International Atomic Energy Agency

INPRO
Area of Reactor Safety

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Content

- INPRO approach to develop BP, UR
- Defence in depth
- Basic principles, User Requirements
- Example of assessment

Six Areas of INPRO Methodology

Approach of INPRO in the Area
Safety of Reactors

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

Fundamental Safety Functions

Nuclear Reactors
- Control Reactivity
- Remove Heat from Core
- Confine Radioactivity and Shield Radiation

Fuel Cycle Installations
- Control Sub-criticality and Chemistry
- Remove Decay Heat from Radio-nuclides
- Confine Radioactivity and Shield Radiation

Defence in Depth
- Prevent abnormal operation and failures
- Control abnormal operation, detect failures
- Control accidents within design basis
- Assure low damage frequencies
- Contain released radioactive materials

Deterministic & Probabilistic Safety Analysis (Holistic Life Cycle Analysis)

Increased Emphasis on Inherent Safety Characteristics

Balanced design options and configurations

Passive Systems

Active Systems

Concept of Defence in Depth

Level of defense-in-depth	INSAG Objectives	Innovation Direction (INPRO)
1	Prevention of abnormal operation and failures.	Enhance prevention by increased emphasis on inherently safe design characteristics and passive safety features, and by further reducing human actions in the routine operation of the plant.
2	Control of abnormal operation and detection of failures.	Give priority to advanced control and monitoring systems with enhanced reliability, intelligence and the ability to anticipate and compensate abnormal transients.
3	Control of accidents within the design basis.	Achieve fundamental safety functions by optimised combination of active & passive design features; limit consequences such as fuel failures; minimize reliance on human intervention by increasing grace period, e.g. between several hours and several days.

Concept of Defence in Depth

Level of defense-in-depth	INSAG Objectives	Innovation Direction (INPRO)
4	Control of severe plant conditions, including prevention and mitigation of the consequences of severe accidents.	Increase reliability and capability of systems to control and monitor complex accident sequences; decrease expected frequency of severe plant conditions; e.g. for reactors, reduce severe core damage frequency by at least one order of magnitude relative to existing plants and designs, and even more for urban-sited facilities
5	Mitigation of radiological consequences of significant releases of radioactive materials	Avoid the necessity for evacuation or relocation measures outside the plant site.

General features of the INPRO Methodology

- INPRO Methodology (i.e. BPs, URs, INs and ALs) for the assessment of an INS is nuclear technology independent.

- INPRO Methodology provides guidance on how to apply these requirements in evaluating a given INS, taking into account local, regional and global boundary conditions of both, developing and developed IAEA Member States.

INPRO Basic Principles in the Area Safety of Nuclear Installations (IAEA-TECDOC-1434)

- **Four Basic Principles** :

  Innovative Nuclear Reactors and Fuel Cycle Installations shall:

  1. *Incorporate enhanced defense-in-depth;*
  2. *Incorporate increased emphasis on inherent safety and passive features to minimize or eliminate hazards;*
  3. *Be so safe that they can be sited in locations similar to other industrial facilities used for similar purpose;*
  4. *Provide confidence based upon experience or appropriate RD&D.*

- **14 User Requirements and 38 Criteria**

INPRO Basic Principle BP1 on Safety

- BP 1: *Installations of an INS shall incorporate enhanced defence-in-depth as a part of their fundamental safety approach and ensure that the levels of protection in defence-in-depth shall be more independent from each other than in existing installations.*
  - UR1.1: *Installations of an INS should be more robust relative to existing designs regarding system and component failures as well as operation.*
  - UR 1.2: …
  - UR 1.3: …

INPRO User Requirement UR1.1 on Reactor Safety

Example: Indicator of UR 1.1

IN1.1.1 Robustness of a nuclear reactor

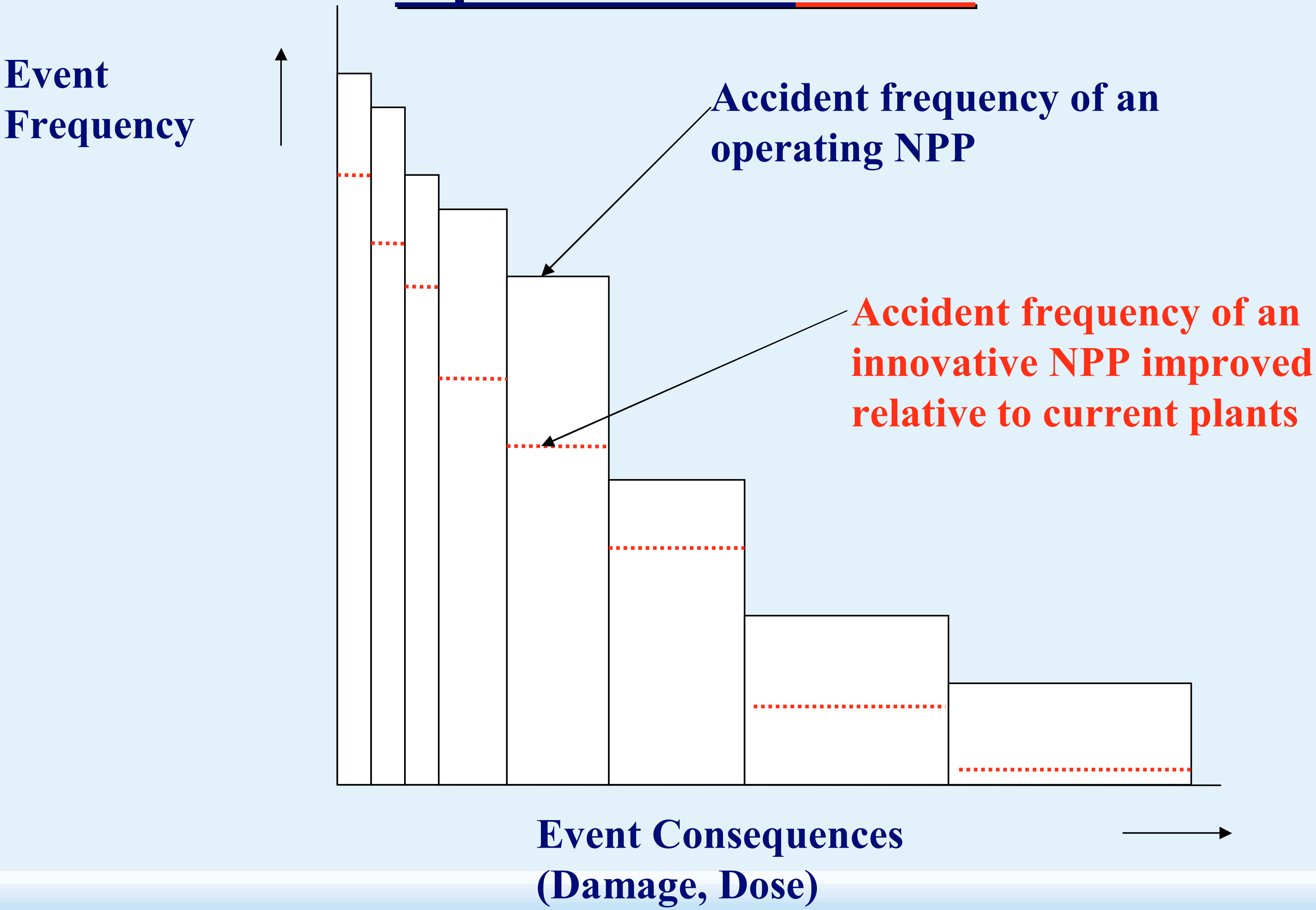
- Increase of robustness can be achieved by a number of variables (e.g. improved materials, increased operating margins, extensive use of passive systems etc.)
- For an operating NPP, the level of robustness can be quantified via PSA by frequencies of relevant operation disturbances and initiating failures.
- For an INS, these PSA event frequencies represent Acceptance Limits not to be exceeded.

INPRO User Requirement UR1.5 on Reactor Safety

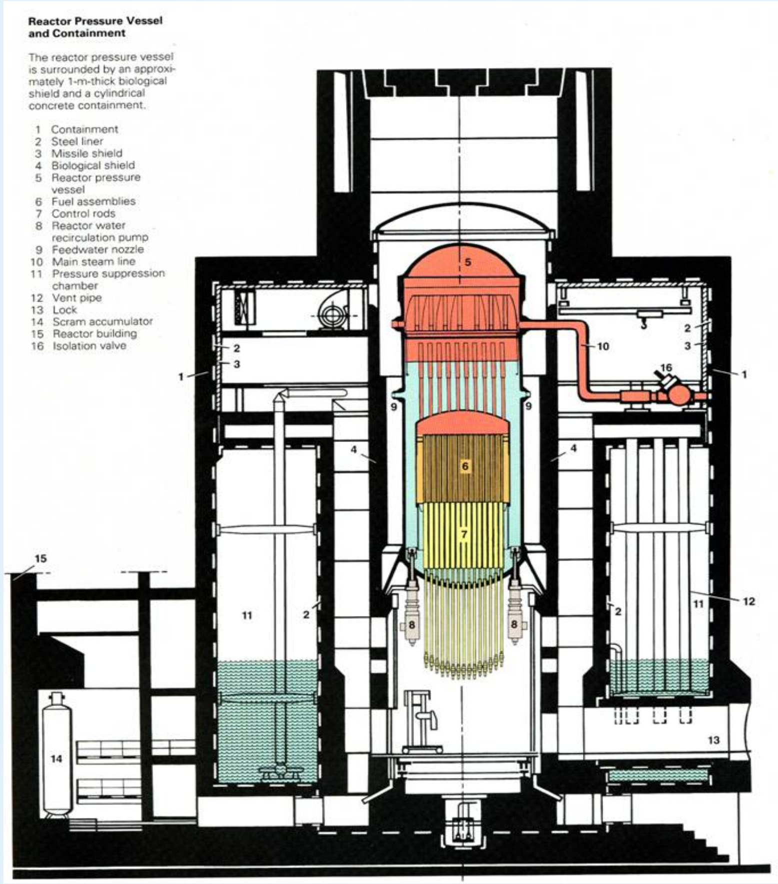
Example: UR 1.5 - No need for evacuation

- UR 1.5 demands that, for INS, there is "no need for evacuation and relocation measures" – even in case of severe accidents;
- Major release of radioactivity into the environment can be calculated using PSA, but the split of frequencies between core damage and claimed containment failure may be different for different NPP types (e.g. in water- cooled plants and gas-cooled plants);
- For UR 1.5, the INS Acceptance Limit is fulfilled if:
  - The predicted release frequency is less than 10^{-6} per plant operating year, or
  - Practical exclusion by design can be demonstrated.

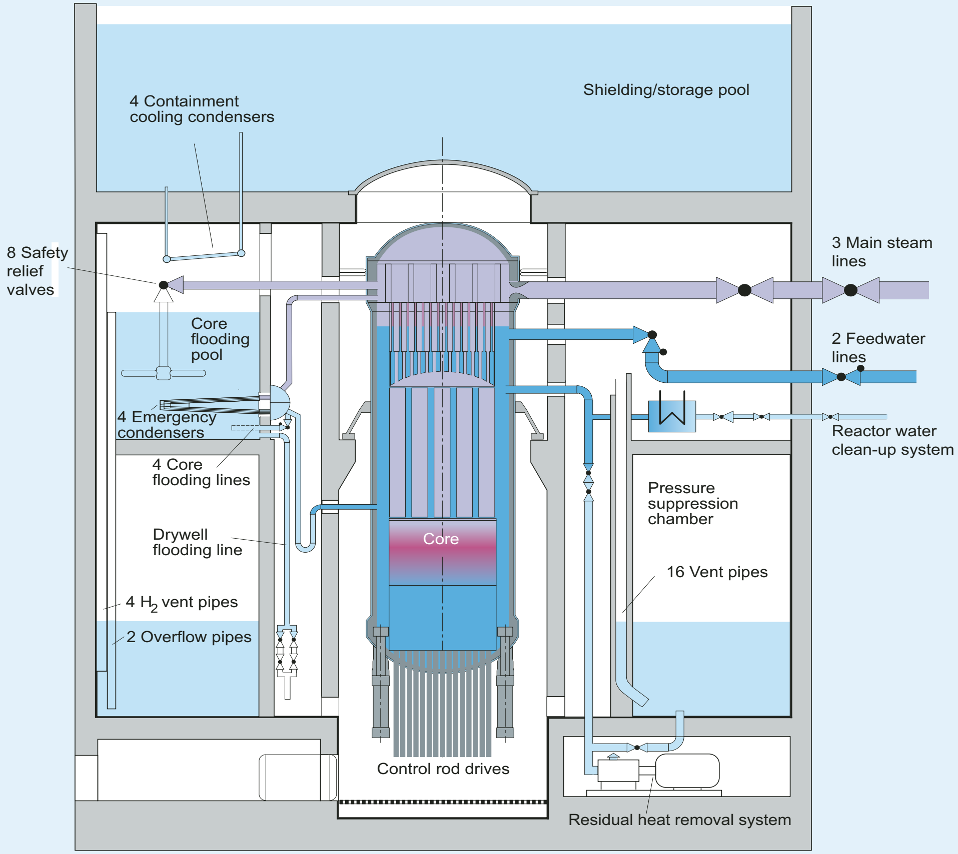
INPRO Manual : Risk Reduction Through Innovative Safety Improvements in Reactor



Example from INPRO Manual on Reactor Safety

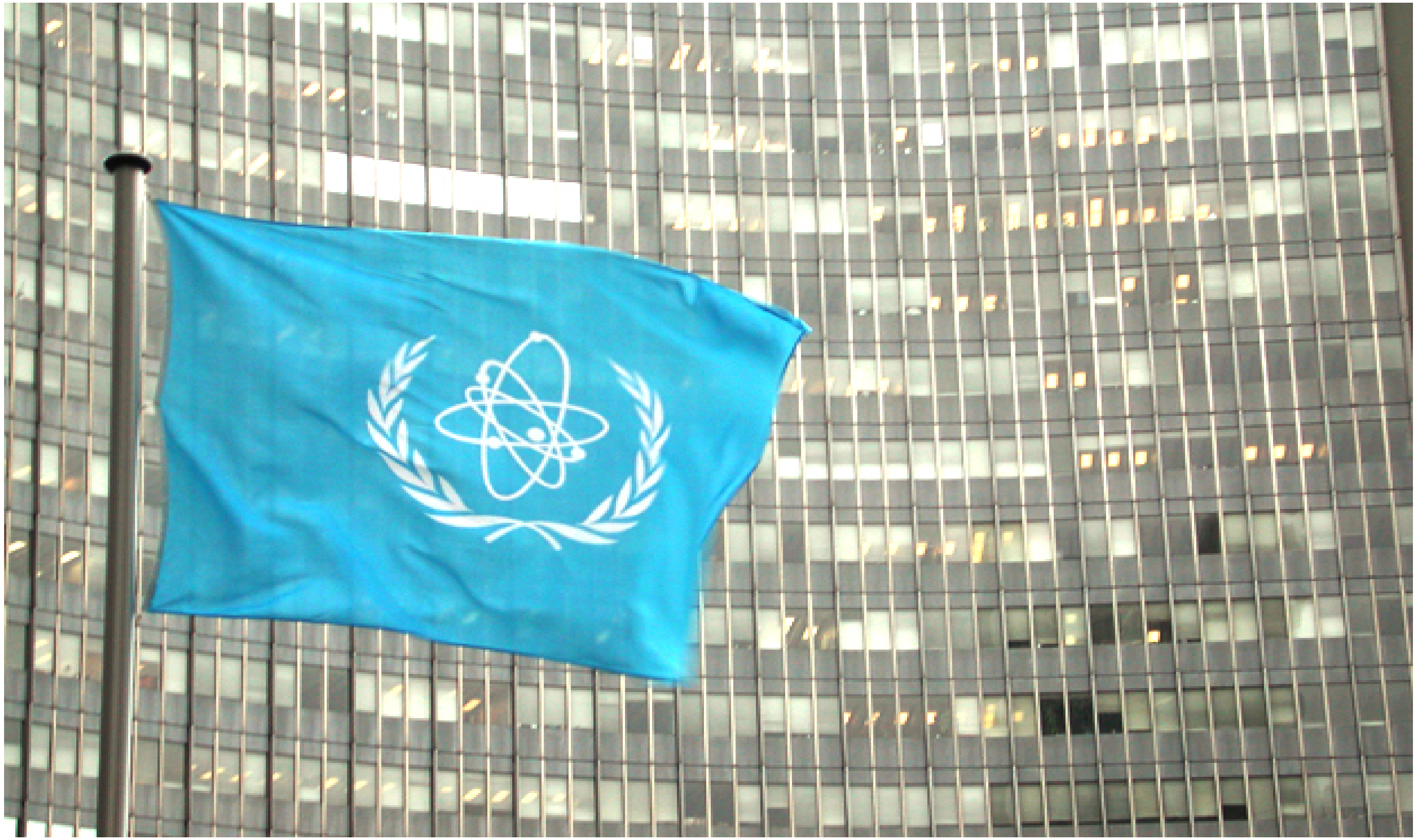


Operating BWR (Gundremmingen B)



Innovative BWR (SWR 1000)

Thank you for your attention



…Thank you for your attention

Safety

Safety Basic Principle **BP1**: ***Installations of an Innovative Nuclear Energy System shall incorporate enhanced defence-in-depth as a part of their fundamental safety approach and ensure that the levels of protection in defence-in-depth shall be more independent from each other than in existing installations***.		
User Requirements	Criteria	
	Indicators	Acceptance Limits
UR1.1[1] *Installations of an INS should be more robust relative to existing designs regarding system and component failures as well as operation.*	1.1.1 Robustness of design (simplicity, margins). 1.1.2 High quality of operation. 1.1.3 Capability to inspect. 1.1.4 Expected frequency of failures and disturbances. 1.1.5 Grace period until human actions are required. 1.1.6 Inertia to cope with transients.	1.1.1. to 1.1.6: Superior to existing designs in at least some of the aspects discussed in the text.
UR1.2 *Installations of an INS should detect and intercept deviations from normal operational states in order to prevent anticipated operational occurrences from escalating to accident conditions*	1.2.1 Capability of control and instrumentation system and/or inherent characteristics to detect and intercept and/or compensate such deviations.	1.2.1 Key system variables relevant to safety (e.g. flow, pressure, temperature, radiation levels) do not exceed limits acceptable for continued operation (no event reporting necessary).

Safety

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User Requirements	Criteria	
	Indicators	Acceptance Limits
UR1.3*The frequency of occurrence of accidents should be reduced, consistent with the overall safety objectives. If an accident occurs, engineered safety features should be able to restore an installation of an INS to a controlled state, and subsequently (where relevant) to a safe shutdown state, and ensure the confinement of radioactive material. Reliance on human intervention should be minimal, and should only be required after some grace period.*	1.3.1 Calculated frequency of occurrence of design basis accidents. 1.3.2 Grace period until human intervention is necessary. 1.3.3 Reliability of engineered safety features. 1.3.4 Number of confinement barriers maintained. 1.3.5 Capability of the engineered safety features to restore the INS to a controlled state (without operator actions). 1.3.6 Sub-criticality margins.	1.3.1 Reduced frequency of accidents that can cause plant damage relative to existing facilities. 1.3.2 Increased relative to existing facilities. 1.3.3 Equal or superior to existing designs. 1.3.4 At least one. 1.3.5 Sufficient to reach a controlled state. 1.3.6 Sufficient to cover uncertainties and to allow adequate grace period.
UR1.4[2] *The frequency of a major release of radioactivity into the containment / confinement of an INS due to internal events should be reduced. Should a release occur, the consequences should be mitigated.*	1.4.1 Calculated frequency of major release of radioactive materials into the containment / confinement. 1.4.2 Natural or engineered processes sufficient for controlling relevant system parameters and activity levels in containment / confinement 1.4.3 In-plant severe accident management	1.4.1 At least an order of magnitude less than for existing designs; even lower for installations at urban sites. 1.4.2 Existence of such processes. 1.4.3 Procedures, equipment and training sufficient to prevent large release outside containment / confinement and regain control of the facility.

Safety

Safety Basic Principle **BP1**: ***Installations of an Innovative Nuclear Energy System shall incorporate enhanced defence-in-depth as a part of their fundamental safety approach and ensure that the levels of protection in defence-in-depth shall be more independent from each other than in existing installations***.		
User Requirements	Criteria	
	Indicators	Acceptance Limits
UR1.5[1] *A major release of radioactivity from an installation of an INS should be prevented for all practical purposes, so that INS installations would not need relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility used for similar purpose.*	1.5.1 Calculated frequency of a major release of radioactive materials to the environment. 1.5.2 Calculated consequences of releases (e.g. dose). 1.5.3 Calculated individual and collective risk.	1.5.1 Calculated frequency $<10^{-6}$ per unit-year, or practically excluded by design. 1.5.2 Consequences sufficiently low to avoid necessity for evacuation. Appropriate off-site mitigation measures (e.g. temporary food restrictions) are available. 1.5 3 Comparable to facilities used for a similar purpose.[2]
UR1.6 *An assessment should be performed for an INS to demonstrate that the different levels of defence-in-depth are met and are more independent from each other than for existing systems.*	1.6.1 Independence of different levels of DID	1.6.1 Adequate independence is demonstrated, e.g. through deterministic and probabilistic means, hazards analysis etc.

Safety

Safety Basic Principle BP2: ***Installations of an INS shall excel in safety and reliability by incorporating into their designs, when appropriate, increased emphasis on inherently safe characteristics and passive systems as a part of their fundamental safety approach.***		
User Requirements	Criteria	
	Indicators	Acceptance Limits
UR2.1 *INS should strive for elimination or minimization of some hazards relative to existing plants by incorporating inherently safe characteristics and/or passive systems, when appropriate.*	**2.1.1. Sample indicators: stored energy, flammability, criticality, inventory of radioactive materials, available excess reactivity, reactivity feedback.** **2.1.2. Expected frequency of abnormal operation and accidents.** **2.1.3. Consequences of abnormal operation and accidents.** **2.1.4. Confidence in innovative components and approaches.**	2.1.1. Superior to existing designs. 2.1.2. Lower frequencies compared to existing facilities. 2.1.3. Lower consequences compared to existing facilities. 2.1.4. Validity established.

Safety

Safety Basic Principle BP3: ***Installations of an INS shall ensure that the risk from radiation exposures to workers, the public and the environment during construction/commissioning, operation, and decommissioning, are comparable to the risk from other industrial facilities used for similar purposes.***		
User Requirements	**Criteria**	
	Indicators	**Acceptance Limits**
UR3.1. *INS installations should ensure an efficient implementation of the concept of optimization of radiation protection through the use of automation, remote maintenance and operational experience from existing designs.*	3.1.1 Occupational dose values.	3.1.1 Less than limits defined by national laws or international standards and so that the health hazard to workers is comparable to that from an industry used for a similar purpose.
UR3.2 *Dose to an individual member of the public from an individual INS installation during normal operation should reflect an efficient implementation of the concept of optimization, and for increased flexibility in siting may be reduced below levels from existing facilities.*	3.2.1 Public dose values.	3.2.1 Less than the limits defined by national laws or international standards and so that the health hazard to the public is comparable to that from an industry used for a similar purpose

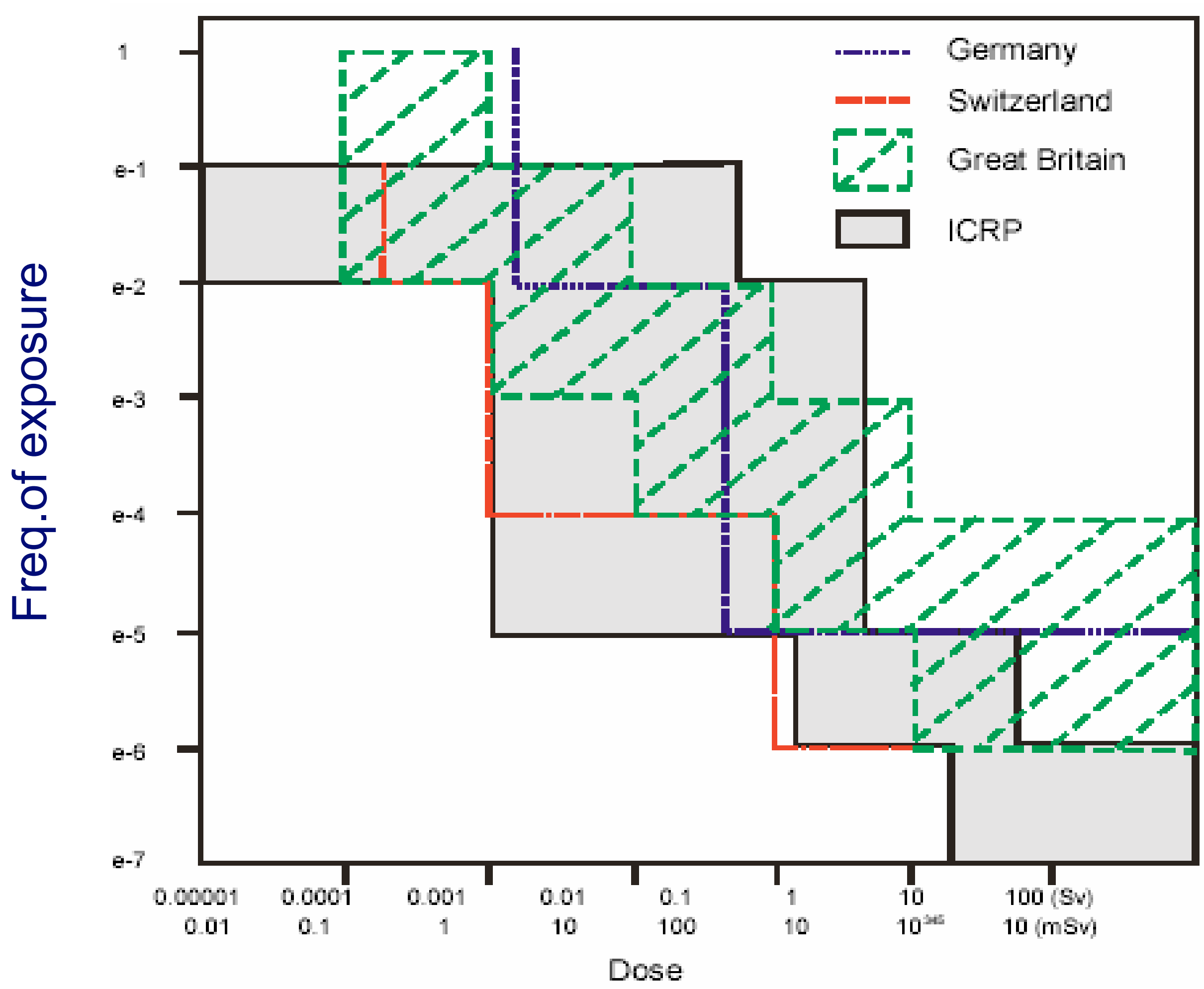
Safety

Safety Basic Principle BP4: ***The development of INS shall include associated Research, Development and Demonstration work to bring the knowledge of plant characteristics and the capability of analytical methods used for design and safety assessment to at least the same confidence level as for existing plants***.		
User Requirements	Criteria	
	Indicators	Acceptance Limits
UR4.1 *The safety basis of INS installations should be confidently established prior to commercial deployment.*	4.1.1 Safety concept defined. 4.1.2. Design-related safety requirements specified. 4.1.3. Clear process for addressing safety issues.	Yes for all.
UR4.2 *Research, Development and Demonstration on the reliability of components and systems, including passive systems and inherent safety characteristics, should be performed to achieve a thorough understanding of all relevant physical and engineering phenomena required to support the safety assessment.*	4.2.1. RD&D defined and performed and database developed. 4.2.2. Computer codes or analytical methods developed and validated. 4.2.3. Scaling understood and/or full scale tests performed.	Yes for all.
UR4.3 *A reduced-scale pilot plant or large-scale demonstration facility should be built for reactors and/or fuel cycle processes, which represent a major departure from existing operating experience.*	4.3.1. Degree of novelty of the process. 4.3.2. Level of adequacy of the pilot facility.	4.3.1a. *High degree of novelty:* Facility specified, built, operated, and lessons learned documented. 4.3.1b. *Low degree of novelty*: Rationale provided for bypassing pilot plant. 4.3.2. Results sufficient to be extrapolated.

Safety

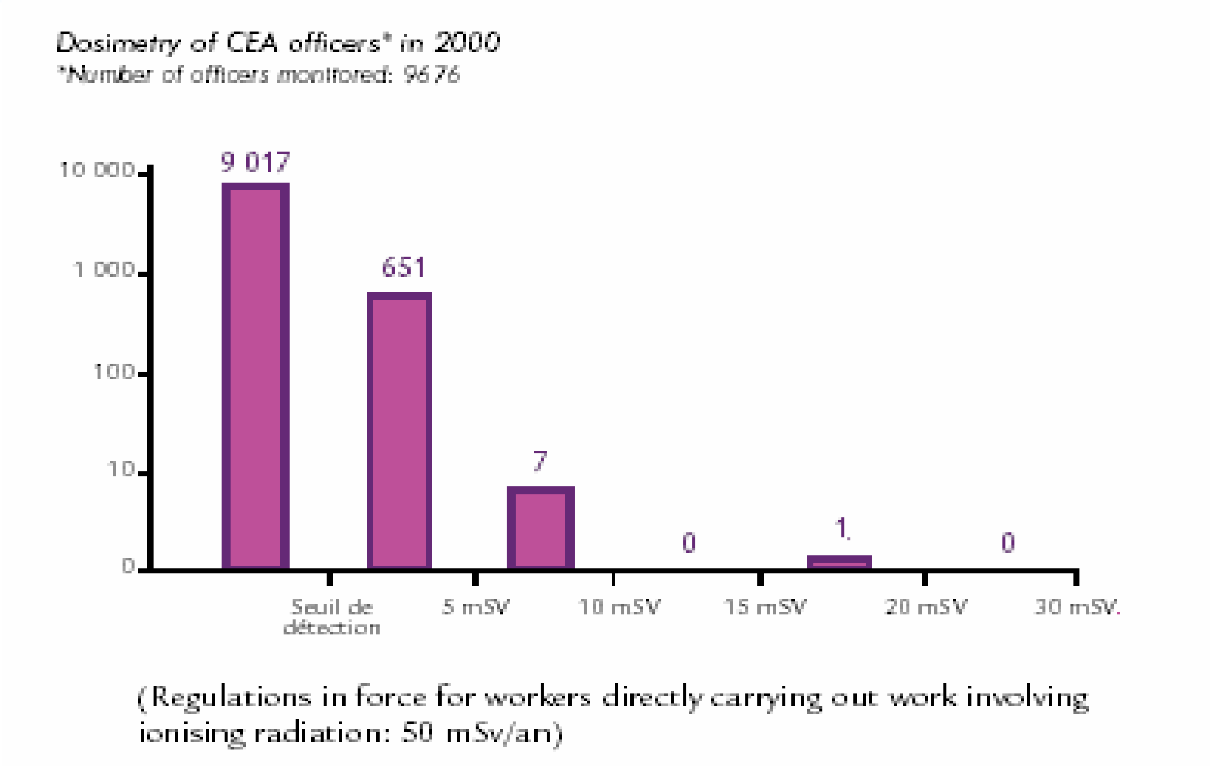
Safety Basic Principle BP4: ***The development of INS shall include associated Research, Development and Demonstration work to bring the knowledge of plant characteristics and the capability of analytical methods used for design and safety assessment to at least the same confidence level as for existing plants.***		
User Requirements	Criteria	
	Indicators	Acceptance Limits
UR4.4 *For the safety analysis, both deterministic and probabilistic methods should be used, where feasible, to ensure that a thorough and sufficient safety assessment is made. As the technology matures, "Best Estimate (plus Uncertainty Analysis)" approaches are useful to determine the real hazard, especially for limiting severe accidents.*	4.4.1. Use of a risk informed approach. 4.4.2. Uncertainties and sensitivities identified and appropriately dealt with.	Yes to all.

Comparison of safety criteria (risk based) for nuclear installations



Frequency of exposure versus the exposure dose

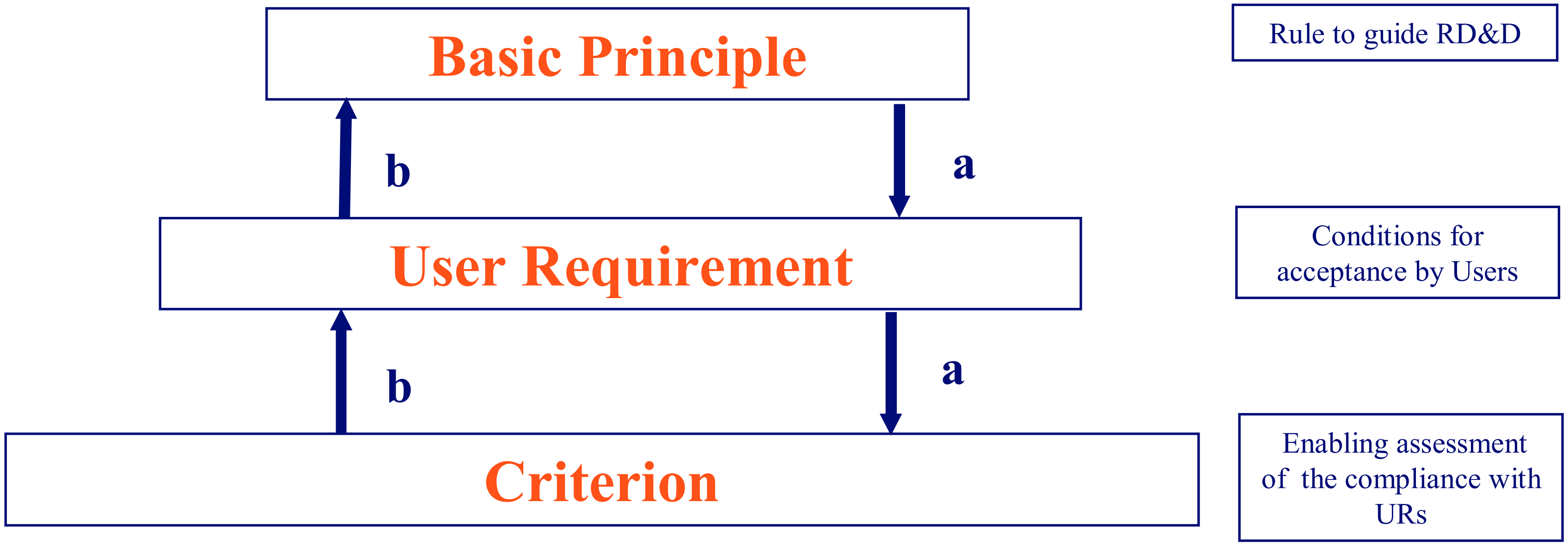
Figure Indicates need for harmonisation



Results reported by CEA illustrating the scope for reduction in annual radiation exposure to workers

Scope for reduction in annual occupational exposure exists

INPRO Hierarchy of Demands on Innovative Nuclear Energy Systems (INS)



a = Derivation of hierarchy
b = Fulfilment of demands on INS