Joint ICTP-IAEA Essential Knowledge Workshop on
Deterministic Safety Assessment and
Engineering Aspects Important to Safety

Postulated Initiating Events

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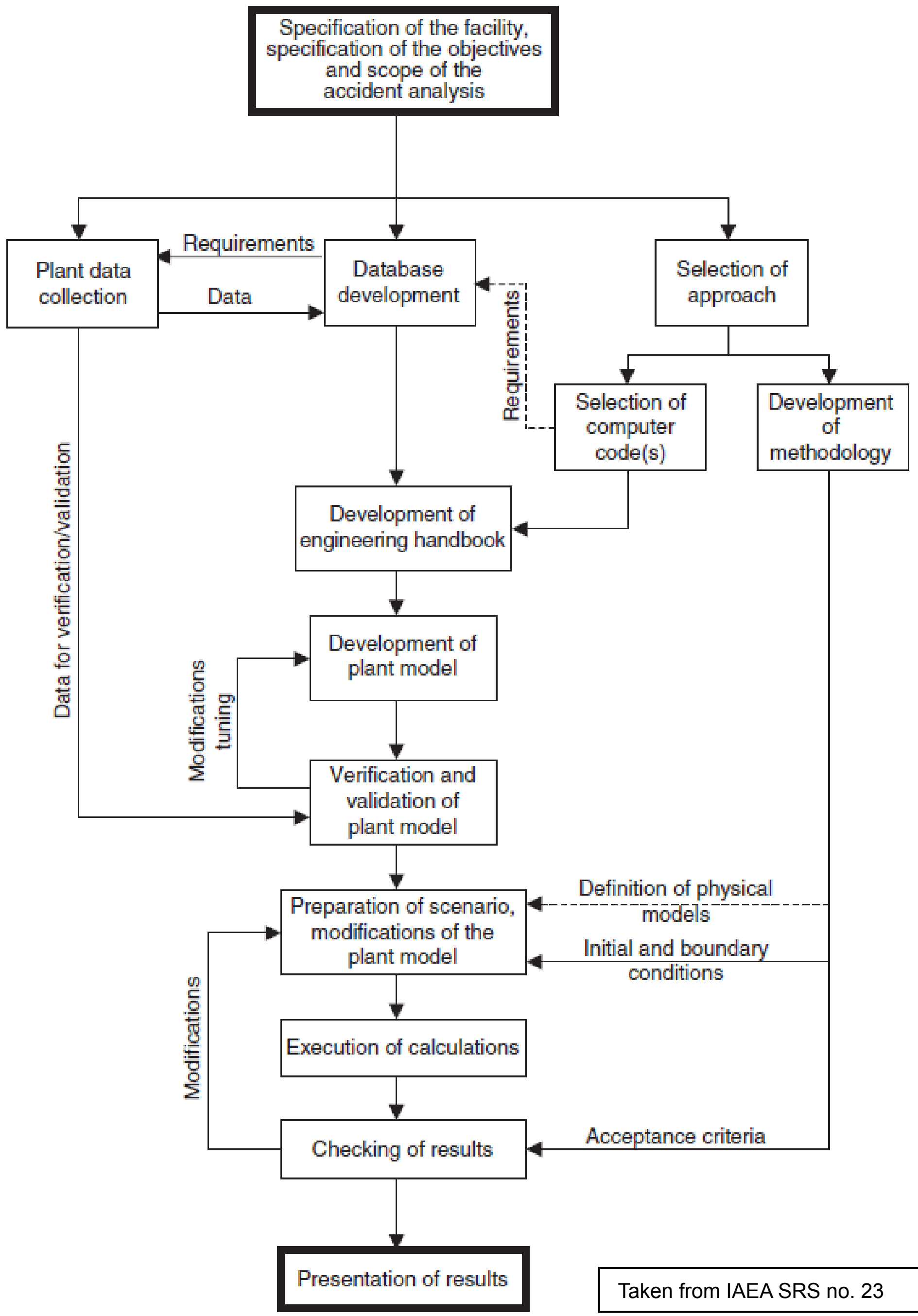
Session Outline

- PIEs in IAEA SS
  - Regulatory perspective
  - Design perspective
  - Safety analysis perspective
- Identification of PIEs
- Grouping of PIEs
- Examples
- Categorization
- Regulatory review

Steps of safety analysis

- Scope of the analysis
  - Type of facility
  - PIE
  - Acceptance criteria
- Approach
  - Definition of methodology
- Selection of appropriate computer code and construction of the input model (V&V)
- Assumptions
  - Definition of boundary and initial conditions (BIC)
  - Availability of systems and components
  - Single failure
  - Operator action
- Analysis and evaluation of the results

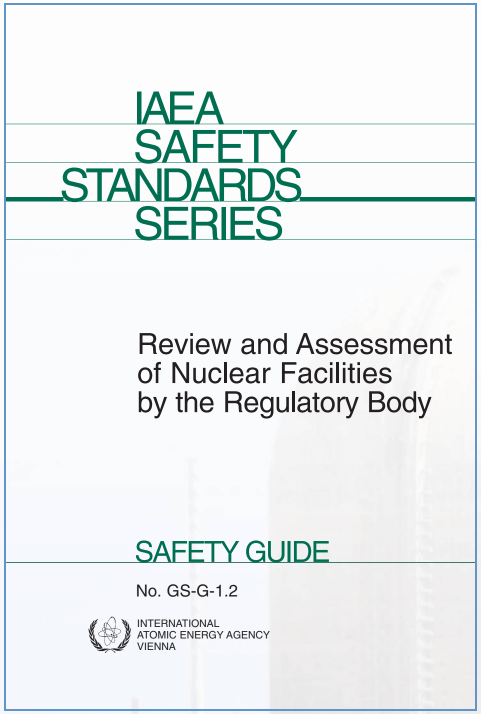


Taken from IAEA SRS no. 23

Postulated initiating events

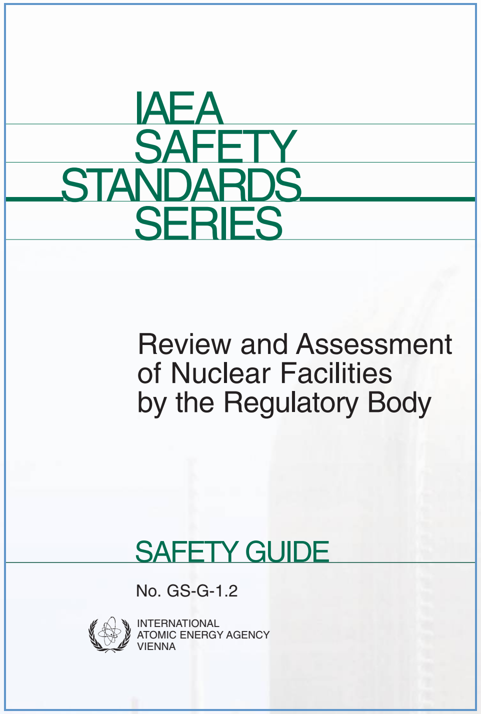
- An initiating event is an event that creates a disturbance in the plant and has a potential to lead to core damage, depending on the successful operation of the various mitigating systems of the plant
- The starting point for the safety analysis is the set of postulated initiating events that need to be addressed. A PIE is defined as an “identified event that leads to anticipated operational occurrences or accident conditions”. PIEs include events such as equipment failure, human errors and human induced or natural external events (hazards). The deterministic safety analysis and the PSA should normally use a common set of PIEs

PIE – regulatory perspective (GS-G-1.2)



- The identification of the PIEs which should be taken into account in the safety analysis is the first step in the review and assessment process
- The method used should be systematic and auditable
- Moreover, as complete as possible a listing of PIEs should be provided
- An important feature of the review and assessment process should be considering whether the operator’s method of identification meets these requirements and whether the operator’s list of PIEs is acceptable as the basis for the safety analysis

PIE – regulatory perspective (GS-G-1.2)



- PIEs can be grouped in various ways. One commonly used method is to separate them into:
  - External hazards, which are outside the control of the operator and may result from natural or human made causes such as a seismic event, an aircraft crash or an explosion of flammable liquid gas in transport
  - Internal faults that result from inherent failures of the facility, such as mechanical or electrical failures or loss of services
  - Internal hazards such as fire or spillage of corrosive material resulting from failures of systems that are within the operator's control but are not directly considered in the review and assessment process
- Consideration should also be given to human errors, which may be initiators in their own right or may exacerbate a fault
- It is usual to classify the PIEs relating to internal faults according to the initiating frequencies of the PIEs and their potential consequences. The purpose of such a classification is to help decide on the type and level of analysis that should be undertaken

PIE – design perspective (SSR-2/1)

- The design for the nuclear power plant shall apply a systematic approach to identifying a comprehensive set of postulated initiating events such that all foreseeable events with the potential for serious consequences and all foreseeable events with a significant frequency of occurrence are anticipated and are considered in the design
  - The postulated initiating events shall be identified on the basis of engineering judgement and a combination of deterministic assessment and probabilistic assessment
  - The postulated initiating events shall include all foreseeable failures of structures, systems and components of the plant, as well as operating errors and possible failures arising from internal and external hazards, whether in full power, low power or shutdown states
  - An analysis of the postulated initiating events for the plant shall be made to establish the preventive measures and protective measures that are necessary to ensure that the required safety functions will be performed

PIE – design perspective (SSR-2/1)

- The expected behaviour of the plant in any postulated initiating event shall be such that the following conditions can be achieved, in order of priority:
  - (1) A postulated initiating event would produce no safety significant effects or would produce only a change towards safe plant conditions by means of inherent characteristics of the plant
  - (2) Following a postulated initiating event, the plant would be rendered safe by means of passive safety features or by the action of systems that are operating continuously in the state necessary to control the postulated initiating event
  - (3) Following a postulated initiating event, the plant would be rendered safe by the actuation of safety systems that need to be brought into operation in response to the postulated initiating event
  - (4) Following a postulated initiating event, the plant would be rendered safe by following specified procedures

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PIE – design perspective (SSR-2/1)


IAEA Safety Standards
for protecting people and the environment

Safety of
Nuclear Power Plants:
Design

Specific Safety Requirements
No. SSR-2/1

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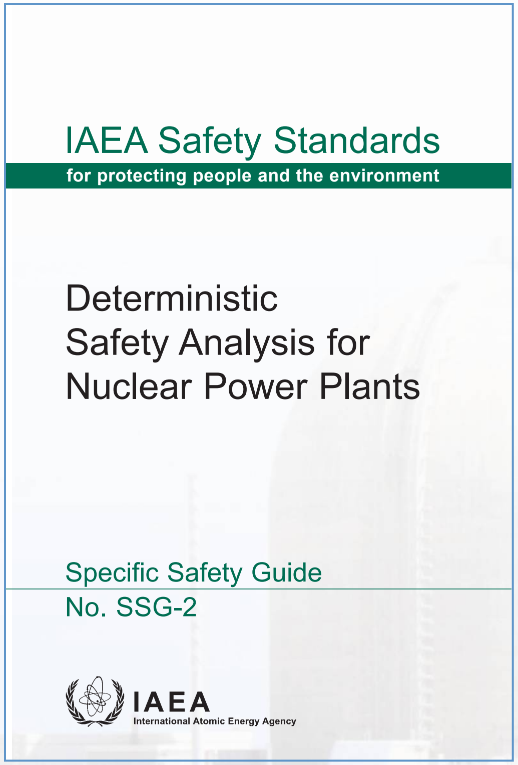
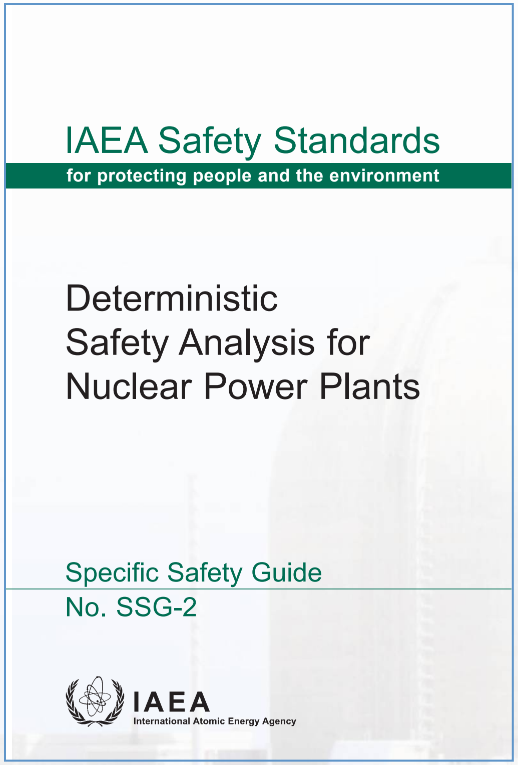
- The postulated initiating events used for developing the performance requirements for the items important to safety in the overall safety assessment and the detailed analysis of the plant shall be grouped into a specified number of representative event sequences that identify bounding cases and that provide the basis for the design and the operational limits for items important to safety
- A technically supported justification shall be provided for exclusion from the design of any initiating event that is identified in accordance with the comprehensive set of postulated initiating events

PIE – deterministic safety analysis perspective (SSG-2)



- For all plant states, a comprehensive listing of postulated initiating events (PIEs) should be prepared for ensuring that the analysis of the behavior of the plant is complete
- An initiating event is an event that leads to anticipated operational occurrences or accident conditions. This includes
  - Operator errors and equipment failures (both within and external to the facility)
  - Human induced or natural events, and
  - Internal or external hazards

PIE – deterministic safety analysis perspective (SSG-2)



- Postulated initiating events and the consequential transients should be specified to ensure that all possible scenarios are being addressed
- When performing deterministic safety analyses for anticipated operational occurrences, design basis accidents and beyond design basis accidents, all postulated initiating events and associated transients should be grouped into categories
- There are different sets of criteria for grouping initiating events and transients into categories, and each set of criteria will result in a different event list. One approach is to group events according to the principal effects that could result in the degradation of safety systems

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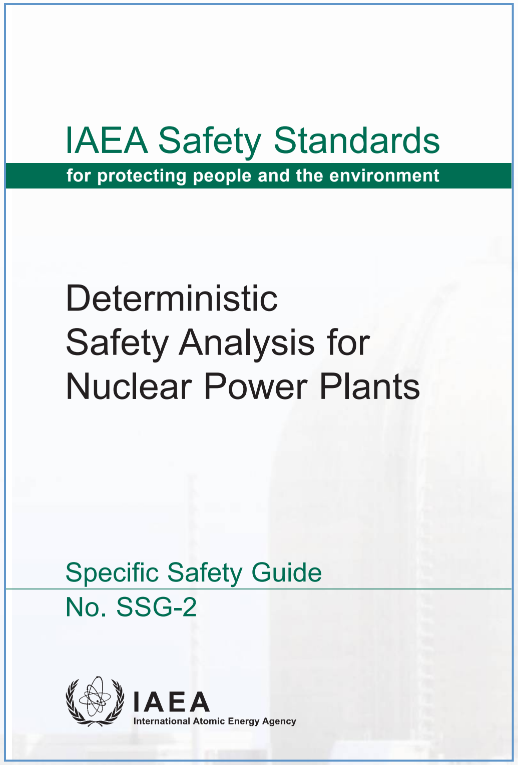
PIE – deterministic safety analysis perspective (SSG-2)



- Computational analysis of all possible design basis accident scenarios may not be practicable
- A reasonable number of limiting cases - bounding or enveloping scenarios, should be selected from each category of events
- These bounding or enveloping scenarios should be chosen so that they present the greatest possible challenge to the relevant acceptance criteria and are limiting for the performance parameters of safety related equipment
- In addition to design basis accidents, anticipated transients without scram (ATWS) have traditionally been analysed for light water reactors. It is becoming increasingly common for the analysis of other beyond design basis accidents to be required

Identification of PIE

- Process shall be systematic and auditable
- As complete as possible
- Sources
  - PSA
  - Engineering judgment
  - Operational experience (worldwide)
  - Generic lists (e.g. IAEA SRS 30)

Grouping of PIE

- For the purposes of accident analysis, it is reasonable to group all initiating events into categories
- There are different sets of criteria for grouping, thus leading to different event lists
- The most typical categories used in DBA are based on grouping by:
  a) **Principal effect on potential degradation of fundamental safety functions**
  b) Principal cause of the initiating event
  c) Frequency and potential consequences of the event
  d) Relation of the event to the original NPP design (for existing plants)

Grouping - DBA

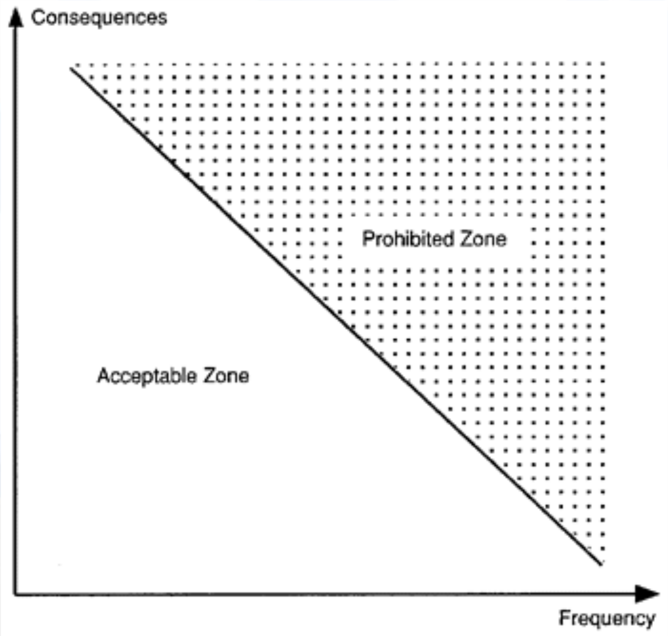
- Grouping by principal effect leading to potential degradation of fundamental safety functions
  - Increase in heat removal by the secondary side
  - Decrease in heat removal by the secondary side
  - Decrease in flow rate in the reactor coolant system
  - Increase in flow rate in the reactor coolant system
  - Anomalies in distributions of reactivity and power
  - Increase in reactor coolant inventory
  - Decrease in reactor coolant inventory
  - Radioactive release from a subsystem or component

Grouping - Increase in heat removal by the secondary side

- PIEs
  - o Steam line breaks (A);
  - o Inadvertent opening of steam relief valves (T);
  - o Secondary pressure control malfunction with increase of steam flow rate (T);
  - o Feedwater system malfunction leading to increase of heat removal (T)

Categorization

- Application of the graded approach
- Frequency of the occurrence -> from PSA Level 1
- Reflected in acceptance criteria



Categorization

Occurrence (1/reactor year)	Characteristics		Terminology	Acceptance criteria
10^{-2}–1 (Expected in the life of the plant)	Expected	Anticipated operational occurrences	Anticipated transients, transients, frequent faults, incidents of moderate frequency, upset conditions, abnormal conditions	No additional fuel damage
10^{-4}–10^{-2} (Chance greater than 1% over the life of the plant)	Possible	DBAs	Infrequent incidents, infrequent faults, limiting faults, emergency conditions	No radiological impact at all or no radiological impact outside the exclusion area
10^{-6}–10^{-4} (Chance less than 1% over the life of the plant)	Unlikely	BDBAs	Faulted conditions	Radiological consequences outside exclusion area within limits
$<10^{-6}$ (Very unlikely to occur)	Remote	Severe accidents	Faulted conditions	Emergency response needed

Design Extension Conditions

Practically eliminated conditions

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List of PIE – examples: PWR, full power

Reactivity initiated accidents and power distribution disturbances
Uncontrolled withdrawal of a control rod group during start-up
Uncontrolled withdrawal of a control rod group during power operation
Uncontrolled movement of control rods
Incorrect connection of an inactive reactor coolant system loop
Control assembly ejection
Decrease of boron concentration in primary circuit
Inadvertent loading of a fuel assembly into an improper position

Decrease of primary coolant flow
Inadvertent closure of one main isolation valve in a reactor coolant system loop
Seizure of one reactor coolant pump
Shaft break of one reactor coolant pump
Single or multiple RCP trip

Increase of primary coolant inventory
Inadvertent actuation of the high pressure ECCS during power operation
Incorrect operation of makeup system which increases reactor coolant inventory

List of PIE – examples: PWR, full power

Increase of heat removal by the secondary side
Feed water system malfunction with an decrease of feed water temperature
Feed water system malfunction with an increase of feed water flow rate
Secondary pressure control malfunction with an increase of steam flow rate
Inadvertent opening of SG safety valves or steam relief valves
Steam line break

Decrease of heat removal by the secondary side
Secondary pressure control malfunction with an decrease of steam flow rate
Loss of external electric load
Turbine stop valves closure
Steam line valves closure
Loss of condenser vacuum
Main feed water pumps trip
Loss of off-site and on-site power
Feed water line break

List of PIE – examples: PWR, full power

Loss of coolant accidents
Spectrum of postulated leakage sizes within the reactor coolant pressure boundary
Break of PRZ steam line between PRZ and safety valves
Inadvertent opening of PRZ safety valve
Break of pipe connected to primary system and penetrating the containment walls
Inadvertent opening of one check or isolation valve separating reactor coolant boundary and low-pressure part of the system

Primary to secondary system leakages
Steam generator tube rupture or SG primary collector cover lift
Inadvertent opening of SDV-A SG4

Containment thermal-hydraulic response to DBA
Primary circuit breaks
Secondary circuit breaks

List of PIE – examples: PWR, full power

Radiological consequences analysis of envelope DBA
Main primary cooling loop break (LOCA 2x500 mm)
Inadvertent opening of SDV-A SG4
Break of pipe connected to primary system and penetrating the containment walls (IFLOCA 32 mm)
SG primary collector head lift-off
Inadvertent opening of the PRZ safety valve

Ra-release from subsystem and components
Radioactive Gas Treatment System Leakage or Failure
Radioactive Liquid Waste System Leakage or Failure
Downfall of Fuel Assembly during Fuel Reloading
Downfall of a Container with Fresh or Spent Fuel

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List of PIE – examples: PWR, shutdown

Transients and accidents at shutdown operational modes
Reactivity induced events
Inadvertent loss of primary coolant
Loss of residual heat removal in consequence of degradation of primary coolant circulation
Loss of residual heat removal in consequence of devices failure
Reactor coolant inventory increase
Events of spent fuel pool cooling
Spent fuel pool damage during the refueling

List of PIE – examples: PWR, PTS

Pressurized thermal shocks
Spectrum of postulated leakage sizes within the reactor coolant pressure boundary
Inadvertent opening of PRZ safety valve
Primary to secondary system leakage
Inadvertent actuation of ECCS injection to primary system
Incorrect operation of make up system
Inadvertent actuation of PRZ heaters
Inadvertent opening of SG safety valves (SV SG), SDV-A or SDV-C
Steam line breaks
Feed water line breaks
External reactor pressure vessel cooling

List of PIE – examples: PWR, BDBA

Anticipated transients without scram
Transients for event with reactivity insertion (ATWS)
Transients with primary coolant flow rate decrease (ATWS)
Transients with increase of primary coolant inventory (ATWS)
Transients with increased heat removal from primary circuit by secondary circuit (ATWS)
Transients with decreased heat removal from primary circuit by secondary circuit (ATWS)

Selected BDBA evaluation
Station blackout
Loss of ultimate heat sink
Total loss of feed water
Primary coolant leakage combined with ECCS failure
Loss of reactor coolant in the mode of nature circulation cooling
Total loss of essential service water
Loos of heat removal from the core for reactor shutdown
Loss of spent fuel pool cooling
Uncontrolled boron dilution in reactor
Multiple steam generator tubes rupture
Steam line break together with a SG tube rupture
Loss of required safety systems in the long term after a postulated initiating event
Break of the main pressure components

Safety aspects of PIE – example LOCA

- Identification
  - Loss of integrity of the primary circuit or its associated pipes and devices.
- Cause
  - Material defect, material fatigue, an external impact (internal missiles or heavy loads) or a device failure during the operation of the plant

Safety aspects of PIE – example LOCA

- Safety aspects
  - The high velocity of the escaping primary coolant -> jet forces and reaction forces (leading to pipe whip) that endanger other systems
  - Mechanical damage of the MCP rotor
  - Pressure wave propagation in the primary circuit at the very initial stage of the accident leads to pressure differences across the reactor internals with large forces acting on the internals
  - Core dry-out and loss of coolability of the core -> integrity of the fuel rods and cladding
  - Cladding ballooning and geometrical distortions of the fuel assemblies -> endanger the long term coolability of the reactor core.
  - At high temperatures the cladding material reacts with the steam in an exothermic reaction (additional heat) and hydrogen is generated
  - Oxidation of the cladding material
  - Pressurization of the containment
  - Release of the radioactivity into containment and environment

Grouping - Increase in heat removal by the secondary side

- Characteristics
- Safety aspects

Grouping - Increase in heat removal by the secondary side

- **Characteristics**
  - Increased heat transfer to the secondary side -> cooling down (non-symmetrical) of the primary side -> positive reactivity insertion
  - Loss of the secondary inventory -> depressurization of secondary side -> pressurization of the containment

- **Safety aspects**
  - Reactor recriticality and power increase
  - Non-symmetrical reduction of coolant temperature
  - Increase of the primary side temperature and pressure -> integrity of the primary side
  - Integrity of the containment

Regulatory review

- Identification of PIEs – method, systematization
- Completeness and compliance with national regulations (formal and content)
- Categorization
  - o Based on PSA results
  - o Corresponding acceptance criteria