IAEA
International Atomic Energy Agency
*Atoms for Peace and Development*

# Overview of IAEA activities on the safety of GEN-IV systems

Interregional Workshop on Advances in Design of Generation-IV SMRs

**Beijing, China – 3-7 June 2024**

Vincenzo Tiberi

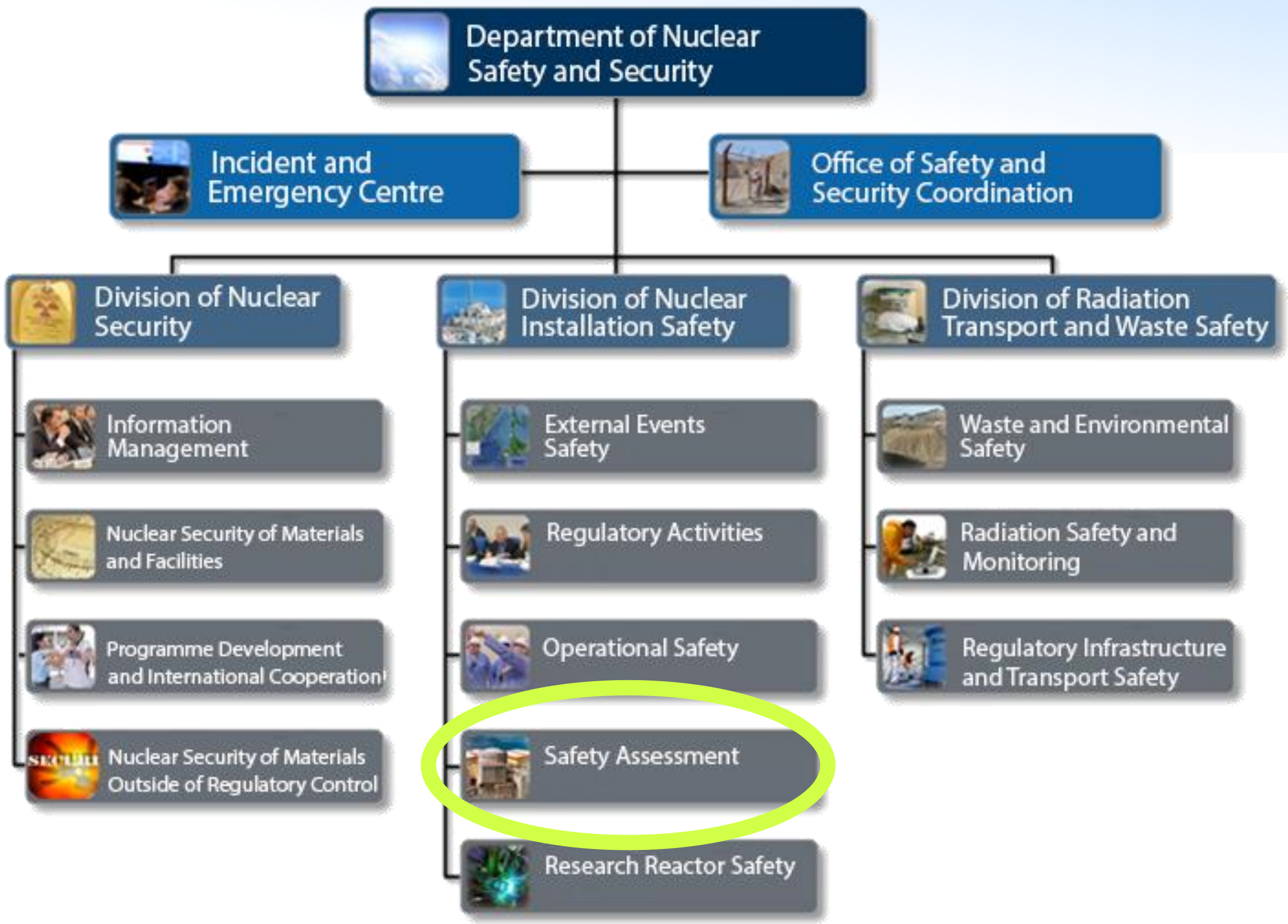
IAEA, Safety Assessment Section
Division of Nuclear Installation Safety
Department of Nuclear Safety and Security

# IAEA Structure

| | | |
|---|---|---|
| Nuclear Energy | Nuclear Safety and Security | Safeguards |
| Nuclear Sciences and Applications | Technical Cooperation | Management |

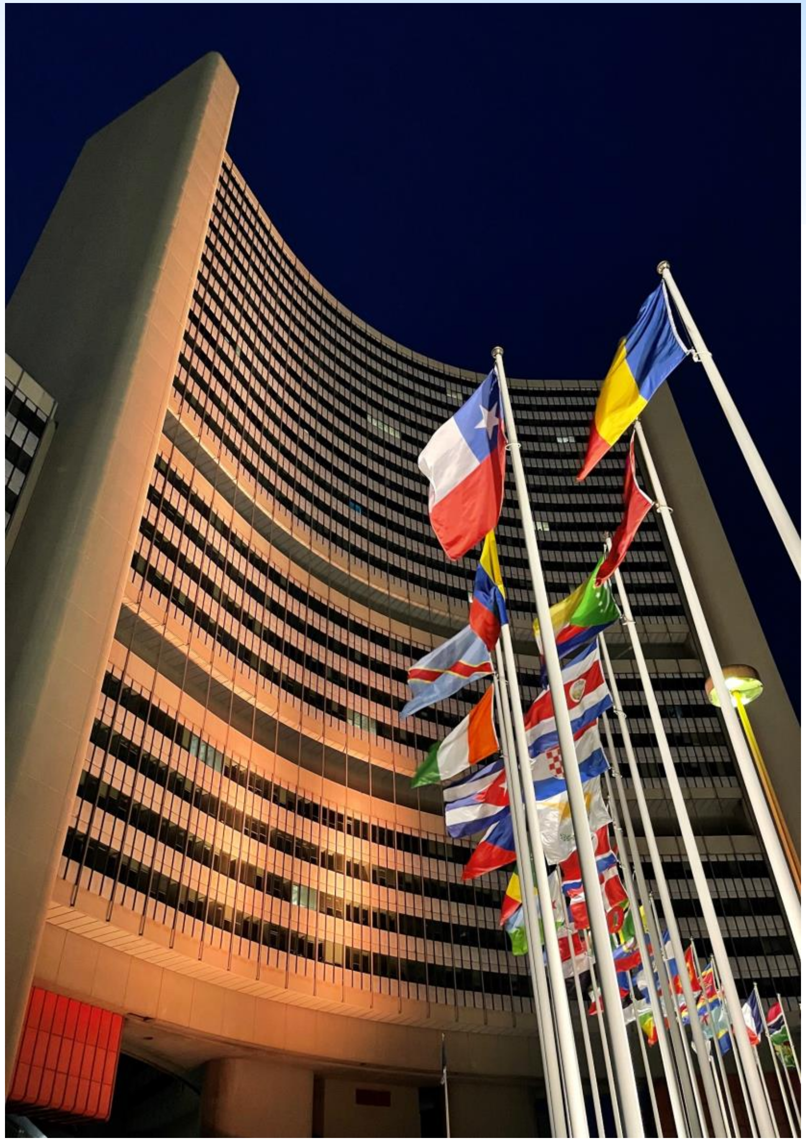
# Department of Nuclear Safety and Security (NS)

- The protection of people, society and the environment from the harmful effects of ionizing radiation is at the heart of the Department for Nuclear Safety and Security's work
- The Department supports the Member States in their national efforts to further strengthen nuclear safety and nuclear security



# Safety Assessment Section (SAS)

- Helps to improve the capability of Member States in carrying out **effective safety assessments** and **enhancing the safety of nuclear installations**
- Undertakes **Technical Safety Reviews** (TSRs) that can be tailored to the needs of requesting parties
- SAS' work covers existing, evolutionary and innovative reactors, including small modular reactors (SMRs), non-water-cooled reactors and fusion facilities



# SAFETY STANDARDS


Contents by Article and Title



# ARTICLE III: Functions

## A. The Agency is authorized:

**6.** To establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property (including such standards for labour conditions), and to provide for the application of these standards to its own operations as well as to the operations making use of materials, services, equipment, facilities, and information made available by the Agency or at its request or under its control or supervision; and to provide for the application of these standards, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of atomic energy;

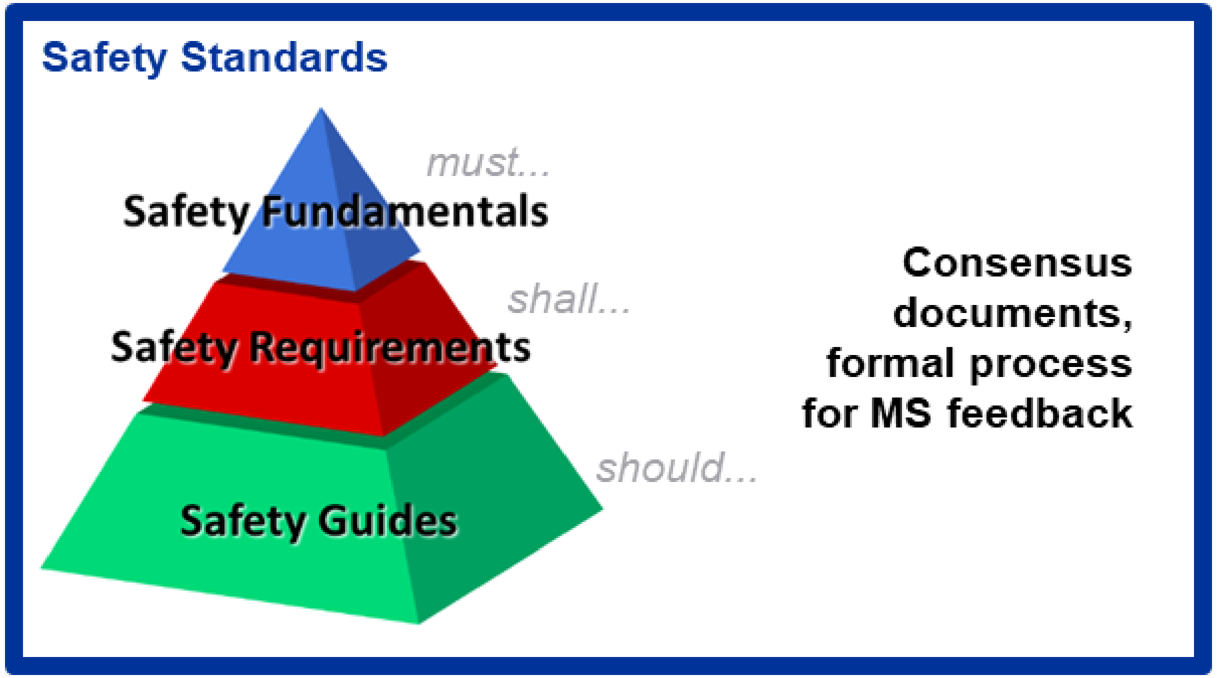


## Safety Standards


**Consensus documents, formal process for MS feedback**

https://www.iaea.org/resources/safety-standards



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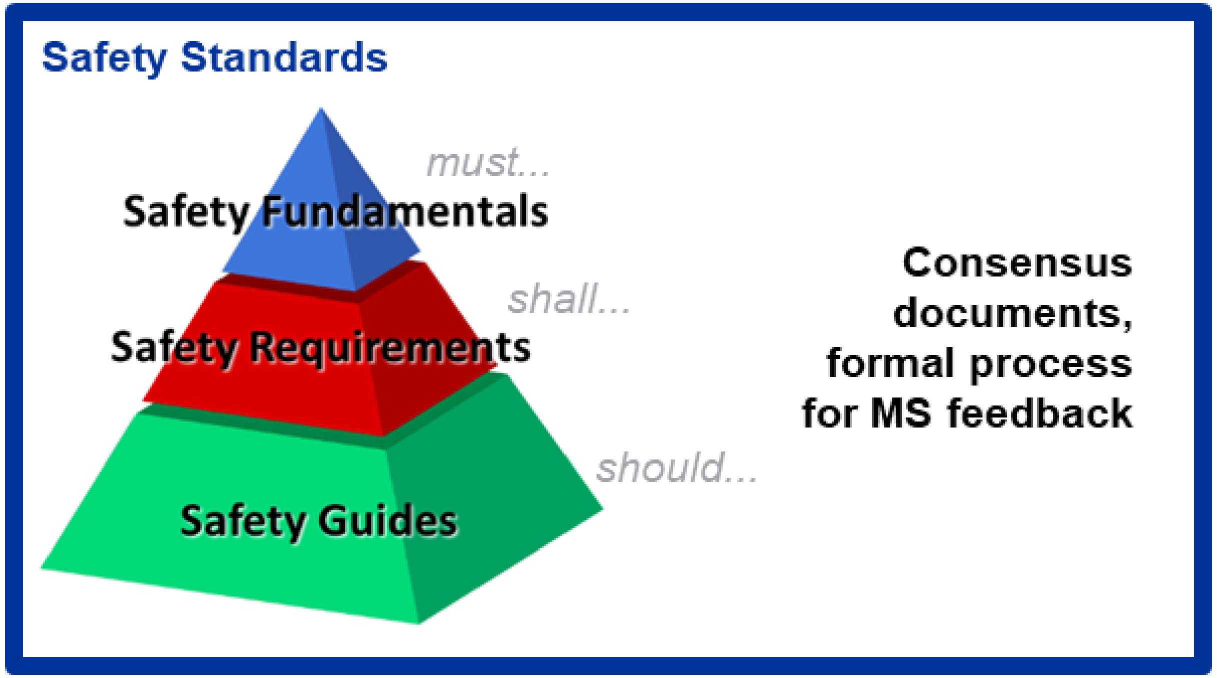


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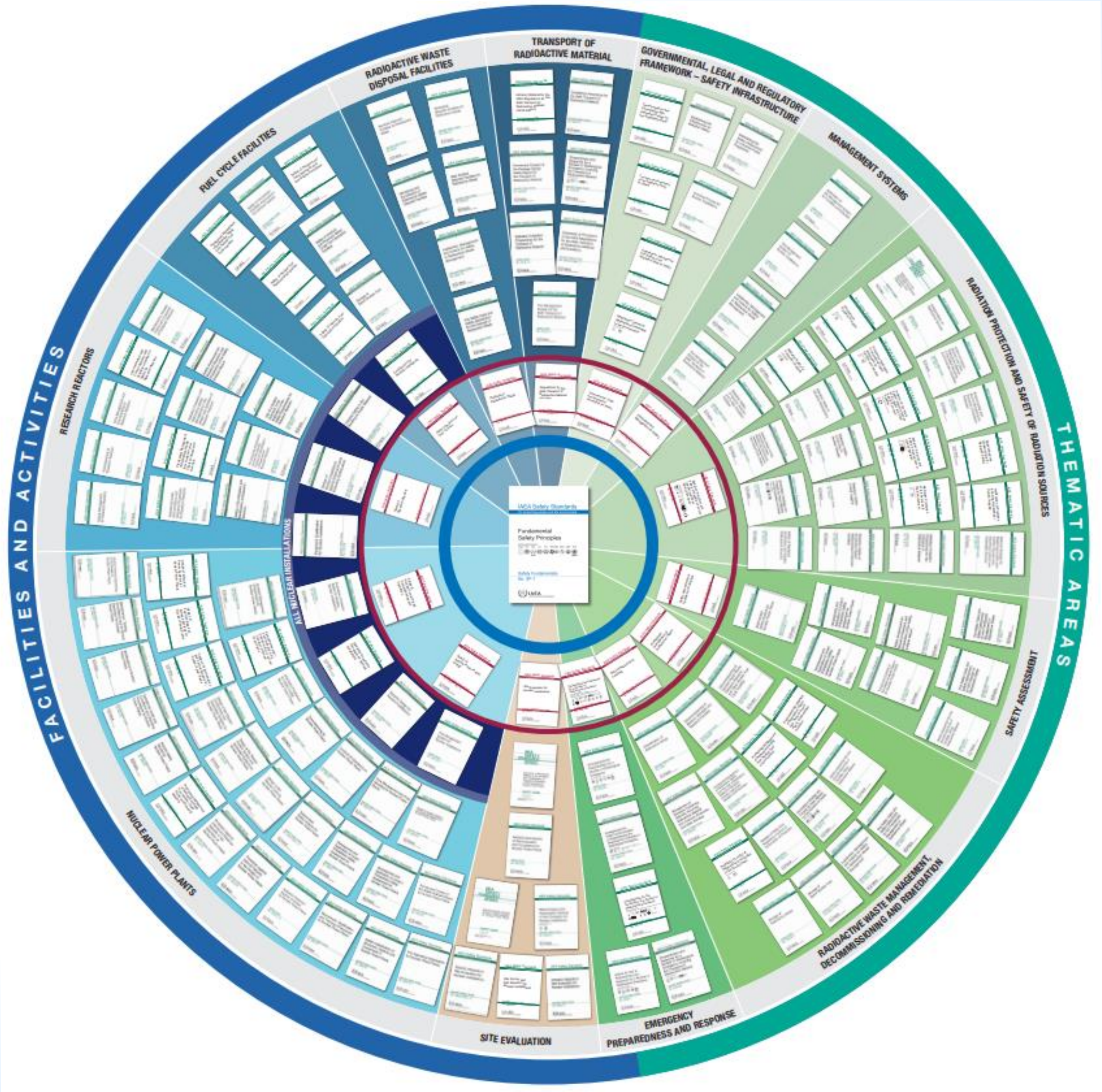
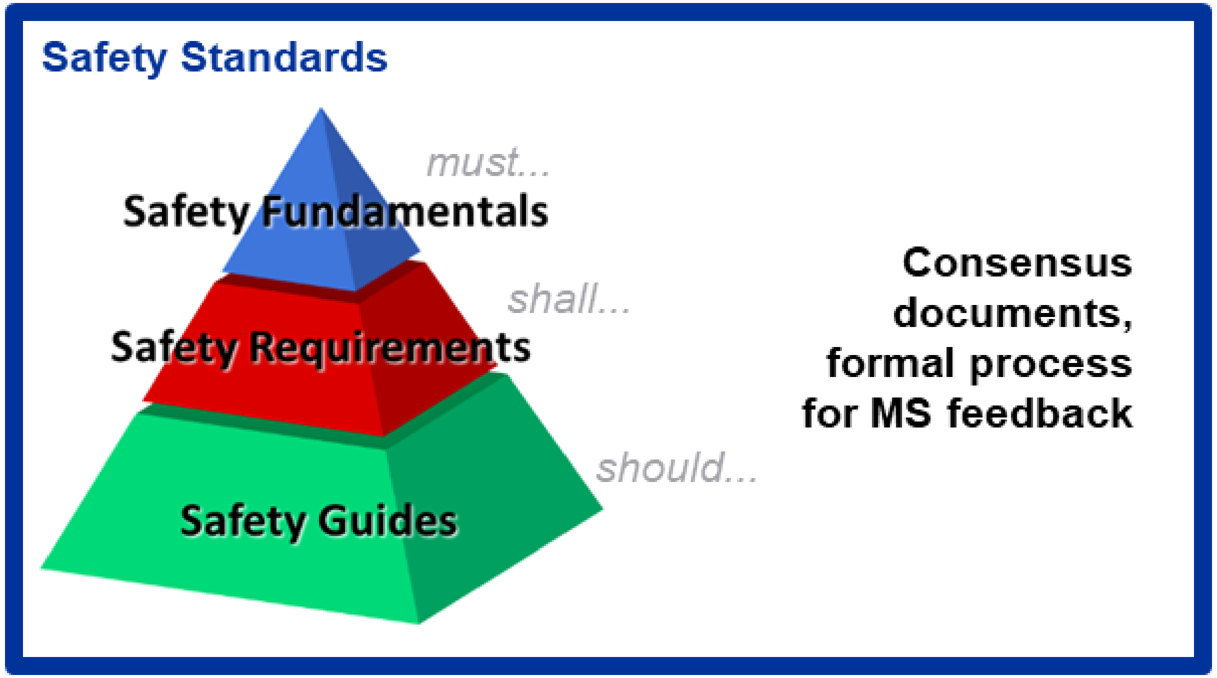


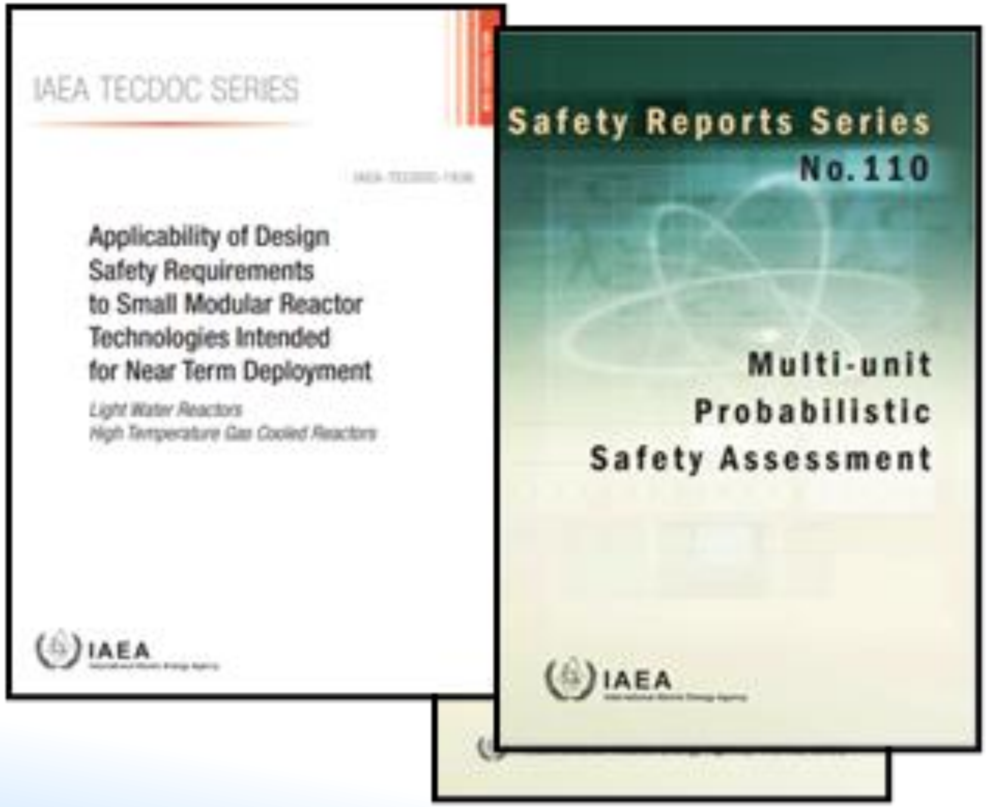





https://www.iaea.org/resources/safety-standards

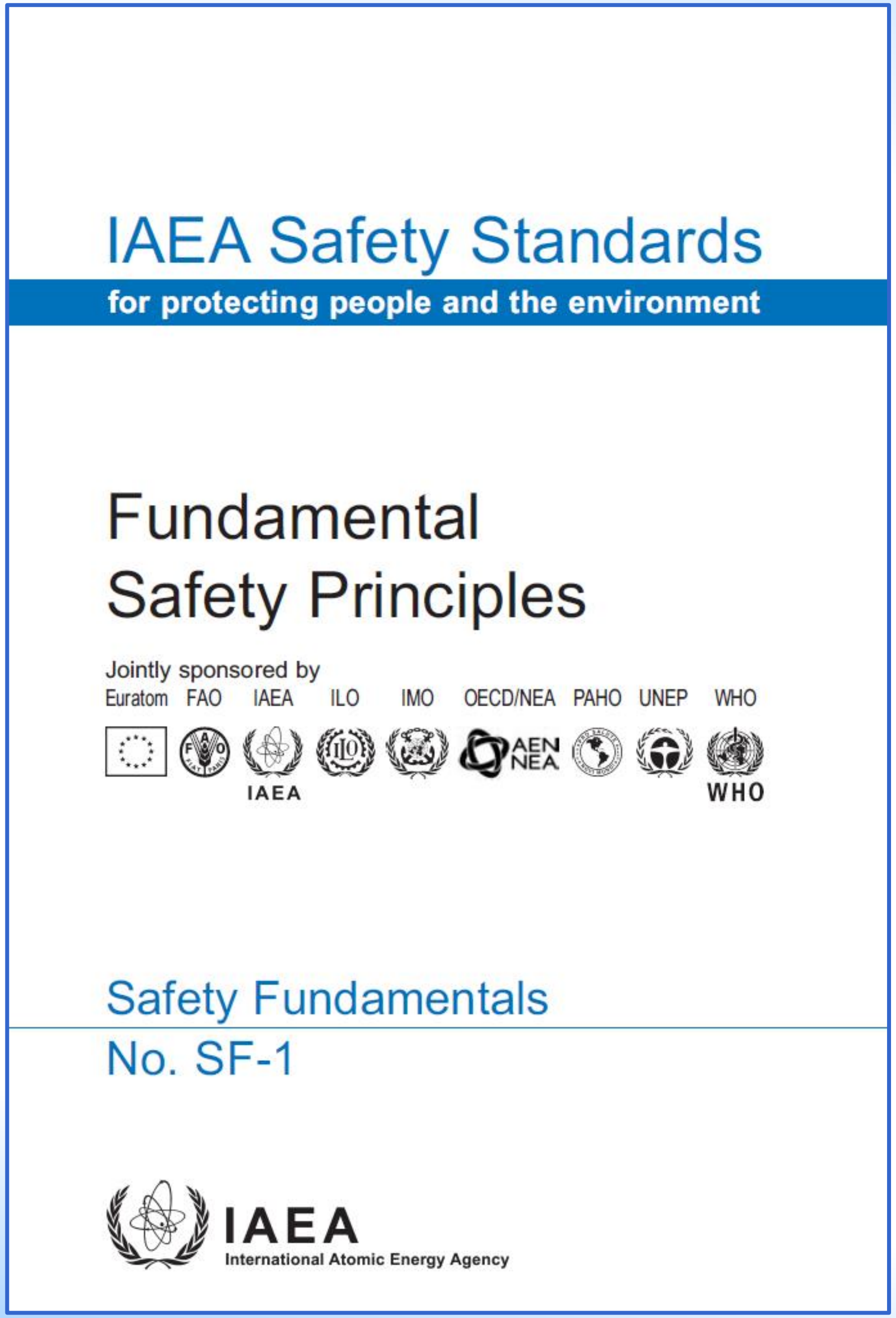
# These ARE NOT Safety Standards!!

## TECDOCs & Safety Reports




Describing best practices and MS experience, challenges for specific topic. More detailed, but not consensus documents

# IAEA Safety Standards:
## NPPs subset




## SAFETY OBJECTIVE

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

## SAFETY PRINCIPLES

- **Principle 1:** Responsibility for safety
- **Principle 2:** Role of government
- **Principle 3:** Leadership and management for safety
- **Principle 4:** Justification of facilities and activities
- **Principle 5:** Optimization of protection
- **Principle 6:** Limitation of risks to individuals
- **Principle 7:** Protection of present and future generations
- **Principle 8:** Prevention of accidents
- **Principle 9:** Emergency preparedness and response
- **Principle 10:** Protective actions to reduce existing or unregulated radiation risks

# 82 REQUIREMENTS:


- Management of safety in design **(R1 to R3)**
- Principal technical requirements **(R4 to R12)**

- General plant design:
  - Design basis **(R13 to R28)**
  - Design for safe operation over the lifetime of the plant **(R29 to R31)**
  - Human factors **(R32)**
  - Other design considerations **(R33 to R41)**
  - Safety analysis **(R42)**

- Design of specific systems:
  - Reactor core and associated features **(R43 to R46)**
  - Reactor coolant systems **(R47 to R53)**
  - Containment structure and containment system **(R54 to R58)**
  - I&C systems **(R59 to R67)**
  - Emergency power supply **(R68)**
  - Supporting systems and auxiliary systems **(R69 to R76)**
  - Other power conversion systems **(R77)**
  - Treatment of radioactive effluents and radioactive waste **(R78 - R79)**
  - Fuel handling and storage systems **(R80)**
  - Radiation protection **(R81 – R82)**

# In relation to SSR-2/1 (Rev. 1)…

**Requirement 4: Fundamental safety functions**

**Fulfilment of the following fundamental safety functions for a nuclear power plant shall be ensured for all plant states: (i) control of reactivity; (ii) removal of heat from the reactor and from the fuel store; and (iii) confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases.**

**Requirement 7: Application of defence in depth**

**The design of a nuclear power plant shall incorporate defence in depth. The levels of defence in depth shall be independent as far as is practicable.**

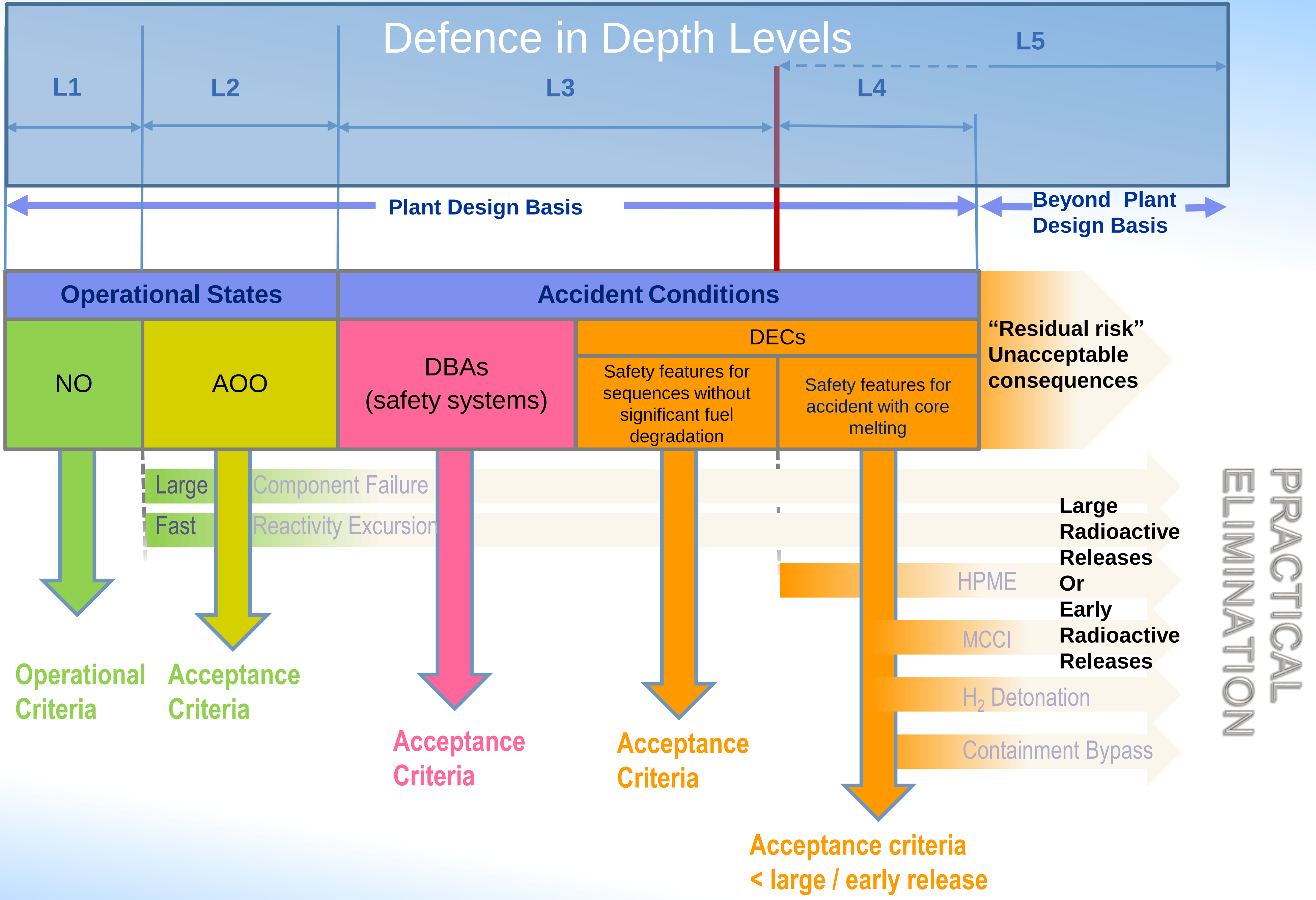
# In relation to SSR-2/1 (Rev. 1)…

**Requirement 13: Categories of plant states**

**Plant states shall be identified and shall be grouped into a limited number of categories primarily on the basis of their frequency of occurrence at the nuclear power plant.**

**Requirement 14: Design basis for items important to safety**

**The design basis for items important to safety shall specify the necessary capability, reliability and functionality for the relevant operational states, for accident conditions and for conditions arising from internal and external hazards, to meet the specific acceptance criteria over the lifetime of the nuclear power plant.**



Defence in Depth Levels
L1
L2
L3
L4
L5
Plant Design Basis
Beyond Plant Design Basis
Operational States
Accident Conditions
NO
AOO
DBAs (safety systems)
DECs
Safety features for sequences without significant fuel degradation
Safety features for accident with core melting
"Residual risk" Unacceptable consequences
Large
Component Failure
Fast
Reactivity Excursion
HPME
MCCI
$H_2$ Detonation
Containment Bypass
Large Radioactive Releases Or Early Radioactive Releases
PRACTICAL ELIMINATION
Operational Criteria
Acceptance Criteria
Acceptance Criteria
Acceptance Criteria
Acceptance criteria < large / early release

# In relation to SSR-2/1 (Rev. 1)…

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**Requirement 8: Interfaces of safety with security and safeguards**

**Safety measures, nuclear security measures and arrangements for the State system of accounting for, and control of, nuclear material for a nuclear power plant shall be designed and implemented in an integrated manner so that they do not compromise one another.**

**Requirement 12: Features to facilitate radioactive waste management and decommissioning**

**Special consideration shall be given at the design stage of a nuclear power plant to the incorporation of features to facilitate radioactive waste management and the future decommissioning and dismantling of the plant.**

# …and related Safety Guides

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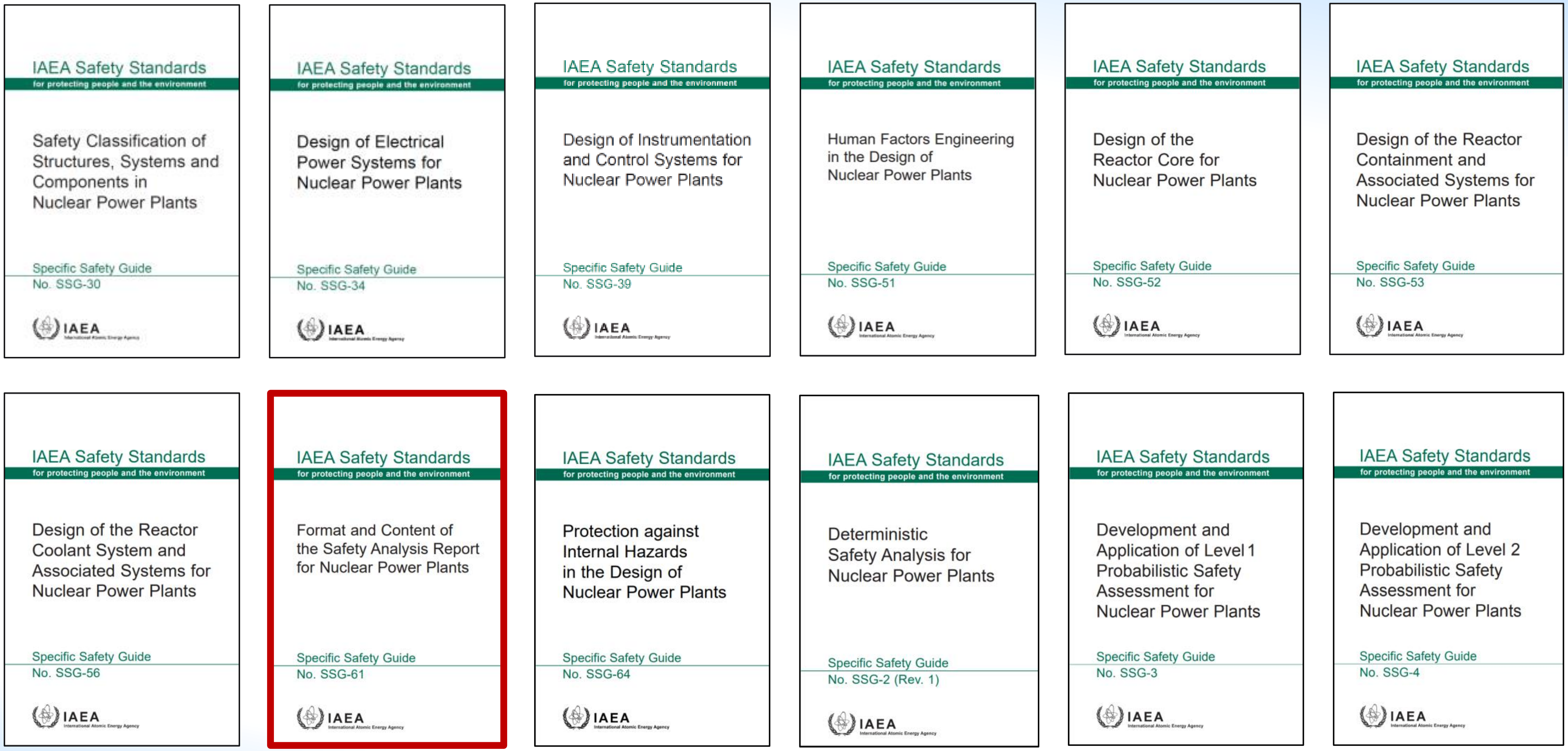

IAEA Safety Standards
for protecting people and the environment
Safety Classification of Structures, Systems and Components in Nuclear Power Plants
Specific Safety Guide
No. SSG-30
IAEA

IAEA Safety Standards
for protecting people and the environment
Design of Electrical Power Systems for Nuclear Power Plants
Specific Safety Guide
No. SSG-34
IAEA

IAEA Safety Standards
for protecting people and the environment
Design of Instrumentation and Control Systems for Nuclear Power Plants
Specific Safety Guide
No. SSG-39
IAEA

IAEA Safety Standards
for protecting people and the environment
Human Factors Engineering in the Design of Nuclear Power Plants
Specific Safety Guide
No. SSG-51
IAEA

IAEA Safety Standards
for protecting people and the environment
Design of the Reactor Core for Nuclear Power Plants
Specific Safety Guide
No. SSG-52
IAEA

IAEA Safety Standards
for protecting people and the environment
Design of the Reactor Containment and Associated Systems for Nuclear Power Plants
Specific Safety Guide
No. SSG-53
IAEA

IAEA Safety Standards
for protecting people and the environment
Design of the Reactor Coolant System and Associated Systems for Nuclear Power Plants
Specific Safety Guide
No. SSG-56
IAEA

IAEA Safety Standards
for protecting people and the environment
Format and Content of the Safety Analysis Report for Nuclear Power Plants
Specific Safety Guide
No. SSG-61
IAEA

IAEA Safety Standards
for protecting people and the environment
Protection against Internal Hazards in the Design of Nuclear Power Plants
Specific Safety Guide
No. SSG-64
IAEA

IAEA Safety Standards
for protecting people and the environment
Deterministic Safety Analysis for Nuclear Power Plants
Specific Safety Guide
No. SSG-2 (Rev. 1)
IAEA

IAEA Safety Standards
for protecting people and the environment
Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants
Specific Safety Guide
No. SSG-3
IAEA

IAEA Safety Standards
for protecting people and the environment
Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants
Specific Safety Guide
No. SSG-4
IAEA

…and many more

IAEA Safety Standards

for protecting people and the environment

Format and Content of the Safety Analysis Report for Nuclear Power Plants

Specific Safety Guide

No. SSG-61

IAEA

International Atomic Energy Agency

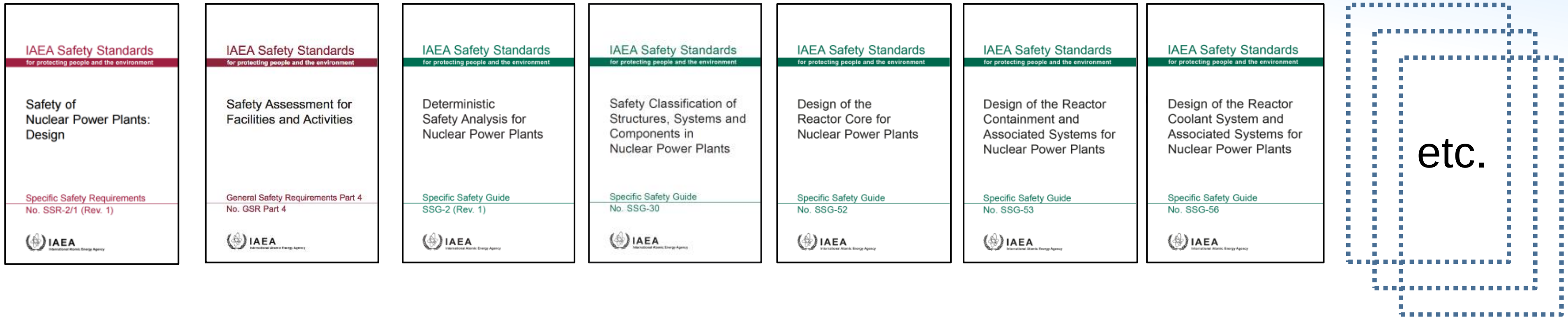
# CONTENT AND STRUCTURE OF THE SAR



- **Chapter 1:** Introduction and general considerations
- **Chapter 2:** Site characteristics
- **Chapter 3:** Safety objectives and design rules for structures, systems and components
- **Chapter 4:** Reactor
- **Chapter 5:** Reactor coolant system and associated systems
- **Chapter 6:** Engineered safety features
- **Chapter 7:** Instrumentation and control
- **Chapter 8:** Electrical power
- **Chapter 9:** Auxiliary systems and civil structures
- **Chapter 10:** Steam and power conversion systems
- **Chapter 11:** Management of radioactive waste
- **Chapter 12:** Radiation protection
- **Chapter 13:** Conduct of operations
- **Chapter 14:** Plant construction and commissioning
- **Chapter 15:** Safety analysis
- **Chapter 16:** Operational limits and conditions for safe operation
- **Chapter 17:** Management for safety
- **Chapter 18:** Human factors engineering
- **Chapter 19:** Emergency preparedness and response
- **Chapter 20:** Environmental aspects
- **Chapter 21:** Decommissioning and end of life aspects

# Advanced Reactors

IAEA Safety Standards for NPPs are based on WCRs, primarily LWRs. They may be applied with judgement to other types.




The IAEA is working with Member States to develop and implement a programme of work to:

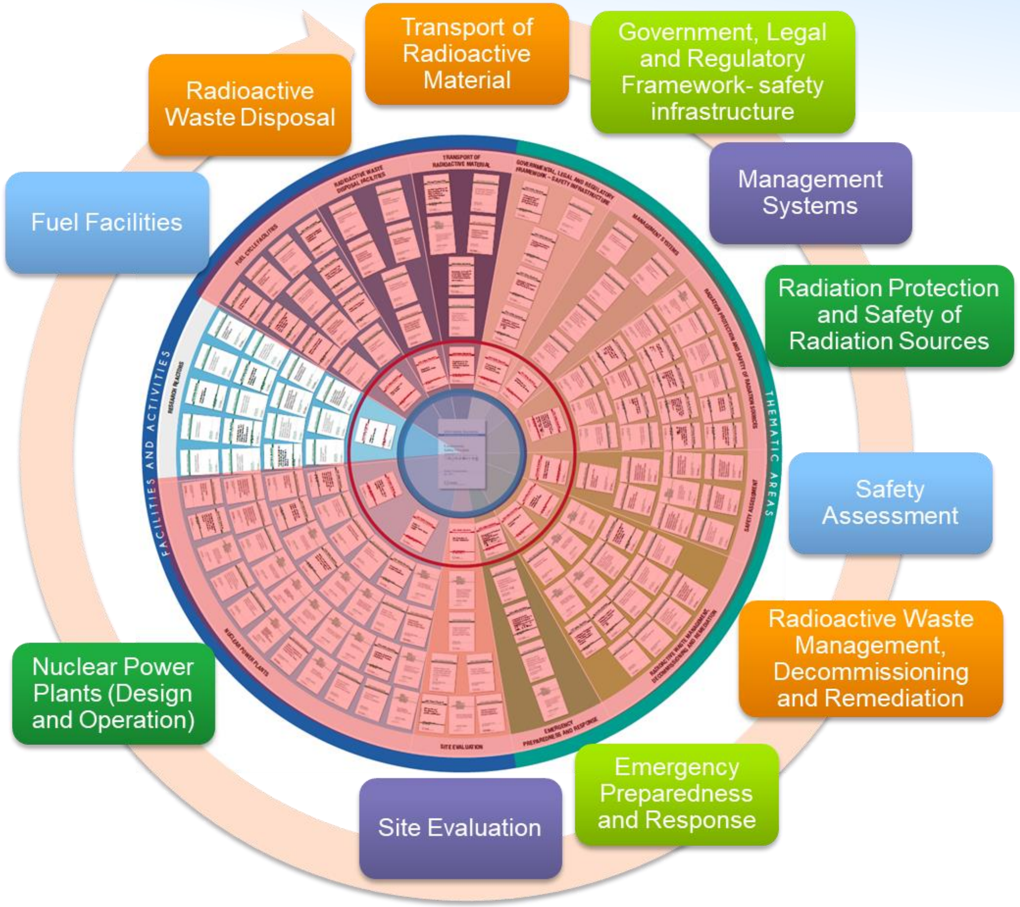
1. Enhance applicability of safety standards to SMRs and NWCRs as part of planned ‘reviews’ of safety standards (Dep. of Nuclear Safety and Security)
2. Providing fora for information exchange on the safety of NWCRs, e.g. LMFR, HTGR and MSR (including joint IAEA-GIF Workshops)
3. Support Member States in the development of advanced reactors’ technology, including NWCRs (Department of Nuclear Energy)

# Applicability of IAEA Safety Standards to Non-Water-Cooled Reactors and Small Modular Reactors

- Consideration of NWCRs and SMRs
- The vast majority of safety standards
- More than 150 experts from 30 countries and 40 organizations

***Safety Reports Series No. 123***

Published in December 2023



# Main findings - Examples (SSR-2/1 (Rev.1))

IAEA

- *“Areas of non-applicability”*

Requirement 13, para 5.1

*Plant states shall typically cover: (a) Normal operation; (b) Anticipated operational occurrences, which are expected to occur over the operating lifetime of the plant; (c) Design basis accidents; (d) Design extension conditions, including accidents with core melting.*

Significant fuel damage and core damage including core melting scenarios are claimed to be precluded in some EIDs (e.g., HTGR and some MSR designs).

Requirement 58

6.28. The capability to remove heat from the containment shall be ensured, in order to reduce the pressure and temperature in the containment, and to maintain them at acceptably low levels after any accidental release of high energy fluids […]

in the case of some EIDs, such as LFRs, no pressure increase is expected. For SFRs, sodium leakage and combustion may be a cause of pressure increase.

# Main findings - Examples (SSR-2/1 (Rev.1))

IAEA

- *"Areas of non-applicability"*

Requirement 55, para 6.20

*The containment structure and the systems and components affecting the leaktightness of the containment system shall be designed and constructed so that the leak rate can be tested after all penetrations through the containment have been installed and, if necessary, during the operating lifetime of the plant, so that the leak rate can be tested at the containment design pressure.*

Some EIDs, especially HTGRs, apply a confinement concept rather than a containment system by claiming that sufficient retention is ensured by other barriers. Currently, most HTGR designs are not equipped with a containment structure. In general, the containment structure (if there is one) may be claimed to have minor importance for retention of radioactive substances in these EIDs.

Requirement 43

*Fuel elements and assemblies for the nuclear power plant shall be designed to maintain their structural integrity, and to withstand satisfactorily the anticipated radiation levels and other conditions in the reactor core, in combination with all the processes of deterioration that could occur in operational states.*

Some designs (e.g., MSRs and HTGRs) may not use fuel elements and assemblies as traditionally understood and therefore structural integrity requirements would need to be interpreted to, for example, the equivalent physical barriers.

# Main findings - Examples (SSR-2/1 (Rev.1))

IAEA

- *“Gaps and areas for additional consideration”*

Requirement 17, para 5.16

*The design shall take due account of internal hazards such as fire, explosion, flooding, missile generation, collapse of structures and falling objects, pipe whip, jet impact and release of fluid from failed systems or from other installations on the site. Appropriate features for prevention and mitigation shall be provided to ensure that safety is not compromised.*

Even though the list of hazards indicated in this requirement does not intend to be a comprehensive list of hazards to be considered, examples of internal hazards that are specific to EIDs are not explicitly mentioned (e.g., sodium fire and sodium−water reaction for SFRs, graphite fire for HTGRs).

Requirement 33

*Each unit of a multiple unit nuclear power plant shall have its own safety systems and shall have its own safety features for design extension conditions.*

If ‘unit’ is interpreted as ‘module’, a common external pool, confinement system or other shared safety features foreseen in some EIDs, these EIDs would not comply with this requirement.

# Main findings - Examples (SSR-2/1 (Rev.1))

IAEA

- *"Gaps and areas for additional consideration"*

Requirement 50

Adequate facilities shall be provided at the nuclear power plant for the removal from the reactor coolant of radioactive substances, including activated corrosion products and fission products deriving from the fuel, and non-radioactive substances.

Specific issues associated with control of the chemical behaviour of a molten salt, and specifically with corrosion control, are not covered. In the same way, LFRs require adequate corrosion control from a point of view of core coolability; this is also not mentioned.

Requirement 78

Systems shall be provided for treating solid radioactive waste and liquid radioactive waste at the nuclear power plant to keep the amounts and concentrations of radioactive releases below the authorized limits on discharges and as low as reasonably achievable.

This requirement may not account for gaseous radioactive waste from EIDs. In particular, two relevant aspects are gaseous radioactive waste coming from the helium purification system in an HTGR and managing polonium in LFRs.

# Main findings - Examples (SSR-2/1 (Rev.1))

IAEA

- *“Gaps and areas for additional consideration”*

Requirement 68

*The design of the nuclear power plant shall include an emergency power supply capable of supplying the necessary power in anticipated operational occurrences and design basis accidents, in the event of a loss of off-site power. The design shall include an alternate power source to supply the necessary power in design extension conditions.*

EIDs technology designs might:

- Do not require safety grade AC power;
- Rely more on DC power supply for controlling loss of off-site power and accident conditions, but may only need compartmentalized or even no DC power for some of the functions mentioned in the text;
- Do not need to foresee an alternate power source;
- Do not foresee a prime mover;
- Do not need non-permanent equipment except for DC power supply;
- And, consequently, have a different electrical power system architecture with reduced levels of redundancy, diversity, and capacity.


## New Safety Guide under development (DS537)

Will provide recommendations on approaches to address, mitigate, and/or resolve unknowns associated with innovative technology to support safety demonstrations for these reactors.

The approach is technology neutral and aims to complement existing Safety Standards.

Target publication date: 2026

IAEA-TECDOC######

***Analysis and Modelling of Severe Accidents for LMFRs: Report of a Technical Meeting***

DRAFT



30 representatives, 11 Member States from R&D organizations, design organizations, national regulators and TSO

# Objectives and scope

To illustrate the status of knowledge (and in some cases, particularly for SFRs, the state-of-the-art) in the understanding of physical phenomena, development of models and numerical tools, and validation through experimental data, pertaining to severe accident in LMFRs.

The scope covers the various phases of progression of severe accident sequences in SFRs and, as applicable, also to LFRs.

Target publication date: Q4 2024

IAEA-TECDOC######

***Considerations on the safety of Liquid Metal Cooled Fast Reactors***

1. *Introduction*
2. *General features of LMFRs*
3. *Approaches for design and safety assessment for the prevention and mitigation of accidental sequences leading to severe accidents*
4. *LMFRs features which influence safety*
5. *Conclusion*



Regulators/TSOs and designer organizations from BEL, CHN, FRA, IND, JPN, RUS, USA

# Objectives and scope

To present safety approaches and design features adopted by Member States in the design and safety assessment of LMFRs (SFRs and LFRs, including LBE) with an emphasis on accident sequences leading to severe accidents.

The TECDOC illustrates practices by design organizations and licensee organizations in developing the safety demonstration related to the consideration of severe accidents, as well as practices by national regulatory bodies in reviewing the corresponding safety.

Target publication date: Q1 2025

IAEA-TECDOC######

***Considerations on the safety of High Temperature Gas Cooled Reactors***

Design organizations, regulators/TSOs, research institutes
FRA, GER, USA, CHN, JPN

# Objectives and scope

To present the main safety characteristics of HTGRs and the available operating experience on the safety of this reactor technology.
The TECDOC illustrates HTGRs key safety design features, including the approaches for satisfying the fundamental safety functions and the systems typically used to fulfil these functions.

Two types of HTGRs: pebble-bed and prismatic
Review of existing designs with a focus of one pebble-bed and one prismatic reactor (design basis, DEC, etc.)

IAEA-TECDOC######

***Considerations on the safety of Molten Salt Cooled Reactors***

Design organizations, regulators/TSOs, research institutes
FRA, CAN, USA, DEN

# Objectives and scope

To present the main safety characteristics of MSRs and the available operating experience on the safety of this reactor technology.
The TECDOC illustrates MSRs key safety design features, including the approaches for satisfying the fundamental safety functions and the systems typically used to fulfil these functions.

Liquid and solid fuel, fast and thermal spectrum, fluoride and chloride salt, refueling/no-refueling during operation.
Review of existing designs, design considerations for design basis, DEC, etc.

Consultancy meeting planned
**8-12 July 2024** in Vienna

# CAPACITY BUILDING

# Upcoming events related to NWCRs

- *Technical Meeting on Severe Accident Analysis and Management for Non-Water-Cooled Reactors,* **14-17 Oct 2024, Vienna**
- *Technical Meeting on Advanced Manufacturing and Qualification Programmes for New Materials for Small Modular Reactors and Non-Water-Cooled Reactors: Safety Considerations,* **18-22 Nov 2024, Vienna**

- *Interregional Workshop on Safety, Security and Safeguards by Design in Small Modular Reactors EVT2306208, 4 to 8 November 2024, Oak Ridge, TN, US.*
- *Training Course on Safety aspects of Small Modular Reactors and other innovative reactor technologies, EVT2304103, 4 to 8 November 2024, Fukui, Japan.*
- *Training Course on Design Safety and Safety Assessment for a Nuclear Power Plant, including SMRs, October 2024, St. Petersburg, Russian Federation.*

# TECHNICAL SAFETY REVIEWS (TSR)

# Technical Safety Review (TSR) Services

The TSR services encompass six technical subject areas dedicated to:

- Accident Management (AM)
- Design Safety (DS)
- Generic Reactor Safety (GRS)
- Safety Requirements (SR)
- Periodic Safety Review (PSR)
- Probabilistic Safety Assessment (PSA)

… and we are now adding “Safety, Security and Safeguards by design” (3S).


[Technical Safety Review (TSR) | IAEA]


IAEA

# Nuclear Harmonization and Standardization Initiative (NHSI)

NHSI was initiated in 2022 with the **goal** of enabling the the **effective global deployment of safe and secure advanced nuclear reactors**.

➢ **Regulatory Track**

To set a roadmap for increasing regulatory collaboration towards global **harmonisation in the pre-licensing process**, and international certification of selected SMR designs – with an agreed expectation of the high levels of safety and security for such advanced designs.

➢ **Industrial Track**

To set a roadmap for technology holders and operators to develop **more standardized industrial approaches** for design, manufacturing, construction, commissioning, and operation of SMRs, as well as generic users' requirements and criteria.

# NHSI Regulatory Track Phase I (2022-2024)

## TYPES OF COOPERATION

**Collaborative reviews**: independent review against national requirements, discussing with other regulatory bodies but reaching different decisions

**Joint reviews**: team of regulatory bodies jointly review a design against common requirements reaching joint decision

**Leveraging** of regulatory reviews: review against national requirements with use of other regulatory bodies' reviews

## NHSI WG1

Framework for **information sharing**

- Agreements to share controlled information and repository collating publicly available information

## NHSI WG2

**Towards harmonization:** multinational pre-licensing review process

- A single team and a single review outcome
- Early identification of design "showstoppers"
- **Commitment to avoid duplication**

## NHSI WG3

SMR REGULATORS' FORUM

Two processes increasing cooperation – building on **current initiatives**

1. Leveraging existing regulatory reviews
2. Collaborative reviews: collaboration between national reviews (independent national reviews in parallel but with information exchange)

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*Thank you for your attention*

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