Overview of IAEA Activities on the Safety of Fast Reactors

Technical Meeting on Advances and Innovations in Fast Reactor Design and Technology

Vienna, 29 September - 3 October 2025

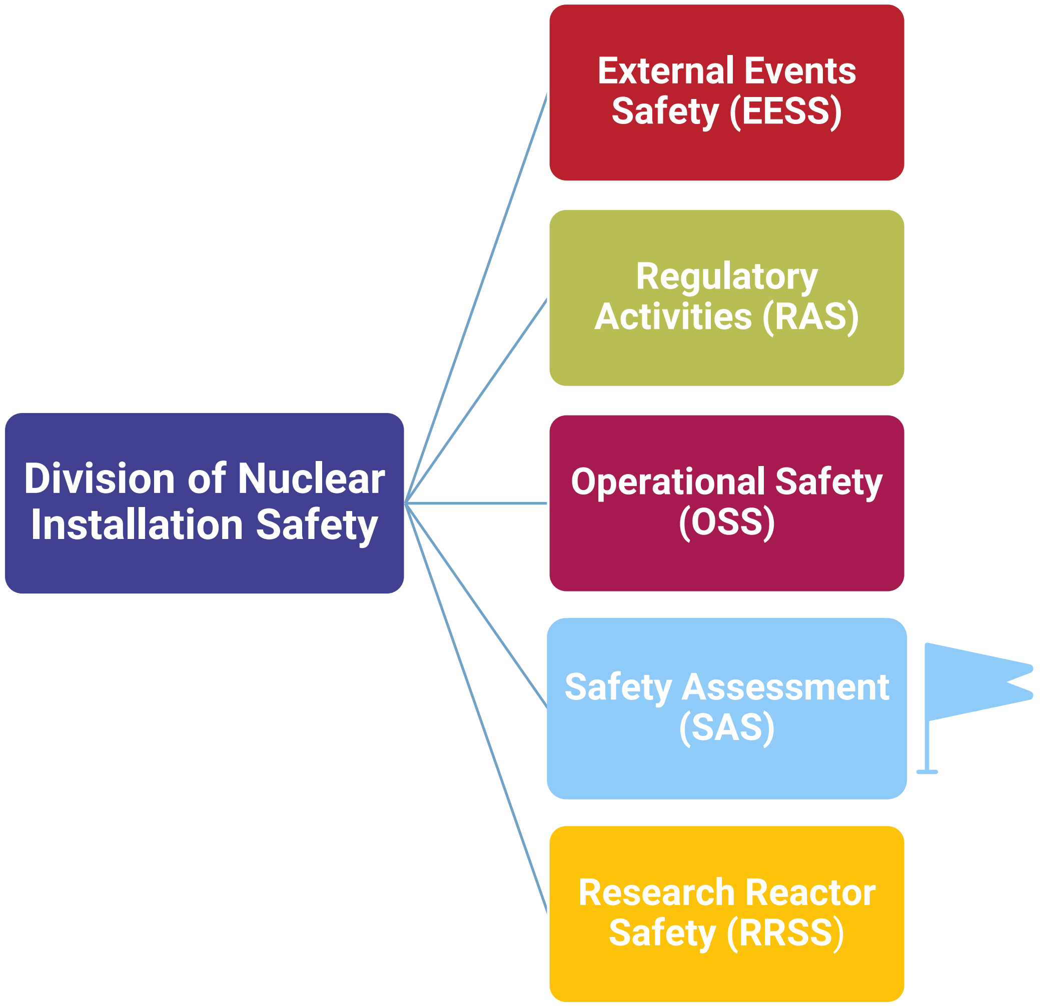
Vincenzo Tiberi

IAEA, Safety Assessment Section

Division of Nuclear Installation Safety

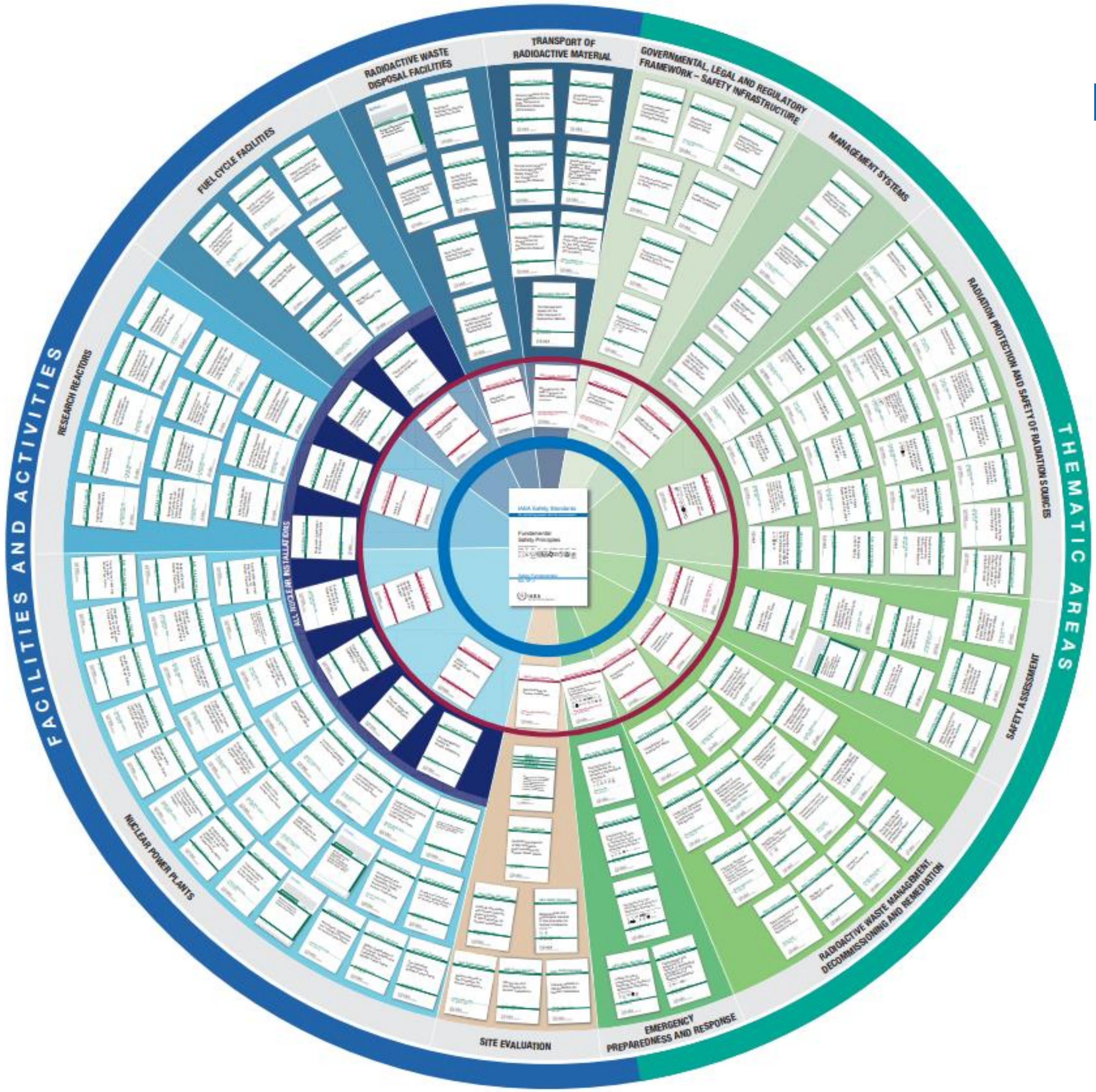
Department of Nuclear Safety and Security

DIVISION OF NUCLEAR INSTALLATION SAFETY (NSNI)

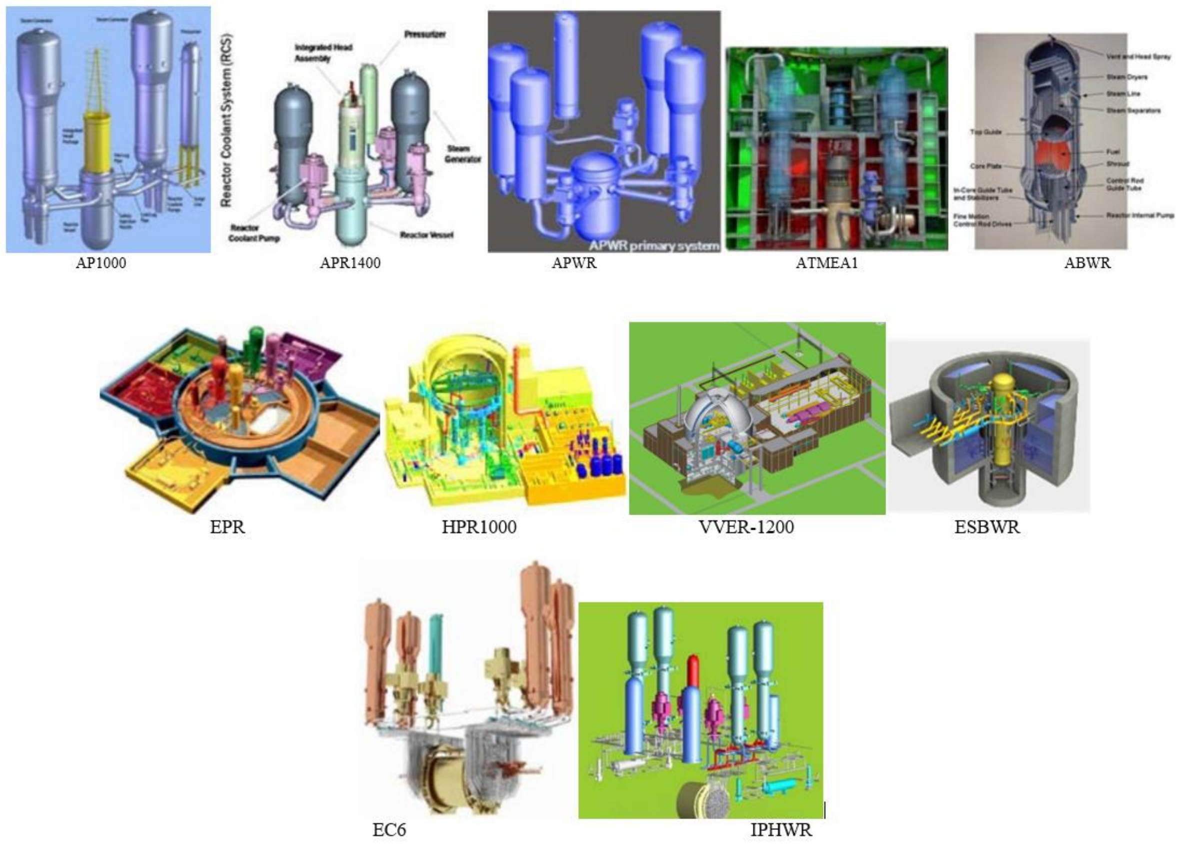


- Development of **safety standards** for nuclear installations
- Provision of **safety reviews and advisory services** to support the effective application of the safety standards
- Support to Member States in building and sustaining **capability and capacity** in nuclear safety

Safety Standards

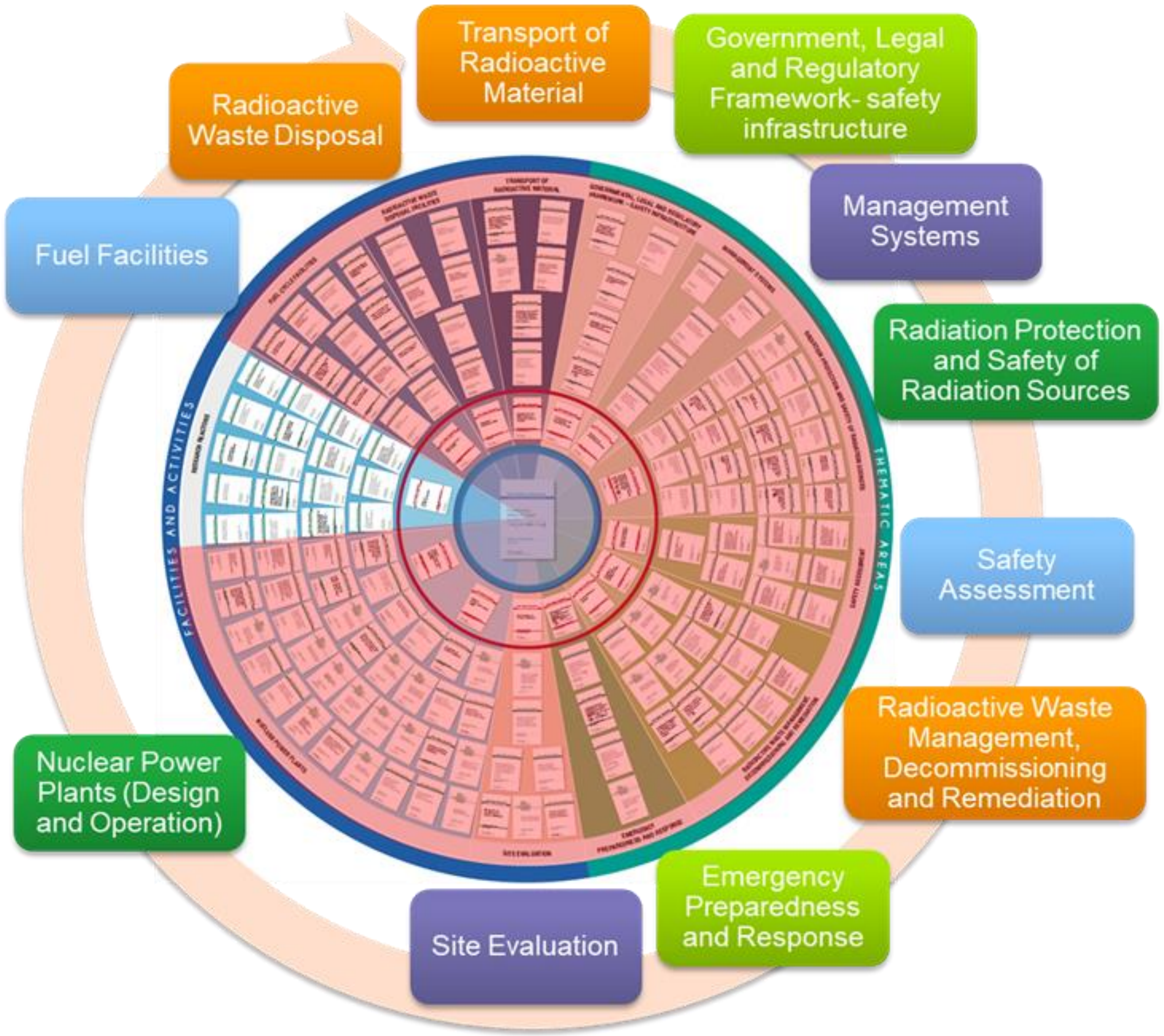


Land based stationary NPPs with water cooled reactors



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

Applicability of IAEA Safety Standards to NWCRs and SMRs



Are Safety Standards sufficient and relevant to ensure the safety of SMRs and Non Water Cooled Reactors?

[*Safety Reports Series No. 123*]()

SUMMARY OF REVIEW OUTCOMES

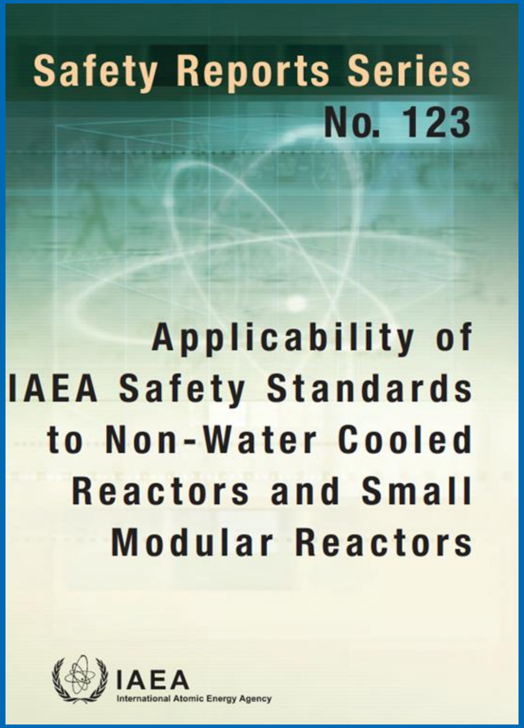
	No applicability considerations (areas of non applicability, gaps, areas for further consideration)	Small number of applicability considerations/ very small impact on safety standard	Some applicability considerations/ small impact on safety standard	Numerous applicability considerations/ more than a third of the safety standard impacted
Siting		SSR-1 SSG-35 SSG-9 SSG-18 SSG-21 NS-G-3.6 NS-G-3.1 NS-G-3.2		
Design and Construction	SSG-30	SSG-68 SSG-67 SSG-69 DS524	**SSR2/1** SSG-64 SSG-34 SSG-39 SSG-62 SSG-38 SSG-51	SSG-52 SSG-56 SSG-53 SSG-63
Commissioning and Operation	SSG-50	SSG-70 SSG-71 SSG-72 SSG-73 SSG-74 SSG-75 SSG-76 SSG-77 SSG-13 SSG-28 SSG-48	**SSR2/2**	
Fuel Cycle Facilities	SSG-27 SSG-43	**SSR4** SSG-5 SSG-6 SSG-7 SSG-42		
Radiation Protection and Safety	**GSR- Part3** GSG-8 RS-G-1.7	GSG-7 GSG-9 GSG-10		
Management of Waste and Spent Fuel	GSG-16 SSG-45 GSG-3 DS512 SSG-31 SSG-23	**GSR-Part 5** GSG-1 WS-G-6.1 **SSR-5** SSG-14 SSG-40 SSG-29	SSG-41 SSG-15	
Decommiss.	WS-G-5.1 W-G-5.2	**GSR-Part6** SSG-47		
LMfS		**GSR- Part2** GS-G-3.5		
Safety Assessment		**GSR-Part4** SSG-25 NS-G-2.13	SSG-2 SSG-3 SSG-54	SSG-4
EPR	**GSR-Part7** GSG-2 GSG-11 SSG-14	GS-G-2.1 SSG-65		
Legal and Regulation Transport	GSG-6	**GSR-Part1** SSG-12 GSG-13 GSG-9 SSG-16		**SSR-6**

Design Safety and Safety Assessment of Advanced NPPs: IAEA's 10 years vision

Requirements and Safety guides	Year	2025				2026				2027				2028				2029				2030				2031				2032				2033				2034				2035			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
SSR-2/1 (Rev.1) Design requirements	2016		1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	8	8	9, 10	11	12	12	13	14																		
SSG-30 Safety Classification of SSCs	2014						1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14																			
SSG-34 Electrical systems	2016								1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14																	
SSG-38 Construction of NPPs	2015												1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14													
SSG-39 Instrumentation and control	2016								1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14															
SSG-51 Human Factors Engeineering	2019												1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14											
SSG-52 Reactor core design	2019						1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14																	
SSG-53 Reactor containment	2019						1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14																	
SSG-56 Reactor coolant	2020						1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14																	
SSG-62 Auxiliary systems	2020														1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14									
SSG-63 Fuel handling and storage	2020										1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14													
SSG-64 (Internal hazards	2021														1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14											
SSG-69 Equipment qualification	2021																		1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14							
SSG-88 Practical elimination	2024																						1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14			
SSG-90 Radiation protection	2024																		1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14							
SSG-61 Safety Analysis report	2021																		1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14							
GSR Part 4 (Rev.1) Safety assessment	2016						1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	13	14																		
SSG-2 (Rev.1) Deterministic safety analysis	2019												1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14													
SSG-3 (Rev.1) Level 1 PSA	2024																																												
SSG-4 (Rev.1) Level 2 PSA	2025	12	12	14																													1	2	3	4	4	5	5	5	5	5	6	7	7
SSG-X (L3PSA) Level 3 PSA	New	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14																									
SSG-X (DS537) Safety demonstration	New	7	8	9, 10	9, 10	11	12	14																																					
SSG-25 (Rev.1) Periodic safety review	2013	7	7	8	9, 10	9, 10	11	11	12	12	14																																		
SSG-54 Accident management	2019												1	2	3	4	4	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	14													
SSR-XX (New safety requirements Fusion)	New								1	2	3	4	4	5	5	5	5	5	5	5	6	7	7	8	8	9, 10	11	12	12	13	14														

4-7 March 2025, 25-27 June 2025 : 1st and 2nd Consultancy meetings on the revision of SSR 2/1

OUR PROGRAMME OF WORK



- New technical documents
- Compilation of inputs to future revision of relevant safety standards
- Enhancement of our training efforts
- Strengthen our Technical Safety Review services
- Plan our future work

Ensuring that we always respond to the needs of our Member States

NEW SAFETY GUIDE IN DEVELOPMENT

Why?

Because it’s not enough to state that a reactor is safe….

… it has to be demonstrated!

SAFETY OF ADVANCED TECHNOLOGIES

...and more

CROSS CUTTING TOPICS

Design Safety
&
Safety Assessment

IAEA-Safety Report#####

Safety Assessment for Small Modular Reactors and Non-Water-Cooled Reactors

IAEA-TECDOC####

Progress in the Performance Assessment and Regulation of Passive Safety Features in Advanced Nuclear Power Plant Designs

DRAFT

IAEA-Safety Report#####

Deterministic Safety Analysis for Operational States and Accident Conditions at Nuclear Power Plants
(Rev. 1 of Safety Series Report No 23)

IAEA-TECDOC####

Demonstration on DID Implementation using Deterministic and Probabilistic Approaches

IAEA-TECDOC####

Consideration for Qualification of Advanced Manufacturing and Materials for Components Important to Safety in Small Modular Reactors and Non Water Cooled Reactors

DRAFT

IAEA-TECDOC####

Safety Considerations in Non-Water-Cooled Reactor Core Design

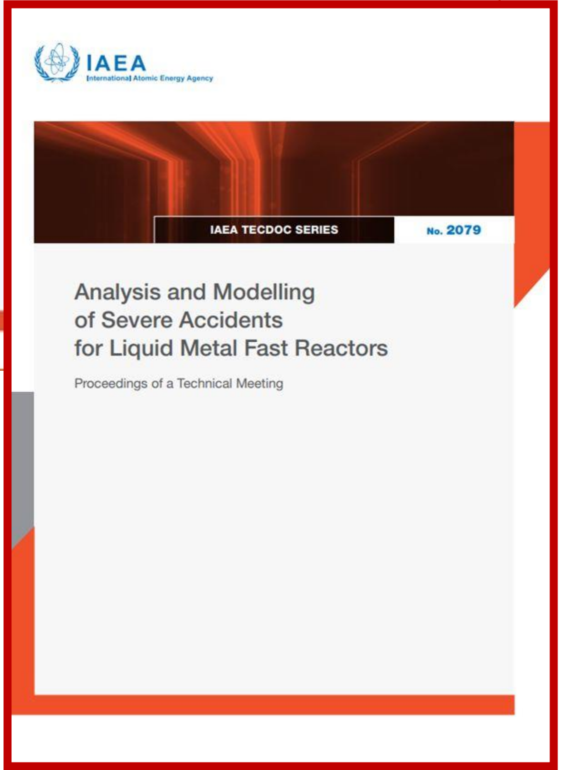
IAEA-TECDOC####

Safety and Security Implications of the use of Artificial Intelligence in Nuclear Power Plants

DRAFT

SAFETY OF ADVANCED TECHNOLOGIES

TECHNOLOGIES



IAEA-TECDOC####

Considerations on the safety of Liquid Metal Cooled Fast Reactors

DRAFT

Technical Report on Design Safety and Security Considerations of Floating Nuclear Power Plants

DRAFT

IAEA-TECDOC####

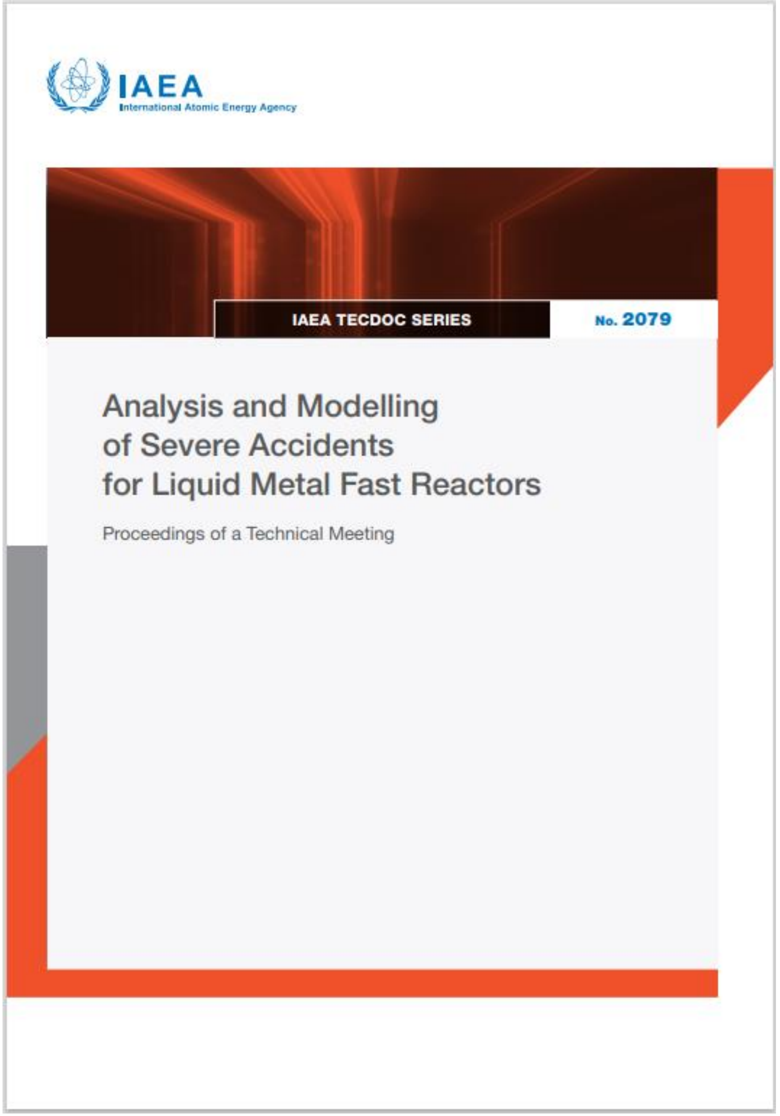
Considerations on the safety of Molten Salt Reactors

DRAFT

IAEA-TECDOC####

Considerations on the safety of High Temperature Gas Reactors

DRAFT



Objectives

This TECDOC aims to illustrate the status of knowledge of physical phenomena, development of models and numerical tools, and validation through experimental data, in relation to the progression of severe accidents in LMFRs.

For SFRs, the status of knowledge discussed at the technical meeting can be considered as being the state of the art in the field, considering that the attendees included a large majority of the key parties from design organizations, regulatory bodies, technical support organizations and R&D organizations, including both modellers of numerical codes and experimenters.

TECDOC – Analysis and Modelling of Severe Accidents for LMFRs

- The TECDOC encompasses severe accident sequences not ‘practically eliminated’ for LMFRs
  - **Deterministic modelling and analysis** of the severe accident progression
  - **Numerical codes** development and validation
  - Related **experimental programmes** for SFRs and, as applicable, LFRs

Mechanistic models for core degradation under severe accident conditions:

- fuel pin behaviour
- initiation/primary phase
- transition/secondary phase
- expansion phase
- material relocation
- long-term behaviour

+

- Radioactive material release and transport in-vessel and ex-vessel
- Conservative simplified/parametric fast-running models
- Code development and performance optimization, multi-physics approaches, platform architecture
- Experimental programmes, code validation, uncertainty analyses

TECDOC – Analysis and Modelling of Severe Accidents for LMFRs

Primary phase (initiating phase)

Fuel damage process starting from the intact state of the core

This phase ends with the failure of the fuel assembly duct

Expansion phase

Sequences encountered in case of an extreme mechanical energy release

Large mechanical energy release

Secondary phase (transition phase)

Core damage progression and relocation of the core materials after the fuel assembly hexagonal can failure

Long-term (post-accident) phase

Ability to cool the degraded core, including core material relocated on the core catcher, if any

TECDOC – Analysis and Modelling of Severe Accidents for LMFRs

SFR

- Severe accident analysis and experimental validation for SFRs (9 papers, France, Germany, Japan, USA, Russia)
- Primary and transition phases of severe accidents for SFRs (4 papers, USA, Japan, India)
- Expansion phase and long-term behaviour for SFRs (4 papers, Japan, France)

LFR

- Accident analysis and experimental programmes for LFRs (6 papers, Romania, Russia, China, Italy, Egypt)

TECDOC – Analysis and Modelling of Severe Accidents for LMFRs

SFR - Conclusions

- Severe accident methodologies have been developed in MS
  - One of the objectives: evaluate the **effectiveness of design measures implemented to cope with SA**
  - It is essential to **simulate all potential phenomena** along with their corresponding **interrelations**
- One important aspect of severe accident analysis for SFRs: evaluate the **mechanical energy releases which may damage the containment structures**, including the features implemented to maintain sub-criticality and to cool the core debris
- **Progress in the development and improvement of simulation tools for severe accidents analysis to model additional phenomena** and to account for mitigation systems in SFRs designs to achieve higher levels of confidence in safety assessments
- On-going **experimental programmes** support verification and validation of the physical and mathematical models

TECDOC – Analysis and Modelling of Severe Accidents for LMFRs

SFR - Conclusions

- Simulation tools for modelling the initiation/primary and transition/secondary phases developed and/or expanded to **include modelling of the additional phenomena to reduce the number of conservative assumptions** often made in severe accident analysis
- Simulation tools for the expansion phase and long-term behaviour have reached a **high level of complexity and address the most important phenomena of interest** (e.g. fluid structure interaction, FCI, fuel behaviour in degraded core and on core catcher)
- Complexity of phenomena -> high calculation time -> development of **fast-running codes**
- Efforts are also being devoted towards **high-performance communication** among these simulation tools
- A **rich experimental matrix** has been created. Additional experimental tests are needed to progress in the validation of physical correlations and of calculation tools for specific SFRs designs

TECDOC – Analysis and Modelling of Severe Accidents for LMFRs

SFR - Perspectives

- Knowledge and simulation of phenomena likely to damage the reactor structure. R&D is now mainly moving into the later phases of accident
- Integral code system development is underway for the systematic analysis of various accident sequences
- Phenomenological knowledge, analytical models, and experimental data, R&D needs
  - **Primary and secondary phase**: e.g., molten fuel discharge through the steel duct, jet impingement, continued code development to model more phenomena and reduce conservatisms, …
  - **FCI**: e.g., experimental programme to support the validation of FCI with large masses of corium
  - **Expansion phase**: expansion phase and fluid-structure interaction
  - **Long term material relocation and cooling**: debris bed behaviour, molten material behaviour and crust formation in the core catcher, coupling of thermo-hydraulic and neutronic models of the debris bed
  - **FP** release, transport, and retention under severe accident sequences (both for MOX and metal fuel)

TECDOC – Analysis and Modelling of Severe Accidents for LMFRs

LFR - **Conclusions and perspectives**

- **Lack of consensus on what accidental sequences leading to core degraded conditions are required to be mitigated**. A guidance is needed Integral code system development is underway for the systematic analysis of various accident sequences
- **The information provided on modelling of SA for LFRs is limited**. A good start can be the development of simplified models. A joint effort by the entire LFR community is recommended
- More **information was provided on the research facilities** (phenomena that play an important role in the normal operation and in accident conditions – no link with SA)

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 design features implemented to prevent and mitigate a severe accident
5. Conclusions

Objective

The objective of the publication is to present the safety approaches adopted by Member States in the design and safety assessment of LMFR, with an emphasis on accident sequences leading to severe accidents, while also highlighting specific design features of LMFR at preventing the occurrence, and mitigating the consequences, of such sequences.

The TECDOC presents 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 cases.

Target publication date: **Q4 2025**

TECDOC – Considerations on the Safety of LMFR

Definition of severe accidents for LMFRs

- The IAEA safety glossary (2022 edition) defines a severe accident as an "***accident more severe than a design basis accident and involving significant core degradation***".
- Similarly to LWR approach, **a core meltdown has been considered for previous SFRs and this is still the case for most of new SFRs designs**. **For LFRs and some of the new SFRs, the vendors claim that their design has inherent safety characteristics that allow to preclude a core meltdown**. If this approach is accepted by the regulators, the severe accident sequences to consider as DEC-B will be discussed in the licensing process.
- It can be noted that the consideration of severe accidents is associated with a potential radiological release. Although the core is a major potential contributor to the radiological release, other potential contributors will also need to be considered (e.g., the spent fuel handling and storage systems or the polonium production in lead or LBE of LFRs).

TECDOC – Considerations on the Safety of LMFR

Prevention of severe accidents

- Focus on **DEC-A**:
  - Combinations of **frequent initiators** with the **failure of active shutdown systems**
  - Combinations of **frequent initiators** with the **failure of some DHR systems**
- Regulators may request to assess as DEC-A **additional accident conditions related to LMFR-specific risks**, like local core faults.
- **Identification of sequences** that could develop into a severe accident (e.g., loss of forced flow through the core, local loss of flow in a fuel subassembly).
- **Orientations** guiding the design of prevention of severe accidents (passive features, redundancy, diversity…).

TECDOC – Considerations on the Safety of LMFR

Mitigation of severe accidents

- **Identification of sequences** considered as a severe accident (**DEC-B**. e.g., ULOF)
- **Severe accidents phenomena** (e.g., potential mechanical energy release inside the reactor vessel, dispersion of core debris inside the primary circuit, risk of recriticality, …)
- **Orientations guiding the design** for mitigation of severe accidents (e.g., core and fuel design characteristics, debris tray, containment)
- **Safety demonstration** supporting the robustness of mitigation features (deterministic and probabilistic safety analysis, sensitivity studies)

TECDOC – Considerations on the Safety of LMFR

Rationale for ‘practical elimination’

- Accident conditions leading to an **important mechanical energy release** that could jeopardize the capability of the containment to confine the radionuclides released during the sequence
- Accident conditions leading to the damage of reactor and containment structures due to the **total loss of their cooling functions**
- Accident conditions occurring with **no confinement measures implemented** to withstand the consequences of the severe accident (e.g., fuel handling procedures)
- For some designs: “practical elimination” of any accident condition leading to a whole core meltdown

Resources available to Member States

OUR SERVICE: TECHNICAL SAFETY REVIEW (TSR)

- **Independent peer review** of a reactor design safety assessment documentation
- Scope and level of detail **tailored to the needs of the MS** requesting it
- It may cover:
  - The entire safety analysis report (**SAR**)
  - **Specific parts of the SAR**, e.g., reactor, I&C, DSA, PSA, etc
  - Related safety areas, i.e., accident management programme, PSR, or national safety requirements

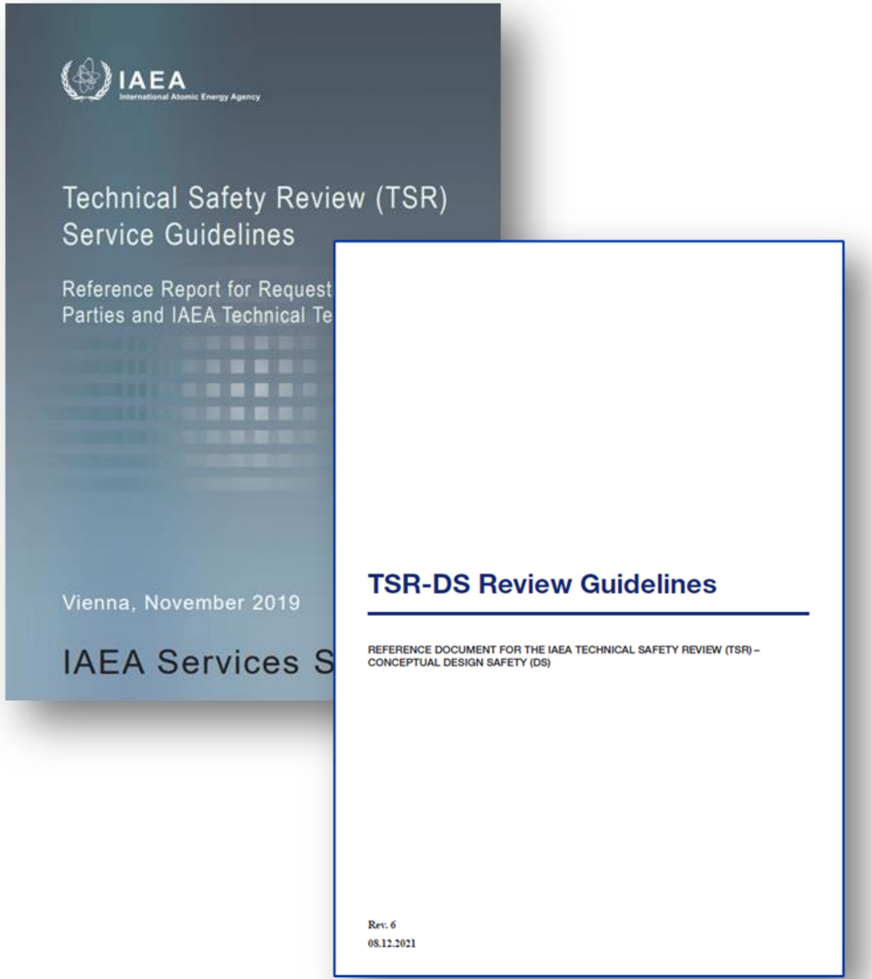
TSR

IAEA

TECHNICAL SAFETY REVIEW

Reference: IAEA Safety Standards

TECHNICAL SAFETY REVIEW (TSR)



[Technical Safety Review (TSR) | IAEA]

SMR SAFETY ACADEMY

Week 1

Improve participants practical knowledge on SMR safety characteristics and challenges

Week 2

Improve participants practical knowledge on how to conduct design safety reviews of SMRs

Technologies addressed: **Water-cooled SMRs**, Sodium-cooled fast reactors (**SFRs**), Lead- and lead-bismuth cooled Fast Reactors (**LFRs**), High Temperature Gas Reactors (**HTGRs**), Molten Salt Reactors (**MSRs**)

IAEA-GIF Joint Workshop on the Safety of NWCRs

INTERNATIONAL
CONFERENCE

Topical issues in nuclear installation safety

Learning from the past to accelerate the future

29 JUNE – 3 JULY 2026
Vienna, Austria

THANK YOU

v.tiberi@iaea.org