IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Overview of IAEA Safety Standards in the area of safety analysis

focus on innovative reactors

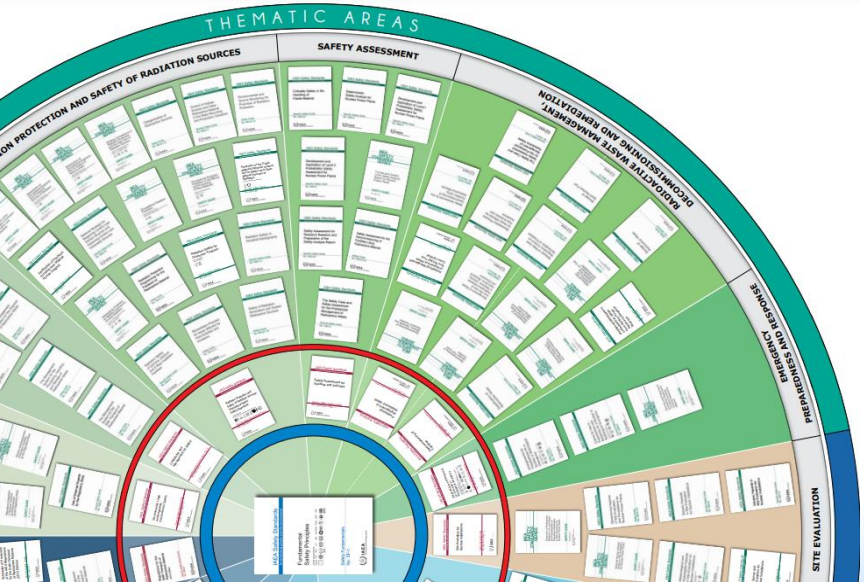
Shahen POGHOSYAN
Safety Assessment Section (SAS)
Division of Nuclear Installation Safety (NSNI)
Department of Nuclear Safety and Security (NS)
International Atomic Energy Agency (IAEA)

R2CA final open workshop, 29-30 November 2023

Outline

- **Intro:** overview of main IAEA activities on safety analysis
- **IAEA Safety Standards** & innovative reactors (e.g. SMRs)
- **Other IAEA publications** on safety analysis relevant to SMRs
- **Technical Safety Reviews** based on IAEA Safety Standards
- **IAEA events** on SMRs

Overview of IAEA Safety Standards on Safety Analysis



MUST
Safety objectives and safety principles

SHALL
Functional conditions required for safety

SHOULD
Guidance on what should be done to fulfil the requirements

IAEA publications on safety assessment

Safety Standards

Consensus documents, formal process for MS feedback

Safety Standards

- GSR Part 4(Rev.1): Safety Assessment for Facilities and Activities

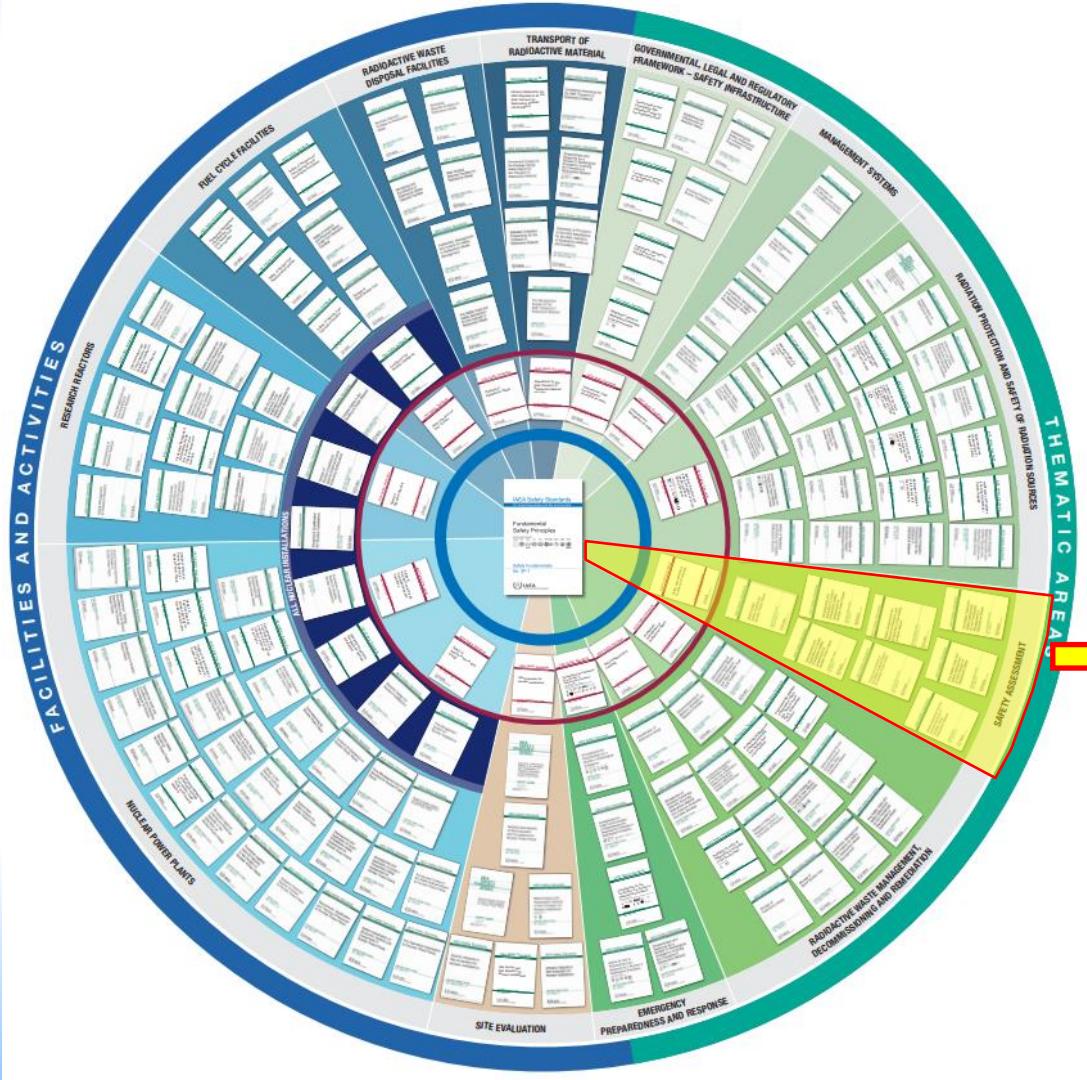
- SSG-2(Rev.1): **DSA for NPP**
- SSG-3(Rev.1): **Level 1 PSA** (under revision Step 14 out of 14)
- SSG-4: **Level 2 PSA** (under revision Step 8 out of 14)
- SSG-?: **Level 3 PSA** (to be initiated, proposed by NUSSC)
- SSG-61: **Format and content** of SAR

TECDOCs & Safety Reports

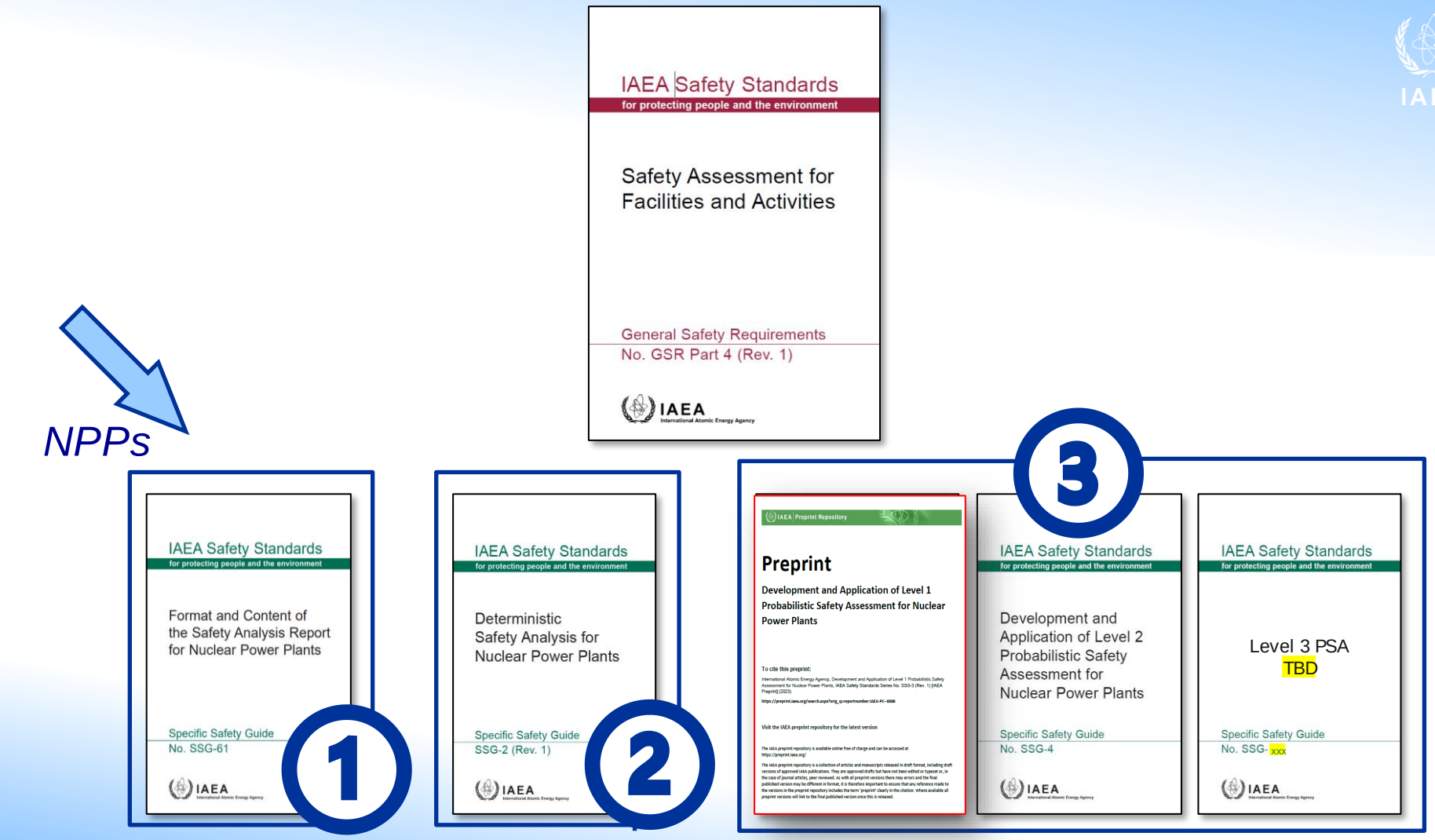
Describing best practices **and MS experience, challenges for specific topic. More detailed, but not consensus documents**

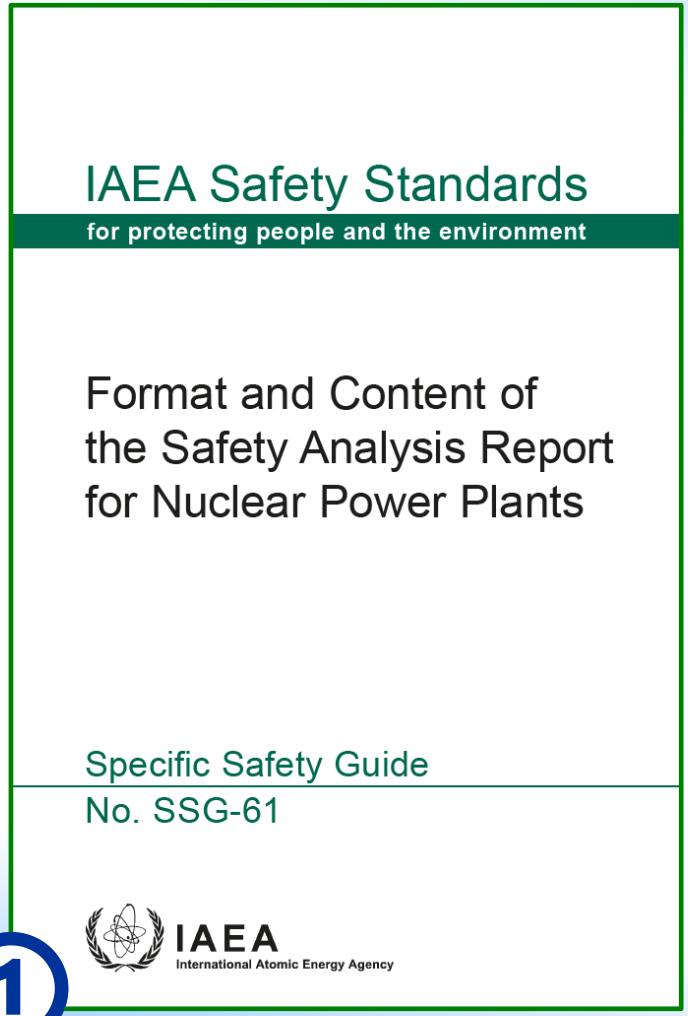
Safety Reports & TECDOCs

- Multi-unit PSA (No 110)
- Research Reactors PSA (No107)
- Applicability of Saf.Stnd. to NWCR and SMR (see 4.11) (No 123)
- DiD assessment (No 46 Rev.1)
- Seismic PSA (TECDOC-1937)
- Risk aggregation (TECDOC-1983)
- CANDU PSA (L1 & L2)
- Human Reliability Analysis*
- Safety Assessment for SMRs
- Passive systems in Design & SA
- Use of PSA & DSA for security
- Advanced PSA methods
- L2 PSA practices (TM results)
- PSA in design (TM results)
- Sev.Acc. analysis for NWCR


FACILITIES AND ACTIVITIES
RESEARCH REACTORS
FUEL CYCLE FACILITIES
RADIOACTIVE WASTE DISPOSAL FACILITIES
TRANSPORT OF RADIOACTIVE MATERIAL
GOVERNMENTAL, LEGAL AND REGULATORY FRAMEWORK – SAFETY INFRASTRUCTURE
MANAGEMENT SYSTEMS
RADIATION PROTECTION AND SAFETY OF RADIATION SOURCES
THEMATIC AREAS
SAFETY ASSESSMENT
RADIOACTIVE WASTE MANAGEMENT, DECOMMISSIONING AND REMEDIATION
EMERGENCY PREPAREDNESS AND RESPONSE
SITE EVALUATION
NUCLEAR POWER PLANTS
IAEA Safety Standards
Fundamental Safety Principles


IAEA Safety Standards
Safety Assessment for Facilities and Activities
General Safety Requirements
No. GSR Part 4 (Rev. 1)
IAEA Safety Standards
Criticality Safety in the Handling of Fissile Material
Specific Safety Guide
No. SSG-27
IAEA Safety Standards
Deterministic Safety Analysis for Nuclear Power Plants
Specific Safety Guide
No. SSG-2 (Rev. 1)
IAEA Safety Standards
Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants
Specific Safety Guide
No. SSG-3
IAEA Safety Standards
Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants
Specific Safety Guide
No. SSG-4
IAEA Safety Standards
Format and Content of the Safety Analysis Report for Nuclear Power Plants
Specific Safety Guide
No. SSG-61
IAEA Safety Standards
Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report
Specific Safety Guide
No. SSG-20
IAEA Safety Standards
Safety Assessment for the Decommissioning of Facilities Using Radioactive Material
Safety Guide
No. WS-G-5.2
IAEA Safety Standards
The Safety Case and Safety Assessment for the Disposal of Radioactive Waste
Specific Safety Guide
No. SSG-23
IAEA Safety Standards
The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste
General Safety Guide
No. GSG-3
SAFETY ASSESSMENT

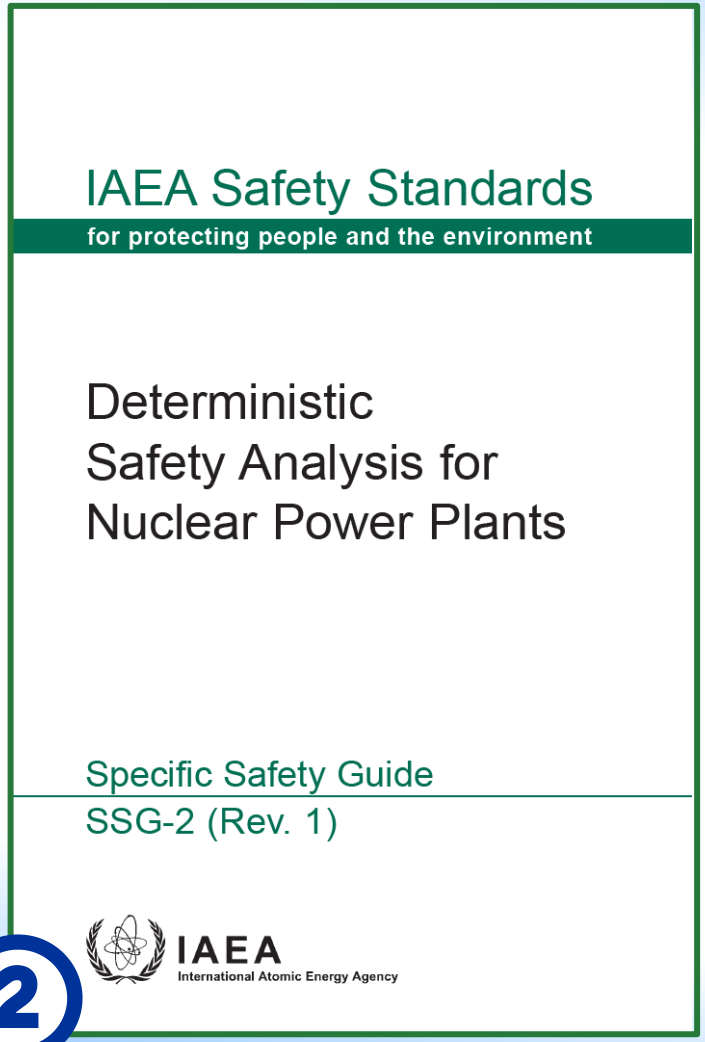

IAEA Safety Standards
for protecting people and the environment
Safety Assessment for Facilities and Activities
General Safety Requirements
No. GSR Part 4 (Rev. 1)
IAEA
International Atomic Energy Agency
NPPs
IAEA Safety Standards
for protecting people and the environment
Format and Content of the Safety Analysis Report for Nuclear Power Plants
Specific Safety Guide
No. SSG-61
IAEA
1
IAEA Safety Standards
for protecting people and the environment
Deterministic Safety Analysis for Nuclear Power Plants
Specific Safety Guide
SSG-2 (Rev. 1)
IAEA
2
3
IAEA Preprint Repository
Preprint
Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants
To cite this preprint:
Visit the IAEA preprint repository for the latest version
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
IAEA Safety Standards
for protecting people and the environment
Level 3 PSA
TBD
Specific Safety Guide
No. SSG-xxx
IAEA



1

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



2

Chapter 1: Introduction

Chapter 2. General considerations

Chapter 3. Identification categorization and grouping of initiating events and accident scenarios

Chapter 4. Acceptance criteria for DSA

Chapter 5. Use of computer codes for DSA

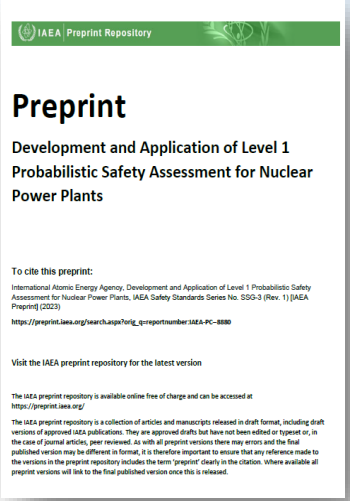
Chapter 6. General approaches for ensuring safety margins in DSA

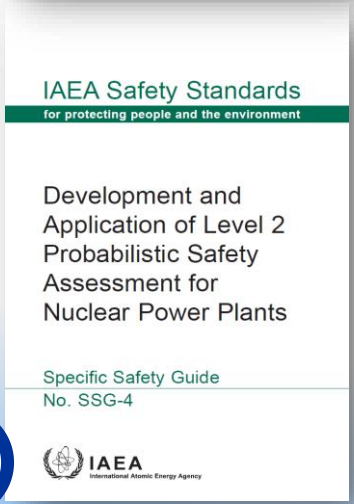
Chapter 7. DSA for different plant states

Chapter 8. Documentation, review and updating of DSA

Chapter 9. Independent verification of DSA by the licensee

Annex. Applications of deterministic safety analysis

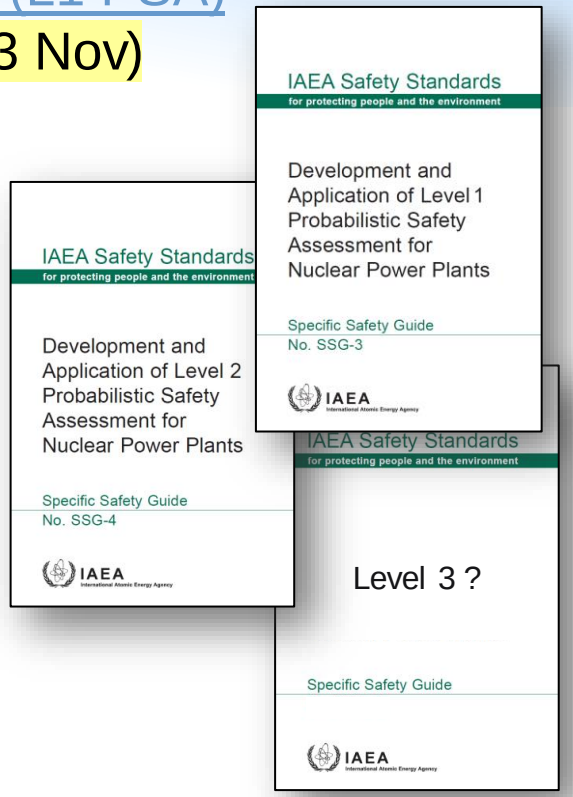




- **Promote** a standard framework, standard terms and a standard set of documents for PSA
- **Detailed recommendations** on L1 and L2 PSA: what analyses should be performed and what issues should be addressed to ensure that the PSA meets GSR Part 4 (Rev.1)
- Scope:
  - All hazards
  - All operational states
  - For reactor core only
  - Malicious acts excluded
- **Supplemented with examples** & illustrative annexes (e.g. examples of plant operational states and associated initiating events)
- Currently **revision is ongoing**

Revision of the IAEA safety guides on PSA

- Published in 2010: currently under revision SSG-3 (L1 PSA) and SSG-4 (L2 PSA) (Sent for MS comments till 13 Nov)
- **Scope**: L1&L2, all operating states, all hazards
- Currently both under **revision**:
  - Spent Fuel Pool and Multi-unit considerations
  - Passive & software systems reliability
  - Modelling of the portable equipment
  - HRA developments (e.g. EOC)
  - More on combination of hazards
  - Recent developments in PSA applications
  - Feedback to current guides (e.g. from CPWG)



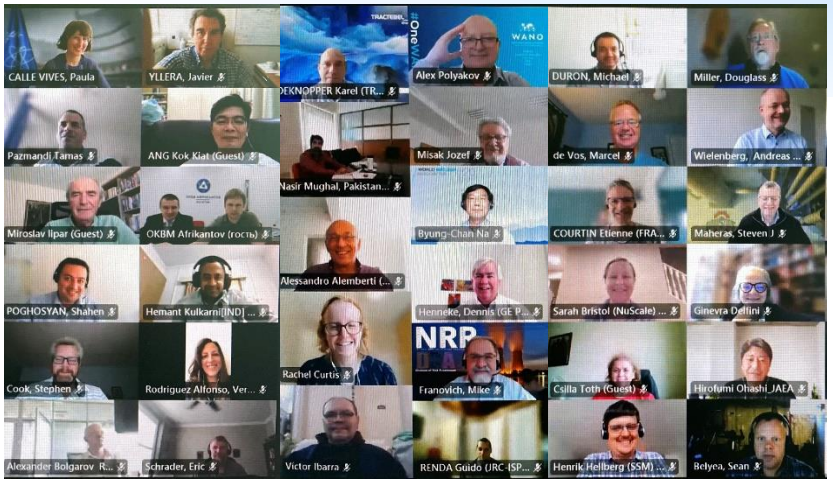
3 Plans for New Safety Guide on **Level 3 PSA**

IAEA Safety Standards and innovative reactors (e.g. SMRs)

Review of applicability of Safety Standards

Review of applicability of IAEA Safety Standards to Evolutionary and Innovative Reactor Designs covered various technologies

- including small modular reactors (SMRs), high temperature gas cooled reactors (HTGRs), sodium fast reactors (SFRs), lead fast reactors (LFRs), molten salt reactors (MSRs), marine-based SMRs and micro-sized reactors



150 international experts, from 30 Member States and 40 organisations including regulatory bodies and technical safety organisations

Extensive work in 2021, **wide participation** from various stakeholders from Member States

Review of applicability of Safety Standards: DSA

- Review of IAEA SSG-2 (Rev.1) – Deterministic Safety Analysis for NPPs
- Most of the recommendations are applicable ‘as is’
- Applicability or further guidance needed
  - **PIEs for specific technology**, understanding of the plausible scenarios leading to release
  - **Further guidance is needed on acceptance criteria** to reflect differences in technologies (barriers, phenomena, damaging mechanisms)
  - **Challenging to fully comply** with the recommendations on independent verification
  - **NWCR examples** are needed to illustrate ‘should’ statements (in general)
  - **Annex I: DSA applications** for SAMGs requires additional guidance (core melt concept)

No.	Chapter[2] (paragraphs[3]) of SSG-2 (Rev.1)	WCR	HTGR	LMFR	MSR
1.	2. GENERAL CONSIDERATIONS • Objectives of deterministic safety analysis (2.1–2.4) • Acceptance criteria for deterministic safety analysis (2.5, 2.6) • Uncertainty analysis in deterministic safety analysis (2.7) • Approaches to deterministic safety analysis (2.8–2.15) • Source term for a release of radioactive material to the environment (2.16–2.19)	Whole section 2 (including description of the objectives, acceptance criteria, uncertainty analysis approaches to ensure margins and determination of the source term in deterministic safety analysis) is written in a technology neutral way and is applicable as is to all types of SMRs			
2.	3. IDENTIFICATION, CATEGORIZATION AND GROUPING OF POSTULATED INITIATING EVENTS AND ACCIDENT SCENARIOS (3.1–3.7) • Management system (3.8) • Normal operation (3.9, 3.10) • Postulated initiating events (3.11–3.22) • Identification of postulated initiating events for anticipated operational occurrences and design basis accidents (3.23–3.36)	Applicable but further guidance needed. The comments below apply to all SMRs: For SMRs with long refuelling period with factory refuelling some normal operation regimes	In major part applicable but further guidance needed. In addition to comments on water cooled reactors, the following applies. Examples of specific events to be	In major part applicable but further guidance needed. In addition to comments on water cooled reactors, the following applies. Examples of specific events to be considered include	In major part applicable but further guidance needed. In addition to comments on water cooled reactors, the following applies: Examples of specific events to be considered include reactivity accidents
	• General considerations for identification of design extension conditions (3.37, 3.38) • Identification of design extension conditions without significant fuel degradation (3.39–3.44) • Identification of design extension conditions with core melting (3.45–3.50) • Identification of postulated initiating events due to internal and external hazards (3.51–3.54) • Event sequences and accident scenarios to be ‘practically eliminated’ (3.55–3.57)	may be irrelevant. Identification of postulated initiating events needs to consider specific configuration of modules, absence of some components, use of passive systems. Transportable / floating SMRs may be exposed to special events due to unstable position. Different vulnerabilities to the hazards, to operator errors and to common cause failures need to be taken into account.	considered include air or steam ingress leading to chemical reactions or reactivity insertion, compaction of the pebble bed core, releases form special waste treatment systems. Recommendations on core melt analysis are not applicable as irrelevant. A gap exist what kind of accident could be postulated as potentially leading to large radioactive releases.	more attention to pay to reactivity induced accidents, chemical reaction of sodium with water, coolant freezing, or leakages from the inert gas system covering the coolant level in the reactor Events initiated in the loops, events resulting in loss of integrity of the reactor coolant systems due to high pressure or events pressurizing the containment are not relevant, but temperature induced damages are becoming more important.	cause by addition of fissile material to the core, water ingress or sudden collapse of the gas bubble, reactivity induced accidents in the chemical reprocessing plant or in emergency drain tank. In opposite, control rod ejection is irrelevant due to low reactor pressure. Specific events can be initiated by salt control system failures, salt freezing in the system, graphite fire, or releases of fission products from the off-gas tank.

[2] Number indicates the number of the Chapter in the Safety Guide.
[3] Numbers in the brackets indicate the paragraphs associated to corresponding topic

Review of applicability of Safety Standards: PSA

- Review of IAEA SSG-3 (Level 1 PSA) and SSG-4 (Level 2 PSA)
- Majority of the recommendations are applicable ‘as is’
- Applicability or further guidance needed
  - **Risk metrics** (core melt vs severe accident)
  - **Generic information** sources (data, lists)
  - **New type of IEs** require further guidance
  - **Containment recommendations** in L2PSA are incompatible with “functional containment” concept
- Gap in regard with Level 3 PSA

#	Chapters (paragraphs)	WCR	LFR	SFR	HTGR	MSR
2.	3. IDENTIFICATION OF DESIGN ASPECTS IMPORTANT TO SEVERE ACCIDENTS AND ACQUISITION OF INFORMATION • Identification of design aspects important to severe accidents (3.1–3.3) • Acquisition of information important to severe accident analysis (3.4–3.6)	**Applicable but further guidance needed** Further guidance would be needed support the selection of design impacts that are important to safety case of the reactor and not require novel reactors to realistically model every barrier which can inhibit radionuclide transport out of the plant, especially those barriers which are not needed to demonstrate the releases from the plant are acceptably low. As such the acceptability of a PSA to choose not to model design features which can reduce off-site consequences needs to be established, especially in light of requirements that require the treatment of barriers that can impact the release characteristics with realistic release models.			**Not applicable.** See WCR Para 3.2 imply a structural containment and is incompatible with a “functional containment” approach used by HTGRs, and other reactor concepts, using TRISO fuel.	**Applicable but further guidance needed** See WCR
3.	4. INTERFACE WITH LEVEL 1 PSA: GROUPING OF SEQUENCES (4.1–4.2) Plant damage states for PSA for internal initiating events for full power conditions (4.3–4.8) Plant damage states for an existing Level 1 PSA (4.9) Extension of scope of Level 2 PSA to other initiating events (4.10) Extension of scope of Level 2 PSA to other power states (4.11–4.12)	**Applicable**	**Not applicable** Further guidance/requirements would be needed support para 4.5 for a low-pressure system. Para 4.7 is not applicable to non-water systems.		**Not applicable.** See WCR The core damage concept specified in para. 4.5 are not applicable, because HTGRs, and likely other designs with TRISO fuel, are likely to take a “functional containment” approach. A gap exists to redefine core damage in terms of L3 risk metrics. Para 4.2, 4.3, 4.5, 4.7 4.9, 4.11 imply a structural containment and is incompatible with a “functional containment” approach used by HTGRs, and other reactor concepts, using TRISO fuel. Para 4.7 is not applicable to non-water systems.	**Not applicable.** See SFR The core damage concept specified in para. 4.5 are not applicable, because MSRs have molten fuel at steady state. A gap exists to redefine core damage in terms of L3 risk metrics.

Concerns related to Safety Assessment of FOAK SMRs

Limited information on phenomenology, uncertainty

- lack of comprehensive knowledge about phenomena and their interactions may impact a wide range of technical areas (e.g. physical, chemical, structural material properties).

No or limited operating experience

Lack of applicable codes and technical standards

Limited applicability of current design safety approaches

- system design criteria and functional design criteria.

Limitations in application of traditional approaches and methods for safety assessment

Safety Guide: Safety demonstration of innovative reactors

- **Proposed New Specific Safety Guide (DS537) to**
  - describe what should be done to overcome specific challenges of innovative reactors
  - complement existing safety standards in areas which are not sufficient
  - capture experience available
- **Provide recommendations** on approaches to address and/or mitigate, and/or resolve unknowns associated with innovative technology
- **Technology inclusive** and considering SSCs, materials and advanced manufacturing

First consultancy meeting on DS537 Safety demonstration of innovative reactors, 25-27 April 2023, Vienna

DS537: new safety guide

- Safety demonstration of first of a kind reactor designs

entire reactor design?

- Safety demonstration of ~~first of a kind~~ **technology** in reactor designs

everything was FOAK at some point?

- Safety demonstration of **innovative** technology in reactor designs

Needs to be defined in DS537!

research reactors?

- Safety demonstration of innovative technology in **power** reactor designs

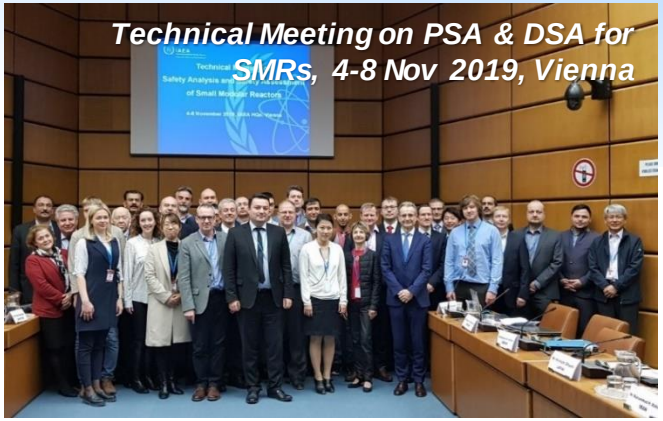
DS537 structure

#	Chapter
1	**INTRODUCTION**
2	**DEFINITION OF INNOVATIVE TECHNOLOGY AND RELATED ISSUES**
3	**GENERAL APPROACHES TO ENSURING SAFETY FOR INNOVATIVE TECHNOLOGY**
3.1	Identification of issues, knowledge gaps and uncertainties
3.2	Actions to manage the knowledge gaps and uncertainties (e.g. reduce the uncertainties)
3.3	Application of a graded approach
4	**SPECIFIC STRATEGIES TO ENSURE SAFETY FOR INNOVATIVE TECHNOLOGY**
4.1	Limited knowledge on relevant phenomena (physical, chemical)
4.2	Lack of simulation tools
4.3	Limited or no directly relevant operating experience
4.4	Lack of applicable regulations, codes and technical standards
4.5	Limited applicability of design safety and safety assessment approaches
5	**SAFETY DEMONSTRATION OF SPECIFIC INNOVATIONS**
5.1	New fuel concepts
5.2	Passive safety features
5.3	Innovative Control and Instrumentation
5.4	Implications of innovative technologies for operators
5.5	Innovative manufacturing and construction techniques
5.6	Innovative material solutions
5.7	Non-electrical applications (e.g. heating, hydrogen)
5.8	Multi-modularity (reactor modularity)
5.9	Transportability concepts
6	**CONSIDERING INTERFACES WITH SECURITY AND SAFEGUARDS WHEN DEMONSTRATING SAFETY**

Safety Report: DSA/PSA for SMRs

- **IAEA Safety Report** on Safety Assessment for SMRs
- **Main SMR technologies** are being addressed
- **Main body of the report finalized** (covers DSA / PSA typical tasks vs SMRs, Integrated use of DSA/PSA, PSA applications)
- **Annexes** for the part on PSA
  - **Annex I** - PRISM (SFR),
  - **Annex II** – HTR-PM (HTGR),
  - **Annex III** – NUSCALE (WCR),
  - **Annex IV** - IMSR (MSR),
  - **Annex V** – ?? (LFR),
  - **Annex VI** – Regulatory perspective (CNSC)

Practical examples, e.g. PIE lists



Design Safety		
SSR-2/1 (Rev.1)	Safety of Nuclear Power Plants: Design	2016
NS-G-1.13 (DS524)	Radiation Protection Aspects of Design for Nuclear Power Plants	2005 (in revision)
SSG-30	Safety Classification of Structures, Systems and Components in Nuclear Power Plants	2014
SSG-34	Design of Electrical Power Systems for Nuclear Power Plants	2016
SSG-39	Design of Instrumentation and Control Systems for Nuclear Power Plants	2016
SSG-51	Human Factors Engineering in the Design of Nuclear Power Plants	2019
SSG-52	Design of the Reactor Core for Nuclear Power Plants	2019
SSG-53	Design of the Reactor Containment and Associated Systems for Nuclear Power Plants	2019
SSG-56	Design of the Reactor Coolant System and Associated Systems for Nuclear Power Plants	2020
SSG-62	Design of Auxiliary Systems and Supporting Systems for Nuclear Power Plants	2020
SSG-63	Design of Fuel Handling and Storage Systems for Nuclear Power Plants	2020
SSG-64	Protection against Internal Hazards in the Design of Nuclear Power Plants	2021
SSG-69	Equipment Qualification for Nuclear Installations	2021

Safety Assessment		
GSR Part 4 (Rev.1)	Safety Assessment for Facilities and Activities	2016
SSG-2 (Rev.1)	Deterministic Safety Analysis for Nuclear Power Plants	2019
SSG-3 (Rev.1)	Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants	2023
SSG-4 (DS528)	Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants	2010 (In revision)
SSG-25	Periodic Safety Review for Nuclear Power Plants	2013 (In revision)
SSG-54	Accident Management Programmes for Nuclear Power Plants	2019
SSG-61	Format and Content of the Safety Analysis Report	2021
DS508 (new)	Assessment of the Safety Approach for Design Extension Conditions and Application of the Practical Elimination Concept in the Design of Nuclear Power Plants	In development
DS537 (new)	Safety Guide on Safety Demonstration of Innovative Technology in Power Reactor Designs	In development
DSxxx (new)	Development and Application of Level 3 Probabilistic Safety Assessment for Nuclear Power Plants	In planning

Technical Safety Reviews on safety assessment

Technical Safety Reviews

- **Review** is performed by the team of independent international experts
  - Wide experience
  - Technology experts
  - Language
  - No conflict of interests

- **IAEA Safety Standards** are the basis for the review (cannot be reviewed against national standards)

TSR Services Conducted since 1988

North America 1

Europe 82

Total: 118 TSR Services

Asia and the Pacific 29

Africa 3

Latin America and the Caribbean 3

TSR services evolution

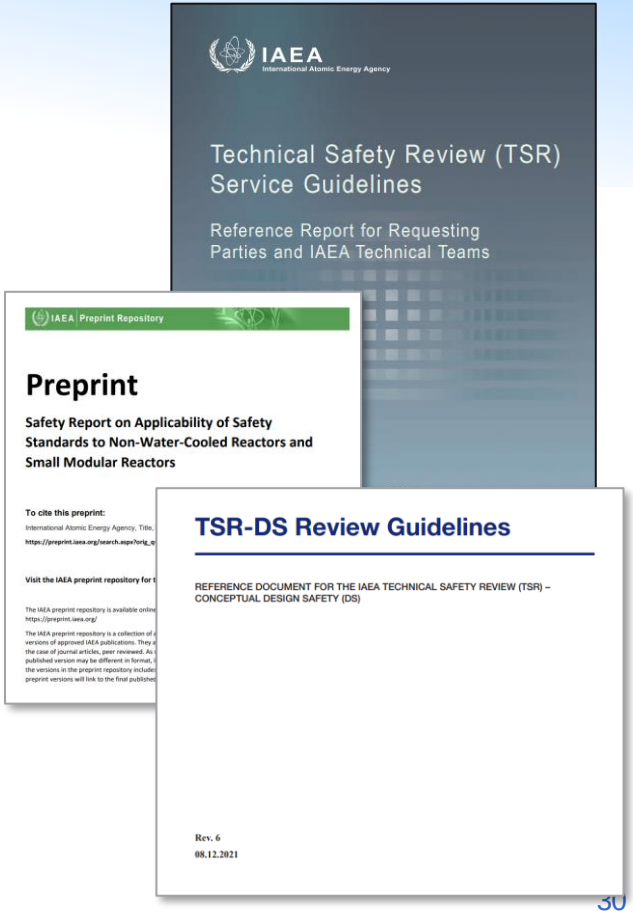
TSR Services Guidelines streamlined, revised and published (SRS-41)

Development of **detailed technical guidelines** for the review of topical areas

SMR focused review guidelines:

- Conceptual design review (SMRs)
- Safety, security and safeguards interfaces

Reviewing reports & electronic models



Summary and future IAEA events

Summary and path forward

- **IAEA continues efforts** in the area of safety assessments
- **Ongoing publications on** safety assessment
- **Reviews and Trainings:** tailored support to Member States:
- **Risk-informed approaches** beyond safety (security, safeguards)
- **Focus on SMRs**

  - Further integrated use of PSA and DSA
  - Driving design solutions
  - FOAK designs
  - Information sharing

Some relevant IAEA events in 2023-24

- **16-20 Oct 2023:** Safety Implications of the Use of AI in NPPs (IAEA)
- **13-16 May 2024:** Joint IAEA–GIF Workshop on the Safety of NWCRs
- **18-21 Jun 2024:** Interregional Workshop on Experimental Testing and Validation for Design and Safety Analysis Computer Codes for SMRs (IAEA)
- **14-17 Oct 2024:** Technical Meeting on Severe Accident Analysis and Management for Non-Water Cooled Reactors
- **21-25 Oct 2024:** International Conference on Small Modular Reactors and their Applications
- **26 - 29 Nov 2024:** Technical Meeting on Advanced Manufacturing and Qualification Programmes for New Materials for SMRs and NWCRs: Safety Considerations
- **4-8 Nov 2024:** Interregional Workshop on Safety, Security and Safeguards by Design in Small Modular (ORNL)

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thank you!