactors. For operating reactors, there are likely to be fewer practical opportunities for enhancing safety. These have to be considered on a case-by-case basis."

WENRA guidance on part b of article 8a of the NSD (ref. /21//22/)

"In comparing safety of an existing NPP with new reactor standards it is important to look at the safety outcome not just the specific technology used to achieve that outcome. The objective is to implement reasonably practicable improvements to prevent and mitigate radioactive releases. There is no standard set, or tick list, of specific engineering or operational improvements that will be appropriate for all reactors and operational regimes […]"
"certain safety improvements that may be reasonable at one reactor may not be necessary at another or conversely may be insufficient so better or more measures might be called for. Being proportionate should also take account of the individual circumstances of a facility and its future lifetime."

ONR guidance on the application of the ALARP principle (ref. /22/):

"6.2 For an existing facility, relevant good practice is established by using the standards that would be applied to a new design as a benchmark and then subjecting any shortfalls to the test of reasonable practicability. Unless the sacrifice entailed in moving towards the benchmark is grossly disproportionate to the safety benefit, the licensee should make that move."

ASN guide 22 (ref. /23/):

"Le présent guide s'applique aux REP. […]
Ayant pour champ d'application premier la conception des nouveaux REP, les recommandations de ce guide pourront également être utilisées, à titre de référence, pour la recherche d'améliorations à apporter aux réacteurs existants, par exemple à l'occasion de leurs réexamens périodiques de sûreté, conformément à l'article L. 593-18 du code de l'environnement et aux articles 8 bis et quater introduits par la directive européenne du 8 juillet 2014.
[The present guide applies to PWRs. […]
Having the design of new reactors for primary scope of application, the recommendations from this guide would also be used, as being a reference, when looking for improvements to be added to existing reactors, for example as part of their periodic safety reviews, compliant with article L. 593-18 of the environment code and with articles 8a and 8d of the European Nuclear Safety Directive of 8th July 2014.]"

Finnish Regulation YVL B.1 (ref. /11/):

"Rules for application
The publication of a YVL Guide shall not, as such, alter any previous decisions made by STUK. After having heard the parties concerned STUK will issue a separate decision as to how a new or revised

> *YVL Guide is to be applied to operating nuclear facilities or those under construction, and to licensees' operational activities. The Guide shall apply as it stands to new nuclear facilities.*
> *When considering how the new safety requirements presented in the YVL Guides shall be applied to the operating nuclear facilities, or to those under construction, STUK will take due account of the principles laid down in Section 7 a of the Nuclear Energy Act (990/1987): The safety of nuclear energy use shall be maintained at as high a level as practically possible. For the further development of safety, measures shall be implemented that can be considered justified considering operating experience, safety research and advances in science and technology."*

OECD NEA report on the Implementation of Defence in Depth following Fukushima Daichi Accident (ref. /18/:

> *"The implementation of the practical elimination concept is most effective through design features, and thus it is easier to implement in new reactors. For operating reactors, there are likely to be fewer practical opportunities for enhancing safety. These have to be considered on a case-by-case basis."*

A2.5 Quotations of section A.1.1

IAEA specific safety requirement SSR-2/1 rev.1 (ref. /5/):

> *2.11 - See text already quoted above.*

IAEA Fundamental Safety SF-1 Principles (ref. /16/):

> *Principle 8: See text already quoted above"*

IAEA safety standard SSR-2/1 rev. 1 (ref. /5/) - section 2 footnote 2:

> *See text already quoted above.*

A2.6 Quotations of section A.1.2

IRSN guidance on Practical Elimination (ref. /12/):

> *"Following the Three Mile Island and Chernobyl accidents, the need of a significant improvement of the safety of reactors to be built from the start of the 21st century compared to the ones in operation or under construction at the end of the 20th century has been recognized at the international level. This improvement seemed to be achievable for water-cooled reactors taking into account the state of knowledge achieved on core melt accidents.*
> *It was in this context that the fourth level of defence in depth was developed, implying the implementation of design provisions aimed at limiting the consequences of accidents with reactor core melt. However, in some core melt situations that could be envisaged at least theoretically, it appeared impossible to implement realistic provisions that would reduce the radiological consequences at an acceptable level and to demonstrate their robustness. For this reason the concept of Practical Elimination was introduced during the 1990s.*
> *For water-cooled reactors, these situations were characterized by rapid high-energy phenomena that could drive to a sudden failure of the containment and lead to "large early releases". An objective of elimination was set for these situations, but since the elimination was not strictly demonstrable except in case of physical impossibility, the term "practically eliminated" was coined, meaning that the applicant shall implement "all reasonable provisions" to ensure that the accident situation could, by mutual agreement with the relevant safety authority, be considered extremely unlikely with a high degree of confidence.*
> *The term Practical Elimination appeared for the first time in 1993 in the definition of the general safety objectives for the future pressurised water reactors [1]."*

German and French Technical Guidelines (ref. /9/):

> *"A.1.1.*

d) Moreover, an important objective is to achieve a significant reduction of potential radioactive releases due to all conceivable accidents, including core melt accidents.
For accident situations without core melt, there shall be no necessity of protective measures for people living in the vicinity of the damaged plant (no evacuation, no sheltering).
<u>Accident situations with core melt which would lead to large early releases have to be "practically eliminated</u>": if they cannot be considered as physically impossible, design provisions have to be taken to design them out. This objective applies notably to high pressure core melt sequences.
Low pressure core melt sequences have to be dealt with so that the associated maximum conceivable releases would necessitate only very limited protective measures in area and in time for the public. This would be expressed by no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in consumption of food."
A.1.4: See text already quoted above.

International conference on safety topical issues regarding Practical Elimination approach in Finland (ref. /19/):

See text already quoted above.

IAEA INSAG 12 (ref. /8/):

See text already quoted above.

IAEA INSAG-3 (ref. /7/):

"19. Objective: To prevent with high confidence accidents in nuclear plants; to ensure that, for all accidents taken into account in the design of the plant, even those of very low probability, radiological consequences, if any, would be minor; and to ensure that the likelihood of severe accidents with serious radiological consequences is extremely small."

IAEA INSAG 10 (ref. /6/):

"124. […]The confinement function for advanced reactors will be strengthened by approaches and initiatives consistent with the following concepts:

- *For advanced designs, it would be demonstrated, by deterministic and probabilistic means, that hypothetical severe accident sequences that could lead to large radioactive releases due to early containment failure are essentially eliminated with a nigh degree of confidence.*
- *Severe accidents that could lead to late containment failure would be considered explicitly in the design process for advanced reactors. This applies to both the prevention of such accidents and mitigation of their consequences, and includes a careful, realistic (best estimate) review of the confinement function and opportunities for improvement in such scenarios.*
- *For accident situations without core melt, it will need to be demonstrated for advanced designs that there is no necessity for protective measures (evacuation or sheltering) for people living in the vicinity of a plant. For those severe accidents that are considered explicitly in the design, it would be demonstrated by best estimate analysis that only protective measures that are very limited in scope in terms of both area and time would be needed (including restrictions in food consumption)."*

For advanced designs, it would be demonstrated, by deterministic and probabilistic means, that hypothetical severe accident sequences that could lead to large radioactive releases due to early containment failure are essentially <u>eliminated</u> with a high degree of confidence".

IAEA INSAG 12 (ref. /8/):

"27 The target for existing nuclear power plants consistent with the technical safety objective is a frequency of occurrence of severe core damage that is below about 10^{-4} events per plant operating year. Severe accident management and mitigation measures could reduce by a factor of at least ten the probability of large off-site releases requiring short term off-site response. Application of all safety principles and the objectives of para. 25 to future plants could lead to the achievement of an improved goal of not more than 10^{-5} severe core damage events per plant operating year. Another objective for these future plants is the practical elimination of accident sequences that could lead to

large early radioactive releases, whereas severe accidents that could imply late containment failure would be considered in the design process with realistic assumptions and best estimate analyses so that their consequences would necessitate only protective measures limited in area and in time."
129 - see text already quoted above.

IAEA safety guide NS-G-1.10 (ref. /25/):

"6.5 For new plants, possible severe accidents should be considered at the design stage of the containment systems. The consideration of severe accidents should be aimed at practically eliminating the following conditions:

- *Severe accident conditions that could damage the containment in an early phase as a result of direct containment heating, steam explosion or hydrogen detonation;*
- *Severe accident conditions that could damage the containment in a late phase as a result of basemat melt-through or containment over-pressurisation;*
- *Severe accident conditions with an open containment - notably in shutdown states;*
- *Severe accident conditions with containment bypass, such as conditions relating to the rupture of a steam generator tube or an interfacing system LOCA."*

Footnote 14 "In this context, the possibility of certain conditions occurring is considered to have been practically eliminated if it is physically impossible for the conditions to occur or if the conditions can be considered with a high degree of confidence to be extremely unlikely to arise"

IAEA safety standard SSR-2/1 2012 version:

"2.11. The design for safety of a nuclear power plant applies the safety principle that practical measures must be taken to mitigate the consequences for human life and health and the environment of nuclear or radiation incidents (Ref. [1], Principle 9): plant event sequences that could result in high radiation doses or radioactive releases must be practically eliminated and plant event sequences with a significant frequency of occurrence must have no or only minor potential radiological consequences. An essential objective is that the necessity for off-site intervention measures to mitigate radiological consequences be limited or even eliminated in technical terms, although such measures might still be required by the responsible authorities.“
"Footnote 1: The possibility of certain conditions occurring is considered to have been practically eliminated if it is physically impossible for the conditions to occur or if the conditions can be considered with a high level of confidence to be extremely unlikely to arise."

IAEA safety standard SSR-2/1 rev.1 (ref. /5/) 2016 version.

2.11: See text already quoted above
2.13: See text already quoted above

"5.31A. The design shall be such that for design extension conditions, protective actions that are limited in terms of lengths of time and areas of application shall be sufficient for the protection of the public, and sufficient time shall be available to take such measures."

"Requirement 5: Radiation protection in design […]
4.3. The design shall be such as to ensure that plant states that could lead to high radiation doses or to a large radioactive release have been 'practically eliminated', and that there would be no, or only minor, potential radiological consequences for plant states with a significant likelihood of occurrence."
"Requirement 20: Design extension conditions
5.27 […] The plant shall be designed so that it can be brought into a controlled state and the containment function can be maintained, with the result that the possibility of plant states arising that could lead to an early radioactive release or a large radioactive release is 'practically eliminated'."
"Requirement 58: Control of containment conditions
6.28A. Design provision shall be made to prevent the loss of the structural integrity of the containment in all plant states. The use of this provision shall not lead to an early radioactive release or a large radioactive release. "
"Fuel handling and storage systems

> *6.68. For reactors using a water pool system for fuel storage, the design shall be such as to prevent the uncovering of fuel assemblies in all plant states that are of relevance for the spent fuel pool so that the possibility of conditions arising that could lead to an early radioactive release or a large radioactive release is 'practically eliminated' and so as to avoid high radiation fields on the site. "*
> *"External hazards*
> *5.21A. The design of the plant shall also provide for an adequate margin to protect items ultimately necessary to prevent an early radioactive release or a large radioactive release in the event of levels of natural hazards exceeding those considered for design, derived from the hazard evaluation for the site."*

EUR (ref./26/) section 2.1:

> *"Definitions:*
> **Early Release: Release for which off-site protective measures are necessary but are unlikely to be fully effective in due time.*
> **Large Release: A release for which off-site protective measures limited in terms of times and areas of application are insufficient to protect people and the environment.*
> **Practically Eliminated: The possibility of certain accident sequences occurring is considered to have been Practically Eliminated* if it is physically impossible for the accident sequence to occur or if the accident sequence can be considered with a high level of confidence to be extremely unlikely to occur."*
>
> *"2.1.1.1.D - The design shall be such as to ensure that accident sequences that could lead to Large Release* or Early Release* are Practically Eliminated."*
> *"2.1.2.5.A Accident sequences that have the potential to cause a Large Release* or Early Release* shall be Practically Eliminated*. The relevant safety demonstration requires identifying accident sequences potentially leading to such unacceptable releases and then bringing the appropriate justification that those accident sequences do not need to be considered in the plant design under the Defence-in-Depth* concept."*

WENRA safety objectives for New Power Reactors (ref. /13/):

> *"Objective O3 'Accidents with core melt':*
>
> - *reducing potential radioactive releases to the environment from accidents with core melt, also in the long term, by following the qualitative criteria below:*
>   - *accidents with core melt which would lead to early or large releases have to be practically eliminated;*
>   - *for accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited protective measures in area and time are needed for the public (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in food consumption) and that sufficient time is available to implement these measures."*

OECD NEA report on the Implementation of Defence in Depth following Fukushima Daichi Accident (ref. /18/):

> *"The goal of level 4 is to prevent or mitigate any significant radioactive releases from such accidents. In some cases, prevention and mitigation through the implementation of DiD should be reinforced, and those sequences leading to significant radioactive releases have to be "practically eliminated".*

IAEA safety glossary Rev. 1 (ref. /24/):

> *"early release of radioactive material*
> *A release of radioactive material for which off-site protective actions are necessary but are unlikely to be fully effective in due time."*
> *"large release of radioactive material*
> *A release of radioactive material for which off-site protective actions that are limited in terms of times and areas of application are insufficient for protecting people and the environment."*

A2.7 Quotations of section A.1.3

Article 3.9 of the Order of 7th February 2012 (ref. /27/):

“The demonstration of nuclear safety must prove that accidents that could lead to large releases of hazardous substances or to hazardous effects off the site that develop too rapidly to allow timely deployment of the necessary population protection measures are physically impossible or, if physical impossibility cannot be demonstrated, that the measures taken on or for the installation render such accidents extremely improbable with a high level of confidence.”

ASN guide 22 (ref. /23/):

« 3.2.6 […] les accidents avec fusion de combustible susceptibles de conduire à des rejets radioactifs importants avec une cinétique qui ne permettrait pas la mise en œuvre à temps des mesures nécessaires de protection des populations sont rendus physiquement impossibles ou, à défaut, des dispositions sont mises en œuvre afin de les rendre extrêmement improbables avec un haut degré de confiance. Les justifications de ces dispositions doivent reposer sur une analyse déterministe, confortée lorsque cela est pertinent par des évaluations probabilistes, en tenant compte des incertitudes dues aux connaissances limitées de certains phénomènes physiques. Sans vocation à l’exhaustivité, les situations concernées peuvent être… »
That could be translated in:
[Core melt accidents with the potential to lead to large releases, for which it would be unlikely that the required protective measures for people off-site will be effective in time, are made physically impossible; or, if not possible, provisions are implemented to make them extremely unlikely to arise with a high level of confidence. Justifications of these provisions should be based upon a deterministic analysis, supported, where relevant, by probabilistic evaluation, accounting for uncertainties due to limited knowledge of some physical phenomena. Without aiming to be comprehensive, the involved situations are…]

IRSN approach to Practical Elimination (ref. /12/):

“[...] situations likely to lead to large releases, because of the simultaneous or successive loss of integrity of all the containment barriers or because of the bypass of these barriers (containment bypass situations):

- *either lead to define provisions allowing to significantly limit their consequences;*
- *or shall be “practically eliminated” where it appears to be impossible to define such provisions or to demonstrate their adequacy with the knowledge and techniques available at the time of the design orientations.”*

“The concept of Practical Elimination of accident situations should not be extended beyond the framework described above. Particularly, it should not be applied without discussions to accident situations for which no provisions would have been implemented to limit their consequences. This highlights how important the discussions between applicants and safety authorities in the early stages of a new design are, primarily with the intention of improving the defence-in-depth.”
“The situations for which this approach [(Practical Elimination)] can be used shall be discussed by applicants and safety authorities from the initial design stages of a new reactor type. The discussions should continue throughout the entire licensing process.
However, any agreements resulting from these discussions are time limited given that they take account of current knowledge and technical possibilities.“

ONR SAPs (ref. /17/):

6.11 - See text already quoted above.

Federal Agency for Nuclear Control (FANC) guidance (ref. /14/) for new nuclear installations:

See text already quoted above.

Finnish Regulation YVL B.1 (ref. /11/):

See text already quoted above.

Approach to Practical Elimination in Finland presented at June 2017 international conference on safety topical issues (ref. /19/):

> *See text already quoted above.*

Swedish National Regulation SSMFS 2018:17 (ref. /31/):

> *See text already quoted above.*

FA3 Pre-Commissioning Safety Report (Translated from ref. /10/):

> *"Accidents with fuel melting which would lead to large early releases shall be « practically eliminated »."*
> *"When accident scenarios which could lead to large early releases cannot be considered physically impossible, design and organisation measures shall be implemented to rule them out." […]*
> *"Situations to be specifically handled to practically eliminate them are those liable to yield large early releases. The situations to be considered are […]*
> *"The severe accident approach relies upon a deterministic approach supported by a probabilistic verification. Regarding situations to be practically eliminated, this deterministic approach aims at identifying phenomena that could give rise to early failure of the containment in severe accident situation. These transients are then functionally analysed in order to identify design provision to be carried out to reduce their consequences (hence protecting confinement) or to prevent their occurrence."*
> *"The design reliability is then assessed through the unlikelihood of the accident sequences leading to large early releases. The demonstration that this situations are practically eliminated do not solely rely upon probabilistic insights, but includes deterministic and probabilistic considerations, accounting for uncertainties due to limited knowledge of some physical phenomena."*

Approach to Practical Elimination in Finland presented at June 2017 international conference on safety topical issues (ref. /19/):

> *See text already quoted above.*

IAEA TECDOC 1791 (ref. /20/):

> *"There is still discussion in several Member States on the actual conditions for which the practical elimination needs to be pursued. The text below, which is an elaboration of what already included in NS-G-1.10 [7], need only be considered as a contribution to promote the discussion and to achieve consensus:"*
> *"The concept of 'practical elimination' must not be misinterpreted or misused. It is to be considered as part of a general approach to safety and its appropriate application <u>as an enhancement of defence in depth</u>. The 'practical elimination' is achieved by prevention of the conditions that could lead to an early radioactive release or a large radioactive release."*
> *"It is a decision of the regulatory body to establish or not what are acceptable targets to support the demonstration of practical elimination. For new designs which adopt the latest technological solutions for a strong implementation of defence in depth, it is expected that a large or early release frequency below 10 -6 per reactor year could be achieved for events of internal origin."*

OECD NEA report on the Implementation of Defence in Depth following Fukushima Daichi Accident (ref. /18/):

> *"Overall, the safety objective for INSAG [10] level 4 provisions is that significant releases would be avoided or minimised. To this end, the regulator may seek to be ensured that accident sequences that lead to significant radioactive releases are "practically eliminated". <u>There has been some debate about what this means in practice.</u> Chapter 4 provides regulators with further guidance in this regard."*
> *"To date, there does not seem to be a common understanding of what that implies for reactor safety systems."*

European Nuclear Society session on Practical Elimination (ref. /33/):

> *"The practical elimination of large or early radioactive releases during nuclear power plant accidents is desired. However, the demonstration of the Practical Elimination is a complex process for which no specific guidance and criteria are available and not sufficient experience is so far generated. The Practical Elimination shall be considered as integral part of the defence in depth."*

A2.8 Quotations of section A.1.4

Federal Agency for Nuclear Control (FANC) guidance (ref. /14/) for new nuclear installations:

> *Safety objective SO3 and 5.3: See text already quoted above.*

Article 3.9 of the Order of 7th February 2012 (ref. /27/):

> *See text already quoted above.*

ASN guide 22 (ref. /23/):

> *See text already quoted above.*

Finnish Regulation YVL B.1 (ref. /11/):

> *"423. Events that may result in a release requiring measures to protect the population in the early stages of the accident shall be practically eliminated.*
> *424. Events to be practically eliminated shall be identified and analysed using methods based on deterministic analyses complemented by probabilistic risk assessments and expert assessments. practical elimination cannot be based solely on compliance with a cut-off probabilistic value. Even if the probabilistic analysis suggests that the probability of an event is extremely low, all practicable measures shall be taken to reduce the risk. As an example events to be practically eliminated include:*
> 1. *a rapid, uncontrolled increase of reactivity leading to a criticality accident or severe reactor accident;*
> 2. *a loss of coolant during an outage leading to reactor core uncovery;*
> 3. *a load jeopardising the integrity of the containment during a severe reactor accident (e.g. reactor pressure vessel breach at high pressure, hydrogen explosion, steam explosion, direct impact of molten reactor core on containment basemat or wall, uncontrolled containment pressure increase); and*
> 4. *a loss of cooling in the fuel storage resulting in severe damage to the spent nuclear fuel."*

Safety Requirements for Nuclear Power Plants (ref. /30/):

> *"2.5 (…] on level of defence 4 […]*
> *Taking into account the measures and equipment for the internal accident management provided on levels of defence 4b and 4c,*
> - *any releases of radioactive materials into the environment of the plant, caused by the early failure or bypass of the containment and requiring measures of the external accident management for the implementation of which there is not sufficient time available (early release), or*
> - *any releases of radioactive materials into the environment of the plant requiring wide-area and long-lasting measures of the external accident management (large release)*
>
> *shall be excluded (1) , or their radiological consequences shall be limited to such an extent that measures of the external accident management will only be required to a limited spatial and temporal extent.[...]*
> *(1) The occurrence of an event or event sequence or a state can be considered as excluded if it is physically impossible to occur or if it can be considered with a high degree of confidence to be extremely unlikely to arise."*

Swedish National Regulation SSMFS 2018:17 (ref. /31/).

> *"Highly improbable events (H5): Events that are not expected to occur; if the event should nevertheless occur, it can result in major core damage. These events are the basis of the nuclear power reactor's mitigating systems for severe accidents.*

> *"Extremely improbable events (residual risks): Events that are so improbable that they do not need to be taken into account as initiating events in connection with safety analysis""*
>
> *"Section 5*
> *The design basis for the reactor containment is events up to and including the event class improbable events, as shown in Section 3. To meet the requirement in Section 5, a safety evaluation should be performed of events and phenomena which may be of importance for containment integrity in highly improbable events. Examples of such events and phenomena which can result in the need to take measures include high pressure melt-through of the reactor pressure vessel, steam explosion, recriticality, hydrogen fire and containment underpressure"*

ONR SAPs (ref. /17/):

> *611: See text already quoted above.*

HPC PCSR3 Sub-Chapter 14.6 section 4 (ref. /29/)

> *"It is recalled that in the EPR specific design measures are implemented to reduce the risk of a large early release of radioactive material to the environment to an insignificant level. Each type of accident sequence that could lead to a large early release of radioactivity is examined and addressed by design measures which must take into account uncertainties due to the limited knowledge of physical phenomena involved in severe accident analysis.*
> *As already outlined in section 2 of this sub-chapter, within the EPR design a two-staged approach to the control of severe accidents is pursued, i.e.:*
>
> 1) *prevention of highly energetic phenomena which have the potential to breach the containment early in an accident and thus result in large early releases, and*
> 2) *maintaining the containment integrity in the long-term with prevention of radiological containment by-pass.*
>
> *The purpose of this section is to emphasise the importance of avoiding phenomena that would challenge the fulfilment of the safety objectives. More specifically, sections 4.1 to 4.3 of this sub-chapter present the safety objectives for (i) high pressure melt accidents, (ii) steam explosions and (iii) hydrogen combustion processes, and then summarise how these objectives are fulfilled"*