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IAEA RTA Key Element 3: Nuclear Plant Safety

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OUTLINE

- Safety Objective
- RTA Key Element 3: Nuclear Plant Safety
- **RTA TABLE FOR KEY ELEMENT 3**
  - **How to complete?**
  - **Examples**

Day 2: Tuesday, 11 June 2019		
13:30	**IAEA RTA Key Element 3:** Nuclear Plant Safety [IAEA NP-T-1.10, Pg. 31] **Case Study**	Mr Matthias Krause IAEA Teams

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Safety Objective

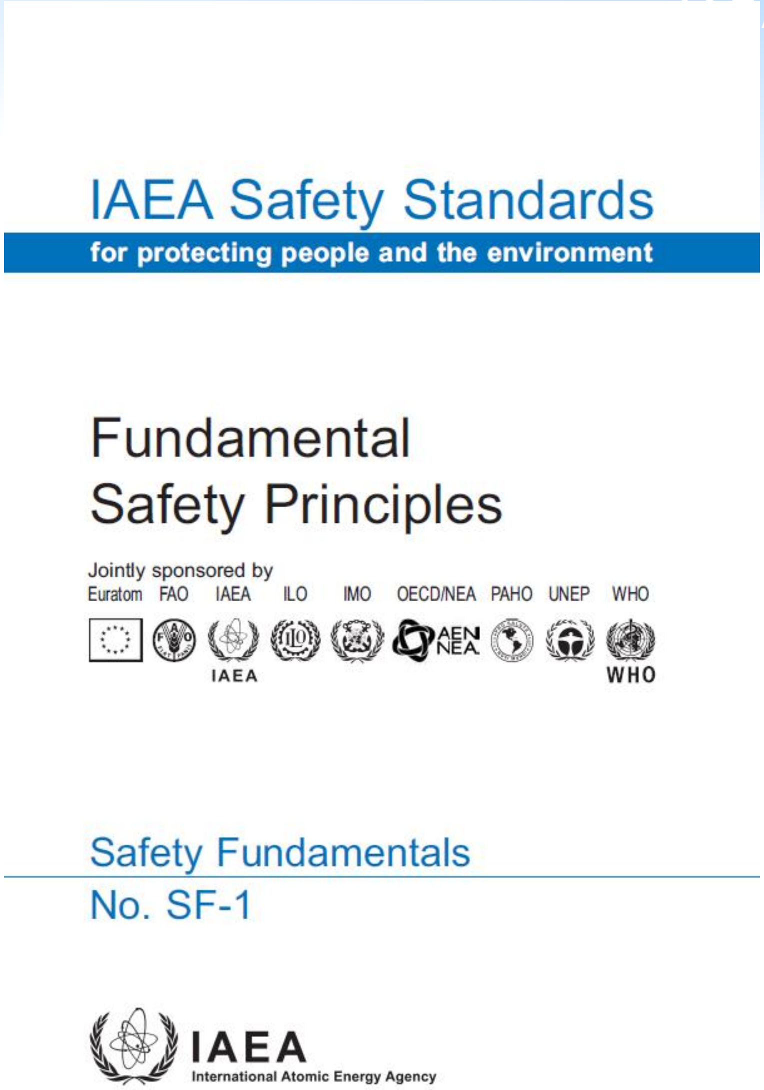
is to protect people and the environment from harmful effects of ionizing radiation

To achieve the highest standards of safety that can reasonably be achieved, measures have to be taken to:

a) Control the radiation exposure of people and the release of radioactive material to the environment;

b) 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) Mitigate the consequences of such events if they were to occur.


IAEA Safety Standards

for protecting people and the environment

Fundamental Safety Principles

Jointly sponsored by

Euratom FAO IAEA ILO IMO OECD/NEA PAHO UNEP WHO

Safety Fundamentals

No. SF-1

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NPP for Retasland must meet this objective

Important Requirements for NPP Design

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

- Radiation protection in NPP design
  - is addressed by RTA Key Element 6

- **Safety in NPP design**
  - To prevent accidents, and to mitigate the consequences of any accidents
  - For all accidents, any radiological consequences would be below the relevant limits and would be kept as low as reasonably achievable
  - To ensure that the likelihood of an accident with serious radiological consequences is extremely low and that the radiological consequences would be mitigated to the fullest extent practicable.

Important Requirements for NPP Design

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

- **Concept of defence in depth (DiD)**
  - to ensure that all safety related activities are subject to independent layers of provisions so that if a failure were to occur, it would be detected and compensated for or corrected by appropriate measures

- **Maintaining the integrity of NPP** design throughout the lifetime of the plant
  - operating organization could set up a formal process to maintain the integrity of the plant's design during the operating lifetime and into the decommissioning stage

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RTA Key Element 3: Nuclear Plant Safety

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The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards:

- **Importance factor range suggested: High**
  - Nuclear safety is expected to be included at the policy objectives level or the highest element contribution level.
  - It has the potential to be a strong differentiator.
  - Gathering consistent and accurate information from technology holders for appropriated comparisons will be required.
  - A wide variety of metrics is available, yet the approach should be to select a reasonable number that will appropriately represent the capability of the facility with respect to nuclear safety.
- Accidents that could cause a loss of function of systems required for maintaining the plant's safety shall be evaluated

RTA Key Element 3: Nuclear Plant Safety

The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards:

- ***Evaluation expectations and relative comparisons*:**
  - The challenge is to examine those elements and features that will best differentiate the safety of different designs.
  - This will be dependent on the spectrum of reactor designs under consideration.
  - Since nuclear safety is a policy objective, it is necessary to conduct the evaluation so that the approach and the results can be clearly explained to policy makers.
  - The evaluation should include plant systems, as well programmes and procedures for emergency and severe accident responses for the plant and its surroundings.

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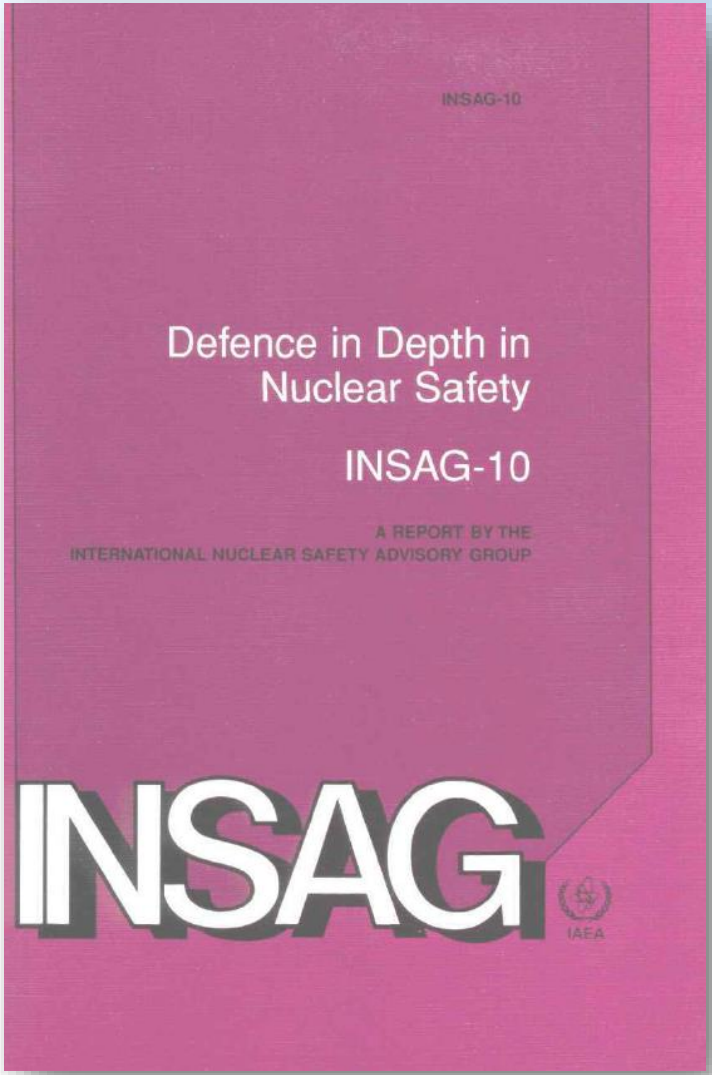
Defence in Depth

Levels of defence in depth	Objective	Essential means
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



Main Characteristics

NuScale

Image Courtesy of NuScale Power, USA

Under Development and licensing (Design Certification)

Integral PWR type SMR

Naturally circulation

- 50 MW(e) / 160 MW(th) per module
- Core outlet temp: 314^{o}C
- Fuel enrichment: <4.95% UO_2
- Modules per plant: 12
- Containment vessel immersed in reactor pool that provide unlimited coping time for core cooling
- Multi-purpose energy use: electricity and process heat applications
- Design update to 60MWe (details not released to IAEA booklet)

SMART

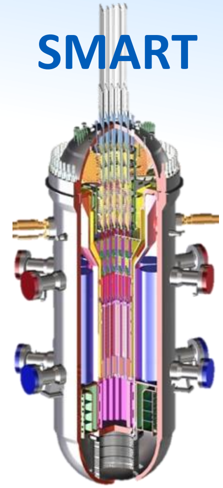


Image Courtesy of KAERI, Republic of Korea

Standard design approval (2012) / reapplication expected in 2019

Integral PWR type SMR

Forced circulation

- 100 MW(e) / 330 MW(th)
- Core outlet temp: 323^{o}C
- Fuel enrichment: <5% UO_2
- Coupling with desalination and process heat application
- Pre-project engineering agreement between Korea and Kingdom of Saudi Arabia for the deployment of SMART in the Gulf country
- Design update with KACARE (increased power and more passive safety features) - to be submitted for design approval

HTR-PM

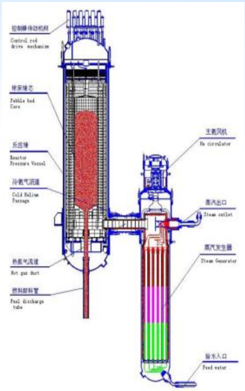


Image Courtesy of Tsinghua University, China

Under Construction; FSAR approval eminent

HTGR pebble type SMR

Forced circulation

- 210 MW(e) / 2x250 MW(th)
- Core outlet temp: 750^{o}C
- Fuel enrichment: 8.5% TRISO coated particle fuel
- Inherent safety, no need for offsite safety measures
- Multiple reactor modules can be coupled with single steam turbine
- Operation of first unit: 2019

Safety Approach : Active and Passive Systems

NuScale

Image Courtesy of NuScale Power, USA

Safety Approach

- Passive safety systems that allow for unlimited coping time after a design basis accident without power, operator action, or makeup water
- Passively safe -cooling water circulates through the nuclear core by natural convection eliminating the need for pumps
- Integrated reactor design -no large-break loss-of-coolant accidents

SMART

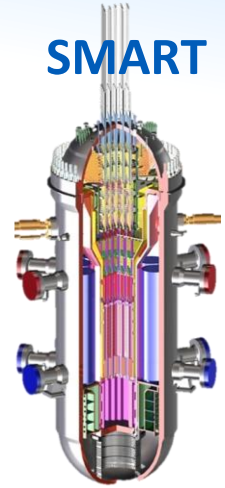


Image Courtesy of KAERI, Republic of Korea

Safety Approach

- Active and passive (new updated design only use passive safety systems)
- passive safety features rely on gravity and natural circulation and require no active controls neither operator intervention to cope with malfunctions and safety events
- Lower power density
- Integrated reactor design -no large-break loss-of-coolant accidents
  - Penetrations are small and none at the bottom of vessel
- Large primary coolant inventory

HTR-PM

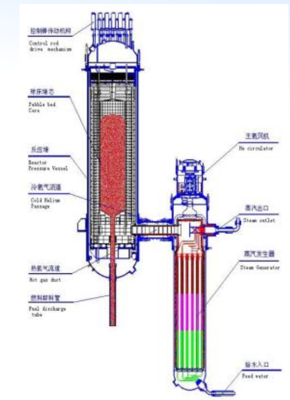


Image Courtesy of Tsinghua University, China

Safety Approach

- Decay heat removal from core by natural means only (from fuel to the vessel by conduction, radiation and if helium is present, by conduction)
- Heat removal from reactor vessel by radiation and some convection in air to reactor cavity cooling system (RCCS)
- RCCS (water panels; 3 trains) always in operation in active mode fail to passive mode
- Much lower power density (~30x lower)
- Largest helium break size Φ 65 mm

Safety Approach: DiD, Diversity and Redundancy

NuScale

Image Courtesy of NuScale Power, USA

Defence in Depth

- **Multiple additional barriers to protect against the release of radiation to the environment**
  - **Fuel, vessel, containment vessel, pool, building**

Diversity and Redundancy

- Each NuScale module has its own set of independent passive safety systems

SMART

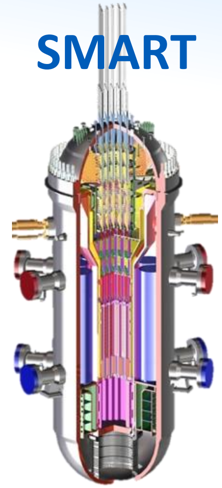


Image Courtesy of KAERI, Republic of Korea

Defence in Depth

- **Fully applied**
- **Multiple barriers to protect against the release of radiation to the environment**
  - **Fuel, vessel, containment building**

Diversity and Redundancy

- Multiple trains (up to four) and diverse systems
- severe accident mitigation features

HTR-PM

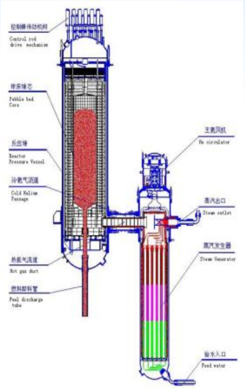


Image Courtesy of Tsinghua University, China

Defence in Depth

- **Fuel coated particle seen as main and strongest barrier**
- **Other barriers also credited to protect against the release of radiation to the environment (graphite matrix, helium pressure boundary, building)**
- **Postulation of large core damage / core melt not considered**

Diversity and Redundancy

- Diverse shutdown systems
- Multiple-trains in RCCS and passive mode
- Double isolation valves to isolate reactor (and SG) in case of a SCRAM

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RTA Key Element 3: Table

Out of 19 Key Topics, 3 Key Topics are selected as follows:

Key element: 3. Nuclear Plant Safety (Suggested High Importance) →						%
19 Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score
Safety approach (e.g. fully active, fully passive, combination)						
Defence in depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage	2	1	4	4	4	3
Degree of diversity and redundancy in providing key safety features						

%	Represents the importance of the key topic
Rationale for percentage	Requires explanation for quantified importance
Rationale for score	Requires explanation of the scoring range:

5 High achievement of criteria
3 Medium achievement of criteria
1 Low or no achievement of criteria, or no information available

RTA Key Element 3: Table

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Key element: 3. Nuclear Plant Safety (Suggested High Importance)						%
Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score
Safety approach (e.g. fully active, fully passive, combination)		Design safety approach assures protection of a public health and safety with the consideration/inclusion of passive safety features				
Defence in depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage		Defence in depth is a fundamental principle for nuclear plant safety				
Degree of diversity and redundancy in providing key safety features		High degree of diversity and redundancy is included providing key safety features				

1

RTA Key Element 3: Table

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Key element: 3. Nuclear Plant Safety (Suggested High Importance)						%
Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score
Safety approach (e.g. fully active, fully passive, combination)	5	Design safety approach assures protection of a public health and safety with the consideration/inclusion of passive safety features				
Defence in depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage	10	Defence in depth is a fundamental principle for nuclear plant safety				
Degree of diversity and redundancy in providing key safety features	5	High degree of diversity and redundancy is included providing key safety features				

2 1

RTA Key Element 3: Table

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Key element: 3. Nuclear Plant Safety (Suggested High Importance)						%
Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score
Safety approach (e.g. fully active, fully passive, combination)	5	Design safety approach assures protection of a public health and safety with the consideration/inclusion of passive safety features				5. Fully passive safety approach 3. Combination active & passive safety approach 1. Fully active safety approach or no info provided
Defence in depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage	10	Defence in depth is a fundamental principle for nuclear plant safety				5. Extensive key safety features to limit plant transients, avoid core damage, contain core damage, and reduce offsite release 3. Fair number of key safety features 1. Very few key safety features or no info provided
Degree of diversity and redundancy in providing key safety features	5	High degree of diversity and redundancy is included providing key safety features				5. High degree of diversity and redundancy 3. Same degree of diversity and redundancy as currently operating NPPs 1. Low degree of diversity and redundancy or no info provided

2 1 3

RTA Key Element 3: Table

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Key element: 3. Nuclear Plant Safety (Suggested High Importance)						%
Key topics	%	Rationale for percentage	HTR-PM	NuScale	SMART	Rationale for score
Safety approach (e.g. fully active, fully passive, combination)	5	Design safety approach assures protection of a public health and safety with the consideration/inclusion of passive safety features	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	5. Fully passive safety approach 3. Combination active & passive safety approach 1. Fully active safety approach or no info provided
Defence in depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage	10	Defence in depth is a fundamental principle for nuclear plant safety	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	5. Extensive key safety features to limit plant transients, avoid core damage, contain core damage, and reduce offsite release 3. Fair number of key safety features 1. Very few key safety features or no info provided
Degree of diversity and redundancy in providing key safety features	5	High degree of diversity and redundancy is included providing key safety features	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	Score 1 or 2 or 3 or 4 or 5	5. High degree of diversity and redundancy 3. Same degree of diversity and redundancy as currently operating NPPs 1. Low degree of diversity and redundancy or no info provided

2 1 4 3

Case Study Toolkit

Teams

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Thank you!