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Atoms for Peace and Development

Welcome to the IAEA Webinar
Applicability of IAEA Safety Standards to the Design of Novel Advanced Reactors including SMRs

While we await for all participants to connect, please kindly observe the following:

- ✓ Stay muted unless speaking
- ✓ Q&A at the end, use the chat to participate or raise your hand
- ✓ Close unused applications from your computer
- ✓ Join using your name and organization (preferable)

8 December 2021

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3. Applicability of Design Safety Specific Requirements
4. Applicability of Core Design Safety Standards
5. Applicability of Reactor Coolant System Safety Standards
6. Applicability of Containment Safety Standards
7. Applicability of Instrumentation & Control and Electrical Systems Safety Standards
8. Applicability of Support Systems Safety Standards
9. Next Steps
10. Q&A session, we also welcome feedback (please use the chat)

Opening Remarks

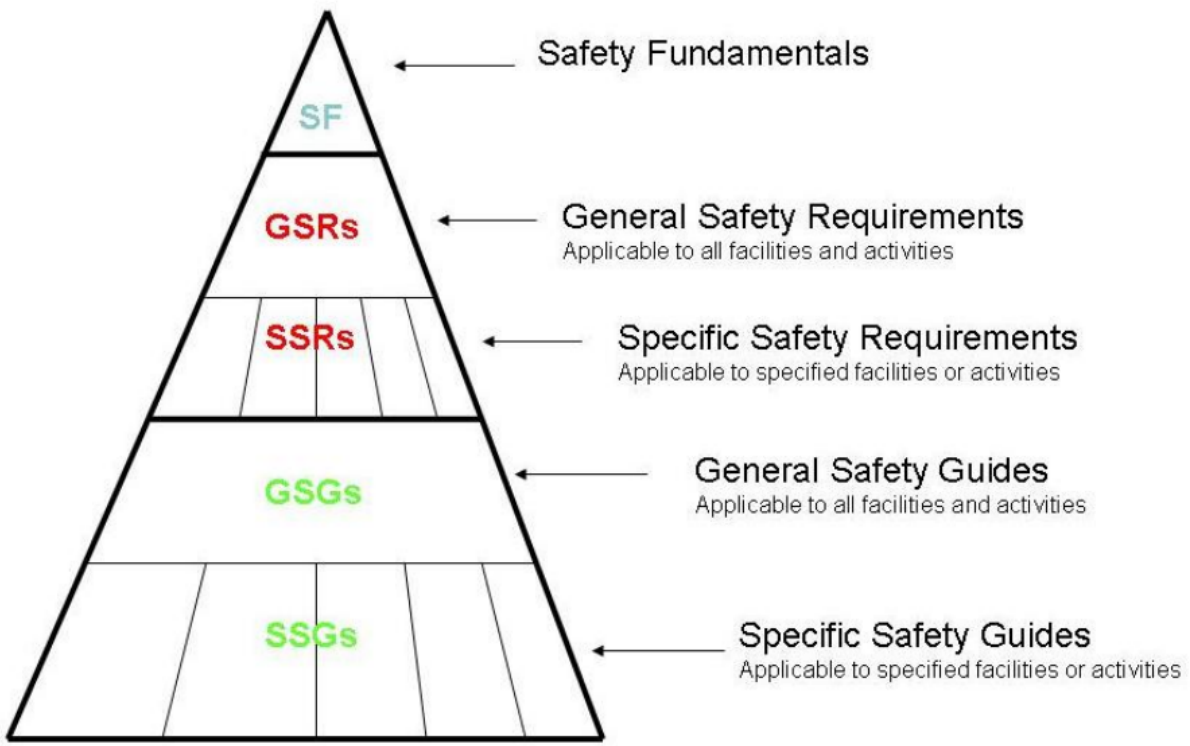
Anna Bradford

Director of Nuclear Installation Safety

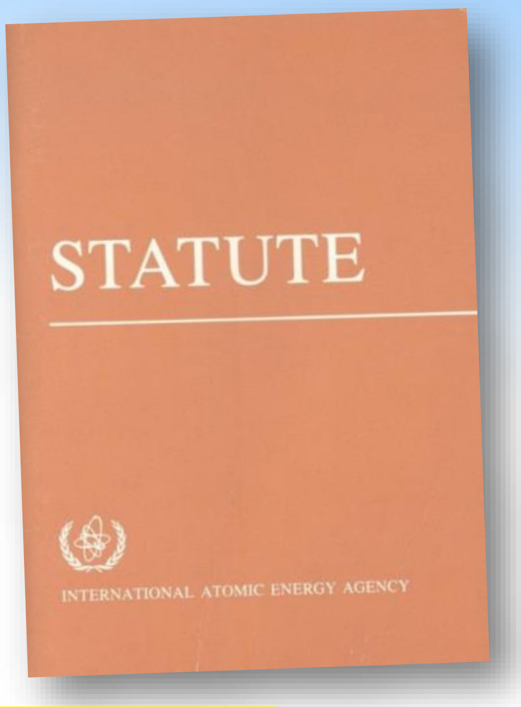
Overview of Review of Applicability of IAEA Safety Standards

Paula Calle Vives
8 December 2021

The IAEA Safety Standards



- *Mostly developed under the prominence of land-based, large water cooled reactors*
- *The development of safety standards is a long process*



"**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**, and to **provide for the application of these standards** to its own operation as well as to the operations making use of materials, services, equipment, facilities, and information made available by the Agency…"

Technologies considered

Growing interest in technologies very different from the current operating fleet:

- Different neutron spectrum
- Different coolants and moderators
- Simplified designs and passive means to maintain safety
- Advances in engineering, materials, manufacturing
- Serial factory, modular construction and standardization
- Deployment models and transportation

Are IAEA safety standards currently in use sufficient and relevant to ensure safety?

Types of Novel Advanced Reactors (NARs) in Scope

Sodium Fast Reactors, SMRs and Microreactors

Lead Fast Reactors, SMRs and Microreactors

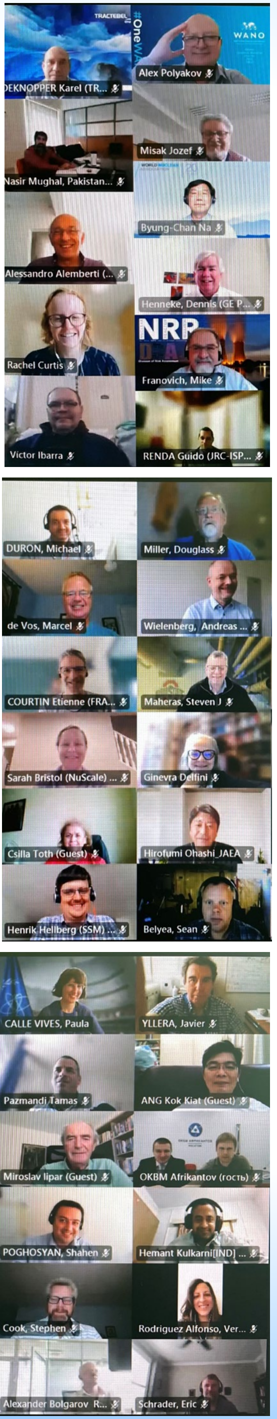
High Temperature Gas Cooled Reactors, SMRs and Microreactors

Molten Salt Reactors, SMRs and Microreactors

Water-cooled SMRs (and Microreactors)

Transportable (including floating) SMRs and Microreactors

Terminology under review



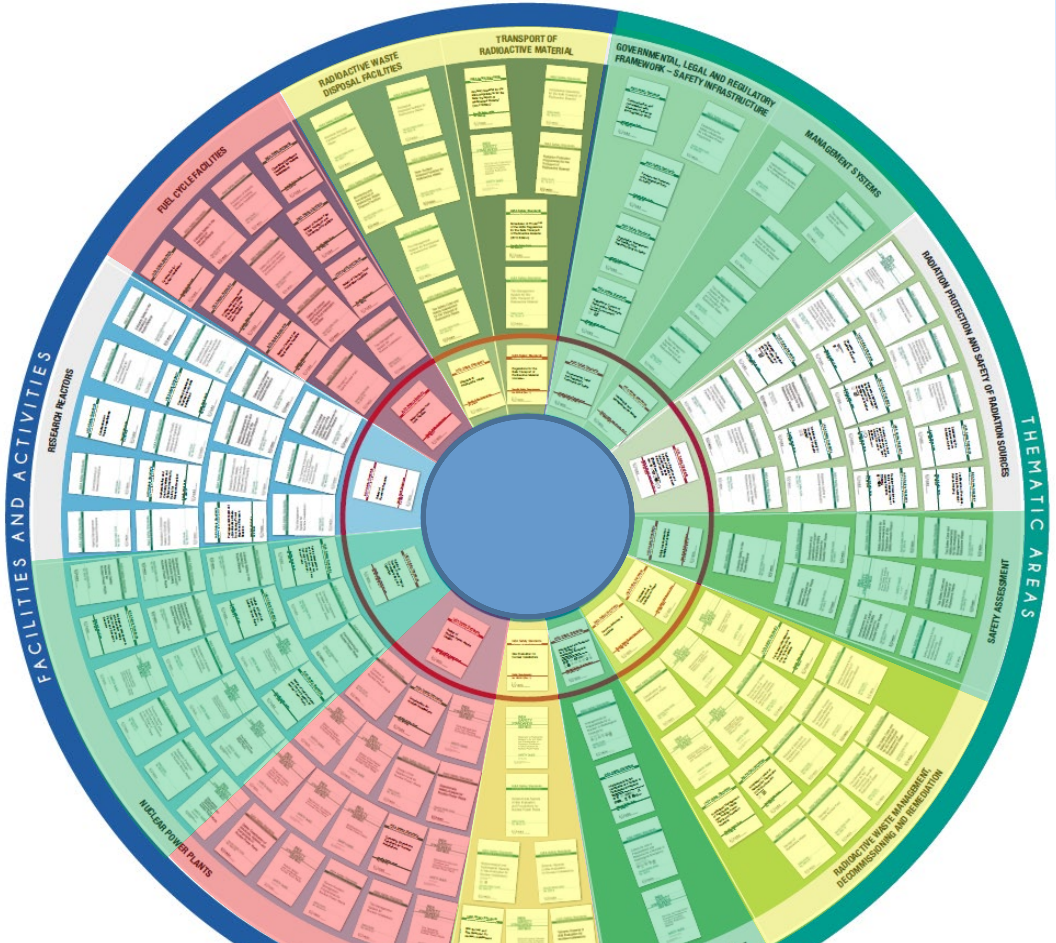
Safety Standards Applicability Review

- The IAEA has completed the review of applicability of safety standards to novel advanced reactors **throughout lifecycle**

- Input provided by vendors/developers via questionnaires

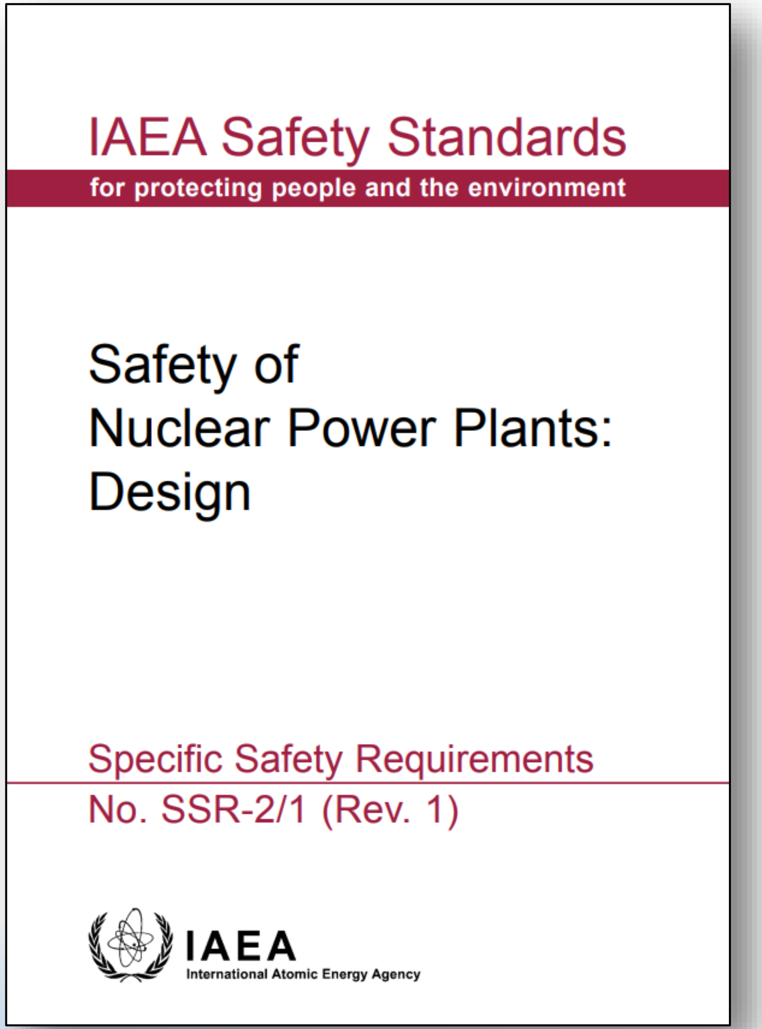
- Working with more than 150 experts from 30 countries and 40 organizations, including representatives of the SMR Regulators Forum

- Safety standards generally applicable
  - Some areas need interpretation
  - Some areas of novelty not fully covered
- Review captured in a safety report



For most cases, issues identified may merit additional work (e.g., technical document development) but not intended to revise the safety standards in the short term.
Collection of information needed and long consultation process

Safety Standards covered by this Webinar



IAEA Safety Standards
for protecting people and the environment

Safety of
Nuclear Power Plants:
Design

Specific Safety Requirements
No. SSR-2/1 (Rev. 1)

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The reactor core (SSG-52)

The containment and associated systems (SSG-53)

The reactor coolant system and associated systems (SSG-56)

The design of electrical power systems (SSG-34)

Instrumentation and control systems (SSG-39)

Auxiliary Systems (SSG-62)

The webinar will provide you with a high-level overview of the findings – covering only technical aspects
The webinar does not provide recommendations on how to address the issues identified
This can only be done after consulting member states

Other Safety Standards covered by the Review

IAEA Safety Standards
for protecting people and the environment
Site Evaluation for Nuclear Installations
Specific Safety Requirements
No. SSR-1

IAEA Safety Standards
for protecting people and the environment
Safety of Nuclear Power Plants: Commissioning and Operation
Specific Safety Requirements
No. SSR-2/2 (Rev. 1)

IAEA Safety Standards
for protecting people and the environment
Leadership and Management for Safety
General Safety Requirements
No. GSR Part 2

IAEA Safety Standards
for protecting people and the environment
Safety of Nuclear Fuel Cycle Facilities
Specific Safety Requirements
No. SSR-4

IAEA Safety Standards
for protecting people and the environment
Disposal of Radioactive Waste
Specific Safety Requirements
No. SSR-5

IAEA Safety Standards
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Predisposal Management of Radioactive Waste
General Safety Requirements Part 5
No. GSR Part 5

IAEA Safety Standards
for protecting people and the environment
Decommissioning of Facilities
General Safety Requirements Part 6
No. GSR Part 6

IAEA Safety Standards
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Safety Assessment for Facilities and Activities
General Safety Requirements
No. GSR Part 4 (Rev. 1)
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Preparedness and Response for a Nuclear or Radiological Emergency
Jointly sponsored by the
FAO, IAEA, ICAO, ILO, IMO, INTERPOL,
OECD/NEA, PAHO, CTBTO, UNEP, OCHA, WHO, WMO
General Safety Requirements
No. GSR Part 7
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IAEA Safety Standards
for protecting people and the environment
Regulations for the Safe Transport of Radioactive Material
2018 Edition
Specific Safety Requirements
No. SSR-6 (Rev. 1)
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IAEA Safety Standards
for protecting people and the environment
Governmental, Legal and Regulatory Framework for Safety
General Safety Requirements
No. GSR Part 1 (Rev. 1)
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IAEA Nuclear Security Series No. 35-G
Implementing Guide
Security during the Lifetime of a Nuclear Facility
IAEA
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IAEA Nuclear Energy Series
No. NP-T-2.9
International Safeguards in the Design of Nuclear Reactors
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And over 50 supporting Safety Guides

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Applicability of Design Safety Specific Requirements

Bernard Poulat

8 December 2021

Objective and Scope

Objective

- Review of the SSR-2/1 Rev. 1 “Shall requirements”* updated after the Fukushima Daiichi accident (2011) to assess their suitability and applicability to light water cooled SMRs and to non-water cooled reactors.
- Identification of areas of novelty and particularities (at a high level).
- Providing insights for future discussion
- The scope did not include proposing modifications of SSR-2/1 Rev. 1 requirements.

*The review was limited to the requirements provided in sections 3, 4 and 5. Requirements provided in sections 6 are plant system specific and their applicability is discussed in the scope of the applicability of the IAEA Safety Guides.

Scope

- Water cooled SMRs
- SFR
- LFR
- HTGR
- MSR

The review was carried out considering inputs from designers/vendors, technology experts, GIF Safety Design Criteria for Generation IV Sodium Cooled Fast Reactor System, IAEA Tecdoc-1936, and GIF Safety Design Criteria for Generation IV Lead cooled Fast Reactor System.

“Shall requirements”

- IAEA “shall requirements” have been developed to meet the 10 Fundamental Principles documented in the top IAEA publication SF-1 and constitute a sound basis for protecting people and the environment from harmful effects of ionizing radiation.
- The IAEA‘s Statute makes the “shall requirements” binding on the IAEA in relation to the implementation of its safety review services requested by the Member States.
- IAEA “shall requirements” are not binding on Member States but can be used by the States as a reference for, or as guidance to their national regulations.
- SSR-2/1 “shall requirements” basically apply to any technology/design of a nuclear power plant knowing that SSR-3 is relevant for research reactors, SSR-4 is relevant for nuclear fuel cycle facilities, SSR-5 is relevant for radioactive waste disposal facilities and SSR-6 is relevant for the transport of radioactive material.

IAEA Safety Standards
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Fundamental
Safety Principles

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Safety Fundamentals
No. SF-1

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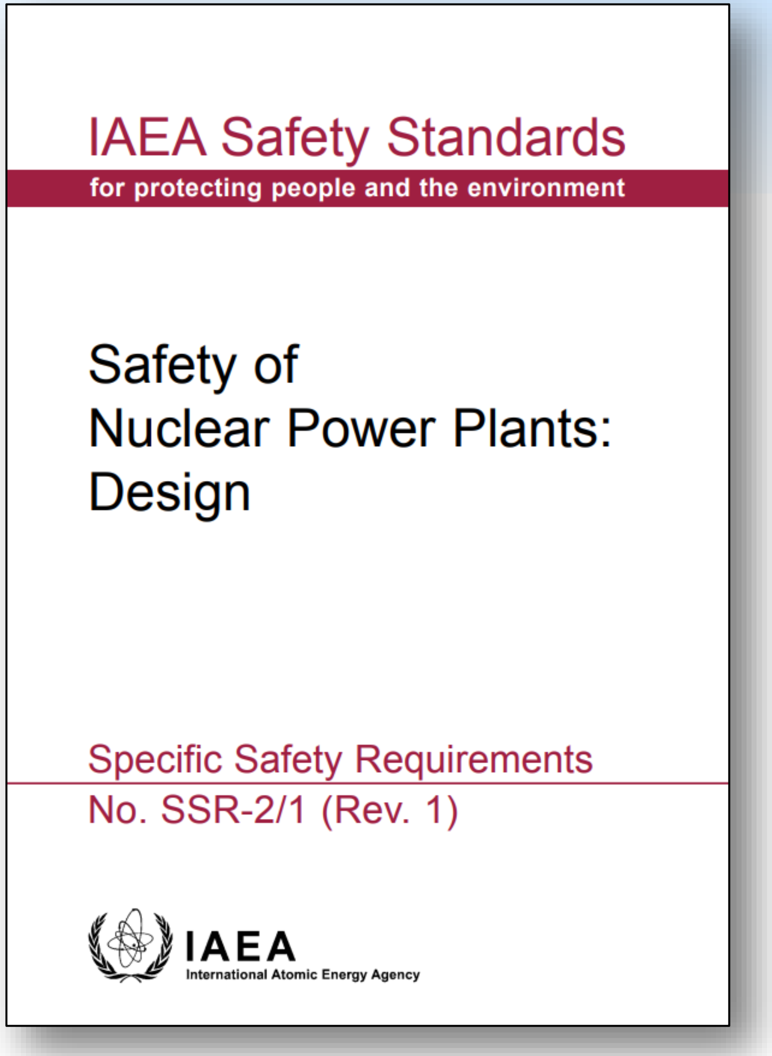
“Shall requirements” for the Design (SSR-2/1)

The “shall requirements” for the design of a NPP have not been identified in one shot but were modified or supplemented several times to reflect the feedback and lessons learnt from operation and events.

SSR-2/1 Revision 1 is the latest published revision and includes recommendations formulated by the INSAG members to enhance the safety of NPPs and the feedback from the Fukushima Daiichi accident.

- Considering that the SSR-2/1 Rev 1 is not a compilation of individual requirements but is an integrated and consistent set of design requirements to be met by a land based NPP to ensure the protection of the people and the environment

- Considering that the SSR-2/1 Rev 1 reflects an international consensus of Member States on what constitutes a high level of safety to be reached



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SSR-2/1 Structure

Section 1: Introduction

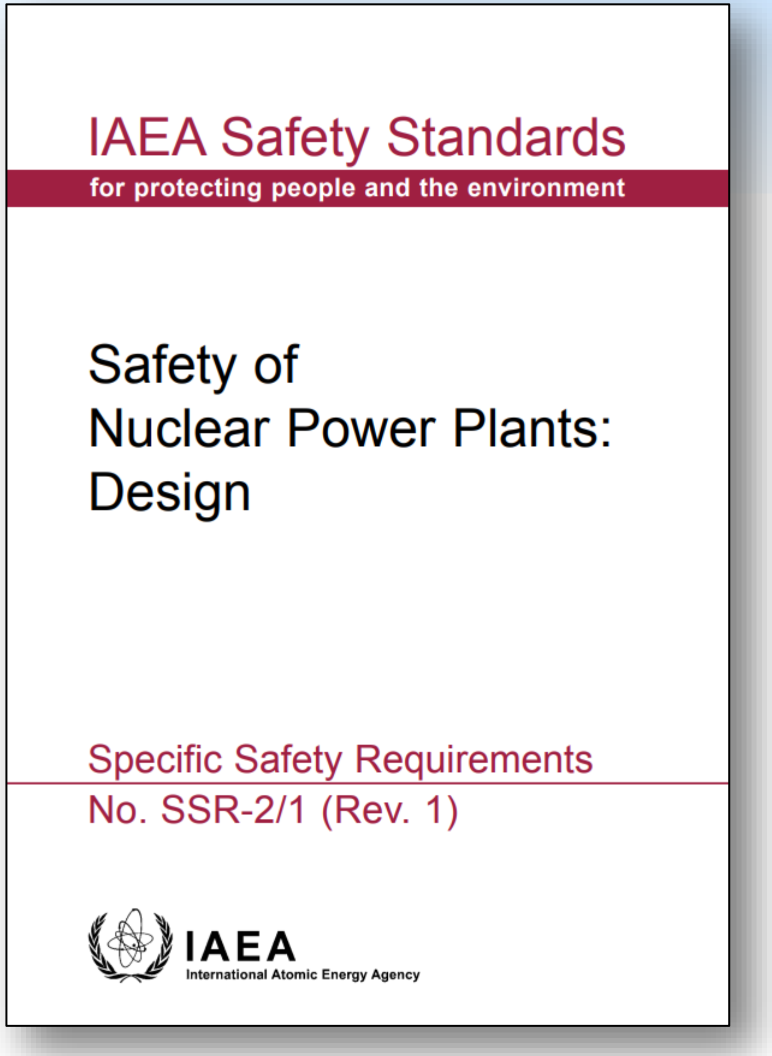
Section 2: Applying the safety principles and concepts

Section 3: Management of safety in design
(Requirements 1 to 3)

Section 4: Principal Technical Requirements
(Requirements 4 to 12)

Section 5: General Plant Design requirements
(Requirements 13 to 42)

Section 6: Design of specific plant systems
(Requirements 43 to 82) (presented later)



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Applicability considerations

Most requirements provided in SSR-2/1 (Rev 1) sections 3, 4 and 5 were considered as applicable to other types of reactors, they leave an adequate flexibility for their application to novel advanced reactors and ensure that the new generation of reactors will not be less safe*:

- ✓ Section 3: “Management of safety in design” : All the requirements are applicable;
- ✓ Section 4: “Principal technical requirements” Requirements 4 to 6, 8 to 11 are applicable
- ✓ Section 5: “General plant design requirements” Requirements: 14 to 15, 18, 22 to 30, 32, to 34, 36 to 42 are applicable

Although most SSR-2/1 Rev 1 requirements were intended to apply to any land based NPP technology, it is recognized that the phrasing/vocabulary is water cooled reactor technology oriented and consequently, for some of them, adjustments in terminology may be necessary without modifying the objective

Applicability considerations

Application of some requirement may account for inherent and specific design characteristics of a technology favourable towards nuclear safety :

- ✓ General plant design requirements 12,13,17, 31 and 35 are not fully technology neutral and need additional consideration for novel advanced reactors

- ✓ The objectives/performances of the levels of defence might need to be clarified
- ✓ Requirements 7 “Application of defence in depth”, 16 “Postulated initiating events”, 19 “Design basis accidents”, 20 “Design extension conditions”, 21 “Physical separation and independence of safety systems”, need additional consideration before they can be applied to NARs

- ✓ DBAs and DECs: Considering that in a deterministic approach, the rules used in the safety analyses may not be the same, a clear definition should be given for these 2 categories

Applicability of key items for safety

SSR-2/1 Rev.1 requirements targeting the quality of the manufacturing, the identification of the postulated events and hazards, the reliability of items whose failure would result in a deviation from normal operating conditions, the reliability of safety systems and safety features designed to mitigate the consequences of the accident conditions, the periodic testing and the inspection of items important to safety are of a prime importance:

✓ Postulated Initiating Events

☐ PIEs should include single initiating events and combinations of events and failures as long as their estimated frequency of occurrence or probability is within the range of probability to be considered for design. PIEs are analyzed as design basis accidents (DBA) or design extension conditions (DEC)*.

Considering that in a deterministic approach, the rules used in the safety analyses may not be the same as for traditional WCRs, a clear definition should be given for DBA and DEC

☐ Severe accident conditions (that are possible and relevant to the technology) need to be analysed to identify the safety features necessary for the mitigation.

Applicability of key items for safety

System(s) performing safety functions with same safety significance in different reactor technologies, are expected to have similar reliabilities

✓ Events of a low probability and high consequences

❑ The consequences of such events should be mitigated as far as reasonably practicable or otherwise "practically eliminated".

✓ Reliability of items important to safety

❑ The reliability of items important to safety is driven by the safety significance of the function to be accomplished by the item or system, and not by the engineering options *

❑ A high reliability claim should be demonstrated based on a set of design characteristics such as inherent safety characteristics, safety classification and seismic categorization, quality of the manufacturing, identification and prevention of the failure modes, identification and removal of the CCF, segregation or physical separation, qualification, use of diversity, implementation of redundancies, etc.

✓ Inspection, testing and preventive maintenance

Are essential to maintain reliability of items important to safety along their whole lifetime. Requirement 29 with its clause 5.47 is applicable.

✓ Proven engineering practices

✓ Requirement 9 can guide considerations on the quality of the manufacturing

Areas not covered

The existence of areas of novelty, specific modes of failures, or phenomena may raise the need for additional design requirements if:

☐ not addressed by complementary requirements they could compromise the safety of the nuclear reactor and raise nuclear risks for the people and the environment, or

☐ modify or make inadequate some of the current plant system requirements (section 6)

Example of areas of novelty that may raise the need for additional design requirements (they also impact the applicability of existing requirements)

- Fuel characteristics (inherently safe)
- More favourable core characteristics: low power density, low decay heat, low radioactive inventory
- More favourable coolant characteristics: high boiling temperature, high calorific capacity, high heat transfer coefficient
- Operating conditions: low pressure, high temperature
- Fuel loading operation at a facility (off site)
- Specific design characteristics providing longer grace periods for operator actions, or for off-site services

- Specific PIEs
- Specific natural hazards or internal hazards
- Specific phenomena
- Sharing of systems among several reactor modules
- New strategy to operate the NPP: remote control, common MCR, less staff
- Novel technologies novel materials: Lack of knowledge, experience, practices, feedback

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Applicability of Core Design Safety Standards to Novel Advanced Reactors

Stephen P. Schultz

8 December 2021

Scope of this work

The following **IAEA Safety Standards** have been reviewed:

- **SSR 2/1 Rev. 1**
  - Key Core Design Requirements 43-46
  - *Reactor core design features impact adherence to other safety requirements*
- **SSG-52**

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Safety of
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Specific Safety Requirements
No. SSR-2/1 (Rev. 1)

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Design of the
Reactor Core for
Nuclear Power Plants

Specific Safety Guide
No. SSG-52

IAEA

The following **reactor design concepts** were examined:

- Water cooled SMRs
- SFR
- LFR
- HTGR

- MSR core designs were only considered for SSR 2/1 at this stage

Areas of Novelty in Fuel and Core Design for NARs

Water Cooled SMRs

- Variations in size/scale and reduction in core power density
- ^{235}U enrichment increases up to 20 w/o
- Non-pelletized ceramic fuel
- Advanced cladding alloys (Cr/Ni alloys – Accident Tolerant fuel)
- Graded axial enrichment to shape flux/burnup; annular pellets
- Burnable absorbers may replace soluble boron in coolant
- Internal control rod drive design eliminates rod ejection
- Passive control features improve facility safety profile

Transportable NPPs

- Integral core / factory fueled transport challenges may apply
- Long duration core designs likely (e.g., for reactor lifetime)

Press Release, AREVA Inc., "NuScale Power Unveil NuFuel- HTP2^{TM} Name for Small Modular Reactor Fuel Design" Charlotte, NC, March 31, 2016

Areas of Novelty in Fuel and Core Design for NARs

Sodium Cooled Fast Reactors (SFRs)

- Fuel matrix designs include metal fuel, carbide or nitride fuel
- ^{235}U enrichment increases up to 20 w/o and/or MOX fuel
- Fuel pin mechanical performance challenges similar to LWR fuel
- No zirconium eutectic formation or exothermic reaction
- Higher temperature and fluence conditions than LWR core
- Core reactivity control mechanisms differences
  - Prevent sodium boiling with two active shutdown systems
  - Inherent negative reactivity feedback (e.g., Doppler effect)
  - Fuel thermal expansion and core radial expansion effects
  - Passive systems: Curie point electromagnetic suspension rods
  - Movable reflector design

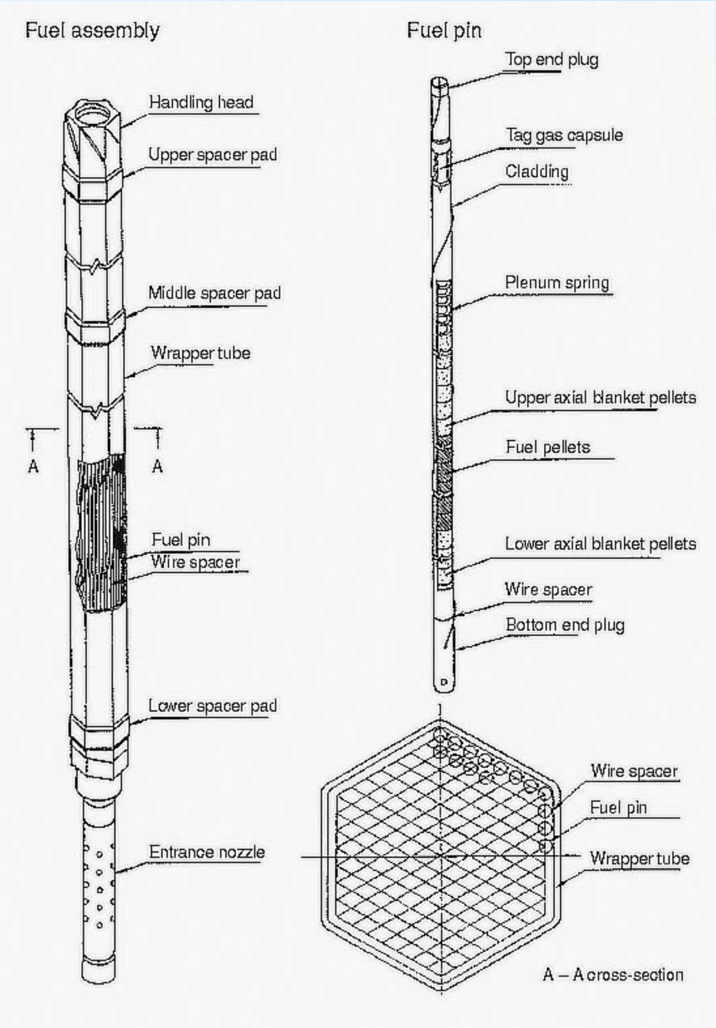

FIG. 3. Representative fuel rod and assembly for MONJU, Japan.
IAEA Nuclear Energy series No. NF-T-4.1
Status and Trends of Nuclear Fuels for Sodium Cooled Fast Reactors

Areas of Novelty in Fuel and Core Design for NARs

Lead Cooled Fast Reactors (LFRs)

- Fuel design novelties are generally similar to 1-5 above for SFRs
- Corrosion and erosion processes based on different mechanisms
- Several fuel rod design challenges are similar to SFRs (and LWRs)
    - Creep damage; swelling; cladding corrosion; vibration/fretting
- Accident phenomena: overheating rupture, fuel melting, FCMI
- Core reactivity control mechanism differences
    - Inherent reactivity feedbacks limit possible reactivity excursion
    - Generally, two active control rod shutdown systems
    - Buoyancy-driven passive devices based on overtemperature

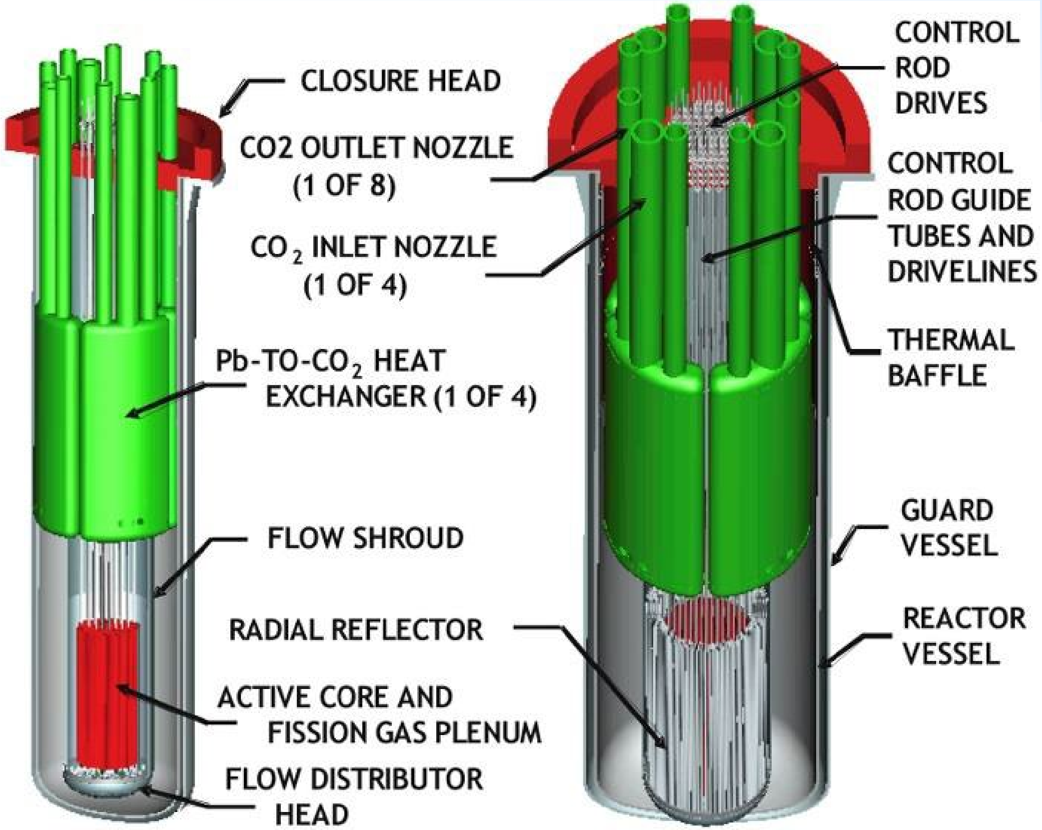

Figure 3.1: Sketch of GIF LFR Reference System

2017 GIF ANNUAL REPORT

Areas of Novelty in Fuel and Core Design for NARs

High Temperature Gas Cooled Reactors (HTGRs)

- Coated fuel particles, compacts or prismatic blocks
- TRISO-coated particles in graphite matrix designs
- UO_2 or Uranium Oxycarbide (UCO); PuO_2 or ThO_2 possible
- Higher operating temperatures, but large thermal margins
- Limit temperature to design limits under all conditions
- Low power density; natural residual heat removal
- Large thermal capacity of graphite
- Challenges: oxidation due to air or water ingress

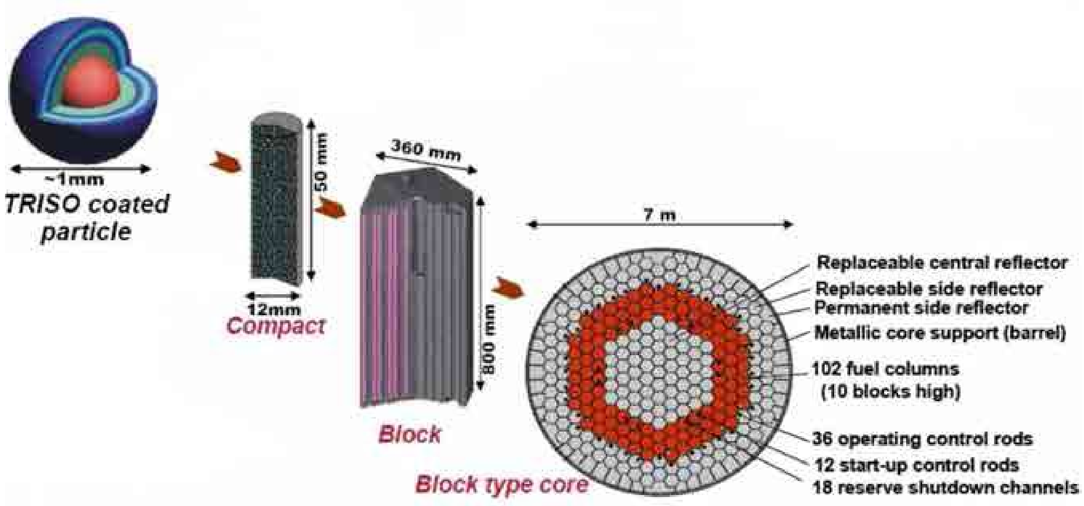

FIG. 2.2 ANTARES fuel design

IAEA-TECHDOC-CD-1674
Advances in High Temperature Gas Cooled Reactor Fuel Technology

Areas of Novelty in Fuel and Core Design for NARs

High Temperature Gas Cooled Reactors (HTGRs)

- No zirconium eutectic formation or exothermic reaction
- Core reactivity control mechanisms differences
  - Inherent reactivity feedbacks
  - Control rod system for low power/shutdown states
  - Pebble Bed – control rods in outer reflector
  - Prismatic – control rods in inner and/or outer reflector
  - Small absorber sphere system - reserve shutdown device
- Fission product containment via TRISO-coated particles / matrix
  - Importance of particle integrity; fabrication control
  - Failure modes to be prevented: kernel migration, chemical attack, abrasion

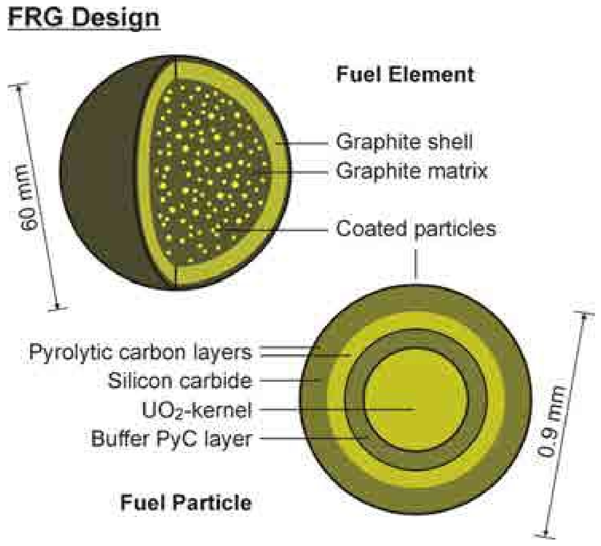

FIG. 3.1 Spherical fuel element with UO2 TRISO coated particles

IAEA-TECHDOC-CD-1674
Advances in High Temperature Gas Cooled Reactor Fuel Technology

SSR 2/1 Applicability considerations

Fuel and Core Design Requirements 43 - 46

- Application of SSR 2/1 requirements are fully applicable to water cooled SMRs

- Application of SSR 2/1 requirements to non-Water Cooled NARs:
  - Some statements do not present with clarity the design requirements that apply to these technologies
  - In some cases, passive and inherent safety features in the design and operation of the new technologies are not credited
  - Some designs claim that melting of the reactor core is precluded (HTGR, some MSRs) so that reference to severe accident events needs consideration

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SSR 2/1 - Summary of general findings

- Requirement 43: Performance of fuel elements and assemblies - Processes of deterioration differ; additional system design features for fission product retention and stresses of fuel handling off-site or by novel processes should be considered
- Requirement 44: Structural capability of the reactor core - Designs rely on differing means for shutdown and control so that design-specific reactivity control requirements may be appropriate to address novel performance issues
- Requirement 45: Control of the reactor core - Low pressure coolant systems or pool reactor design features are not concerned with depressurization changes or related failures
- Requirement 46: Reactor shutdown - Preventing failure of a control rod to insert may need consideration for designs with novel control devices or features

SSG-52 Applicability considerations

- SSG-52 (Rev.1, 2019) recommendations focus on LWR and PHWR global operating experience
- Do not cover areas of novelty described earlier
- Additional qualification and testing recommendations (e.g., for extended core life) may need to be considered
- Do not include new fuel and cladding materials descriptions (e.g., Accident Tolerant Fuel)

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Design of the
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Specific Safety Guide
No. SSG-52

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SSG-52 Applicability Considerations

SSG-52 can be applied in an intelligent fashion to non-water cooled reactors, but requires technical interpretation and adjustments:

- Design terminology, features, and characteristics need adjustment
- Detailed expectations and recommendations (e.g., reactivity control mechanisms, devices, and capabilities) will require interpretation
- Some accidents may not be applicable (e.g., rod ejection or boron dilution)
- Recommendations related to LWR fuel cladding may not apply

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SSG 52 Areas not covered

- Safety classification guidance may vary for each NAR design
- Thermohydraulic and thermomechanical design features, limits, and analyses will vary for non-water cooled reactors
- Core support structures for non-water cooled reactors differ from typical LWR designs
- Mixed oxide core guidance in SSG-52 does not include high plutonium levels in LFRs and SFRs or high breeding ratio designs

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SSG 52 Areas not covered

- The principles, limits, and examples given in SSG-52 related to assuring fuel integrity and preventing fission gas release under accident conditions may not address non-water cooled designs and performance

- Guidance on rules for and acceptability of reliance on inherent negative reactivity feedbacks or passive systems for reactor control and shutdown

- Issues regarding chemical hazards (non-water cooled reactors)

- Post-irradiation issues, including fuel transport, storage, and reprocessing of non-water cooled reactors

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Design of the
Reactor Core for
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Specific Safety Guide
No. SSG-52

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Conclusion

- Application of SSR 2/1 requirements are fully applicable to water cooled SMRs
- Application of SSR 2/1 requirements to non-water cooled reactors:
  - Some statements do not present with clarity the design requirements that apply to these technologies
  - In some cases, passive and inherent safety features in the design and operation of the new technologies are not considered
- Application of SSG-52 recommendations are generally applicable to water cooled SMRs
  - SSG-52 (Rev.1, 2019) recommendations focus on LWR and PHWR global operating experience
- Considerable interpretation of SSG-52 content and recommendations are required to deliver similar high value to non-water cooled designers and operators

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Applicability of Reactor Coolant Systems Safety Standards to Novel Advanced Reactors

Bernard Poulat

8 December 2021

Objective and Scope

Objective

- Assessing applicability of SSR-2/1 Rev. 1, requirements 47 to 53 to light water cooled SMRs and non-water cooled reactors
- Assessing the applicability of SSG-56 recommendations updated after the Fukushima Daiichi accident to light water cooled SMRs and non-water cooled reactors
- Identification of areas of novelty and/or particularities not covered (at a high level)
- Providing insights for a deeper analysis.

Scope

- Water cooled SMRs
- SFR
- LF
- HTGR
- MSR are only considered for SSR2/1

This review is based on a screening of the recommendations, focusing more on their safety objective and less on the used vocabulary that might appear as pressurized water-cooled reactor technology oriented.

GIF report SDC TF/2017/02 Rev 1: Safety Design Criteria for Generation IV Sodium cooled Fast Reactor System; GIF report: Safety Design Criteria for Generation IV Lead cooled Fast Reactor System
Tecdoc-1936 Applicability of Design Safety Requirements to Small Modular Reactor Technologies Intended for Near Term Deployment.

SSR2/1 Applicability considerations

- Requirement 47: Design of reactor coolant systems

Objectives: Adequate design provisions to achieve and maintain a high quality of the components and to minimize the loss of coolant should a break or a leak occur

Applicable to water cooled SMRs and overarching requirement applicable to non water-cooled reactors

- Requirement 48: Overpressure protection of the reactor coolant pressure boundary

Objectives: Preserve integrity of the RCPB against overpressure without releasing radioactive materials into the environment

Applicable to water cooled SMRs

- Requirement 49: Inventory of reactor coolant

Objectives: Keep conditions within a specified range adequate for the cooling of the fuel in operational states

Applicable to water cooled SMRs and non water-cooled reactors with some interpretation

SSR2/1 Applicability considerations

- Requirement 50: Clean up of reactor coolant

Objectives: Detection and removal of fission/ corrosion products and non-radioactive substances from the coolant

Applicable to water cooled SMRs and non water-cooled reactors

- Requirement 51: Removal of residual heat from the reactor core

Objectives: Design provisions to remove core decay heat in shutdown state

Applicable to water cooled SMRs and non water-cooled reactors

- Requirement 52: Emergency cooling of the reactor core

Objectives: Design provisions to restore and maintain cooling of the fuel under accident conditions (even if the integrity of the RCS is not maintained)

Applicable to water cooled SMRs and non water-cooled reactors with some interpretation

- Requirement 53: Heat transfer to an ultimate heat sink

Objectives: Design provisions to transfer decay heat to the ultimate heat sink with a reliability (diverse systems, different accesses, margins to withstand seismic loads higher DBE loads)

Applicable to water cooled SMRs and non water-cooled reactors

SSR2/1 Areas not covered

Consideration of specific features, modes of failures, phenomena:

- More favourable core characteristics
- More favourable coolant characteristics
- Operating conditions: low pressure, high temperature
- Specific design characteristics providing longer grace periods for operator actions, or for off-site services

- Specific PIEs
- Specific natural hazards or internal hazards
- Sharing of systems among several reactor modules

☐ SFR/LFR: sodium leaks, sodium fires, water sodium reaction, sodium freezing, air ingress into the cover gaz.

☐ HGTR: Air ingress, water ingress, graphite fire/oxydation

SSG-56 Scope

Basically:

- Section 3 provides recommendations* to prevent abnormal conditions from escalating to accident conditions
- Section 4 provides recommendations* for :
  - an adequate capacity of the ultimate heat sink and its availability in all plant states.
  - an adequate reliability of the various and necessary systems to transport heat to the ultimate heat sink in the different plant states.
- Section 5 provides recommendations *for :*
  - adequate design provisions* to achieve and maintain a high quality of the RCS components and to minimize the loss of coolant should a break or a leak occur, and
  - detailed recommendations for the design of the main RCS components (for pressurized water-cooled reactors.
- Section 6: specific recommendations for the reactor coolant systems (PWR)
- Section 7: specific recommendations for the reactor coolant systems (BWR)
- Section 8: specific recommendations for the reactor coolant systems (PHWR)

* Not reactor technology oriented

SSG-56 Applicability considerations

Areas of SSG 56 **applicable**:

- *SECTION 3 (144 clauses)*, Recommendations 3.7 to 3.105, 3.115 to 3.124, 3.126 to 3.129, 3.133 to 3.136 and 3.139 to 3.141
- *SECTION 4 (45 clauses):* , Recommendations 4.2 to 4.19
- *SECTION 5 (127 clauses)*:
- Safety items and challenges addressed in section 5 are largely Pressurized water-cooled reactor technology oriented and consequently the recommendations need significant interpretation for non-water-cooled technologies. Those recommendations are applicable to water cooled SMRs with small adjustments.

Considerations in the application of existing recommendations to non-pressurized water-cooled reactors:

- *SECTION 3 (144 clauses)*, :
- Recommendations 3.106 to 3.114 are specific to the in-service inspection of pressure retaining components.
- *SECTION 4 (45 clauses):*
- Recommendations 4.20 to 4.45:
  A graded approach might be applied to the design of heat transport systems to the UHS for reactor technologies with a low decay heat or with a primary coolant having favourable characteristics (e.g; high calorific capacity, high heat transfer coefficient)
- *SECTION 5 (127 clauses)*:
- Recommendations 5.18 to 5.51 : Pressure control and over pressure protection/ RCPB Isolation
- Recommendations 5.77 to 5.127: Specific design aspects of the RCS components
- *SECTION 6*: Specific considerations for PWR technology
- *SECTION 7*: Specific considerations for BWR technology
- *SECTION 8*: Specific considerations for PHWR technology

SSG-56 Applicability considerations

For reactors with some inherent and design characteristics, proved as being beneficial towards nuclear safety, it can be useful to consider a **graded approach** for the application of some requirements, noting that:

Lowering the safety class of an item important to safety might result in an increase of the risk (an increase of the probability for an event to occur, or an increase of the probability of failure of the mitigation provisions)

Claims for a high reliability of a system important to safety justified based on design characteristics: safety classification and seismic categorization, quality of the manufacturing, identification and prevention of the failure modes, identification and removal of the CCF, segregation or physical separation, qualification, use of diversity, implementation of redundancies, etc.

Single failure criterion applies to any component subjected to failure mechanisms

Equipment failure or phenomena that could lead to an early radioactive release or a large radioactive release and for which mitigation is not reasonably achievable shall be practically eliminated

SSG-56 Areas not covered

Areas of novelty in Reactor Vessel and the Reactor Coolant Systems:

- Recommendations to achieve a high quality in the design and manufacturing of the Primary Circuit could be customized with a focus to the specific mechanisms that could challenge the integrity of the components considering that materials, type of coolant, neutron energy, operating parameters, loading conditions, etc.
- Inherent characteristics of the coolant (high boiling temperature, high heat transfer coefficient) modify the dynamic of the transients in the event of a loss of cooling and therefore have consequences on the engineering options
- For pool type reactor designs, a large LOCA is not relevant. A loss of coolant is less important for the fuel cooling but could result in hazards with serious consequences and may need provisions to prevent, detect and mitigate the consequences (sodium leaks, toxic gas leaks, etc.)
- Recommendations for the protection of the Primary Circuit and the coolant systems against the effects of internal hazards could be customized considering that the layout of systems and components is different and that some hazards are specific to a reactor technology
- The recommendations for inspection, in-service inspection and testing need adaptation considering the areas to be inspected, the nature of materials and the accessibility to components are different

Conclusion

- SSR 2/1 is largely technology neutral and mostly applicable to water cooled SMRs and non-water cooled reactors (few adjustments and interpretation might be necessary)

- The phrasing of the SSG-56 recommendations is oriented to land based pressurized water cooled nuclear power plants. However the recommendations provided in sections 3 and 4 have been phrased to be technology neutral and therefore can be considered for most of them applicable to water cooled SMRs and non-water cooled reactors.

- Consideration of multi-module aspects not addressed in SSG-56

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Applicability of Containment Safety Standards to Novel Advanced Reactors

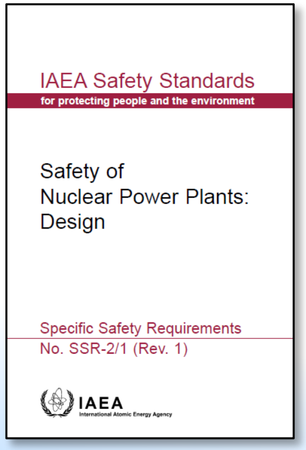
Kay Nünighoff

8 December 2021

Scope of this work

The following **IAEA Safety Standards** have been reviewed:

- **SSR 2/1 Rev. 1**
  - Requirements 54-58
  - *Other requirements have an impact too, but were not considered in this task*
- **SSG-53**



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Safety of
Nuclear Power Plants:
Design

Specific Safety Requirements
No. SSR-2/1 (Rev. 1)

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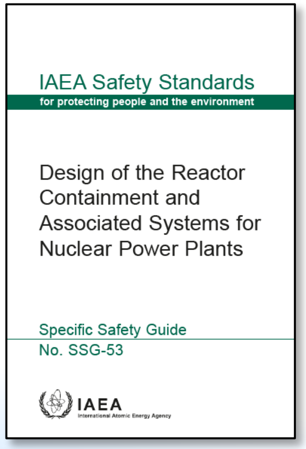

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Design of the Reactor
Containment and
Associated Systems for
Nuclear Power Plants

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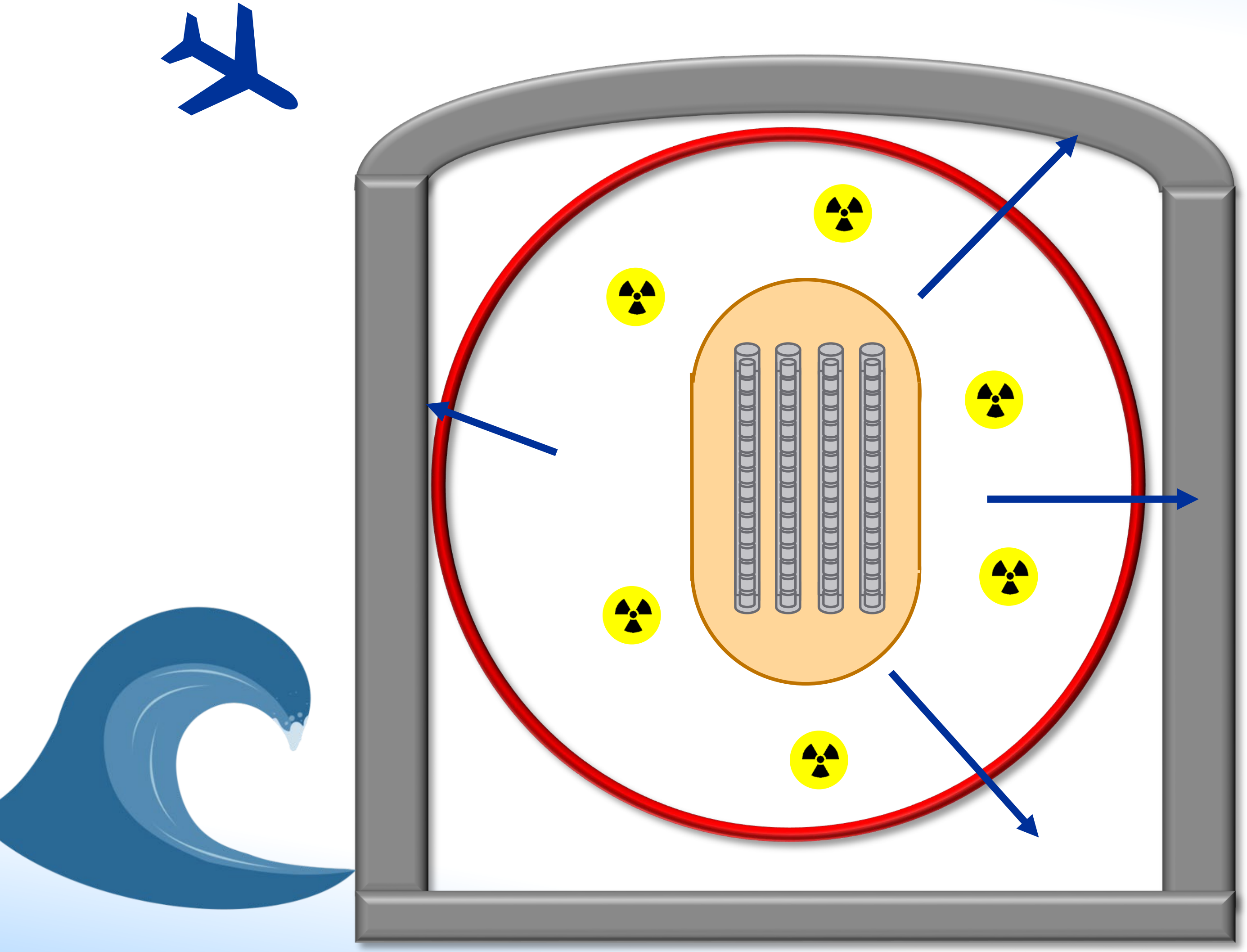
The following **reactor designs** have been taken into account:

- Water cooled SMRs
- SFR
- LFR
- HTGR
- MSR

Safety functions of the containment



Safety functions of the containment according to SSR 2/1 Rev.1 Requirement 54:

i. Confinement of radioactive substances in operational states and in accident conditions

ii. Protection of the reactor against natural external events and human induced events

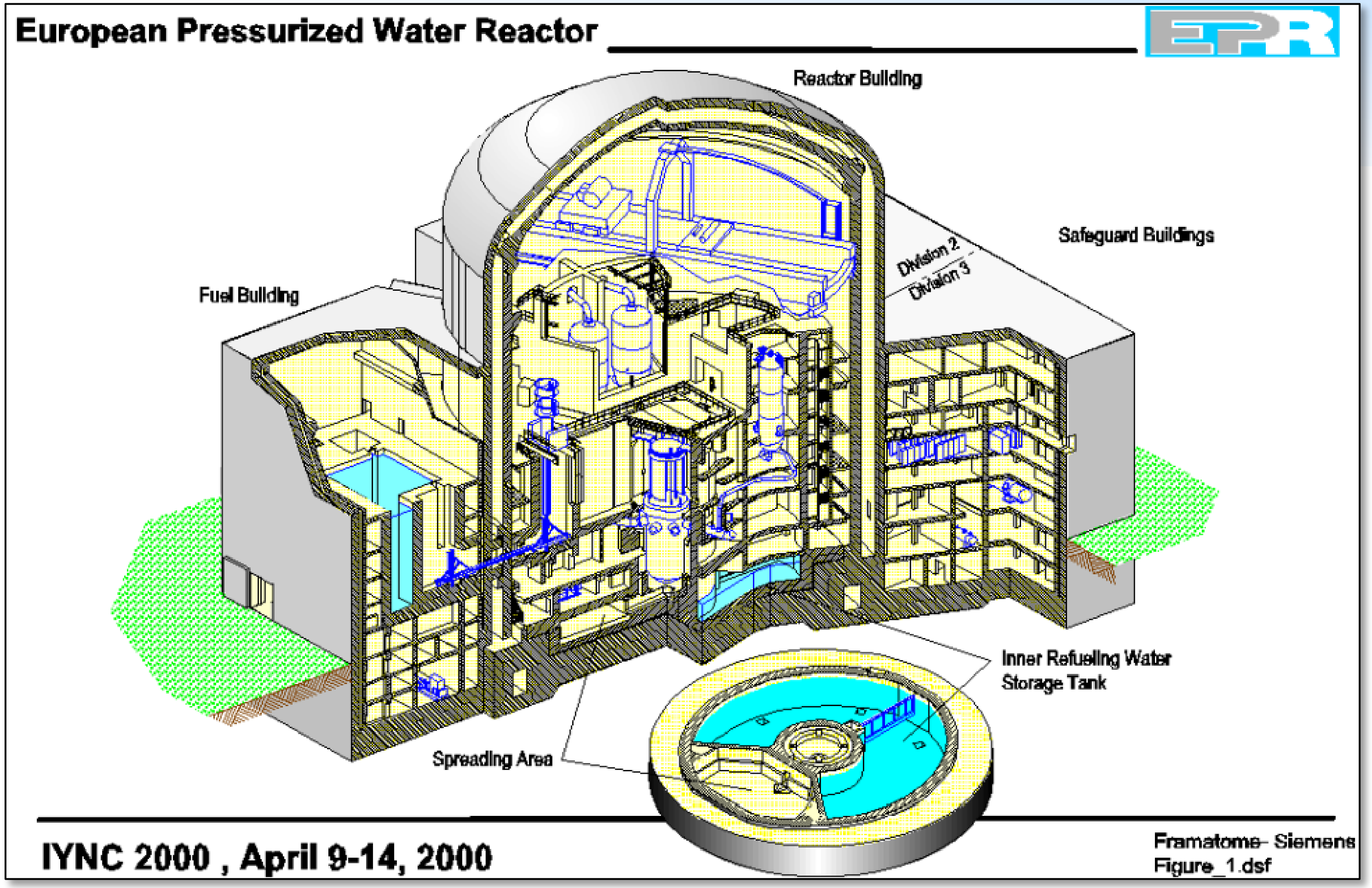
iii. Radiation shielding in operational states and in accident conditions

SSR 2/1 Rev.1 Requirements 55 to 58 contains more specific general requirements.

Different technical solutions exist for LWRs!

Example EPR Containment

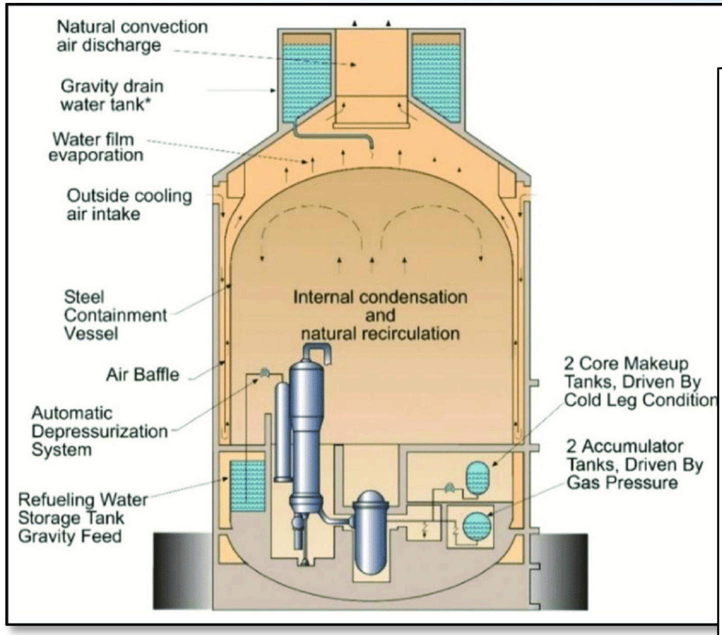
- Double wall containment
  - Inner containment with steel liner
  - Outer containment to protect reactors against external hazards
- Number of barriers
  - Fuel matrix / cladding
  - Reactor coolant pressure boundary
  - Inner containment
  - Outer containment

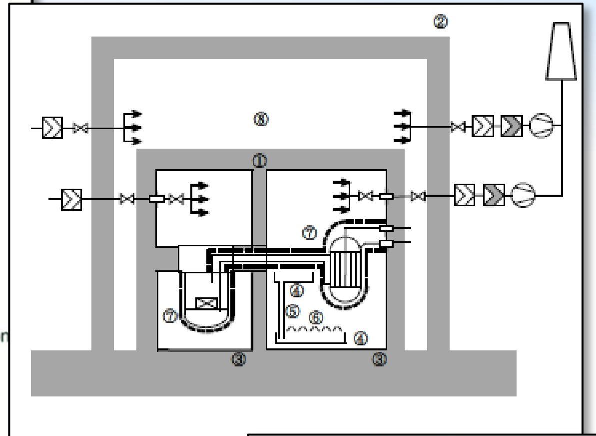


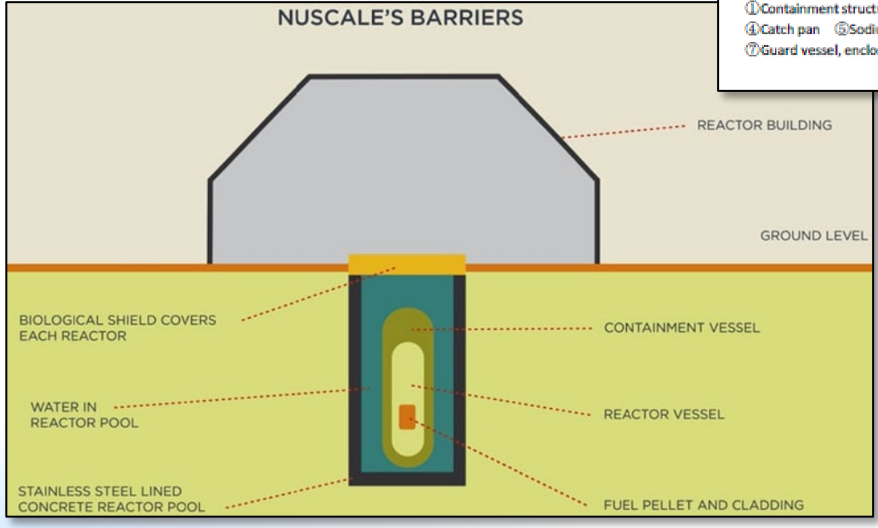
source: https://inis.iaea.org/collection/NCLCollectionStore/_Public/33/011/33011210.pdf

General areas of novelty

- Passively air cooled containments
- Underground/submerged installations of reactors / containment vessels
- Different technical solutions for access to containment vessels (e.g. bolted flanges instead of airlocks)
- Tiny containments
- Multi-module plants
- Mobile / transportable reactors
- Factory-fuelled SMRs (confinement function during transport)
- Containment fulfils safety function “residual heat removal”
- Coolant operated at atmospheric pressure







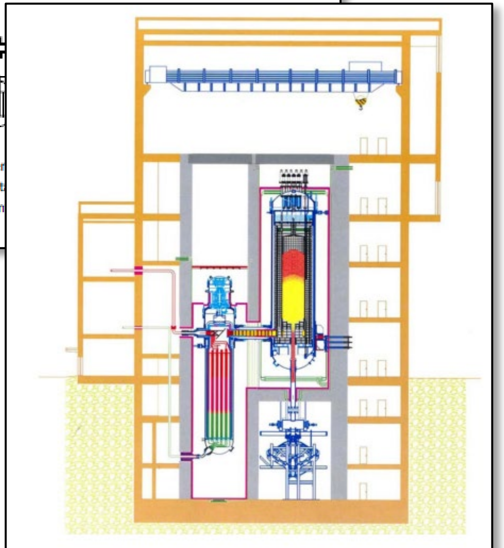
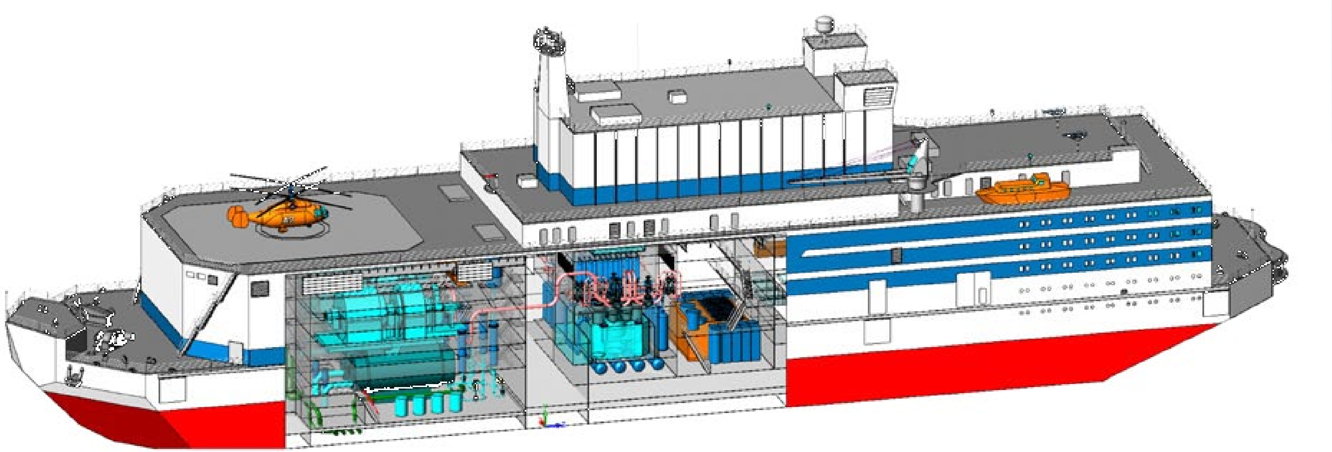


Fig. 1.6. 250 MW-thermal HTR-PM reactor building elevated above ground level with steam generator.

Micro reactors and floating reactors

eVinci Mikroreaktor (Wärmerohr)
source: https://www.westinghousenuclear.com/



Akademik Lomonosov mit KLT-40S (DWR)

Xe-100 Mobile Mikroreaktor (HTGR)

source: https://x-energy.com/reactors/xe-mobile

SSR2/1 Applicability considerations

- Requirements 54-58 and its subsequent paragraphs are formulated in a very general and technology neutral way
  - Directly applicable to LWR-type reactor concepts, but the intent is also applicable for most of the other reactor concepts; this may be achieved by different approaches
- Redundancy requirement in para. 6.28 may not be directly applicable to passively air-cooled containments
- For NAR designs the containment or the reactor building fulfils also the safety function to remove residual heat from the containment.
- Para. 6.29 focusses on H_2 and O_2. For some NARs H_2 and O_2 may not be relevant or other substances may challenge the integrity of the containment (e.g. CO in HTGRs).
- For some designs the coolant is not pressurized and thus terminology needs consideration:
  - Replace “reactor pressure boundary” by a more generic wording like e.g. “reactor coolant boundary”
- Definition of accident conditions challenging the integrity of the containment and/or other elements that provide the function of confinement
  - As for example, the traditional severe accident is associated with DEC with core melt.

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SSG-53 Applicability considerations

	WC SMR	SFR	LFR	HTGR
Section 1	Fully applicable except the restriction to limit the scope to land-based, stationary NPP with water as coolant.			
Section 2	Fully applicable	Mostly applicable		
Section 3	Mostly applicable			
Section 4	Mostly applicable			

- SSG-53 includes many recommendations assuming a core melt accident in a large LWR!

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Design of the Reactor Containment and Associated Systems for Nuclear Power Plants

Specific Safety Guide
No. SSG-53

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SSG-53 Applicability considerations

- SSG-53 includes many recommendations assuming a large LWR with a core melt accident as the most severe accident scenario.
- For some SMRs or non-LWR reactor designs, a discussion seems to be worthwhile on how the defense-in-depth concept has to be applied and what are the accident conditions (DBA and DEC) to be considered.
- Some designs will not face a core melt accident (e.g. HTGRs), and this may lead to less severe impacts on the containment.
  - In such a case, many assumptions behind the recommendations of SSG-53 may not be appropriate.
  - Discussion needed on phenomena in non-LWR type reactors potentially challenging the containment and how it can be addressed in SSG-53.
- The review identified that judgment is needed in 30 areas where direct applicability is limited, and 16 areas not covered in the safety standards
  - Mainly due to different technology applied in NARs

SSG-53 Applicability considerations

- However, the containment represents the **last barrier to prevent releases** to the environment and thus the integrity of this ultimate barrier must be reliably ensured, even for the most penalizing accidents conditions postulated for a certain reactor design.
  - For LWR type concepts, the containment system is the ultimate and rigid barrier to confine radioactive material to prevent unacceptable releases in case of accident conditions.
  - Some designs, in particular HTGR, discusses more a confinement system rather than a containment system by claiming, that sufficient retention is ensured by other barriers.
  - HTGR designs may not be equipped with a containment. Thus, SSG-53 para. 2.7 may not be applicable for HTGRs. However, a discussion is necessary to identify the need for requiring suitable provisions for such reactor designs too
  - It seems to be worthwhile to discuss the barrier concept and the strength of each of the concentric barriers separately, to define the requirements for the containment as the last barrier.

SSG-53 – Areas not covered

- Transportation of a factory fuelled transportable SMR, i.e. transportation of a reactor in cold shutdown
- Broadening the scope to include transportable and floating reactor designs
- List of PIEs need to be adapted to specific PIEs for NARs
- Addressing „multi-module“ accidents potentially challenging the integrity of the containment
- Occurrence of chemical reactions during accident conditions in NARs challenging the integrity of the containment
- In case of floating reactors, measure accelerations instead of seismic
- Humidity may not be an appropriate parameter to indicate a leak from the primary circuit, e.g. HTGR, SFR, LFR, MSR
- Novel containment designs instead of concrete containment designs

Conclusion

- **SSR 2/1 is largely technology neutral** and mostly applicable to novel advanced reactors
  - Only minor adaptation necessary
- **SSG-53 is very specific for stationary water cooled nuclear power plants**
  - Postulated initiating events, severe accidents and related phenomena and their impacts on the containment are largely based on LWRs, in particular sever accidents (i.e. core melt)
- Design extension conditions for water cooled SMRs and non-LWR requires further discussions with respect to their impact of the ultimate barrier.
- Novel impacts need to be considered as not addressed in the current IAEA Safety Standards
  - Transportable NPPs
  - Floating NPPs
  - Underground / submerged installations
- Consideration of multi-module aspects need to be considered as not addressed in SSG-53
  - Units sharing a common containment is already state of the art (e.g. CANDU)

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Applicability of Electrical and I&C Standards to Novel Advanced Reactors

Alexander Duchac (IAEA)

8 December 2021

Scope of the review


IAEA Safety Standards
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Safety of
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Design

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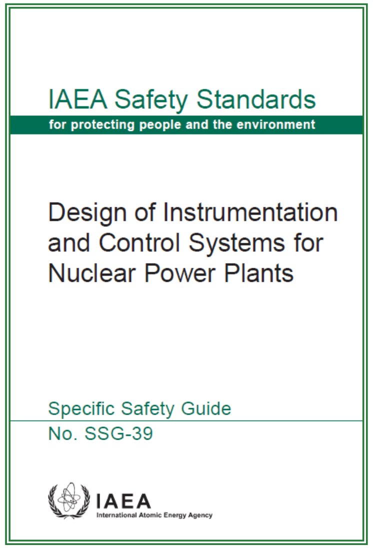
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Design of Instrumentation
and Control Systems for
Nuclear Power Plants

Specific Safety Guide
No. SSG-39

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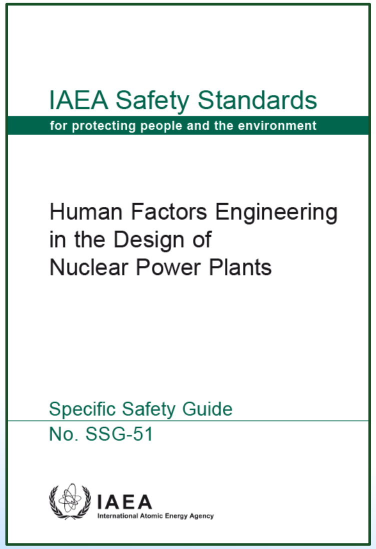
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Human Factors Engineering
in the Design of
Nuclear Power Plants

Specific Safety Guide
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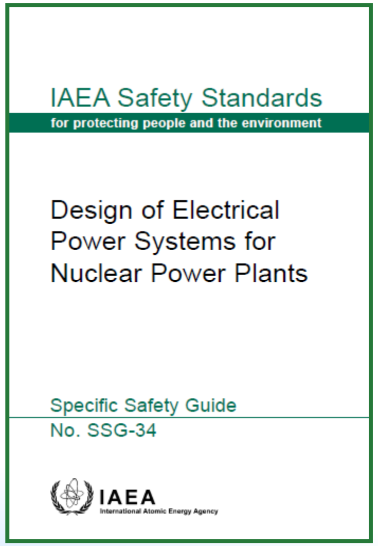
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Design of Electrical
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- Principal safety requirements SSR 2/1 (Rev.1)
- Multipurpose plants
  - Requirement 35: Nuclear power plants used for cogeneration of heat and power, heat generation or desalination
- I&C systems
  - Requirement 59: Provision of instrumentation
  - Requirement 60: Control systems
  - Requirement 61: Protection system
  - Requirement 62: Reliability and testability of instrumentation and control systems
  - Requirement 63: Use of computer based equipment in systems important to safety
  - Requirement 64: Separation of protection systems and control systems
- Human factors engineering for HSI
  - Requirement 32: Design for optimal operator perform
  - Requirement 65: Control room
  - Requirement 66: Supplementary control room
  - Requirement 67: Emergency response facilities on the site
- Electrical systems
  - Requirement 41: Interactions between the electrical power grid and the plant
  - Requirement 68: Design for withstanding the loss of off-site power

General areas of novelty

Electrical power systems

- Extensive use of passive design features and systems whose activation does not rely on AC power
  - Neither LOOP, nor SBO event is an issue for ensuring the heat removal function
- Autonomy for long term safe shutdown state more than 72 hours
- DC power systems play vital role
  - Reliability
  - Sizing
  - Functional and performance criteria
  - Independence

I&C systems

- Extensive use of passive design features and systems
- Integrated designs
- Modular construction
- Mutualised operation
- Mutualised plant systems
- Staged construction
- More extensive use of remote monitoring and support centres
- Consideration of emerging I&C technologies (platforms, sensors)
- Optimised maintenance

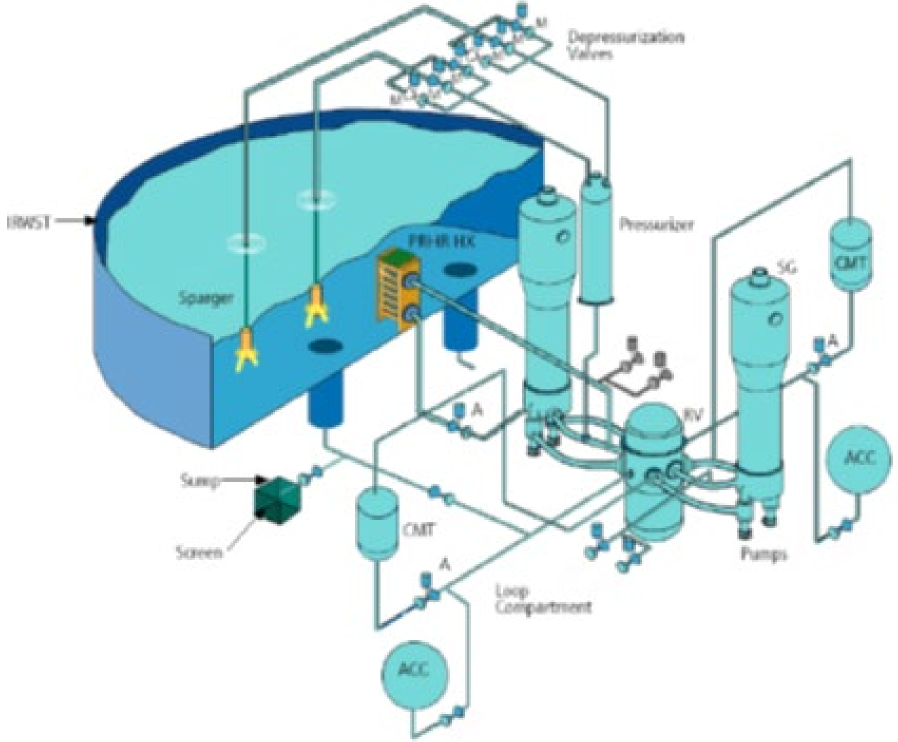
An example of NPP with passive heat removal features

US AP1000

- AP 1000 safety does not rely on AC power
  - Passive decay heat removal
  - Passive safety injection
  - Passive containment cooling

- Long term safe shutdown state
  - 72 hours without operator action

Westinghouse design



Picture curtesy of Westinghouse

An example of NPP with passive heat removal features

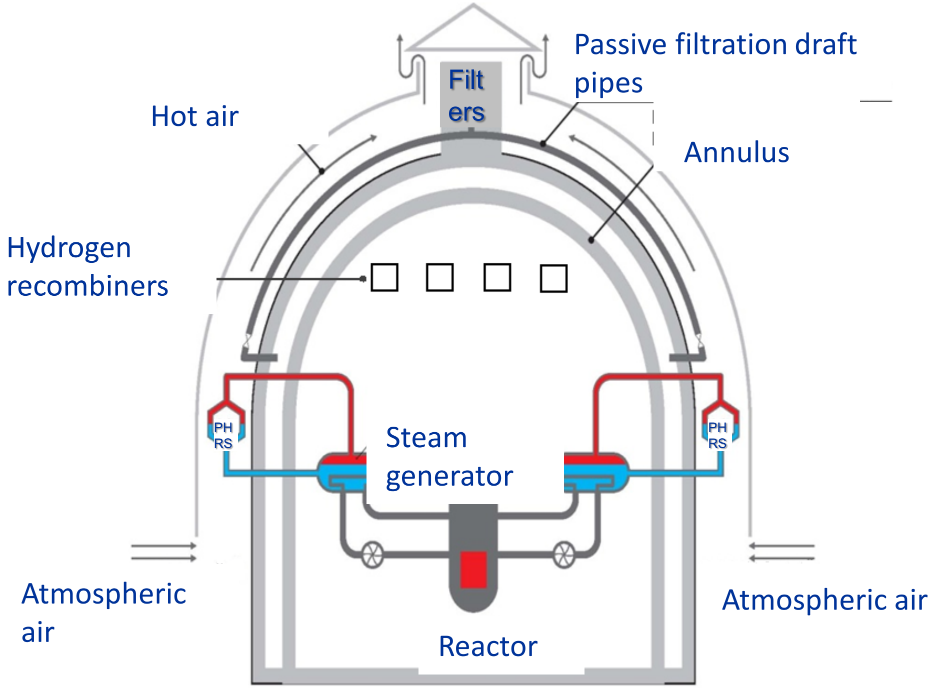
VVER 1200

- Passive heat removal system intended for continuous reactor decay heat removal including the conditions of all power supply loss (SBO)

- Each loop includes heat exchanger modules*, steam and condensate pipelines, air ducts that supply environment air and remove heated air, passive devices of direct action regulating the air consumption

* AEP St. Peterburg design has heat exchanger modules submerged in water

AEP Moscow design



Picture curtesy of ATOMENERGOPROEKT State Corporation "Rosatom" Enterprise

SSG-34 (electrical systems) Applicability considerations

- The electrical power supply systems of SMR and non-water cooled reactors with passive safety features are generally similar to those of traditional water cooled reactors without the requirement for the provision of safety grade AC electrical power supplies needed at the onset of an anticipated operational occurrence or accident conditions to maintain the plant in a controlled state.

- Architecture of electrical power systems and sizing of electrical components (e.g. motor operated valves, electrical motors, circuit breakers, batteries and battery chargers) does not require the same level of redundancy, diversity and capacity to supply necessary loads to bring the plant to the safe state and maintain long term heat removal

- There is more emphasis onto the design and reliability of DC power systems including the associated uninterruptible power supplies (e.g. single failure criterion, independence and diversity) as described in SSG-34

Example of Electrical power systems for SMR

Preferred power supply

The power supply from the transmission system to the safety classified electrical power system

Reliable backup AC power source

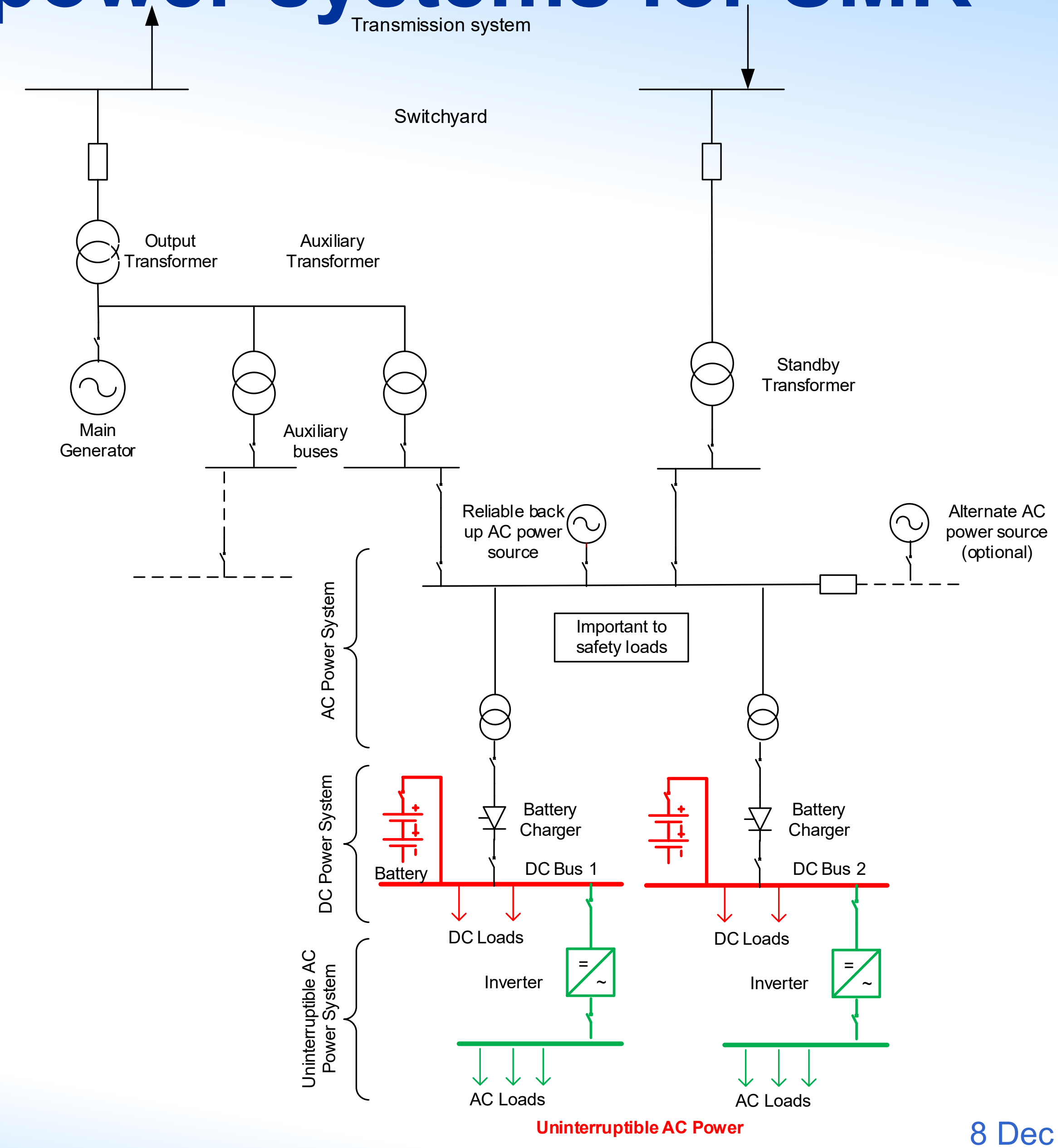
A power source reserved for the use for the power supply to the plant during LOOP event

Safety power system

The DC power source with associated safety buses

Alternate AC power source

Optional power source reserved for the use for the power supply to the plant during long term SBO event



SSG-34 (electrical systems) Applicability considerations

- Architecture of electrical power systems and sizing of electrical components (e.g. motor operated valves, electrical motors, circuit breakers, batteries and battery chargers) does not require the same level of redundancy, diversity and capacity to supply necessary loads to bring the plant to the safe state and maintain long term heat removal

- Design of off-site electrical power systems; the number of off-site power sources, composition of electrical switchyard may be simplified

- Design for withstanding LOOP and SBO event needs to be modified based on the specific design features and architecture of SMRs
  - Sizing of DC power systems
  - Autonomy of interruptible power supply
  - Sizing and performance criteria for reliable AC power systems
  - Guidance on station blackout provided in clauses need to be adapted depending on SMR demonstrated coping capability

- More focus is on the design and reliability of DC power systems including the associated uninterruptible power supplies (SSG-34 applicable)

General areas of novelty for I&C systems

- Extensive use of passive design features and systems
- Integrated designs
- Modular construction
- Mutualised operation
- Mutualised plant systems
- Staged construction
- More extensive use of remote monitoring and support centres
- Consideration of emerging I&C technologies (platforms, sensors)
- Optimised maintenance

Key challenges for I&C system design

- I&C supporting plant states that include operational states and accident conditions
  - Application of design and engineering rules (SFC, Independence, consideration of CCF, diversity)
- Set of postulated initiating events could be used for water cooled SMR designs, however, needs careful revision to include postulated initiating events specific for non-water cooled designs
- Defence in depth for multi-module plants requires consideration of the difference between the defence in depth of a module and the defence in depth of the plant
- Internal and external hazards should account for multi-module plants
  - To clarify what is meant by internal and external hazard, as some hazards are internal to the plant but external to a module, such as those a single module may cause to other modules
- Range of specified service conditions for equipment qualification need to be identified
  - The integrated SMR design may cause different stressor and ageing degradation mechanisms due to specified service conditions inside the module.

SSG-39 (I&C) Applicability Considerations

- I&C functions in the case of multi-unit plants consider of the fact that some functions are related to a module, while others are related to the multi-module plant (in particular in the case of mutualised plant systems).
  - Overall I&C architecture of the multi-module plant, vs I&C architecture of individual modules
- The overall I&C architecture and individual I&C systems architecture remains essentially valid. However, in the case of multi-module plants with mutualised operation and / or mutualised plant systems, a distinction should be made between the overall I&C architecture of the multi-module plant, and the overall I&C architecture of individual modules
- Testing and testability in operation remain valid but it might be worthwhile to consider whether any adjustments are necessary in the case of integrated designs, where accessibility to sensors could be problematic during operation
- Design of sensing devices needs to address the issue of accessibility (e.g. for testing and calibration), which could be more difficult in the case of integrated designs

SSG-39 (I&C) Applicability Considerations

- The following computer security interfaces should be considered:
  - Computer security during transportation to site of modules fully assembled, configured and tested in factory
  - Possible computer security issues raised by staged construction
  - Possible computer security issues and benefits related to reliance on remote monitoring and support centres
  - Possible computer security issues and benefits related to the existence of multiple, quasi identical units in many different geographical sites
  - Separation (from a computer security standpoint) between the units of a multi-unit plant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Design of Instrumentation and Control Systems for Nuclear Power Plants
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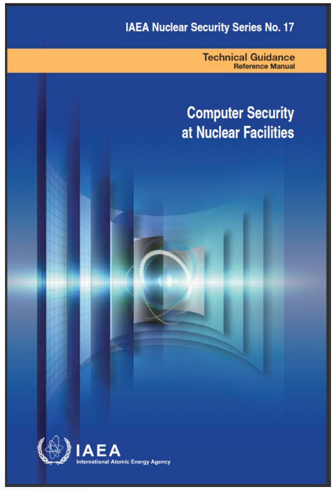
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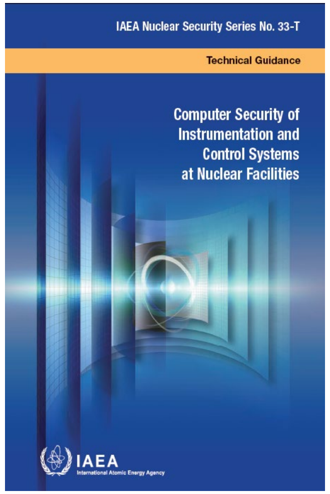
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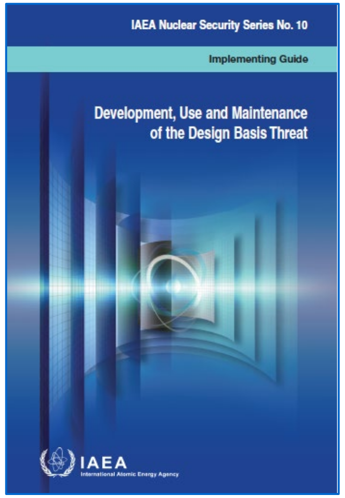
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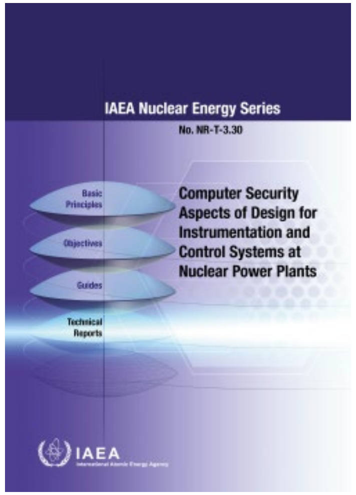
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Overview of key areas of novelty relevant for HFE

- Advanced automation systems having more dynamic human-automation interaction than conventional power plants
- Mutualised operation of multiple units from the same control room
- Mutualised plant systems
  - Multi-module plants, where some systems are shared by all, or some modules, possible impacts on I&C architectures, HIS of control rooms, control room systems, and electrical power systems
- Innovative and optimised concepts of operation and maintenance
- Remote control of a module or other aspects of SMR design
- Employing robotic systems

Key challenges for HSI design

- Concept of operation, functional analysis and assignment in a mutualised operation framework
- The modular aspect of SMRs present some novel challenges to HFE and Human Performance
- The impact to HSI design to multi-module unit which may have modules in different phases of a life cycle (i.e. installation / commissioning, operational, or decommissioned)
- Potential module-to-module differences affecting human performance
- Multiple operational modules can be in different operational states (e.g. refuelling, outage, AOO, emergency)
- HSI design for a shared control room for modules/multi-module units and other shared operational support facilities

SSG-51 (HSI) Applicability considerations

- In an SMR, the novel proposal may be that a single operator is responsible for multiple reactor modules/units, associated unit secondary systems, and possibly common systems.

- From an HSI design perspective, the following key items should be uniquely considered and discussed further:
  - Design for a shared control room between modules/units and other shared operational support facilities;
  - HSIs for common systems;
  - HSIs for the management of simultaneously occurring life-cycle phases and operational states;
  - Potential unit-to-unit differences affecting human performance.

- SSG-39 and SSG-51 do not provide specific guidance on shared control rooms
  - The discussion on common cause failure for I&C systems in IAEA SSG-39 does not include HSI for common systems
  - Simultaneous monitoring and control of multi-module plant is different compared to a single module

- SSG-39 and SSG-51 do not address the potential for unit-to-unit/module-to-module differences

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Applicability of Auxiliary Systems Safety Standards to NARs

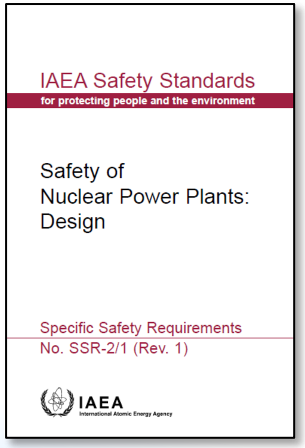
Remy Bertrand

8 December 2021

Scope of the review

The review concerns mainly the 2 following **IAEA Safety Standards**:

- SSR 2/1 Rev. 1: Requirements 37, 70 to 73, 75,76, 78 and 79
- SSG-62

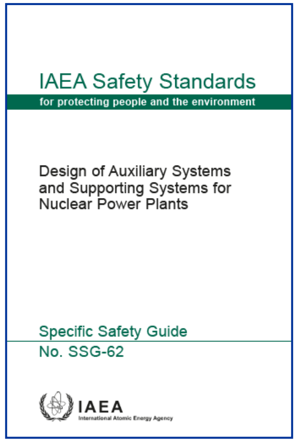


IAEA Safety Standards
for protecting people and the environment

Safety of
Nuclear Power Plants:
Design

Specific Safety Requirements
No. SSR-2/1 (Rev. 1)

IAEA



IAEA Safety Standards
for protecting people and the environment

Design of Auxiliary Systems
and Supporting Systems for
Nuclear Power Plants

Specific Safety Guide
No. SSG-62

IAEA

The following **reactor designs** have been taken into account: Water cooled SMRs, SFR, LFR, HTGR

Auxiliary systems taken into account:

- Communication systems
- Heat transport systems
- Sampling systems
- Compressed air systems
- HVAC systems
- Lighting systems
- Overhead lifting equipment
- Systems for waste treatment
- Systems for effluents treatment
- Supporting systems of EDG

Areas of novelty in the design of support systems of NARs

General areas of novelty

<ins>Heating, Ventilation and Air Conditioning (HVAC) systems:</ins> Some HVAC systems not needed during a long term after an accident (e.g. HVAC of Main Control Room, dynamic confinement insured by passive system, HVAC providing the cooling of rooms containing only passive systems, HVAC of EDGs rooms…)

<ins>Heat transport systems:</ins> Specific cooling of some structures needed for some NARs (e.g. cooling of reactor cavity of HTGR, SFR and LFR)

<ins>Lighting and emergency lighting systems:</ins> Manual actions limited during accident conditions due to the installation of passive systems (plant locations where emergency and SBO lighting must be provided may be different)

<ins>Supporting systems for the emergency power supply and the alternate power source:</ins> in general NAR is designed with a black start capability

Areas of novelty in the design of support systems of NARs

Areas of novelty specific to SMRs (due mainly to multi-module and modular features)

- Auxiliary systems shared between several modules (a failure may impact several modules)
- Module under construction while other modules may be in normal operation (installation of additional modules will increase the load on auxiliary systems, initial design capability has to consider the supplementary loads)
- Buildings shared between different SMRs modules (different modules sheltered by a same reactor building, spent fuel pool common to different modules). Ventilation system design should consider that an accident may impact one module meanwhile an orderly shutdown is initiated on the other modules
- There may be a shared Communication system of a multi-module SMR.
- Lifting equipment other than overhead lifting equipment may be used (e.g. forklifts) due to the limited space or specific equipment may have to be moved (e.g. RPV of integral PWRs)
- Common facility for the management and the storage of radioactive waste of SMRs built on different sites
- Demineralized water reserve and associated system : the residual heat removal may be performed by a passive system that transfers heat to a water reserve. This reserve must be resupplied in the long term.

Areas of novelty in the design of support systems of NARs

Areas of novelty specific to non-water-cooled reactors (1/3)

Process and post-accident sampling system:

For HTGR, SFR and LFR during normal operation sampling of the primary coolant and for SFR and LFR sampling of cover gas. During accident conditions, sampling of the gas of the reactor building.

Heating, Ventilation and Air Conditioning (HVAC) systems: For HTGR, a primary break would cause a quick increase of the pressure of the ‘containment’ due to the air heating. To maintain the integrity of the ‘containment’, a specific device limits the pressure below the design pressure of the reactor building. The opening of this device induces a temporary rupture of the dynamic confinement that should be restored as soon as possible.

Overhead lifting equipment: The extraction of components from the primary circuit of SFRs must be done under neutral gas. For LFRs, the handling is also made under neutral gas in some designs.

Systems for treatment of gaseous effluents:

- To note the special management of fission gases from MSRs as well as tritium generated in the salt of MSRs
- Specific measures must be implemented for the management of Polonium in LFRs
- For HTGR, gaseous radwaste comes from the helium purification system

Areas of novelty in the design of support systems of NARs

Areas of novelty specific to non-water-cooled reactors (2/3)

System for treatment of liquid effluents

- The liquid effluents are completely different for liquid metal coolants and adequate provisions need to be developed specifically for each coolant technology.
- Before introducing spent fuel in the storage pool of some NARs, the fuel must be cleaned. This is the case for SFRs where the fuel is cleaned by water, leading to liquid waste. Similar process for LFRs.

System for treatment of solid waste: There are some solid wastes that are specific to HTGR, such as graphite dust collected during normal operation.

Equipment and floor drainage system : Quick drainage of sodium of some systems needed in case of a sodium leak (intermediate loop if any or residual heat removal system cooled by atmospheric air).

Areas of novelty in the design of support systems of NARs

Areas of novelty specific to non-water-cooled reactors (3/3)

Other systems specific to non-water-cooled reactors

- HTGR :
  - Helium purification system (for removing graphite dust and radionuclides in the helium coolant)
  - helium storage and supply system has the functions of storing, and supplying and recovering of helium to maintain the pressure in the primary circuit within predetermined conditions
- LFR:
  - the cover gas system
  - the coolant heating system
  - the system that detects water in the cover gas (if applicable)
  - the system for protecting the structure against lead corrosion (control of oxygen in lead)
- SFR:
  - the cover gas system
  - the sodium and cover gas purification systems
  - the system for controlling the oxide concentration within the sodium
  - the system for sodium leak detection, and the sodium heating system

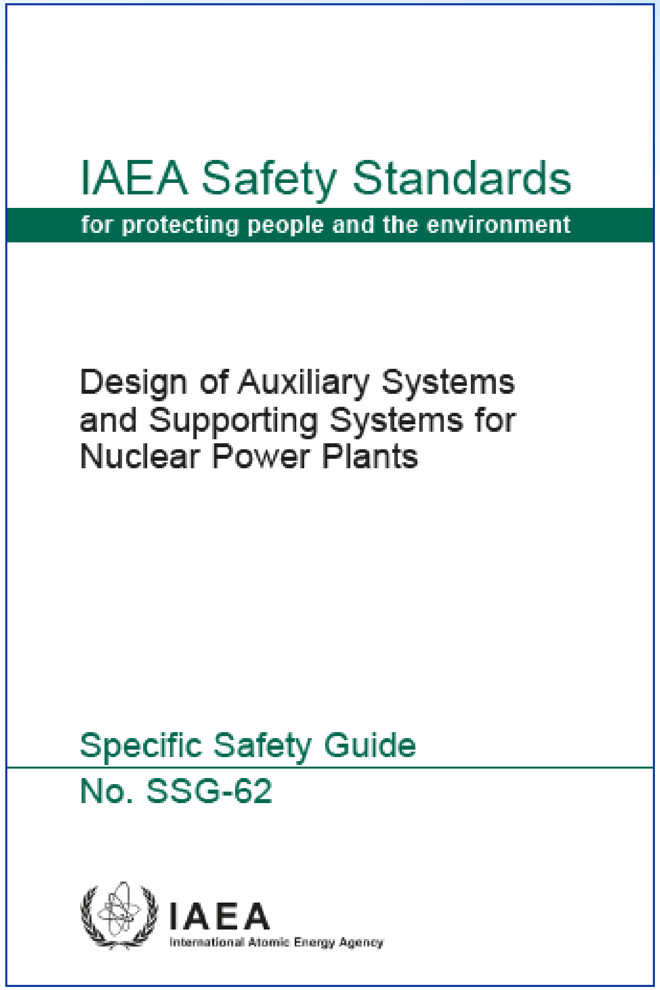
SSG 62 Applicability considerations

Guidance on design of auxiliary systems provided in SSG-62 can be largely applied to the design of auxiliary systems of NARs.

Safety classification: Guidance need interpretation for designs using passive systems in accident conditions. Concern the safety classification level of Heat transport system, compressed air, some HVAC systems and the auxiliary systems of EDG

Equipment and floor drainage system: Reinjection of highly contaminated liquids from the auxiliary buildings into the containment in accident conditions not applicable to LFR, SFR and HTGR

Demineralized water reserve and associated system: Large LWRs may implement long-term residual heat removal by the steam generators in case of loss of the Residual Heat Removal system (notably in case of loss of the UHS or external hazards that may impact the UHS). The recommendations may need interpretation for NARs.



IAEA Safety Standards

for protecting people and the environment

Design of Auxiliary Systems
and Supporting Systems for
Nuclear Power Plants

Specific Safety Guide

No. SSG-62

IAEA
International Atomic Energy Agency

SSG 62 Areas not covered

Communication systems: The gaps to be addressed concern the design of a shared communication system of multi-module SMR

Heat transport systems:

- Considering that safety systems may operate in passive mode in accident conditions (cooling of active components may not be needed), the safety classification level of some heat transport systems as well as the diversification of the chilled water system may be subject to an alternative and well supported safety proposal
- Other safety functions may be added if the cooling of some structures or components has to be performed by a heat transport system (e.g. the cooling of the reactor cavity of HTGR, SFR, and LFR)

Process and post-accident sampling system: The design guidance needs to be completed to introduce:

- Specificities of HTGR: the helium sampling of primary helium coolant during normal operation for analysing its moisture, chemical impurities, and radioactivity. The sample of gas of the reactor building, during accident conditions
- Specificities of LFR and SFR: the sampling of reactor coolant, cover gas, and purification system during normal operation. During accident conditions, the process sampling system provides Sampling within the reactor building in order to detect radioactive releases from the primary side during accident conditions

SSG 62 Areas not covered

Heating, ventilation and air-conditioning systems

- Dynamic confinement is usually performed by a negative pressure within building of large PWR . Other passive means for limiting contamination spread are not considered
- Integrity of the fuel building of some SMRs, in case of boiling of the spent fuel pool, insures by the HVAC system that passively evacuates humid air and steam by the exhaust line of the ventilation. This configuration, not addressed by the SSG-62, raised two issues:
  - The dynamic confinement principle (negative pressure) required by the SSR-2/1 (Rev. 1) is not met
  - The efficiency of the iodine trap usually used is strongly dependent on the air humidity.
- Safety classification level may be subject to an alternative and well supported safety proposal when HVAC is not needed to reach and maintain a safe shutdown state
- Ventilation of buildings sheltering several modules
- HTGR primary break causing a quick increase of the pressure of the reactor building
- Passive HVAC of the Control Room insuring the protection of plant operators against the effects of accidental releases of toxic or radioactive gases

SSG 62 Areas not covered

Overhead lifting equipment:

- Extension of the list of lifting equipment that can be used in addition to the overhead lifting,
- Treatment of the specific cases of SFRs and LFRs that need to extract components from the primary circuit under neutral gas

Systems for treatment of gaseous effluents: Should be taken into consideration:

- Measures for managing polonium in LFRs
- Management of gaseous effluents in vented MSR

Systems for treatment of solid waste: to be included the design guidance related to solid waste of several SMRs located at different sites and treated by a common waste management installation

Supporting systems for the emergency power supply and the alternate power source:

- Safety classification level (safety systems required for safe shutdown only safety class 1 DC power sources, supplied by batteries). AC Emergency power supply may only be needed for recharging the batteries and to restore the inventory of passive residual heat removal system
- Fuel reserve: the fuel oil storage must consider the black start capability
- Shared emergency power supply if any

SSG 62 Areas not covered

Equipment and floor drainage system:

- Design related to quick drainage of the sodium in case of leak impacting an intermediate loop or residual heat removal system cooled by atmospheric air

Other specific systems of non-light water reactors to be taken into consideration: examples of specific systems to be treated:

- HTGR systems: helium purification for removing chemical impurities, graphite dust and radionuclides of the helium coolant
- LFR and SFR systems: purification of gas cover and coolant system, coolant heating system

Areas specific to multi-module:

- Shared auxiliary systems
- Design guidance related to the possible impact of a new module on a share auxiliary system or an HVAC system of a building containing several modules

Conclusion

- **Design guidance of SSG-62 is specific to large PWR, BWR and PHWR** but can be largely applied to the design of auxiliary systems of SMRs and non-water cooled reactors
- Safety classification of some auxiliary systems may need interpretation/ adjustment
- The main findings:
    - ➢ The specific auxiliary systems of SFR, LFR and HTGR reactors that perform safety function not addressed within the SSG 62
    - ➢ The confinement of some buildings in accident conditions
    - ➢ The consideration of multi-module aspects
    - ➢ The auxiliary systems shared between different modules

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Next Steps

Paula Calle Vives

8 December 2021

Development of Program of Work

- A prioritized program of work to develop the necessary guidance and support for the safety standards implementation to novel advanced reactors, based on:
  - The review of applicability of the safety standards to novel advanced reactors
  - Recommendations from SMR Regulators’ Forum
- In close collaboration with the Safety Standards Committees and Commission and the CSS Strategic Planning Working Group
- Reflecting Member States’ needs and priorities

Commission on Safety Standards (CSS)

Nuclear Safety Standards Committee (NUSSC)

Radiation Safety Standards Committee (RASSC)

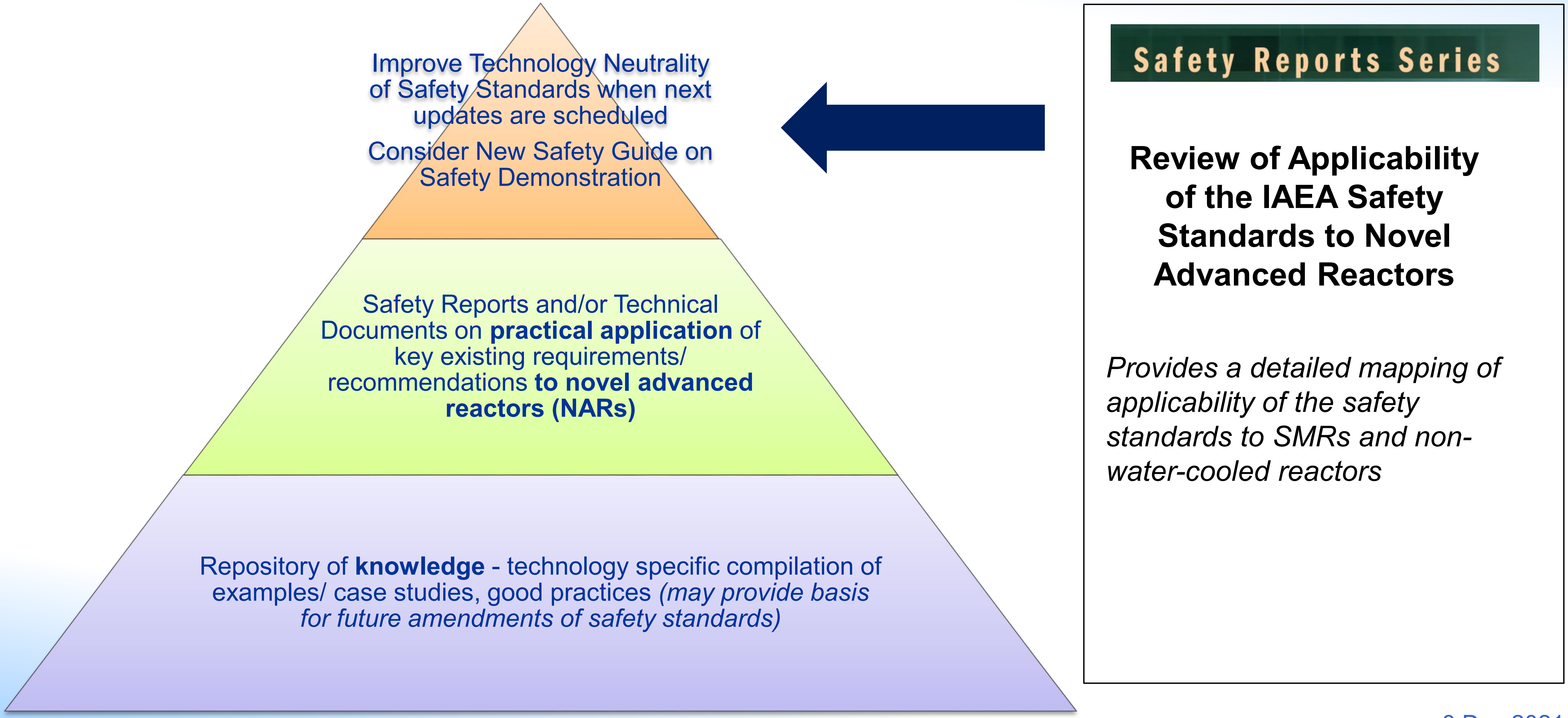
Waste Safety Standards Committee (WASSC)

Transport Safety Standards Committee (TRANSSC)

Emergency Preparedness and Response Standards Committee (EPReSC)

Development of Program of Work

Three workstreams to facilitate the progressive application of Safety Standards



Improve Technology Neutrality of Safety Standards when next updates are scheduled

Consider New Safety Guide on Safety Demonstration

Safety Reports and/or Technical Documents on **practical application** of key existing requirements/ recommendations **to novel advanced reactors (NARs)**

Repository of **knowledge** - technology specific compilation of examples/ case studies, good practices *(may provide basis for future amendments of safety standards)*

Safety Reports Series

Review of Applicability of the IAEA Safety Standards to Novel Advanced Reactors

Provides a detailed mapping of applicability of the safety standards to SMRs and non-water-cooled reactors

Technical Safety Review Conceptual Designs

Technical safety review (TSR) provides the requesting party with:

  - Objective review of documentation presented with respect to IAEA safety standards
  - Recommendations in areas needing improvements to be consistent with IAEA safety standards

- Contribute towards harmonization of safety assessment standards worldwide
- Promote use of IAEA safety standards
- Promote opportunities to identify areas where IAEA safety standards could be further strengthened
- **For conceptual designs, it can help to identify areas that need further development/ research**

- New guidelines under development
- Review against selected subset of safety standards
- **Proposal to work with regulatory team**

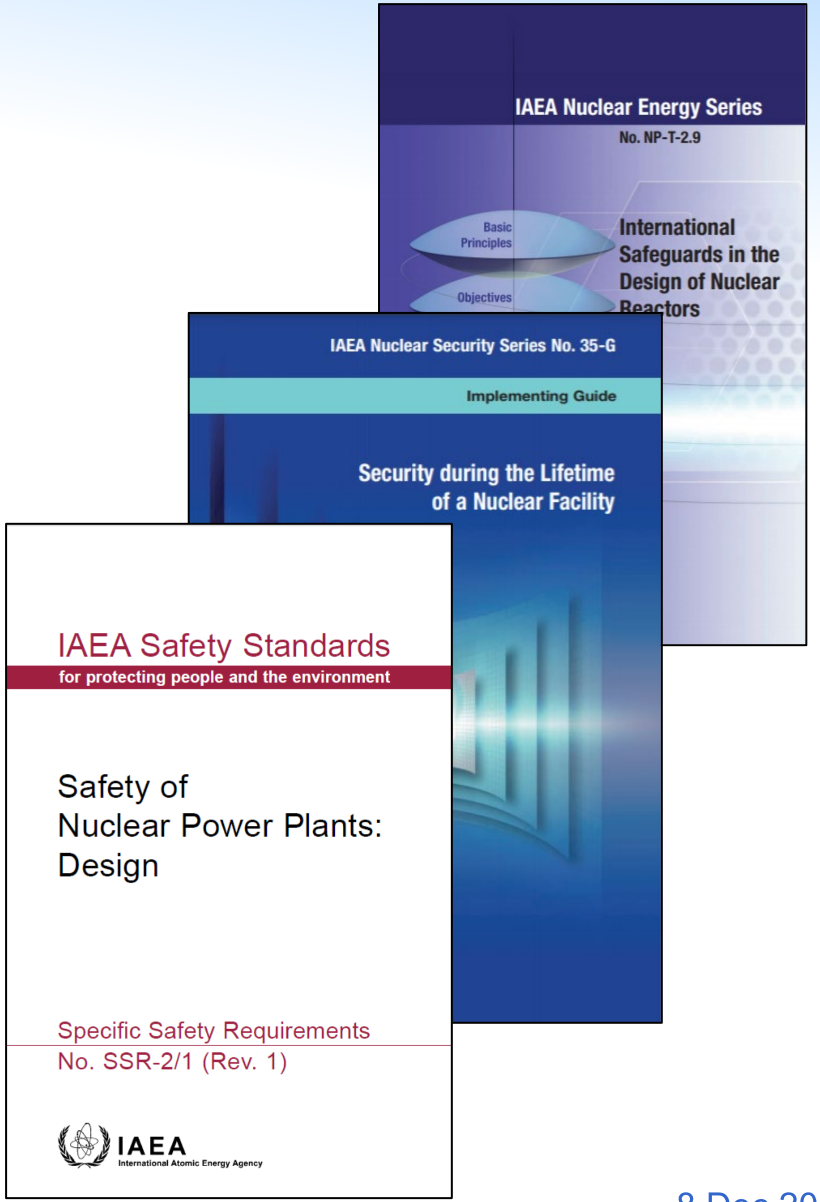
Future Webinars

Webinar on Safety, Security and Safeguards interfaces and challenges for Novel Advanced Reactors
26 January 2022 - 13:00 CET

https://www.iaea.org/ns-webinars/nuclsafety

Objectives:

- Provide an overview to interested stakeholders from industry and regulatory bodies of the outcomes of the IAEA activity on Safety, Security and Safeguards considerations for NARs, covering challenges and interfaces.
- Provide a forum for discussions and promote the holistic approach towards Safety, Security and Safety in early design stages of NARs
- Provide an overview of the further IAEA activities in this area.

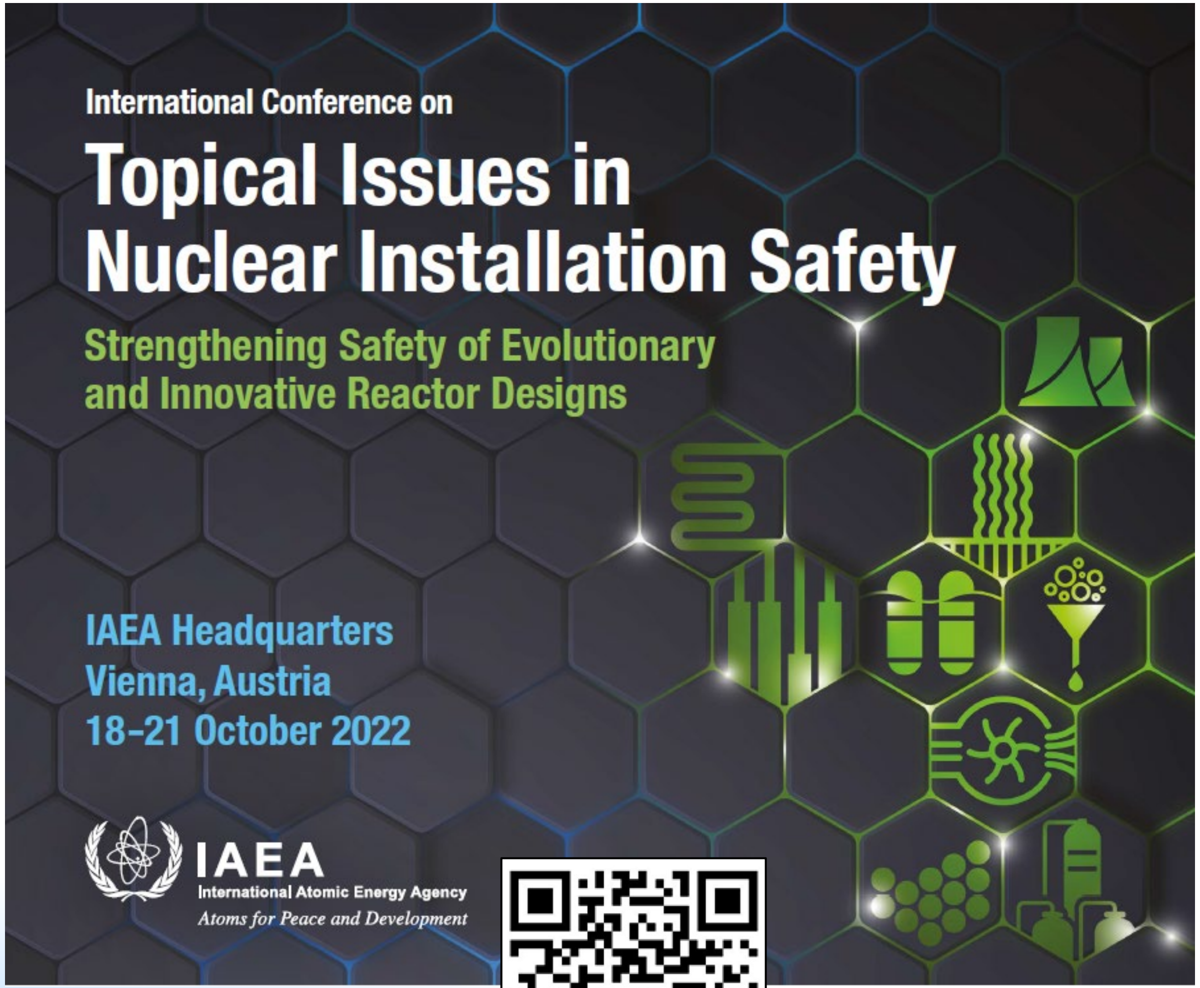


IAEA Nuclear Energy Series
No. NP-T-2.9
International Safeguards in the Design of Nuclear Reactors

IAEA Nuclear Security Series No. 35-G
Implementing Guide
Security during the Lifetime of a Nuclear Facility

IAEA Safety Standards
for protecting people and the environment
Safety of Nuclear Power Plants: Design
Specific Safety Requirements No. SSR-2/1 (Rev. 1)
IAEA International Atomic Energy Agency

TIC2022 conference



International Conference on

Topical Issues in Nuclear Installation Safety

Strengthening Safety of Evolutionary and Innovative Reactor Designs

IAEA Headquarters
Vienna, Austria
18–21 October 2022

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Call for abstracts: open till 31 Jan 2022!

Topic 1. Safety approaches to innovative reactor technologies

Topic 2. Safety of innovative design features

Topic 3. Safety/risk analyses to support integrated decision making

Topic 4. Accelerating innovations for safety assessment through the advanced simulation and modelling, and experimental programmes

Web-site: https://www.iaea.org/events/tic-2022

Contact: tic-2022@iaea.org

Any questions / comments?

Thank you all for your attention!