Assessment of Major Systems Cooling System

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Outline

- Introduction
- Reactor coolant system and associated systems
- Design basis of the RCSASs
- Approach to the assessment of RCSASs based on IAEA safety standards (RCS example)

Objective of the presentation

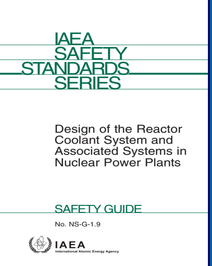
To illustrate a process of reactor coolant system and associated systems assessment based on IAEA safety standards – reactor coolant system is discussed

Functions of the reactor coolant system and associated systems

- To contain the coolant providing a barrier to the release of radioactive materials
- To remove the heat from the core and from components in all plant states considered in the design
- To transfer the heat to the ultimate heat sink
- To maintain the specified physical and chemical characteristics of the coolant.

Extent of the RCS and Associated Systems

- REACTOR COOLANT SYSTEM
- SYSTEMS FOR HEAT REMOVAL IN SHUTDOWN CONDITIONS
- SYSTEMS FOR COOLANT INVENTORY CONTROL IN OPERATIONAL STATES
- SYSTEMS FOR CORE REACTIVITY CONTROL IN OPERATIONAL STATES
- SYSTEMS FOR CORE COOLING AND RESIDUAL HEAT REMOVAL IN ACCIDENT CONDITIONS
- SYSTEMS FOR CORE REACTIVITY CONTROL IN ACCIDENT CONDITIONS
- ULTIMATE HEAT SINK AND RESIDUAL HEAT TRANSFER SYSTEMS IN ALL PLANT STATES ....



Extent of the RCS and Associated Systems

- **RCS**
  - The RCS transports the coolant and thereby heat from the reactor core to the steam generators (PWR and PHWR or directly to the turbine generator).
  - The RCS also forms part of the route for the transfer of heat from the reactor core to the ultimate heat sink during shut-down and in all transient conditions that are considered in the design of the RCS.
  - The RCS includes the reactor pressure vessel, the pressurizer (PWR and PHWR), piping and pumps for the circulation of the coolant and the steam generators for (PWR and PHWR).
  - The RCS forms a pressure retaining boundary for the reactor coolant and is therefore a barrier to radioactive releases to be preserved to the extent possible in all modes of plant normal operation and accident conditions.
- **SYSTEMS FOR HEAT REMOVAL IN SHUTDOWN CONDITIONS**
  - Those systems are systems designed to remove residual heat from the reactor coolant system during shutdown conditions.. They include systems designed to cool down RCS to cold shut-down condition including refuelling condition after shutdown for PWR and BWR.

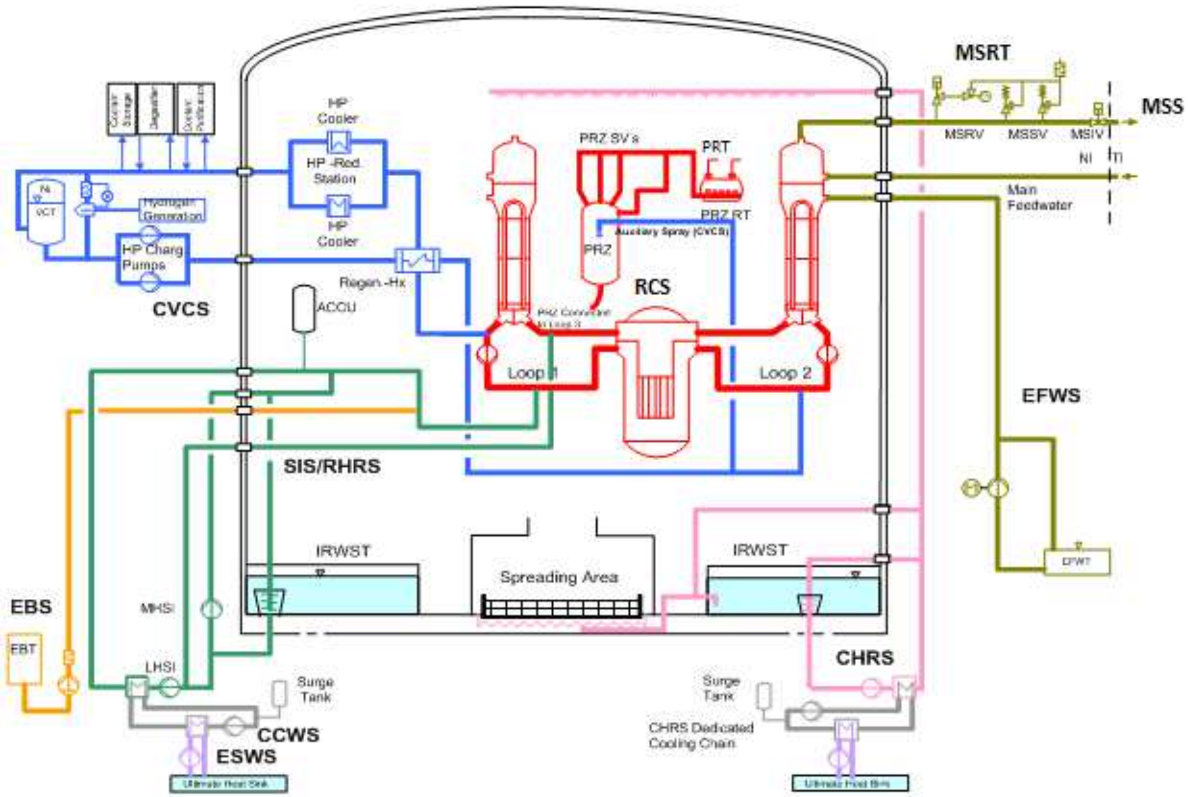
Extent of the RCS and Associated Systems

- SYSTEMS FOR COOLANT INVENTORY CONTROL IN OPERATIONAL STATES
  - Those systems are systems designed to compensate for leakages and to control the reactor coolant inventory in operational states.
- SYSTEMS FOR CORE REACTIVITY CONTROL IN OPERATIONAL STATES
  - Those systems are systems designed to accommodate slow reactivity changes (including control the core power distribution) in power operation and to control margins to re- criticality in shut- down conditions.
- SYSTEMS FOR CORE COOLING AND RESIDUAL HEAT REMOVAL IN ACCIDENT CONDITIONS
  - Those systems are systems designed to remove decay heat from the core in the event of accident with or without a loss of the RCS integrity, systems designed to remove residual heat from and cool RCS in accident conditions until safe shut-down conditions are reached and systems designed to maintain safe shut-down conditions in the long term.

Extent of the RCS and Associated Systems

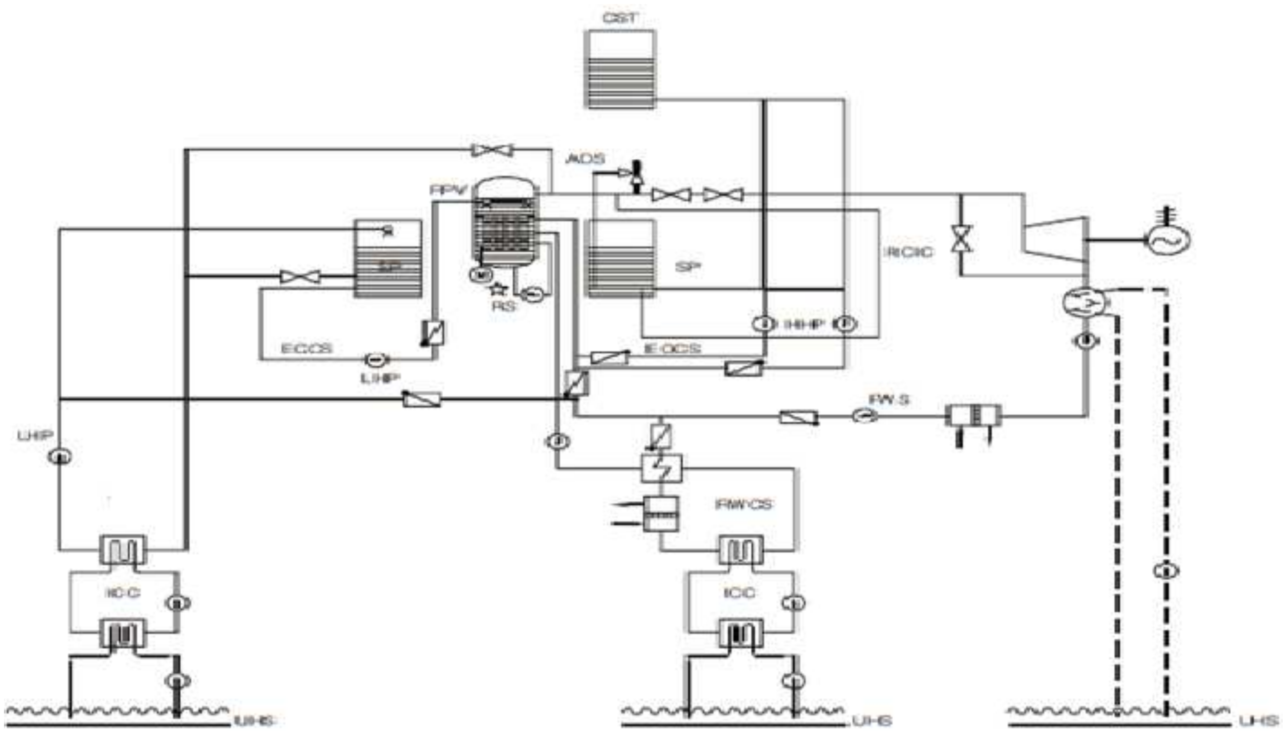
- SYSTEMS FOR CORE REACTIVITY CONTROL IN ACCIDENT CONDITIONS
  - Those systems are systems designed to shut down the reactor, to stop uncontrolled or excessive positive reactivity insertion caused by accident conditions, to limit fuel damage in the event of Anticipated Transients Without Scram (ATWS) and to ensure the core reactivity control until the safe shut-down conditions are reached in accident conditions.
- ULTIMATE HEAT SINK AND RESIDUAL HEAT TRANSFER SYSTEMS IN ALL PLANT STATES
  - Ultimate heat sink is defined as a medium into which the transferred residual heat can always be accepted, even if all other means of removing the heat have been lost or are insufficient. The ultimate heat sink is usually a body of water, the groundwater or the atmosphere.
  - Residual heat transfer systems include systems designed to transfer heat from the residual heat removal systems to the ultimate heat sink.
  - Capabilities to discharge of residual heat to the ultimate heat sink suppose that one heat sink and one heat transfer chain at least is always available for the different shut-down conditions.

PWR DIAGRAM OF THE RCS AND ASSOCIATED SYSTEMS



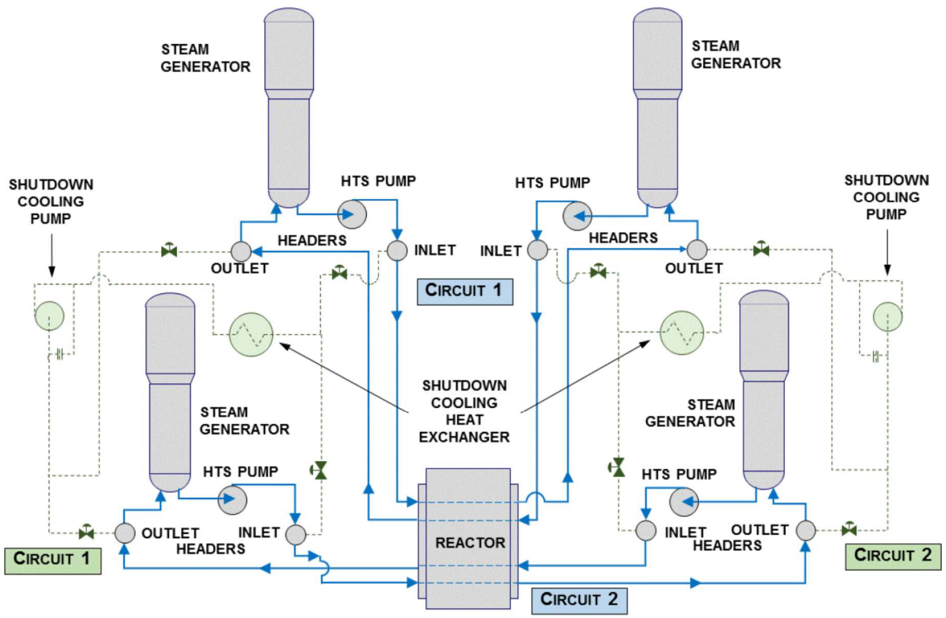
CCWS: Component Cooling Water System
CHRS: Containment Heat Removal System
CVCS: Chemical and Volume Control System
EBS: Emergency Borating System
EFWS: Emergency Feed Water System
ESWS: Essential Service Water System
IRWST: In Containment Reactor Water Storage tank
MSRT: Main Steam Relief Train
MSS: Main Steam System
PRT: Pressurizer Relief Tank
RCS: Reactor Cooling System
RHRS: Reactor Heat Removal System SIS: Safety Injection System

BWR DIAGRAM OF THE RCS AND ASSOCIATED SYSTEMS

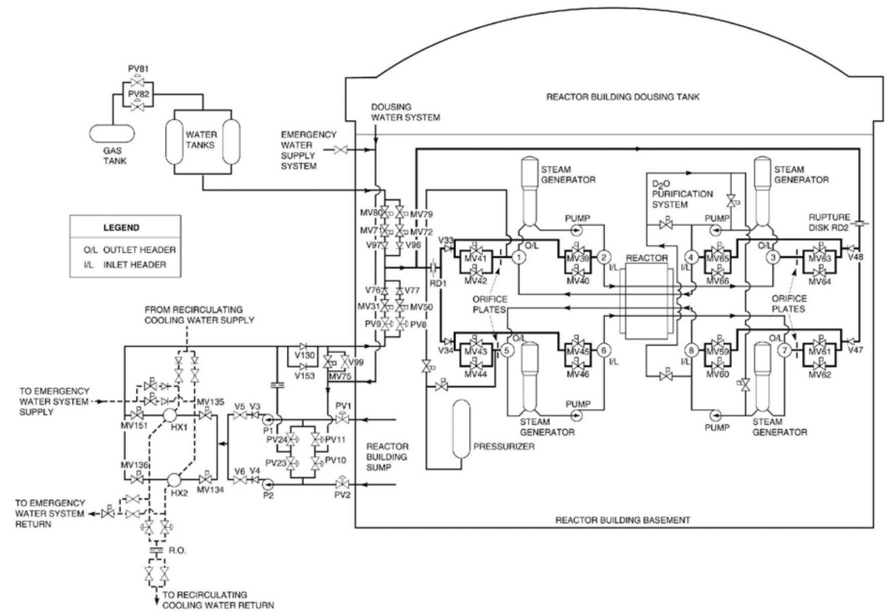


ADS: Automatic Depressurization System
CST: Condensate Storage tank
ECCS: Emergency Core Cooling System
FWS: Feed Water System
HHIP: High Head Injection Pump
ICC: Intermediate Cooling Circuit
LHP: Low Head injection Pump
RCIC: Reactor Core Isolation Cooling
RPV: Reactor Pressure Vessel
SP: Suppression pool
UHS: Ultimate Heat Sink

PHWR DIAGRAM OF THE RCS AND ASSOCIATED SYSTEMS



Typical Reactor Coolant System (Primary Heat Transport System) and Shutdown Cooling System for PHWR



Typical Emergency Core Cooling System for PHWR

Reactor coolant system of a PWR

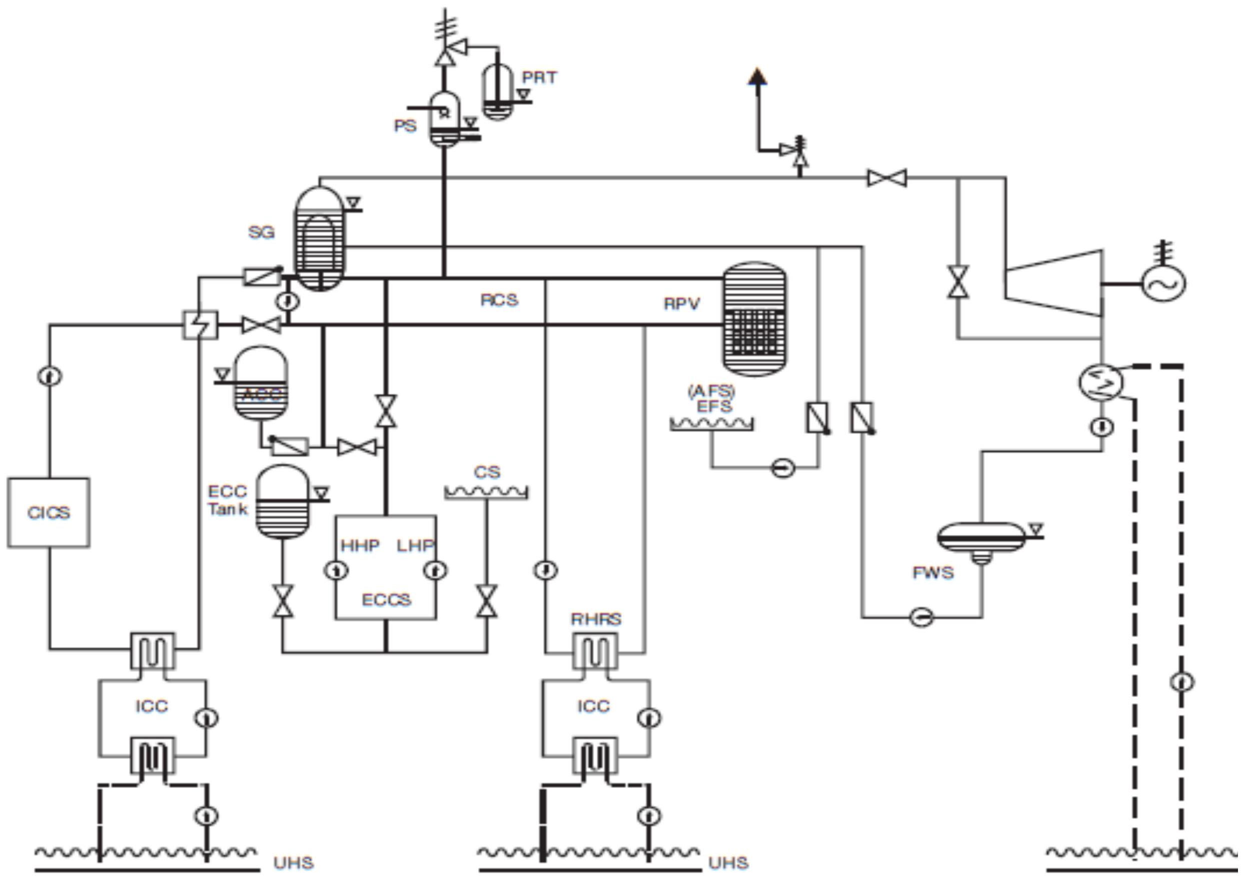


FIG. II–2. RCSASs for a PWR.

Reactor coolant system of a BWR

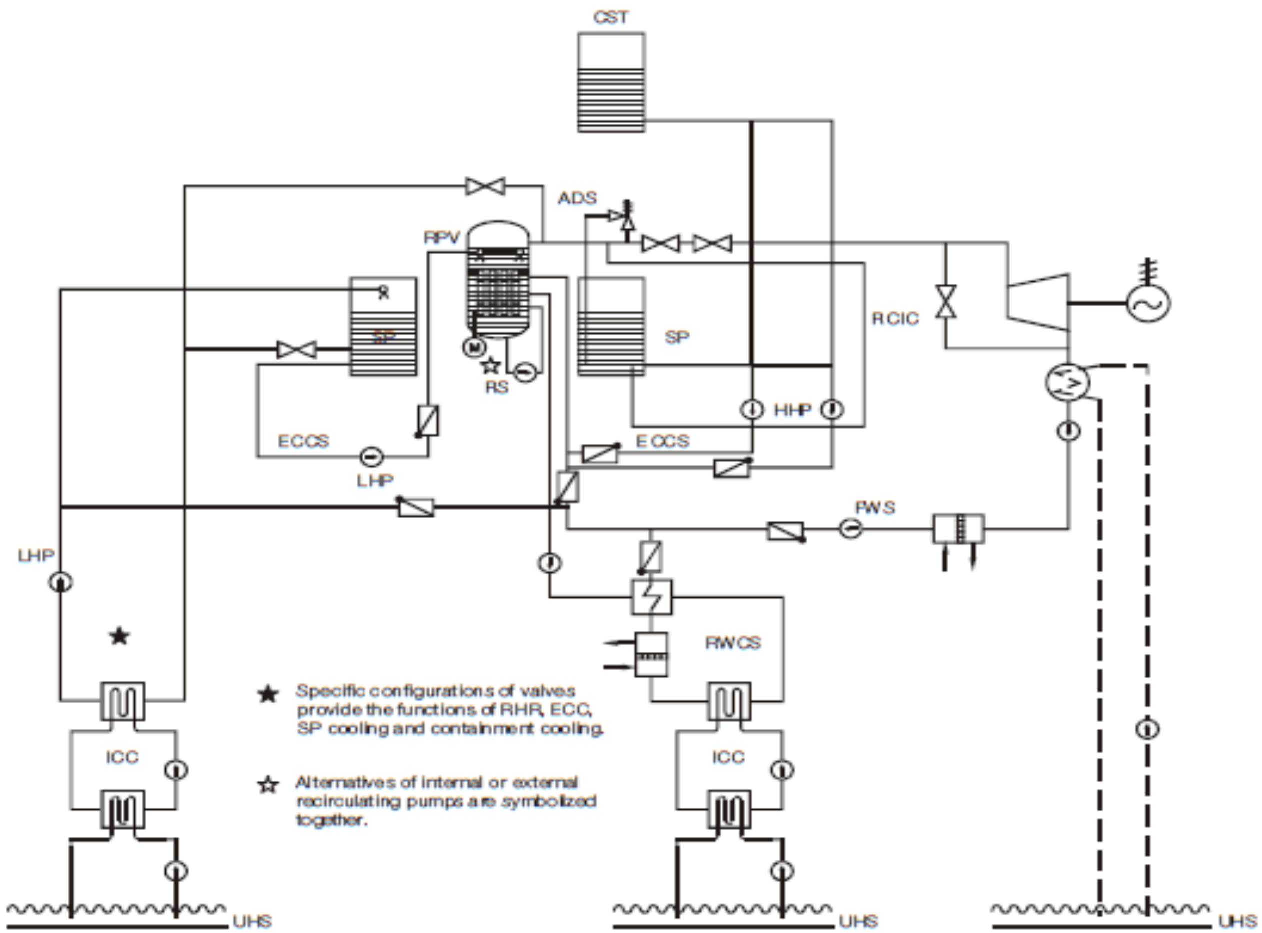


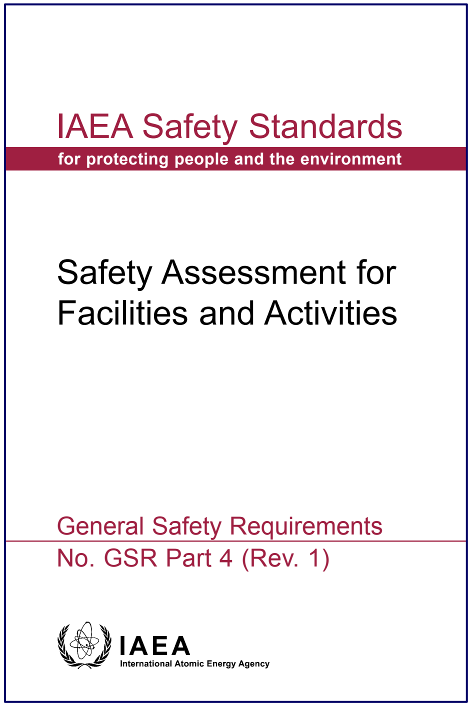
FIG. II–3. RCSASs for a BWR.

Design Basis of the RCSASs

- The safety function(s)
- The postulated initiating events they have to deal with
- The safety classification and associated design and fabrication codes
- Loads and load combinations
- The protection against internal hazards
- The protection against external hazards (e.g. seismic category)
- Design limits and acceptance criteria
- Design criteria (e.g. single failure criteria)
- Reliability
- Environmental conditions for qualification
- Monitoring and control capabilities
- Selection of materials
- Requirements for testing, inspection and maintenance

ASSESSMENT OF REACTOR COOLANT SYSTEM

Purpose of the safety assessment



IAEA Safety Standards
for protecting people and the environment

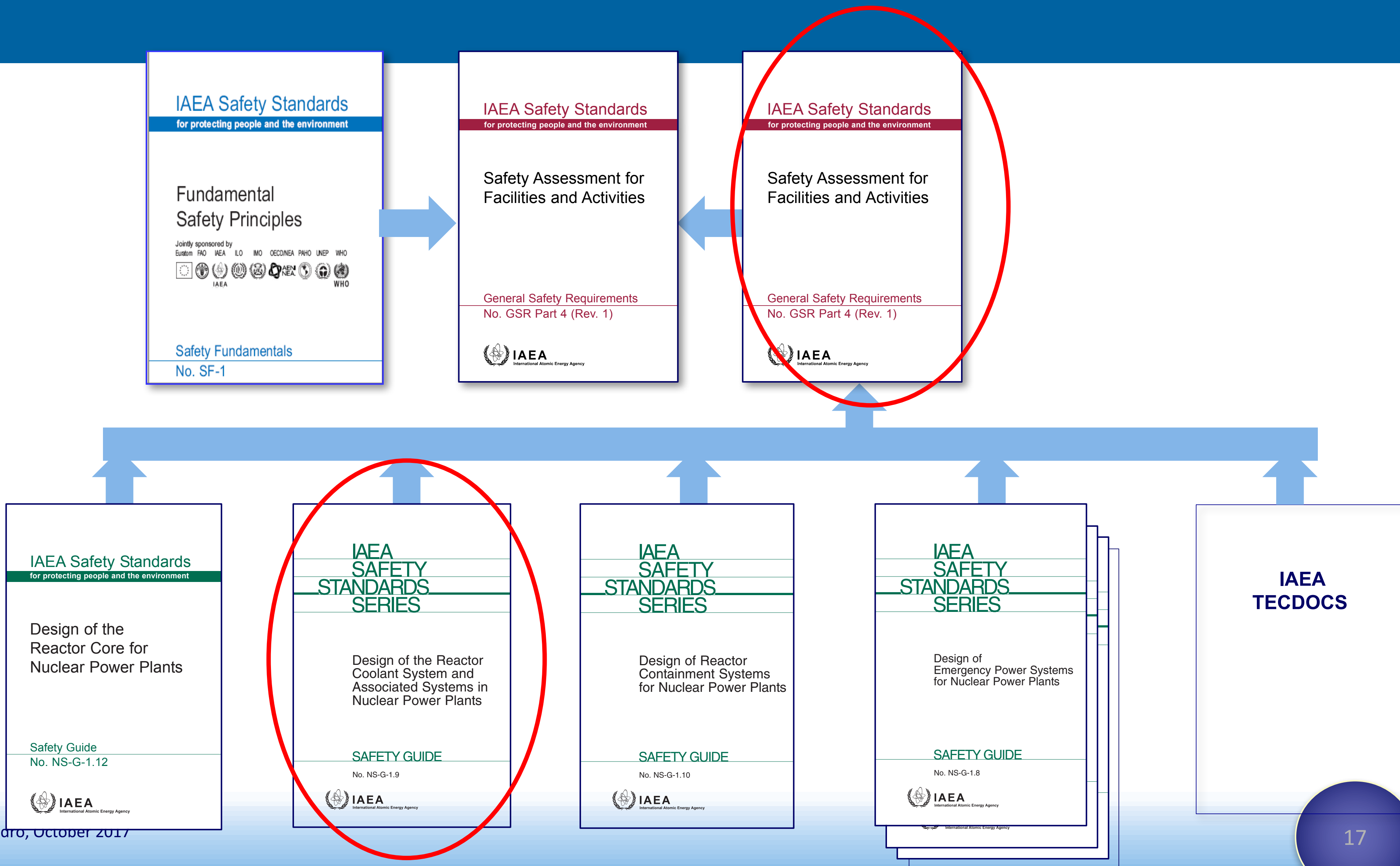
Safety Assessment for Facilities and Activities

General Safety Requirements
No. GSR Part 4 (Rev. 1)

IAEA
International Atomic Energy Agency

- Safety assessment shall determine whether the structures, systems and components and the barriers incorporated into the design fulfil the **safety functions** required of them.
  - It shall also be determined whether adequate measures have been taken to prevent anticipated operational occurrences and accident conditions, and
  - whether any radiological consequence can be mitigated if accidents do occur.
- The safety assessment shall address all radiation risks that arise from **normal operation and from anticipated operational occurrences and accident conditions**.

Relevant IAEA Safety Standards



Functions of the RCS

The Reactor Coolant System has three major functions:

- Transfer the heat from the reactor to the steam generators (PWR) or to the turbine (BWR)
- Maintain the pressure of the coolant within specified limits
- Contain the coolant providing an effective barrier to the release of radioactive materials (integrity of the pressure boundary)

- RCS (PWR example) consists of the following major components:
  - Reactor vessel
  - Steam Generator (Primary side)
  - Reactor Coolant Pump
  - Pressurizer
  - Piping (hot leg, cold leg, surge line)
  - Overpressure protection system
  - Depressurization systems

Specific Requirements for the Design of RCS

Requirement 47: Design of reactor coolant systems

- **The components of the reactor coolant systems for the nuclear power plant shall be designed and constructed so that the risk of faults due to inadequate quality of materials, inadequate design standards, insufficient capability for inspection or inadequate quality of manufacture is minimized.**
  - Pipework connected to the pressure boundary of the reactor coolant systems for the nuclear power plant shall be equipped with adequate isolation devices to limit any loss of radioactive fluid (primary coolant) and to prevent the loss of coolant through interfacing systems.
  - The design of the reactor coolant pressure boundary shall be such that flaws are very unlikely to be initiated, and any flaws that are initiated would propagate in a regime of high resistance to unstable fracture and to rapid crack propagation, thereby permitting the timely detection of flaws.
  - The design of the reactor coolant systems shall be such as to ensure that plant states in which components of the reactor coolant pressure boundary could exhibit embrittlement are avoided.
  - The design of the components contained inside the reactor coolant pressure boundary, such as pump impellers and valve parts, shall be such as to minimize the likelihood of failure and consequential damage to other components of the primary coolant system that are important to safety, in all operational states and in design basis accident conditions, with due allowance made for deterioration that might occur in service.

Specific Requirements for the Design of RCS

Requirement 48: Overpressure protection of the reactor coolant pressure boundary

- **Provision shall be made to ensure that the operation of pressure relief devices will protect the pressure boundary of the reactor coolant systems against overpressure and will not lead to the release of radioactive material from the nuclear power plant directly to the environment.**

Requirement 49: Inventory of reactor coolant

- **Provision shall be made for controlling the inventory, temperature and pressure of the reactor coolant to ensure that specified design limits are not exceeded in any operational state of the nuclear power plant, with due account taken of volumetric changes and leakage.**

Requirement 50: Cleanup of reactor coolant

- **Adequate facilities shall be provided at the nuclear power plant for the removal from the reactor coolant of radioactive substances, including activated corrosion products and fission products deriving from the fuel, and non-radioactive substances.**
  - The capabilities of the necessary plant systems shall be based on the specified design limit on permissible leakage of the fuel, with a conservative margin to ensure that the plant can be operated with a level of circuit activity that is as low as reasonably practicable, and to ensure that the requirements are met for radioactive releases to be as low as reasonably achievable and below the authorized limits on discharges.


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

Specific Requirements for the Design of RCS

Requirement 51: Removal of residual heat from the reactor core

- **Means shall be provided for the removal of residual heat from the reactor core in the shutdown state of the nuclear power plant such that the design limits for fuel, the reactor coolant pressure boundary and structures important to safety are not exceeded.**

Requirement 52: Emergency cooling of the reactor core

- **Means of cooling the reactor core shall be provided to restore and maintain cooling of the fuel under accident conditions at the nuclear power plant, even if the integrity of the pressure boundary of the primary coolant system is not maintained.**
  - The means provided for cooling of the reactor core shall be such as to ensure that:

  (a) The limiting parameters for the cladding or for integrity of the fuel (such as temperature) will not be exceeded;

  (b) Possible chemical reactions are kept to an acceptable level;

  (c) The effectiveness of the means of cooling of the reactor core compensates for possible changes in the fuel and in the internal geometry of the reactor core;

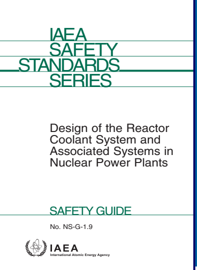
  (d) Cooling of the reactor core will be ensured for a sufficient time.

  - Design features (such as leak detection systems, appropriate interconnections and capabilities for isolation) and suitable redundancy and diversity shall be provided to fulfil the above requirements with adequate reliability for each postulated initiating event.

Specific Requirements for the Design of RCS

Requirement 53: Heat transfer to an ultimate heat sink

- **The capability to transfer heat to an ultimate heat sink shall be ensured for all plant states.**
  - 6.19A. Systems for transferring heat shall have adequate reliability for the plant states in which they have to fulfil the heat transfer function. This may require the use of a different ultimate heat sink or different access to the ultimate heat sink.
  - 6.19B. The heat transfer function shall be fulfilled for levels of natural hazards more severe than those considered for design, derived from the hazard evaluation for the site.



SPECIFIC CONSIDERATIONS IN DESIGN OF THE REACTOR COOLANT SYSTEM (examples)

- Structural design of the reactor coolant system
  - Technical specifications for manufacturing of RCBP and SSBP
  - The following types of failure modes should be considered in the design according to the relevant code requirements and limits:
    - ✓ Excessive plastic deformation;
    - ✓ Elastic or elastoplastic instability (buckling);
    - ✓ Progressive deformation and ratcheting;
    - ✓ Progressive cracking due to mechanical and thermal fatigue;
    - ✓ Fast fracture including brittle fracture, in case of existing defects in the structure.
- Design basis loads and load combinations
- Control of cooling conditions in operational states
- Pressure control and overpressure protection

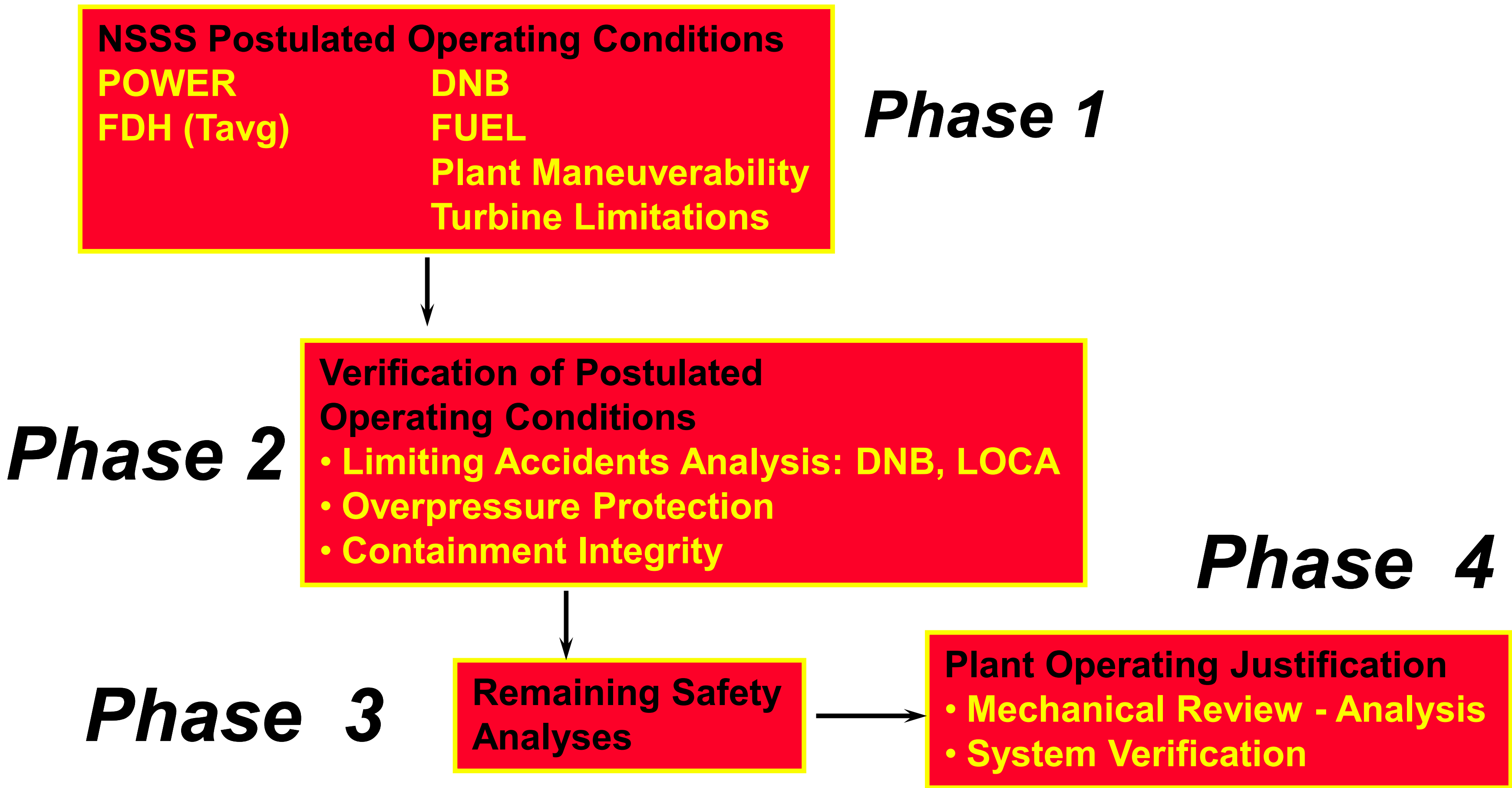
SPECIFIC CONSIDERATIONS IN DESIGN OF THE REACTOR COOLANT SYSTEM (examples)

- Postulated Initiating events - Typical examples are:
  - Loss of off site power sources ;
  - Malfunctioning of RCS control systems (pressure), (RPV water level, RCS reciruclation flow,
  - feed water heating for BWR), (PZR and SG level for PWR and PHWR), etc,
  - Loss of the main condenser vacuum;
  - Piping breaks;
  - Spurious opening of a relief/safety valve;
  - Loss of forced coolant circulation;
  - Reactor Coolant Pump failure;
  - Positive core reactivity insertion.
- Internal Hazards
  - The layout of RCS piping supplemented by local protection devices
    - ✓ A break of a reactor coolant leg should neither propagate to neighbouring RCS leg or to main steam /feed water piping (for PWR and PHWR);
    - ✓ A break of a main steam/feed water piping should neither propagate to neighbouring main steam/feed water piping or to reactor coolant loops;
    - ✓ A break of pressurizer piping should not propagate to neighbouring pressurizer piping (PWR and PHWR).

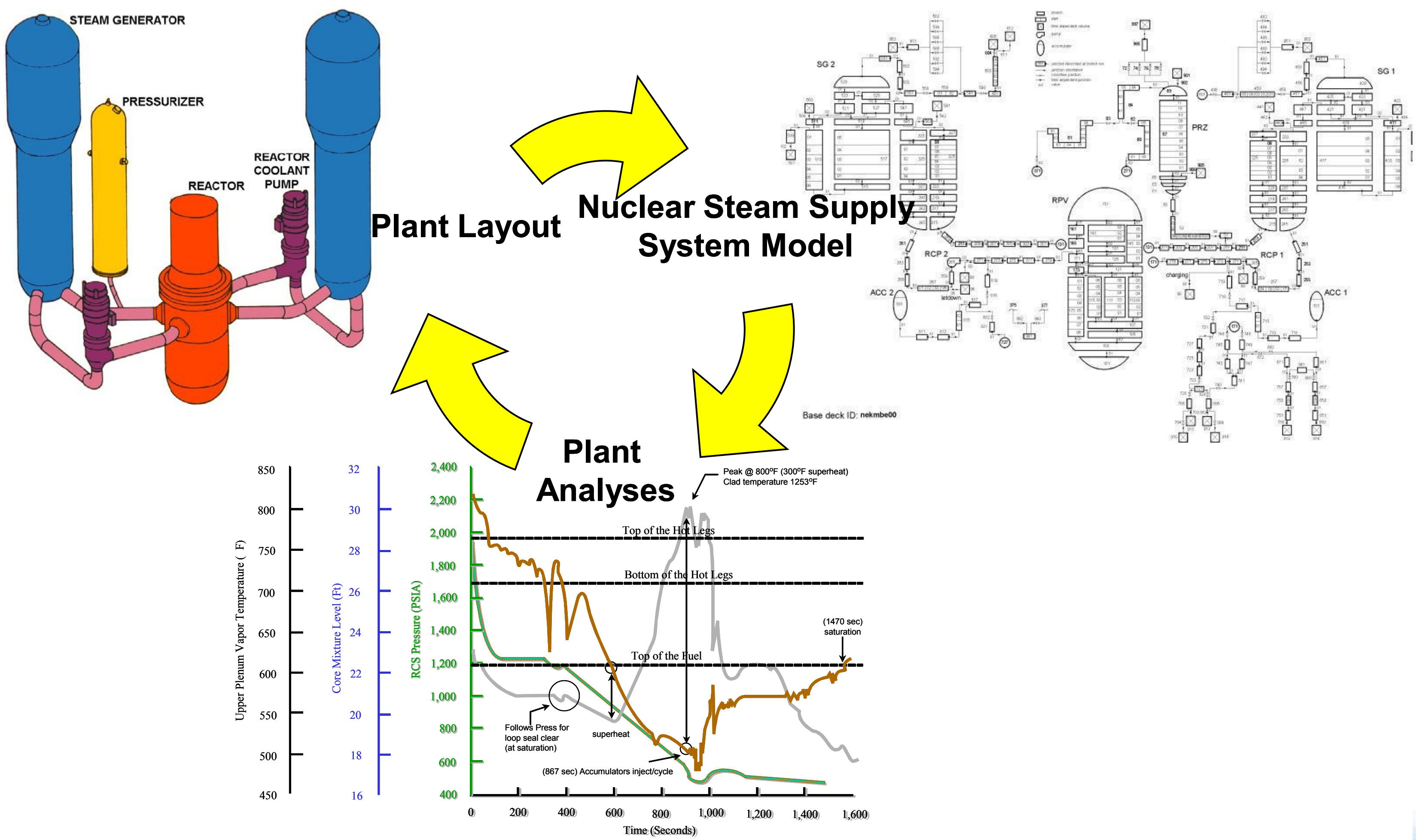
SPECIFIC CONSIDERATIONS IN DESIGN OF THE REACTOR COOLANT SYSTEM (examples)

- External Hazards
- Layout
- Design limits
  - Pressure and temperature
  - Max cooling rate, max heating rate for normal operation;
  - Delta T max between hot leg and pressurizer (for PWR);
  - Delta P max Primary/Secondary (for PWR);
  - Max RCS leak rate;
  - Max RCS/SG leak rate (for PWR and PHWR);
  - Limits regarding the brittle fracture of RPV (for PWR);
  - Component parameters (e.g. Delta P for reactor coolant pump seals, T seals).
- Safety classification
- Environmental qualification
- Pressure tests

Scope of analyses supporting reactor coolant system assessment



Deterministic analyses



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