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REDUCTION OF RADIOLOGICAL ACCIDENT CONSEQUENCES

Title	**Classification of accidents**
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Outline

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

1) SAFETY OBJECTIVES

2) DEFENCE IN DEPT

3) APPLICATION OF DEFENSE IN DEPTH

4) OPERATIONAL STATES AND ACCIDENT CONDITIONS

5) DESIGN BASIS ACCIDENT

6) DESIGN EXTENSION CONDITION

7) CONCLUSIONS

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Safety objectives and concepts

IAEA Safety Standard Series
Safety of Nuclear Power Plants: Design

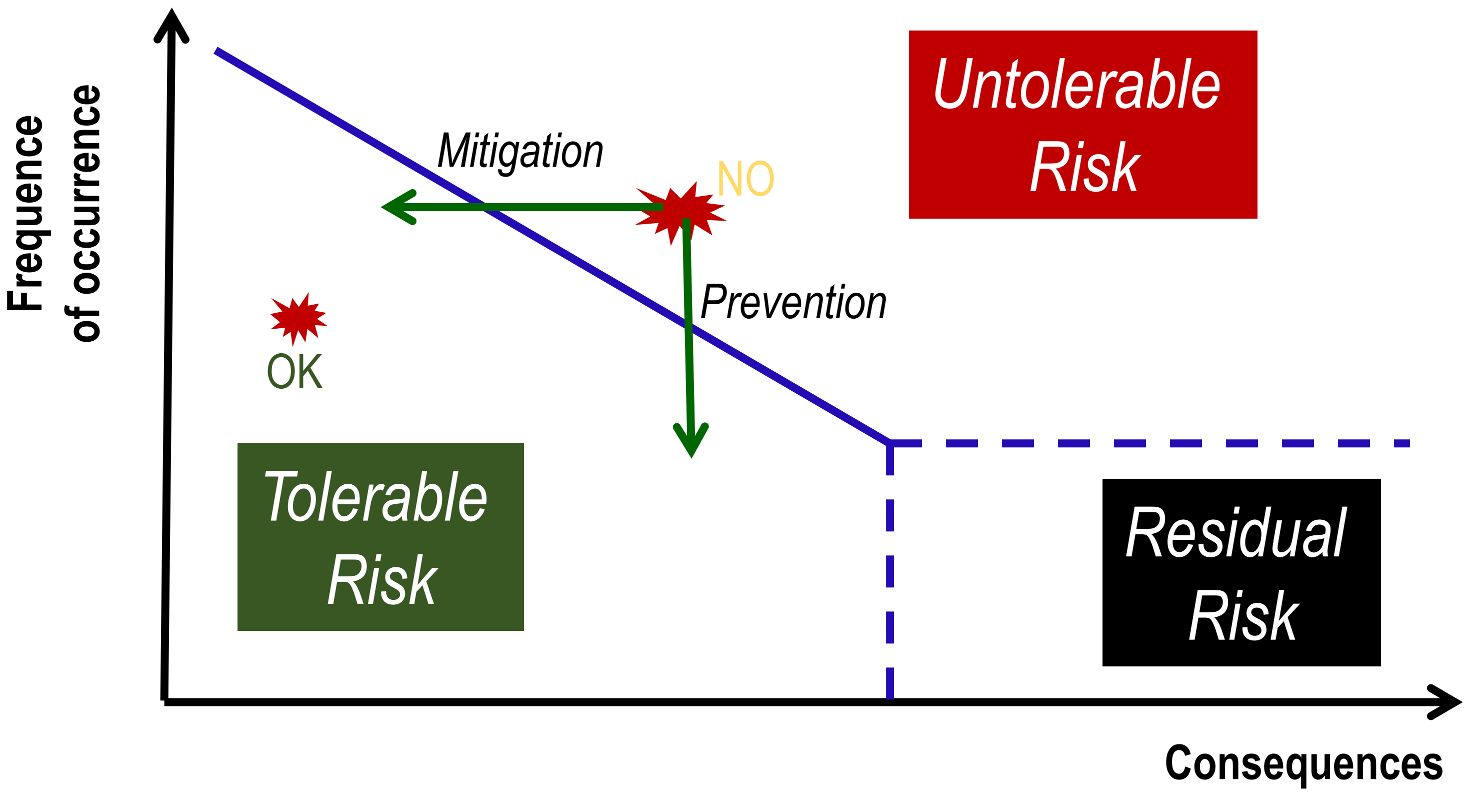
REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- "**General Nuclear Safety Objective:** To protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defences against radiological hazards.

- "**Radiation Protection Objective:** To ensure that in all operational states radiation exposure within the installation or due to any planned release of radioactive material from the installation is kept below prescribed limits and as low as reasonably achievable, and to ensure mitigation of the radiological consequences of any accidents.

- "**Technical Safety Objective:** To take all reasonably practicable measures to prevent accidents in nuclear installations and to mitigate their consequences should they occur; to ensure with a high level of confidence that, for all possible accidents taken into account in the design of the installation, including those of very low probability, any radiological consequences would be minor and below prescribed limits; and to ensure that the likelihood of accidents with serious radiological consequences is extremely low.

The risk domain



The so-called "Farmer Curve"

Safety objectives and concepts

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REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

In order to achieve these three safety objectives, in the design of a nuclear power plant, a comprehensive safety analysis is carried out to identify all sources of exposure and to evaluate radiation doses that could be received by workers at the installation and the public, as well as potential effects on the environment.

Safety analysis

- All planned normal operational modes of the plant;
- plant performance in anticipated operational occurrences;
- design basis accidents;
- Event sequences that may lead to a severe accident;
- Radiological consequences evaluation

The Defence in Depth

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- The Defence in Depth (or DID) principle is the principle according to which the defense against a risk shall be provided not only by a single mean, but by several means diversified and independent from each other.

This general principle is usually implemented in two different ways in nuclear safety:

- The first one is a physical interpretation, i.e. the presence of a series of physical barriers each one capable of containing the radioactive materials.
- The second way of interpretation is a combination of technical and formal measures

Defence in depth

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

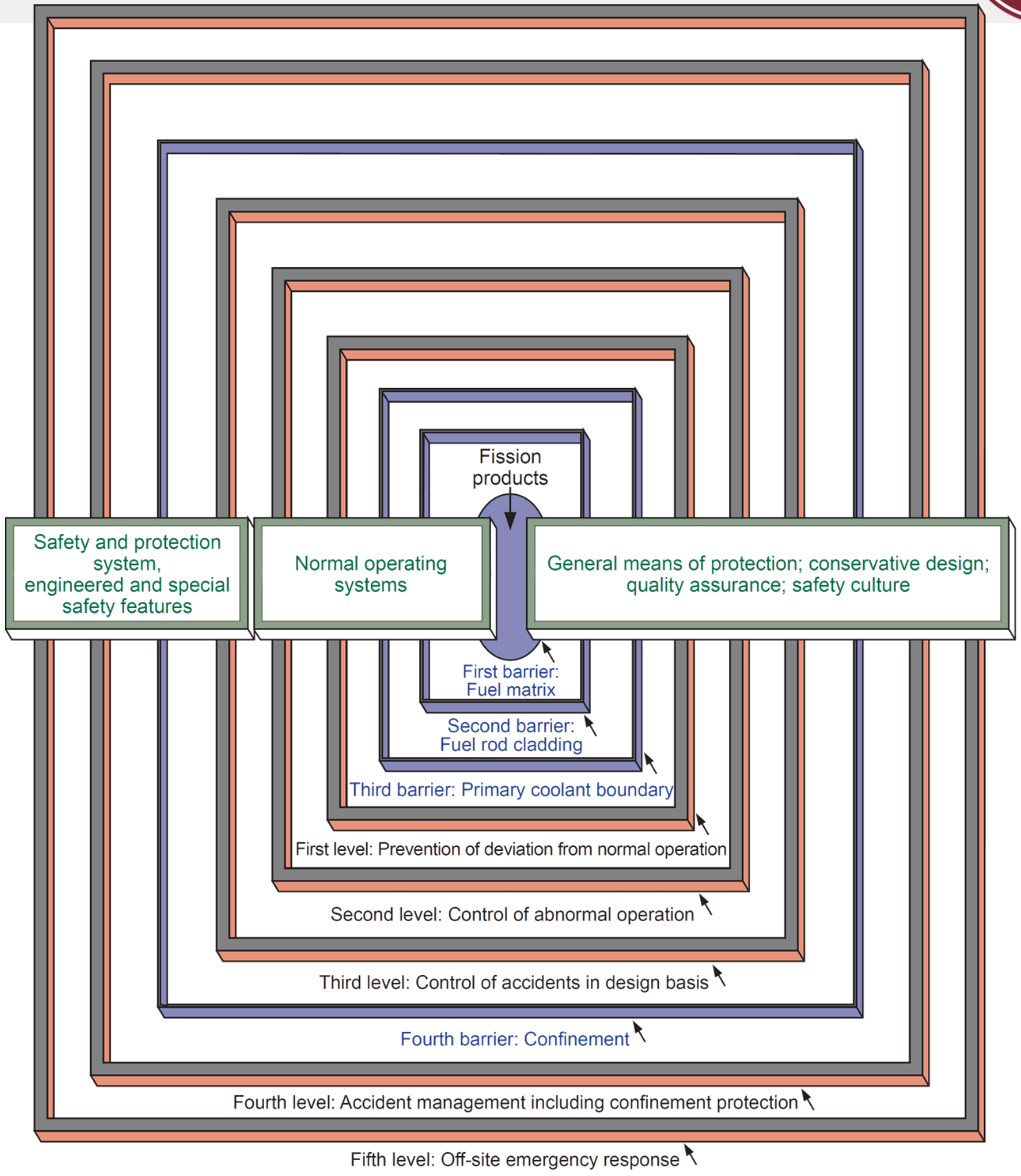
Levels of defence in depth	Objective	Essential means for achieving the objective
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
Level 2	Control of abnormal operation and detection of failures	Control, limiting and protection systems and other surveillance features
Level 3	Control of accidents within the design basis	Engineered safety features and accident procedures
Level 4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Complementary measures and accident management
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	Off-site emergency response

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Defence in depth

- Cf. IAEA - INSAG 12

Strategy	Accident prevention			Accident mitigation	
Operational state of the plant	Normal operation	Anticipated operational occurrences	Design basis and complex operating states	Severe accidents beyond the design basis	Post-severe accident situation
Level of defence in depth	Level 1	Level 2	Level 3	Level 4	Level 5
Objective	Prevention of abnormal operation and failure	Control of abnormal operation and detection of failures	Control of accidents below the severity level postulated in the design basis	Control of severe plant conditions, including prevention of accident progression, and mitigation of the consequences of severe accidents, including confinement protection	Mitigation of radiological consequences of significant releases of radioactive materials
Essential features	Conservative design and quality in construction and operation	Control, limiting and protection systems and other surveillance features	Engineered safety features and accident procedures	Complementary measures and accident management, including confinement prodection	Off-site emergency response
Control	Normal operating activities		Control of accidents in design basis	Accident management	
Procedures	Normal operating procedures		Emergency operating procedures	Ultimate part of emergency operating procedures	
Response	Normal operating systems		Engineered safety features	Special design features	Off-site emergency preparations
Condition of barriers	Area of specified acceptable fuel design limit		Fuel failure; Severe fuel damage	Fuel melt; Uncontrolled fuel melt	Loss of confinement
Colour code	NORMAL		POSTULATED ACCIDENTS		EMERGENCY



PLANT CONDITIONS: operational states and accident conditions (IAEA)

OPERATIONAL STATES:

States defined under normal operation and anticipated operational occurrences.

- **normal operation**: Operation within specified operational limits and conditions. (starting, power operation, shutting down, shutdown, maintenance, testing and refueling)
- **anticipated operational occurrence**: An operational process deviating from normal operation which is expected to occur at least once during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety nor lead to accident conditions (loss of normal electrical power, faults such as a turbine trip)

PLANT CONDITIONS: operational states and accident conditions (IAEA)

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

ACCIDENT CONDITIONS:

Deviations from normal operation more severe than anticipated operational occurrences, including design basis accidents and severe accidents.

- **design basis accident**: Accident conditions against which a nuclear power plant is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within authorized limits.
- **beyond design basis accident**: Accident conditions more severe than a design basis accident.
- **accident management**: The taking of a set of actions during the evolution of a beyond design basis accident:
  - to prevent the escalation of the event into a severe accident;
  - to mitigate the consequences of a severe accident; and
  - to achieve a long-term safe stable state.
- **severe accident**: Accident conditions more severe than a design basis accident and involving significant core degradation.

Barriers and Safety functions

- Barriers resistant, tight and independent are interposed in series between the radioactive sources and the environment.
- A safety analysis shall ensure their effectiveness and durability including under abnormal conditions.
  This analysis also ensures that all technical requirements have been taken so as to always be able to bring and maintain the plant in a safe shutdown state, by mastering the three basic safety functions:
  - **reactivity control;**
  - **evacuation of the energy;**
  - **confinement of radioactive materials.**
- These functions are performed especially when the following objectives are achieved:
  - **integrity of the envelope of the main primary circuit;**
  - **shutdown and continued safe shutdown state of the reactor;**
  - **preventing and limiting the consequences of radiological accidents.**

(from IAEA Safety Standards Series No. SSR-2/1, Safety of Nuclear Power Plants: Design)

IAEA operational states and accident conditions

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Plant states	Operational states	Accident conditions		
			Design extension conditions (DEC)	
Classification	(Normal operation) Anticipated operational occurrences (AAO)	Design basis accidents (DBA)	DEC-A Without significant fuel degradation	DEC-B Severe accidents
Safety objectives	Prevent any significant damage to items important to safety or which lead to accident conditions		Prevent significant fuel degradation and keep releases within acceptable limits	Terminate fuel damage Maintain the integrity of the containment for as long as possible Minimize on-site and off-site releases and their adverse consequences
Accident management strategy	None needed	Preventive		Mitigative
Credited plant equipment	All plant equipment, except as allowed by operating limits and conditions	Safety systems		All available

(from IAEA Safety Standards Series No. SSR-2/1, Safety of Nuclear Power Plants: Design)

IAEA operational states and accident conditions

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Plant states	**Operational states**	**Accident conditions**		
			Design extension conditions (DEC)	
Classification	(Normal operation) Anticipated operational occurrences (AAO)	Design basis accidents (DBA)	DEC-A Without significant fuel degradation	DEC-B Severe accidents
Operating procedures	Normal operating procedures	Abnormal operating procedures	Emergency operating procedures (emergency response procedures and function restoration procedures)	Severe accident management guidelines
Typical decision making responsibility	Plant operators	Plant operator with assistance of shift technical advisors	Emergency response managers with assistance of plant operators	
Expected environmental conditions	Normal	Harsh	Severe	

DEC definition

From WENRA RHWG

- Conditions more complex and/or more severe than those postulated as design basis accidents (DBAs) can occur.
- These conditions shall be investigated as Design Extension Conditions (DEC) so that any reasonably practicable measures to improve the level of safety of a plant, compared to the level reached with the design basis, are identified and implemented.
- As part of the defense in depth, analysis of Design Extension Conditions (DEC) shall be undertaken with the purpose of further improving the safety of the nuclear power plant by:
  - **enhancing the plant's capability to withstand more challenging events or conditions than those considered in the design basis**
  - **minimizing radioactive releases harmful to the public and the environment as far as reasonably practicable, in such events and conditions.**

- **DEC A -> prevention of severe fuel damage in the core or in the spent fuel storage can be achieved**
- **DEC B -> postulated severe fuel damage**

DEC

From WENRA RHWG

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- The analysis shall identify reasonably practicable provisions that can be implemented for the prevention of severe accidents.
- In addition to these provisions, severe accidents shall be postulated for fuel in the core and, if not extremely unlikely to occur with a high degree of confidence, for spent fuel in storage, and the analysis shall identify reasonably practicable provisions to mitigate their consequences.
- A set of DECs shall be derived and justified as representative, based on a combination of deterministic and probabilistic assessments as well as engineering judgement.
- The selection process for DEC A shall start by considering those events, and combinations of events, which cannot be considered with a high degree of confidence to be extremely unlikely to occur and which may lead to severe fuel damage in the core or in the spent fuel storage. It shall cover:
  - **Events occurring during the defined operational states of the plant;**
  - **Events resulting from internal or external hazards;**
  - **Common cause failures.**
- **Where applicable, all reactors (multi-units) and spent fuel storages on the site have to be taken into account.**

DEC exclusions

From WENRA RHWG

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- Events and combinations of events that can be regarded as extremely unlikely with a high degree of confidence, based on information available prior to the DEC selection process or on deliberations performed during this process, do not need to be considered further for the DEC selection.
- For example, this can apply to
  - **a particular natural hazard that is extremely unlikely by appropriate site selection;**
  - **failure of the RPV, if it is considered extremely unlikely due to design, manufacturing, quality control etc.**
  - **It may also concern some common cause failures (CCFs) which can be considered extremely unlikely with a high degree of confidence and thus are screened out, or large reactivity insertion.**

Initiating events for DEC A

From WENRA RHWG

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- initiating events induced by earthquake, flood or other natural hazards exceeding the design basis events
- initiating events induced by relevant human-made external hazards exceeding the design basis events
- prolonged station blackout (SBO; for up to several days)
  - SBO (loss of off-site power and of stationary primary emergency AC power sources)
  - total SBO (SBO plus loss of all other stationary AC power sources), unless there are sufficiently diversified power sources that are adequately protected
- loss of primary ultimate heat sink, including prolonged loss (for up to several days)
- anticipated transient without scram (ATWS)
- uncontrolled boron dilution
- total loss of feed water
- LOCA together with the complete loss of one emergency core cooling function (e.g. HPI or LPI)
- total loss of the component cooling water system
- loss of core cooling in the residual heat removal mode
- long-term loss of active spent fuel pool cooling
- multiple steam generator tube ruptures (PWR, PHWR)
- loss of required safety systems in the long term after a design basis accident

Initiating events for DEC B

From WENRA RHWG

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- **The set of category DEC B events shall be postulated and justified to cover situations, where the capability of the plant to prevent severe fuel damage is exceeded or where measures provided are assumed not to function as intended, leading to severe fuel damage.**

- For DEC B (severe accidents) an approach different from that for the selection of DEC A has to be taken, since there will usually be a very large number of possible scenarios, based on a wide range of plant specific severe accident conditions and phenomena, which cannot all be captured at the start of a selection process. Accordingly, no list of initiating events is provided for DEC B.

- A set of severe fuel damage scenarios has to be identified for analysis, covering the different situations and conditions which can occur at the outset and during the course of a severe accident.
- The selection process of representative scenarios should notably make use of the PSA results, the overall understanding of the physical phenomena involved, the margins in the design and the systems' redundancy and diversity. As far as necessary, preliminary analyses of scenarios should be performed as part of the selection process.

DBA vs DEC

From WENRA RHWG

There are a number of clear and basic differences regarding the treatment of DBA and DEC

- Methodology of analysis:
  - Conservative or best estimate plus uncertainties for DBA, best estimate (with or without uncertainties) acceptable and, in some cases, preferred for DEC;
  - additional postulates like single failures for DBA,
  - no systematic additional postulates for DEC.
- Technical acceptance criteria: Generally, less restrictive and based on more realistic assumptions for DEC.
- Radioactive releases tolerated: Higher consequences are usually tolerated (if it is demonstrated that releases are limited as far as reasonably practicable) for DEC.

Warning of the emergency management authorities

Emergency classification system

Class	Description	On-site Action	Off-site Action
Alert	-Decreased safety - Unknown Conditions	- Partial Activation of Response - Assist Control Room	- Increase Readiness
Site Area Emergency	- Major Decrease in Safety - One more Failure Results in Core damage - High Dose On-Site	- Full On-Site Response - Evacuate or shelter non- essential personnel OnSite - Monitor	- Fully Activated Response
General Emergency	-Substantial Risk of Major Release - Actual or Projected Core Damage - High Dose Off-Site	- Same As Site Area - Recommended Protective Action to Off-site Officials	- Same Site Area - Implement Urgent Protective Actions near the site - Notify IAEA and near by countries

The INES nuclear incident and accident rating scale

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

INES SCALE APPLICATION	OFF-SITE CONSEQUENCES	ON-SITE CONSEQUENCES	DEGRADATION OF DEFENCE IN DEPTH
7 MAJOR ACCIDENT	Major release: considerable effects on health and on the environment		
6 SERIOUS ACCIDENT	Significant release likely to require full implementation of planned countermeasures		
5 ACCIDENT WITH WIDER CONSEQUENCES	Limited release likely to require partial implementation of planned countermeasures	Severe damage to reactor core/to radiological barriers	
4 ACCIDENT WITH LOCAL CONSEQUENCES	Minor release: public exposure close to the prescribed limits	Significant damage to reactor core/to radio-logical barriers/lethal exposure of a worker	
3 SERIOUS INCIDENT	Very slight release: public exposure equivalent to at least a percentage of the limits defined by the IAEA manual	Serious contamination/Acute effects on the health of a worker	Near-accident/loss of barriers
2 INCIDENT		Significant contamination/overexposure of a worker	Incidents with significant failures in safety provisions
1 ANOMALY			Anomaly beyond from authorized operating conditions
0 DEVIATION		No safety significance	
EVENT BELOW SCALE		No safety significance	

International Nuclear and radiological Event classification Scale

Conclusion

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Probabilistic and deterministic combined approach is the base of the nuclear safety

The accident are divided in AOO, DBA, DEC(A) and DEC (B):

- DBAs are aligned with the “old” approach based to guarantee the main safety functions for a list of predetermined accidents (LOCA, LOFA, etc.)
- DEC (A) analysis enlarge the domain of the safety analysis to any accident*, with the aim to reduce as mush as possible the probability of a severe accident
- Ensuring adequate confinement of radioactive substances, especially by protecting the containment integrity, is the main goal in DEC (B), postulating a severe accident. Special consideration should be given to the sequences that could lead to large or early releases to the environment (e.g. high-pressure core melt), in order to attenuate the threats or to show that these sequences become very unlikely to occur with a high degree of confidence

* with the exclusion of very unlikely to occur with a high degree of confidence

Thank you!

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