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IAEA Safety Standards on Safety Assessment of Research Reactors

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Why safety assessment?

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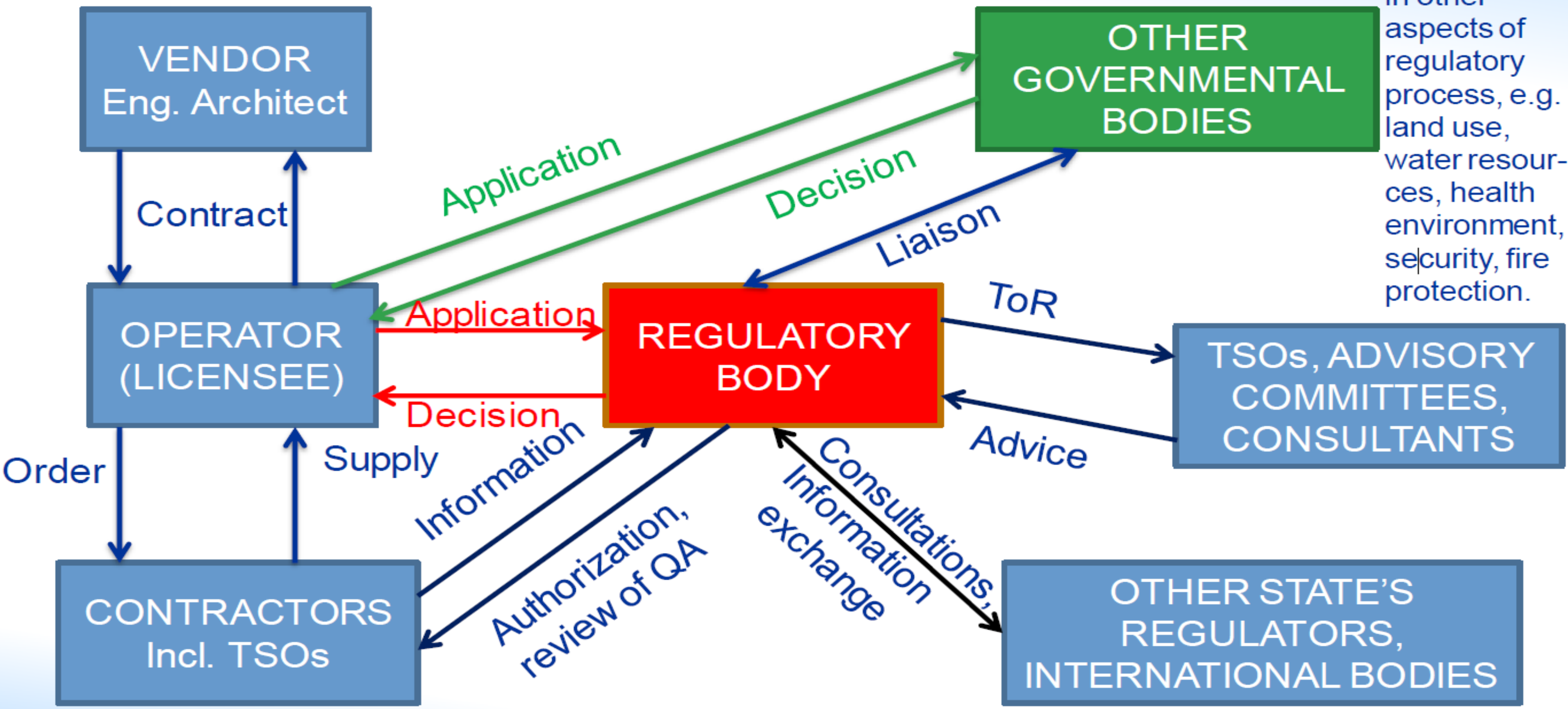
Safety assessment competence is the key to **making the right decisions** in design, operation and licensing

There is no safety without safety assessment

While doing the assessment wonder yourself whether you are convinced that the **fundamental safety objective** is achieved:

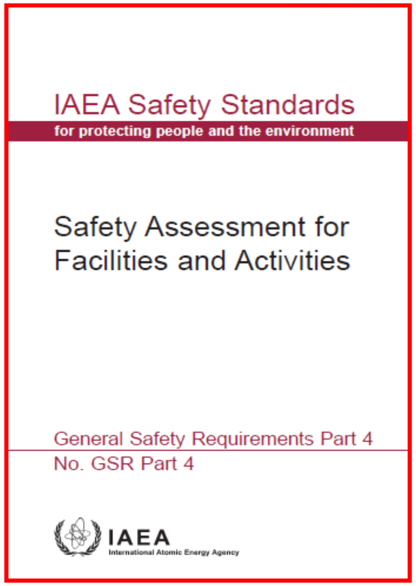
to protect people and the environment from harmful effects of ionizing radiation (SF-1)

Why safety assessment?



Participation in other aspects of regulatory process, e.g. land use, water resources, health environment, security, fire protection.

IAEA Publications on Safety Assessment


IAEA Safety Standards
for protecting people and the environment
Safety Assessment for Facilities and Activities
General Safety Requirements Part 4
No. GSR Part 4
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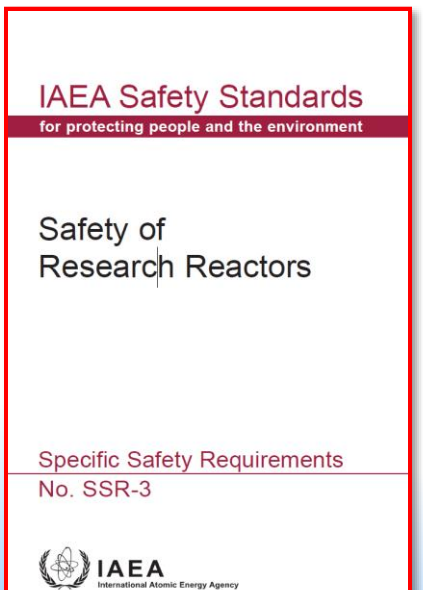
IAEA Safety Standards
for protecting people and the environment
Safety of Research Reactors
Specific Safety Requirements
No. SSR-3
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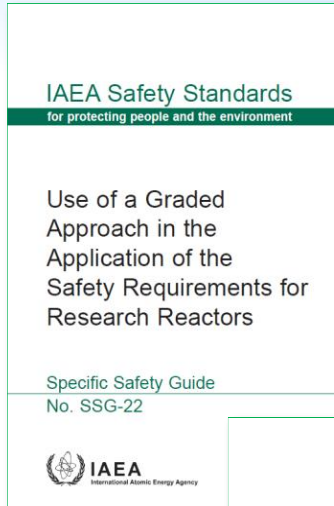
IAEA Safety Standards
for protecting people and the environment
Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors
Specific Safety Guide
No. SSG-22
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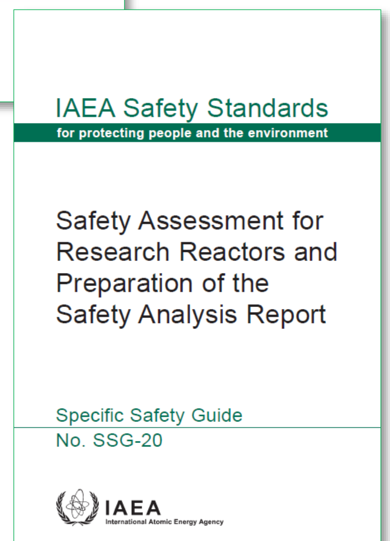
IAEA Safety Standards
for protecting people and the environment
Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report
Specific Safety Guide
No. SSG-20
IAEA
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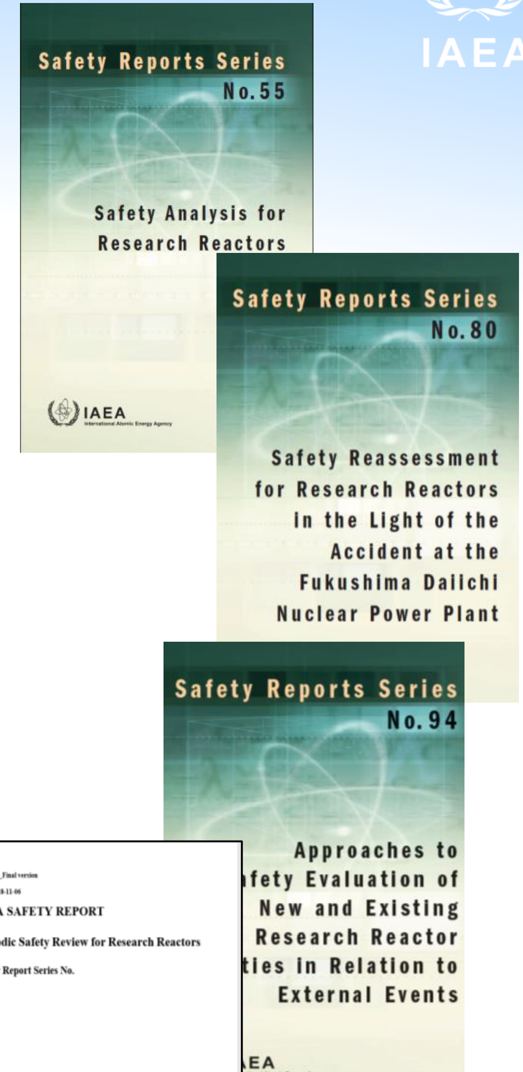

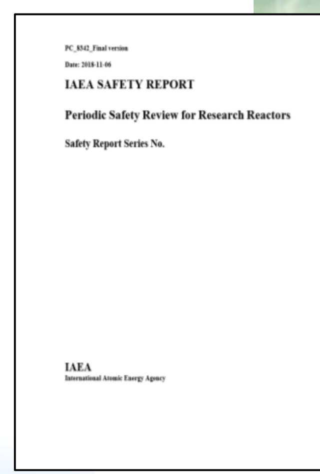
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Date: 2018-11-06
IAEA SAFETY REPORT
Periodic Safety Review for Research Reactors
Safety Report Series No.
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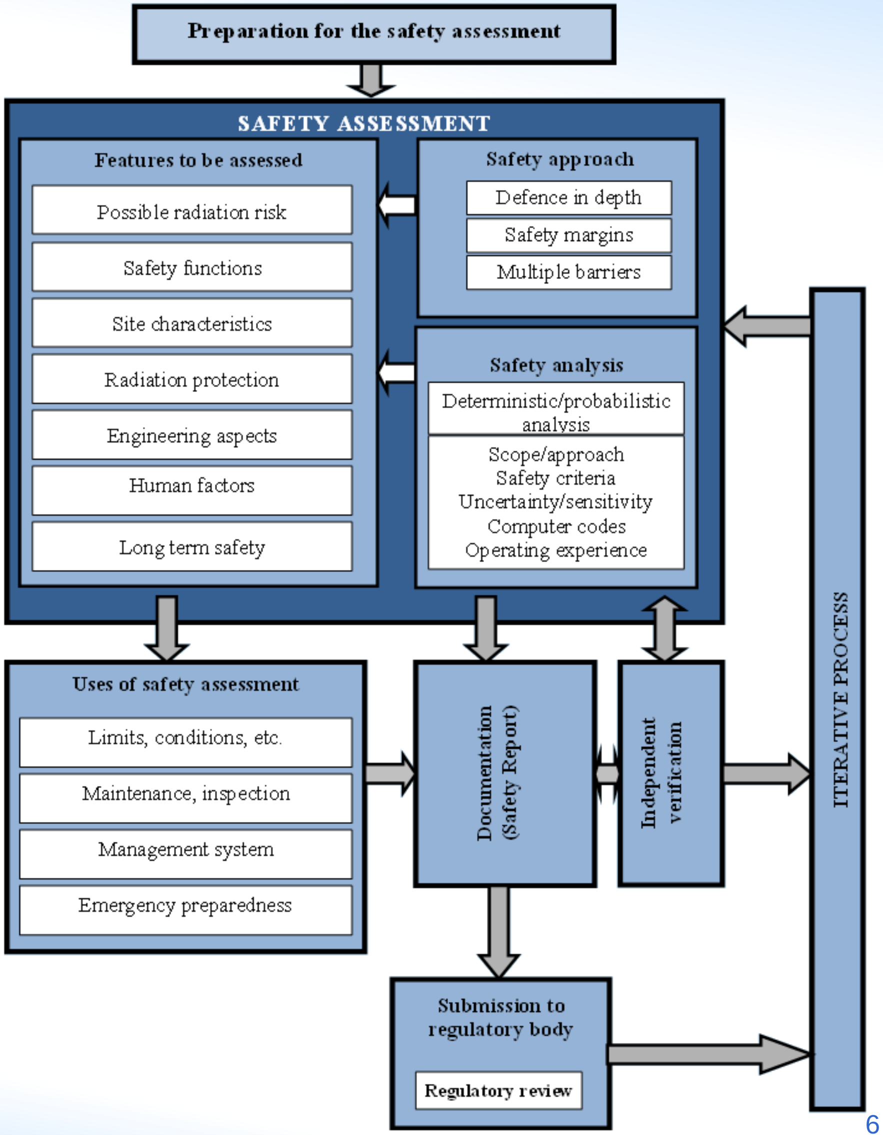
Safety assessment process

- ✓ Is a systematic process that is carried out throughout the lifetime of the facility or activity to ensure that all the relevant safety requirements are met by the proposed or actual design
- ✓ Safety assessment includes, but is not limited to, the formal safety analysis



Safety assessment and safety analysis

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Safety assessment

Safety analysis

Evaluation of engineering factors important to safety

Two complementary methods

Deterministic safety analysis

Probabilistic safety analysis
(for RRs: supplementary to DSA)

- Proven engineering practices
- Defence in depth
- Radiation protection
- Protection against external hazards
- Combination of loads
- Selection of materials
- Single failure criterion
- Redundancy, diversity
- Equipment qualification
- Ageing
- Man-machine interface,...

While the assessment of engineering aspects important to safety may not be explicitly addressed in the safety analysis, it constitutes a relevant part of the safety assessment. For some of these aspects, no well-defined acceptance criteria are available and therefore the assessment of the compliance with the safety requirements is based on good engineering judgement.

Safety analysis

- The results of the safety analysis are used for:
  - Determining appropriate operational limits and conditions (OLCs)
  - Developing the maintenance, periodic testing and inspection programmes
  - Developing the operating procedures
  - Emergency planning
  - Justification of proposals for modifications and experiments

Safety analysis: approach and methods

- The well accepted approach for safety analysis for research reactors is to consider credible PIEs and then apply deterministic methods to estimate the maximum possible releases to the environment

- The results are compared against acceptance criteria established by the regulatory body (or proposed by the operating organization and agreed to by the regulatory body)

Safety analysis methods

- Safety analysis for research reactor is mainly performed using deterministic methods. This approach ensures that the actual plant response to a set of selected conditions is enveloped by the conservative value for that response

- In the deterministic method:
  - Conservative or bounding data and assumptions are used
  - Most unfavourable reactor configuration (e.g. beginning of operation, minimum number of fuel elements, etc.) are considered
  - Uncertainties associated with the parameter of interest are considered
  - Actions by operators are considered not to be taken for a prescribed period of time in a manner consistent with the established operating procedures

Safety analysis methods

- Probabilistic methods may be used to complement deterministic methods
- The probabilistic methods may be used to:
  - Evaluate the likelihood of accident sequences
  - Identify hidden weakness in the design
  - Quantify the value of possible improvements
  - Estimate the conservatism of the deterministic analysis

Types of safety analysis

Safety analysis for design

- Used to support the design of a new reactor or modification to an existing one and to confirm that the design meets the relevant safety requirements
- Iterative process between the design and safety performance
- Accounts for all the challenges that the reactor may expect during its lifetime
- Used in setting characteristics such as equipment sizing, OLCs, dose to the public and the operations personnel

Types of safety analysis

Safety analysis for licensing

- The basis for licensing operation of a research reactor
- To demonstrate that facility design features and the selected OLCs ensure that no creditable accident could lead to unacceptable radiological consequences
- Proceed in parallel with the design process. The scope and level of details increases as design and construction progresses. The final analysis should reflect the as-build facility

Types of safety analysis

Safety analysis for supporting emergency planning

- Describes the reactor behaviours in design extension conditions (DECs)
- Supports development of emergency operating procedures
- The results of DECs, definition of the source term and radiological releases, could also be used for emergency planning

Performing safety analysis for research reactors

Steps

- Identification and selection of PIEs
- Evaluation of event sequences
- Evaluation of event consequences
- Comparison against acceptance criteria

Identification and selection of PIEs

- PIEs are unintended events that directly or indirectly challenge the basic safety functions. Such events necessitate protective actions to prevent or mitigate undesired consequences
- Methods for identifications of PIEs include:
  - Identification of failure modes and events that lead to these failures
  - Comparison with the List of PIEs from the IAEA Safety Standards (SSR-3, Appendix I)
  - Operating experience from the facility or from other similar facilities, including use of the IAEA Incident Reporting System for Research Reactors database
  - Development of fault trees as a part of PSA or by themselves

Identification and selection of PIEs

- To simplify the safety analysis it is reasonable to group all PIEs into categories
- For each category, the event that would be limiting should be determined for further analysis (bounding analysis)
- Selection of the limiting events can be based on more detailed calculations, qualitative comparisons with other events, and engineering judgement

Identification and selection of PIEs

- PIEs Categories (from SSR-3, Appendix I):
  - ✓ Loss of electrical power supply
  - ✓ Insertion of excess reactivity
  - ✓ Loss of flow
  - ✓ Loss of coolant
  - ✓ Erroneous handling or failure of equipment
  - ✓ Special internal events
  - ✓ External events
  - ✓ Human errors

Identification and selection of PIEs

- The selection process should consider the potential for off-site and on-site consequences induced by the external event. The analysis needs to also consider the following issues:
  (a) Effects from and to the collocated facilities
  (b) Concurrence of uncorrelated external events (e.g. earthquake and frequent sandstorm)
  (c) Complex external event scenarios made up of consequent external events of different natures (e.g. earthquake and tsunami)

- Side-wide events and their influence should be covered as well

Evaluation of event sequences

- For every PIE, determination of:
  - The contributors (occurrences that lead to this event)
  - The event sequence and operation of reactor systems:
    - Significant occurrences including the time scale
    - Indication of correct/incorrect functioning of reactor protection system and instrumentation
    - Evaluation of dependant failures
    - Required operator actions, etc.
- Rules for the analysis:
  - Ensure a systematic, consistent approach for the analyses
  - Determine the response of reactor systems
  - Constitute the accident sequence, and determine the sequences that are outside the design basis and thus excluded from further analysis

Evaluation of event sequences

Calculations:

- Use of validated computational methods and tools
- Identification of the input parameters and initial conditions used for the analysis
- Results of the analysis including values of the key parameters as a function of time during the course of the transient
- Determination of damage states

Evaluation of event consequences

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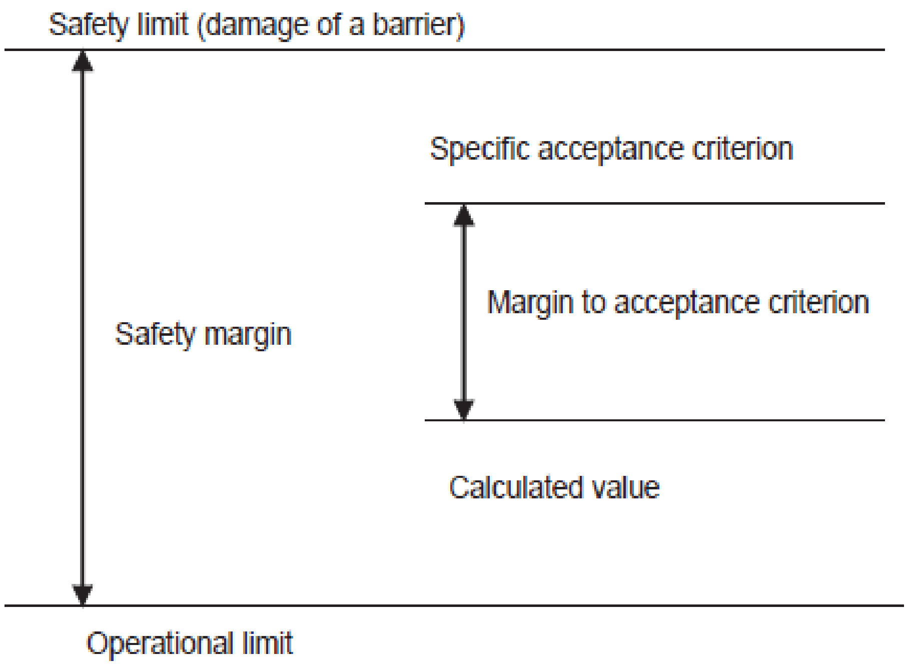
- Estimation of the radiological consequences of the events that are bounding (or limiting) for each category:
  - Public
  - Operations personnel
  - Environment

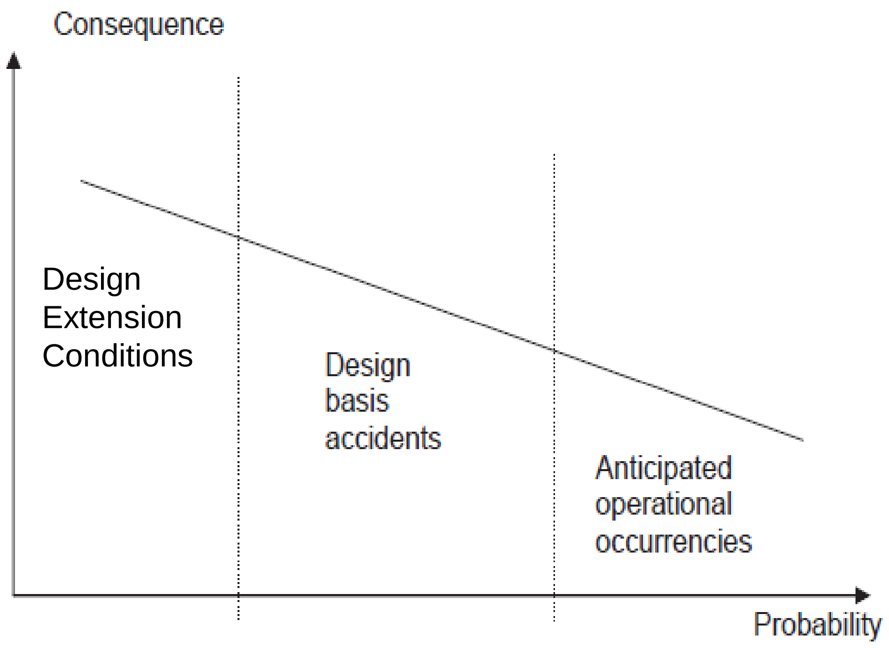
Comparison against acceptance criteria

- The results of the safety analysis should be compared against pre-established acceptance criteria.
- Acceptance criteria may be basic or specific:
  - Examples of basic acceptance criteria are the maximum allowed dose to the public or prevention of fuel cladding failure
  - Specific acceptance criteria are used to include additional margins beyond the basic criteria, such as:
    - Maximum cladding temperature lower than certain value
    - Maximum heat flux not exceeding the CHF or onset of significant voiding
- Acceptance criteria are specified by the regulatory body (or proposed by the operating organization and agreed to by the regulatory body)

Comparison against acceptance criteria

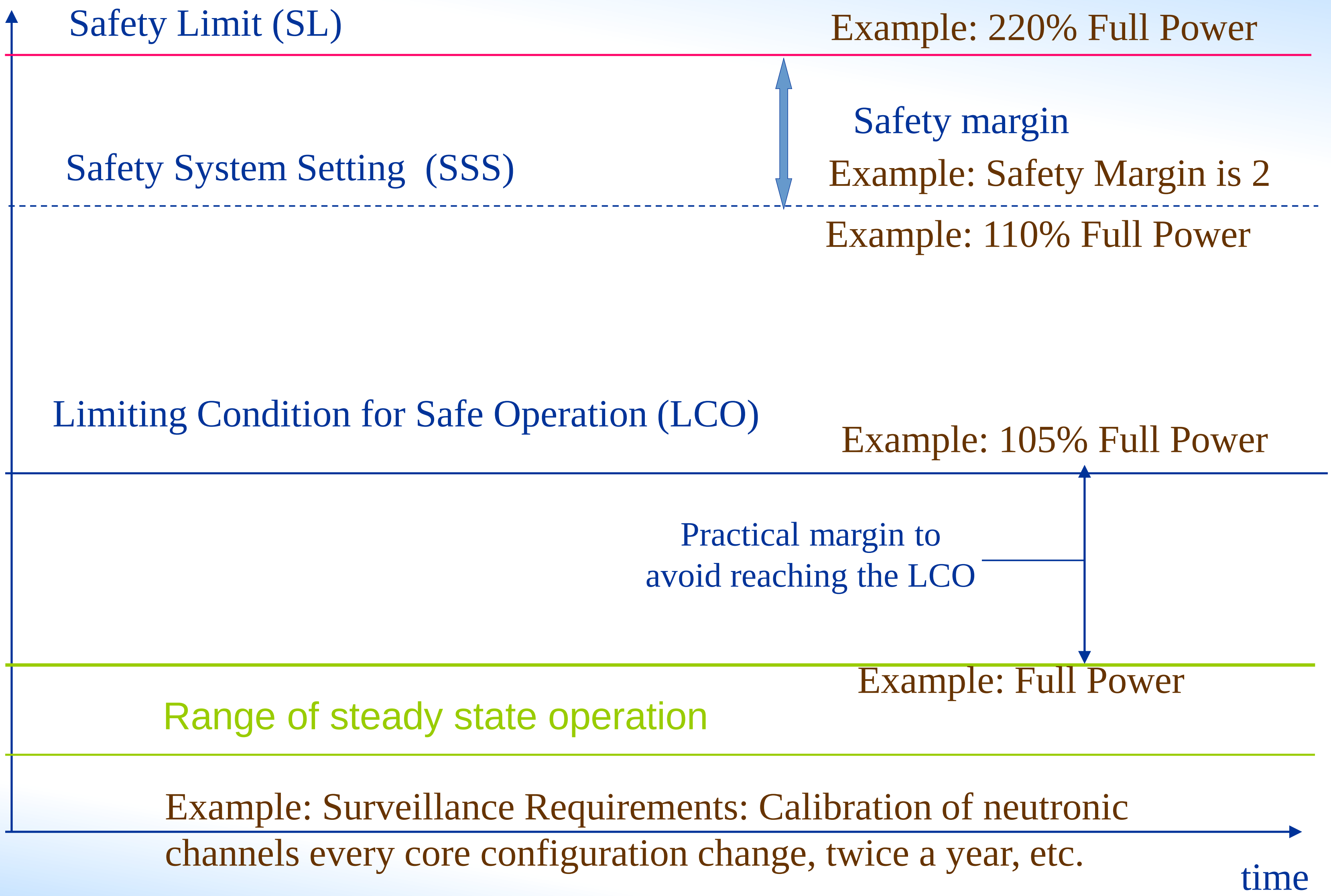


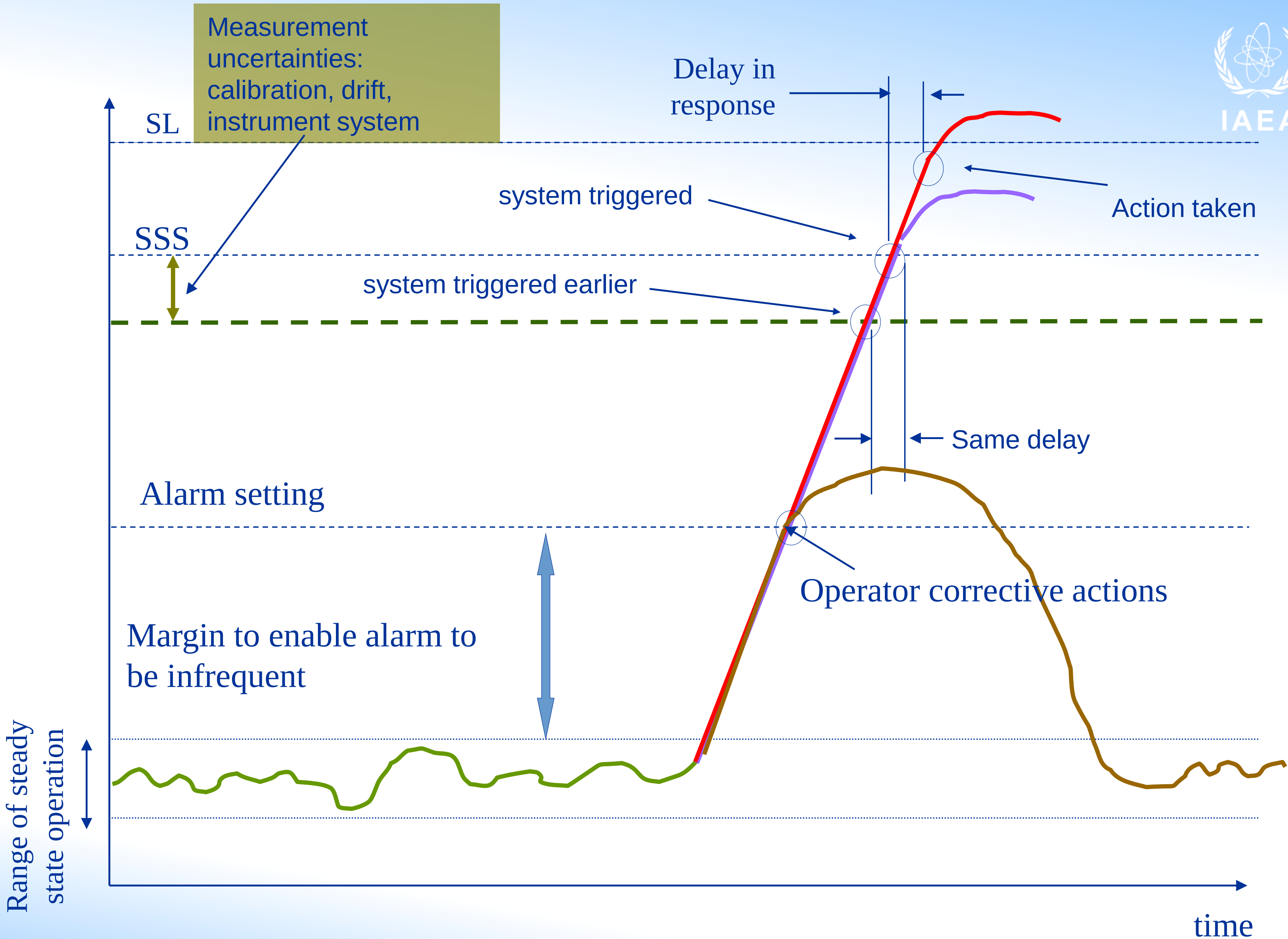
Relationship between the specific acceptance criterion and the safety limit



Schematic diagram of criteria for different probability event sequences

Relation between the SL/SSS/LCO





Measurement uncertainties: calibration, drift, instrument system
Delay in response
SL
system triggered
Action taken
SSS
system triggered earlier
Same delay
Alarm setting
Operator corrective actions
Margin to enable alarm to be infrequent
Range of steady state operation
time

Operational Limits and Conditions

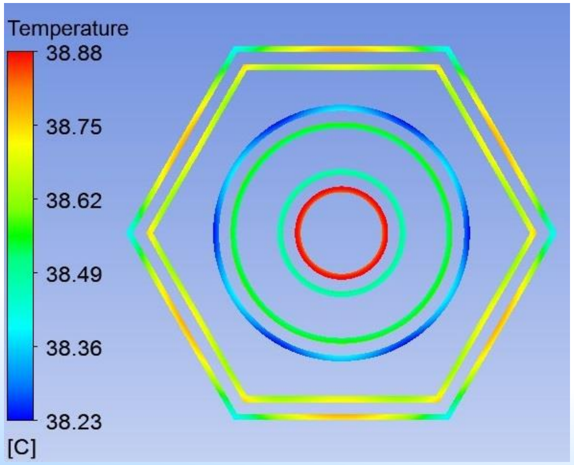
- It is recommended that the OLCs are presented in terms of:
- ✓ Objectives of the specifications
- ✓ Applicability of the specifications
- ✓ Statement of the specifications
- ✓ Bases of the specifications

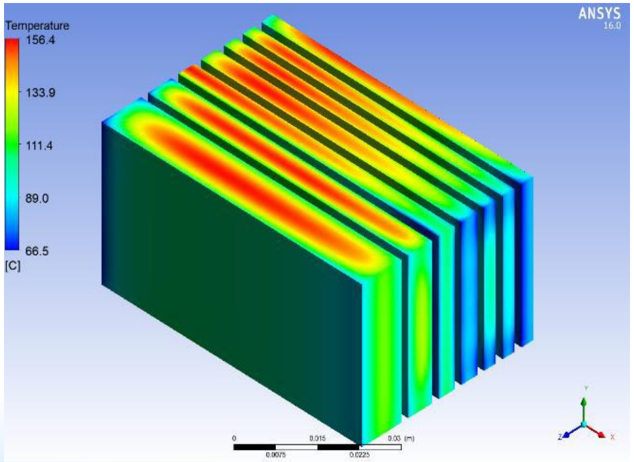
Example: Safety limit on fuel cladding temperature

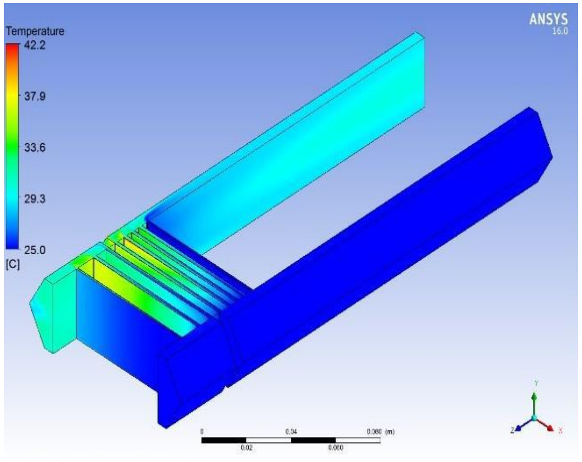
Objective:	To ensure integrity of fuel cladding
Applicability:	Applicable to all reactor states and operation modes
Specifications:	Fuel cladding temperature shall not exceed 500 C
Bases of specifications:	Fuel blistering temperature. Description of the calculation results, assumptions, considerations of uncertainties, etc.

Independent verification of the calculations results (national example)

- Areas of verification: neutron-physics (SCALE), t/h (ANSYS CFX), radiation protection (MCNPX)
- Approach:
  - Independent expert models
  - Different calculation tool







Safety analysis report (SAR)

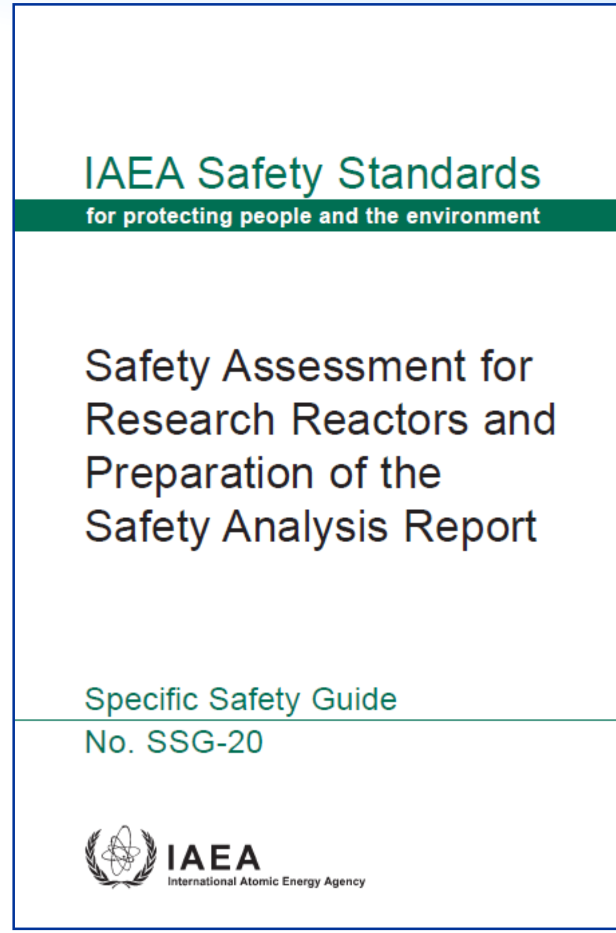
- Prepared by the operating organization for the justification of the site and reactor design, and is the basis for safe operation of the reactor
- SAR is the comprehensive document produced concerning the safety of the facility
- It is the most important link between the operating organization and regulatory body, and is the main document for licensing of the reactor
- It is reviewed and assessed by the regulatory body, during different stages of the RR lifetime

Safety analysis report (SAR)

- Preparation of the SAR begins as early as possible in the RR project. Successive updates to the SAR are anticipated as project proceeds
- The amount of information provided will correspond to the project stage under assessment, and should be sufficient to allow for making a decision on the acceptability of the reactor for that stage
- The SAR also serves other purposes:
  - To aid the designers in confirming that individual systems are integrated correctly;
  - To ensure that the safety analysis has properly identified the safety issues related to the design;
  - To aid in training the reactor operating personnel;
  - To form the basis for the establishing the OLCs for the reactor

Safety analysis report (SAR)

- Provides guidance on the preparation, review and assessment of the safety analysis report (SAR)
- Provides guidance on the initial licensing process for new RRs, and also on re-licensing and periodic safety reviews of existing RRs



Safety analysis report (SAR) – Contents

1. Introduction and general description of the research reactor
2. Safety objectives and engineering design requirements
3. Site characteristics
4. Building and structures
5. The reactor
6. Research reactor cooling systems and connected systems
7. Engineered safety features
8. Instrumentation and control systems
9. Electric power
10. Auxiliary systems

Safety analysis report (SAR) – Contents

11. Research reactor utilization
12. Operational radiation safety
13. Conduct of operations
14. Environmental assessment
15. Commissioning
16. Safety analysis
17. Operational limits and conditions
18. Management systems
19. Decommissioning
20. Emergency planning and preparedness

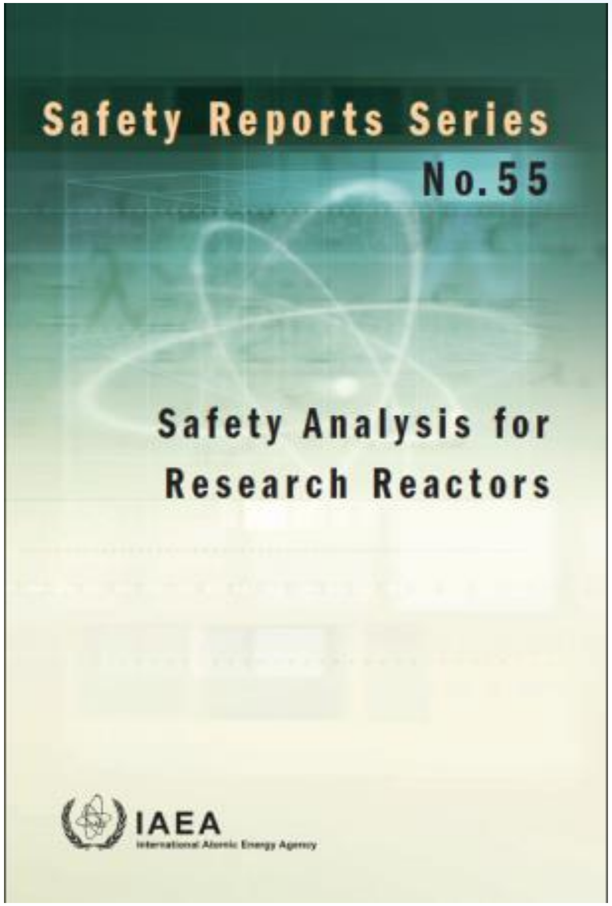
Safety analysis report (SAR)

- The level of detail of the information in the SAR is determined in accordance with the stage of the research reactor project, the reactor type and characteristics (design, power, utilization, etc.), and the site

  However, every topic provided in SSG-20 should be addressed
- Some of the topics may be presented in separate documents (OLCs, operational procedures, etc.). In this case, these topics should be treated briefly in SAR and a reference is made to the appropriate document
- Adequate technical references should be cited in SAR that may be necessary for a thorough review and assessment processes
- The SAR should be periodically reviewed to consider operating experience feedback, including accidents, radiological information, modifications and new experiments, etc.

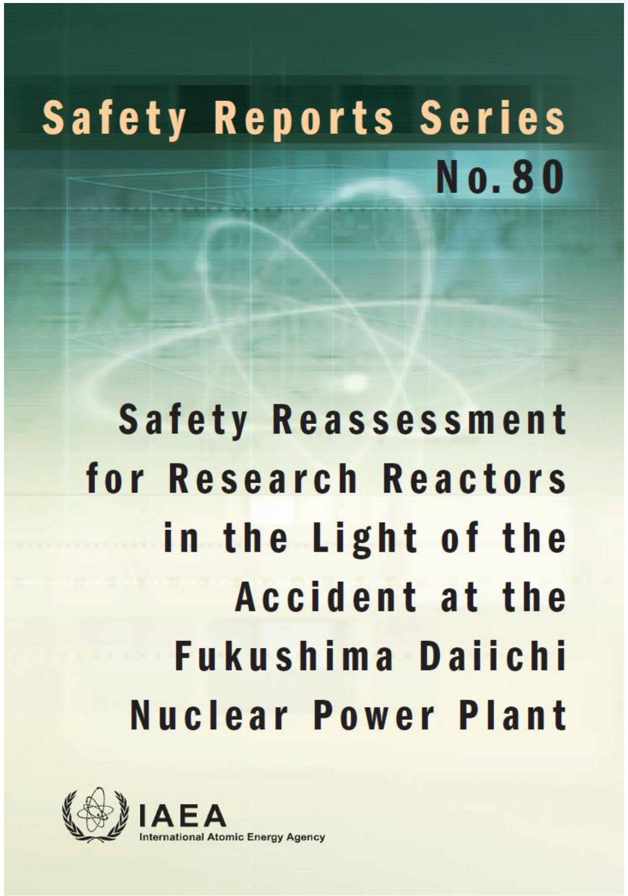
IAEA Safety Report Series No. 55

- Provides a set of suggested methods and practices, both conceptual and formal, for performing all steps of safety analyses
- Covers deterministic and probabilistic analysis methods for research reactor design and licensing
- Useful for operating organizations, regulatory bodies and other organizations involved in the safety of research reactors



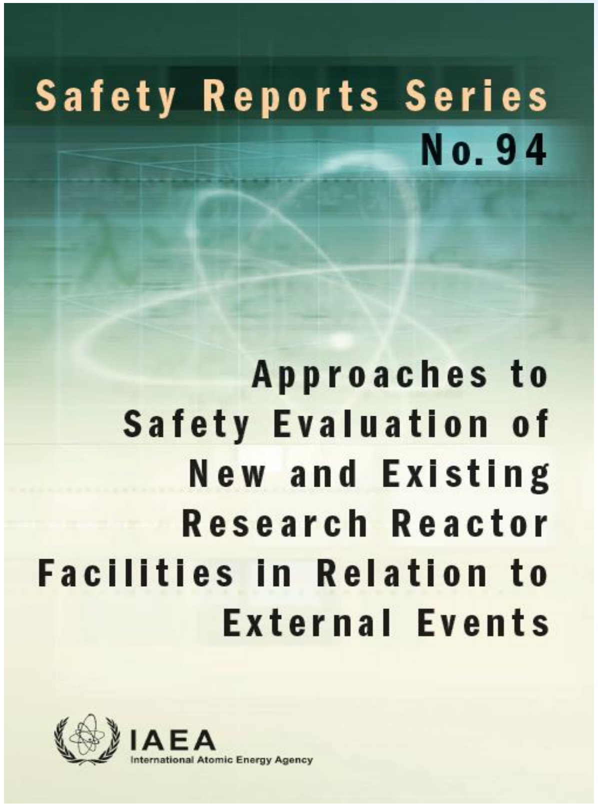
IAEA Safety Report Series No. 55

- Provides a set of suggestions and methods for performing safety reassessments for research reactors (to ensure harmonization of methods and approaches)
- Provides information on the use of the relevant IAEA safety standards in performing reassessments



IAEA Safety Report Series No. 94

- Provides approaches for conducting a safety evaluation of new and existing research reactors in relation to the hazards posed by external events
- Updated information on different aspects related to site investigations, evaluation of external event hazards, re-evaluation of existing facilities and emergency preparedness for research reactors



Periodic safety review (PSR)

- Routine reviews during operation
  - modifications
  - significant events
  - operating experience

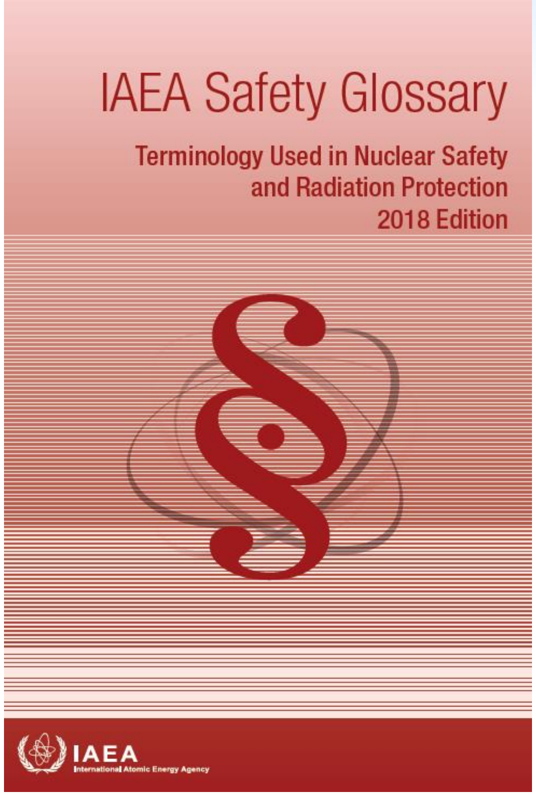
  } primary means of ensuring safety

- PSR introduced to assess cumulative effects of
  - ageing
  - facility modifications
  - operating experience
  - technical developments

  } against applicable current safety standards and operating practices

Periodic safety review (PSR) - Definition

- A systematic reassessment of the *safety* of an existing *facility (or activity)* carried out at regular intervals to deal with the cumulative effects of *ageing*, modifications, operating experience, technical developments and *siting* aspects, and aimed at ensuring a high level of *safety* throughout the *service life* of the *facility (or activity)*



Objectives of PSR

- To determine:
  - safety of the facility until the next PSR
  - extent that current safety standards are met
  - safety improvements and timescales for implementation
  - validity of safety documentation
  - the existence of lifetime-limiting features

PSR Frequency

- Carried out at regular intervals: ~ 10 years
- In such period essential changes expected in
  - safety standards and scientific knowledge
  - operating practices and technology
  - accumulation of facility modifications with adverse affects on safety
  - significant ageing effects or trends
  - natural, industrial or demographic environment
  - staffing levels, experience and safety culture of staff
  - management structures and procedures

PSR Contents

- 14 safety factors relating to
  - Facility
  - Safety analysis
  - Performance and experience feedback
  - Management
  - Environment

common structure

- objectives
- scope
- criteria
- methodology

PSR Contents

Facility

(1) Facility design

(2) Actual condition of SSCs important to safety

(3) Equipment qualification

(4) Ageing

(5) Utilization (new area for RRs)

Safety Analysis

(6) Deterministic safety analysis incl. hazard analysis

PSR Contents

Performance and Experience Feedback

(7) Operating Experience

(8) Experience from other RRs and research findings

Management

(9) Organization, management system, safety culture

(10) Procedures management

(11) Human factors

(12) Emergency planning

PSR Contents

Environment

(13) Operational radiation protection

(14) Radiological impact on the environment

PSR Methodology

- Prerequisites – PSR basis document
  - Agreement on the scope and objectives of the PSR between Operating Organization and Regulatory Body
  - Cut-off dates agreed
    - beyond which changes to codes and standards and new information will not be considered
  - Schedule
  - Methodology
  - Project and quality management processes

PSR Methodology

- Set of safety regulations and standards used during preparation, conduct and evaluation
  - National
    - legislative items, regulatory requirements, guidelines
  - International
    - IAEA, ISO (International Organization for Standardization)
  - Recognized organization of a particular State
    - e.g. ASME (American Society of Mechanical Engineers) or Institute of Electrical and Electronics Engineers (IEEE)

PSR Methodology

- A database of reference material should be developed
- Safety factors should be reviewed considering all relevant operating and accident conditions
- The review method applied should be systematic and independent of the ongoing regulatory oversight of the facility
- Results of other assessments can be used to reduce duplication, and should be documented

PSR Methodology

- Results of Safety Factor Review:
  - Identified weaknesses (Negative Finding)
  - Identified strengths (Positive Findings)
- Corrective actions: resulting from the review that will maintain facility safety
- Safety improvements: which can further enhance safety
- Global assessment to integrate all safety factor assessments, prioritize corrective actions

PSR Methodology

- Safety improvements and corrective actions should be implemented as soon as reasonable and practicable in accordance with the global assessment of safety
- Integrated Implementation Plan
- The risks associated with any negative findings, where action is not reasonable or practical, should be assessed
- Appropriate justification for continued operation should be provided

PSR Methodology

- First PSR at an older facility assesses the whole lifetime and may reveal:
  - Discrepancies between design documentation and actual configuration
  - Incomplete information on design basis of SSCs
- In response:
  - Design documentation should be updated
    - e.g. renewal of obsolete or incomplete SAR
    - e.g. design basis reconstitution
  - A safety justification should be provided

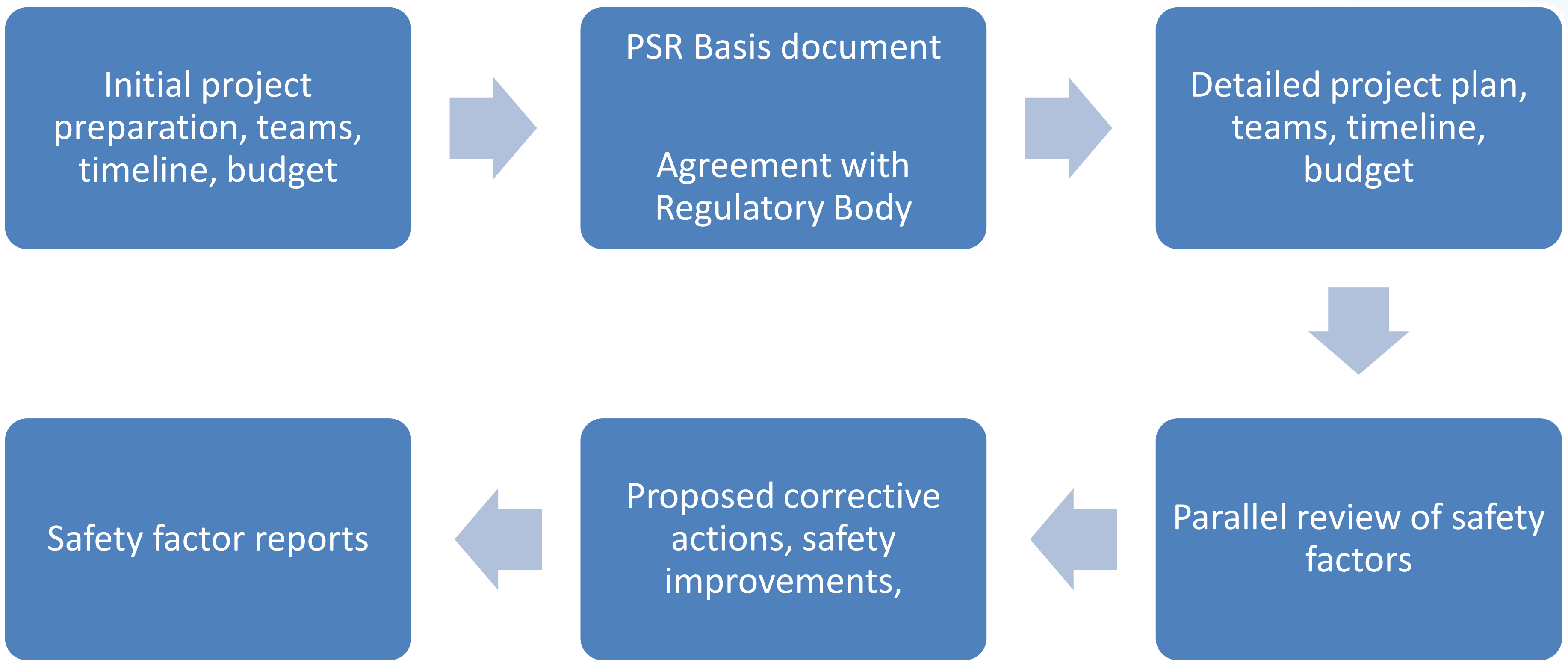
PSR Methodology

- Effort necessary to carry out a subsequent PSR of a facility will often be considerably reduced compared with that for the first PSR
- Subsequent PSRs should focus on changes in
  - requirements
  - facility conditions
  - operating experience and
  - new information
- From the past 10 years, since the previous PSR

PSR Graded Approach

- Dependent on the hazard of the facility and activities
  - Number of safety factors included
  - Combining safety factors together
  - Composition of review teams
  - Depth of Regulatory Body review
  - Prioritization of corrective actions and safety improvements

Process for PSR Project



Process for Global Assessment

Concluding remarks

- ✓ Safety assessment is a comprehensive and systematic process to justify the RRs safety against the acceptance criteria
- ✓ Application of the IAEA Safety Standards will help Member States to establish the safety assessment process in order to achieve the highest level of safety for RRs

Thank you for your attention !