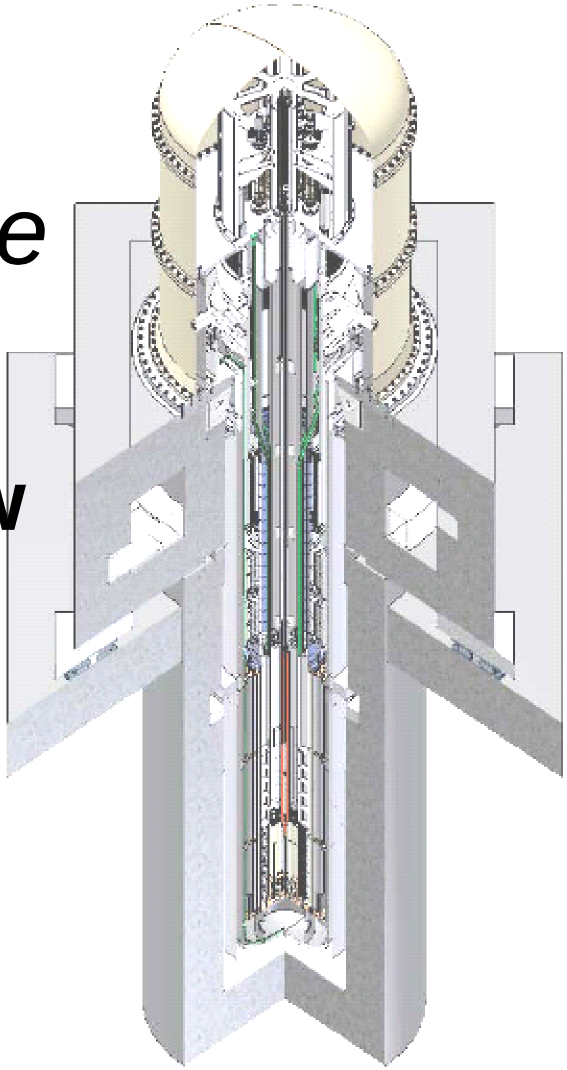
PSNE Control Number:PSN-2008-0959
Document Number:AFT-2008-000068rev.000(1)

4S Reactor
Super-Safe, Small and Simple



Fourth Pre-Application Review Meeting with NRC

August 8th, 2008

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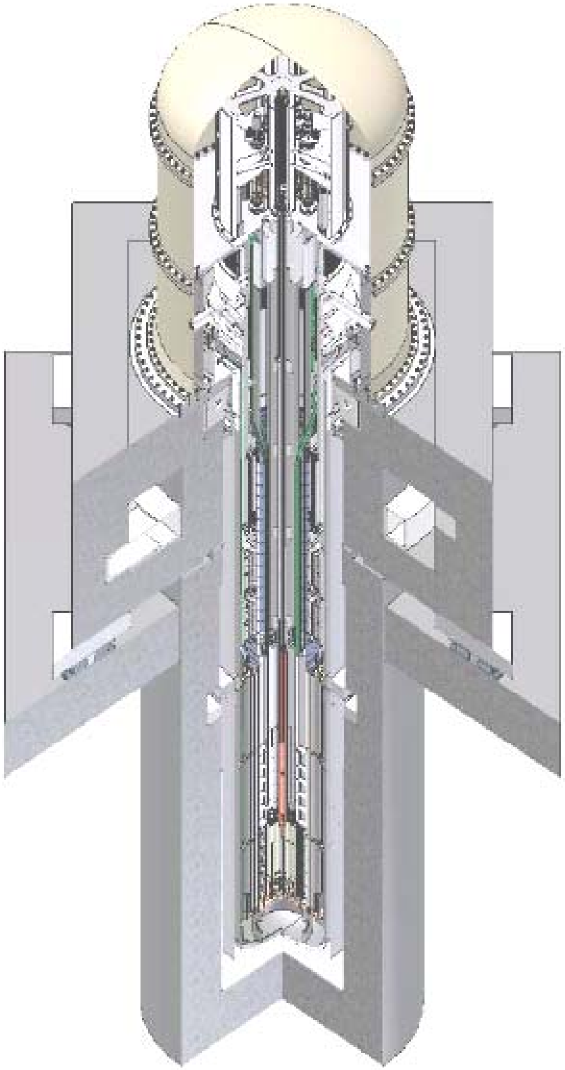
Presentation Purpose

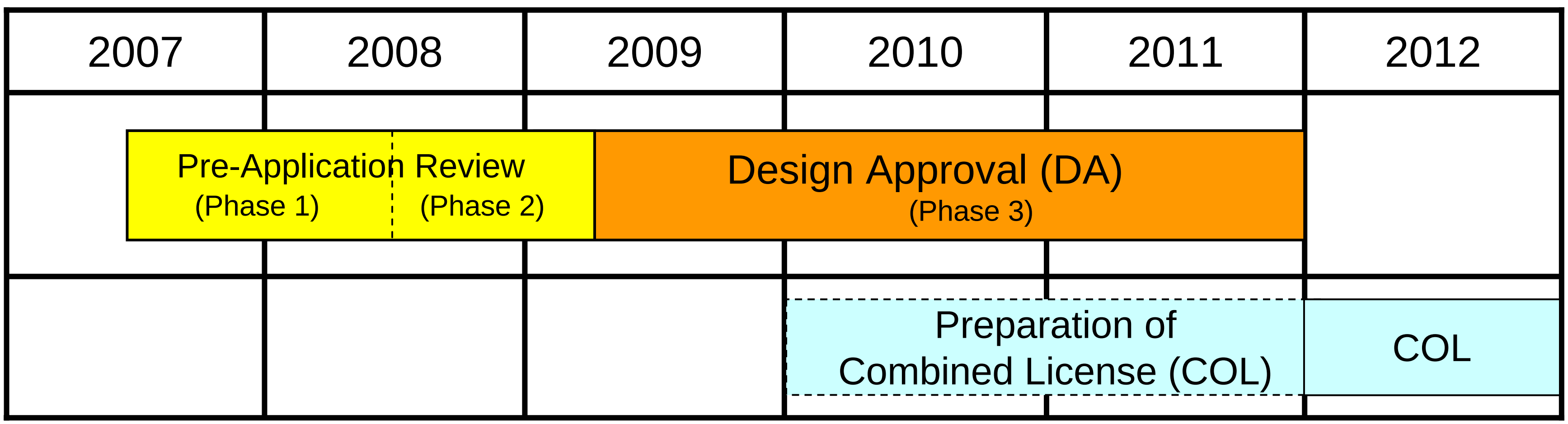
- Familiarize the NRC with the 4S Phenomena Identification and Ranking Table (PIRT)
- Familiarize the NRC with the 4S safety design in relation to "Regulation of Advanced Nuclear Power Plants; Draft Statement of Policy" (73FR26349)
- Obtain NRC feedback

Program Overview



Proposed Licensing Approach

- **Submit Design Approval application in 2009**
  - **Phase 1:** Complete a series of meetings with NRC to identify issues to be addressed before Design Approval application
  - **Phase 2:** Submit technical reports and obtain NRC feedback to address the issues identified in Phase 1
  - **Phase 3:** Submit Design Approval application and obtain FSER
- **Toshiba expects a U.S. customer will submit a COL application referencing Design Approval.**



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Phase 1 – Proposed Licensing Approach

	2007	2008		
	4Q	1Q	2Q	3Q
1st Meeting High level overview	▼			
2nd Meeting System design Long-life metallic fuel		▼		
3rd Meeting Safety design and regulatory conformance			▼	
4th Meeting - Today PIRT, Design conformance to policy statement				▼

Phase 2 – Proposed Licensing Approach

- **Schedule of technical reports for NRC review**
  - Long-life metallic fuel
    - Analysis methodology
    - Fuel performance — June 30 2008
  - Safety design and safety analysis
    - Principal design criteria
    - Evaluation criteria
    - Analysis methodology
    - Safety analysis results — October 2008
  - PIRT and test program — November 2008
  - Seismic isolation — December 2008
  - Responses to NRC questions — December 2008

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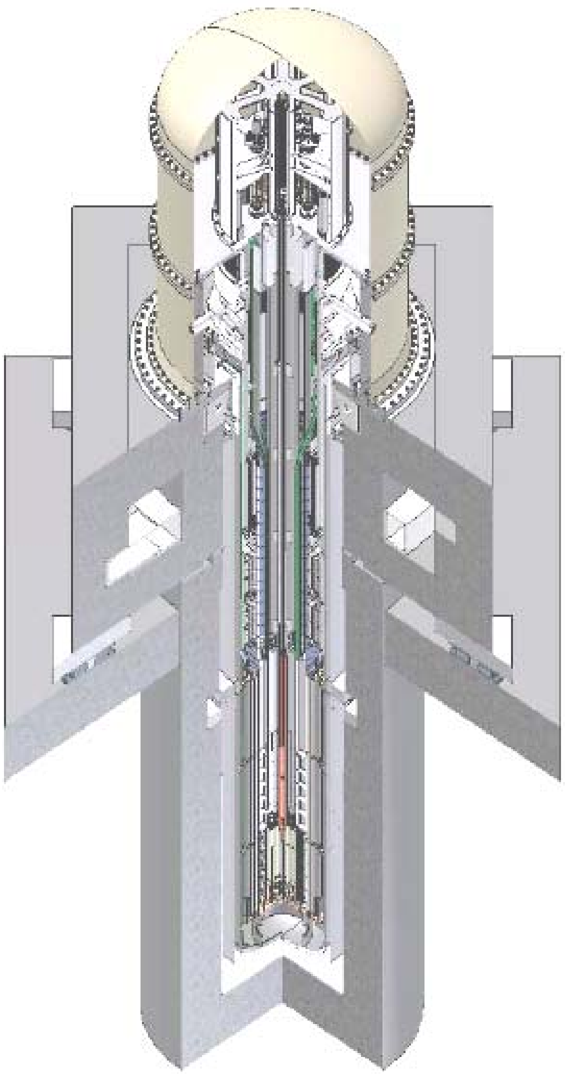
Phenomena Identification and Ranking Table (PIRT)



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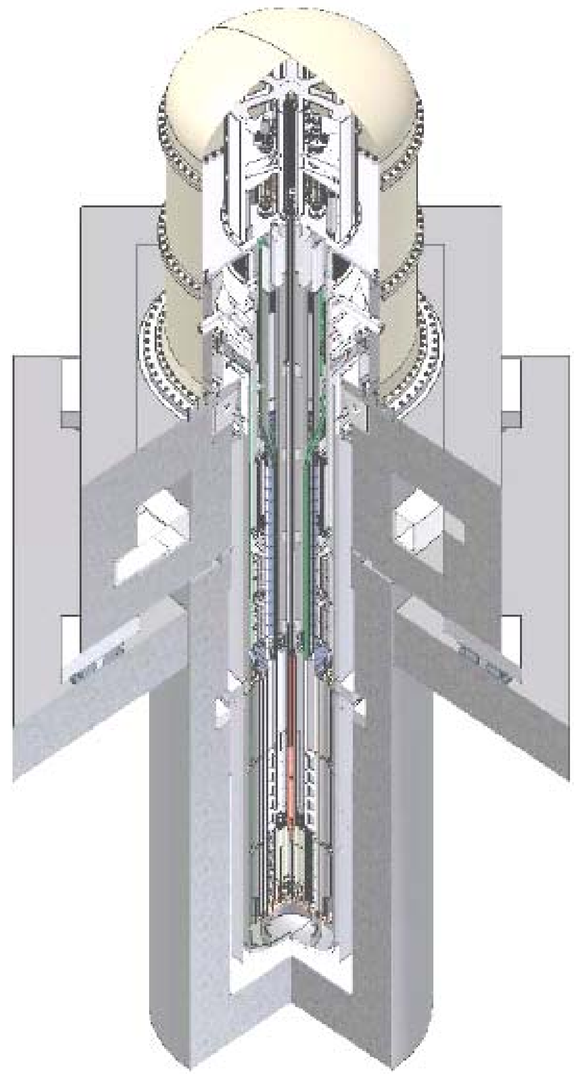
Presentation Structure

- Overview of PIRT Process
- Details of PIRT Process
  - Issue, Objective and Event Selection
  - Description of Events,
    Partitioning of Events, and
    Partitioning of Plant Systems
  - Figures of Merit
  - Identification of Plausible Phenomena
  - Ranking of Phenomena Importance and State of Knowledge,
    Performing of Sensitivity Studies
- Development of Priority and Scope for Further Investigation

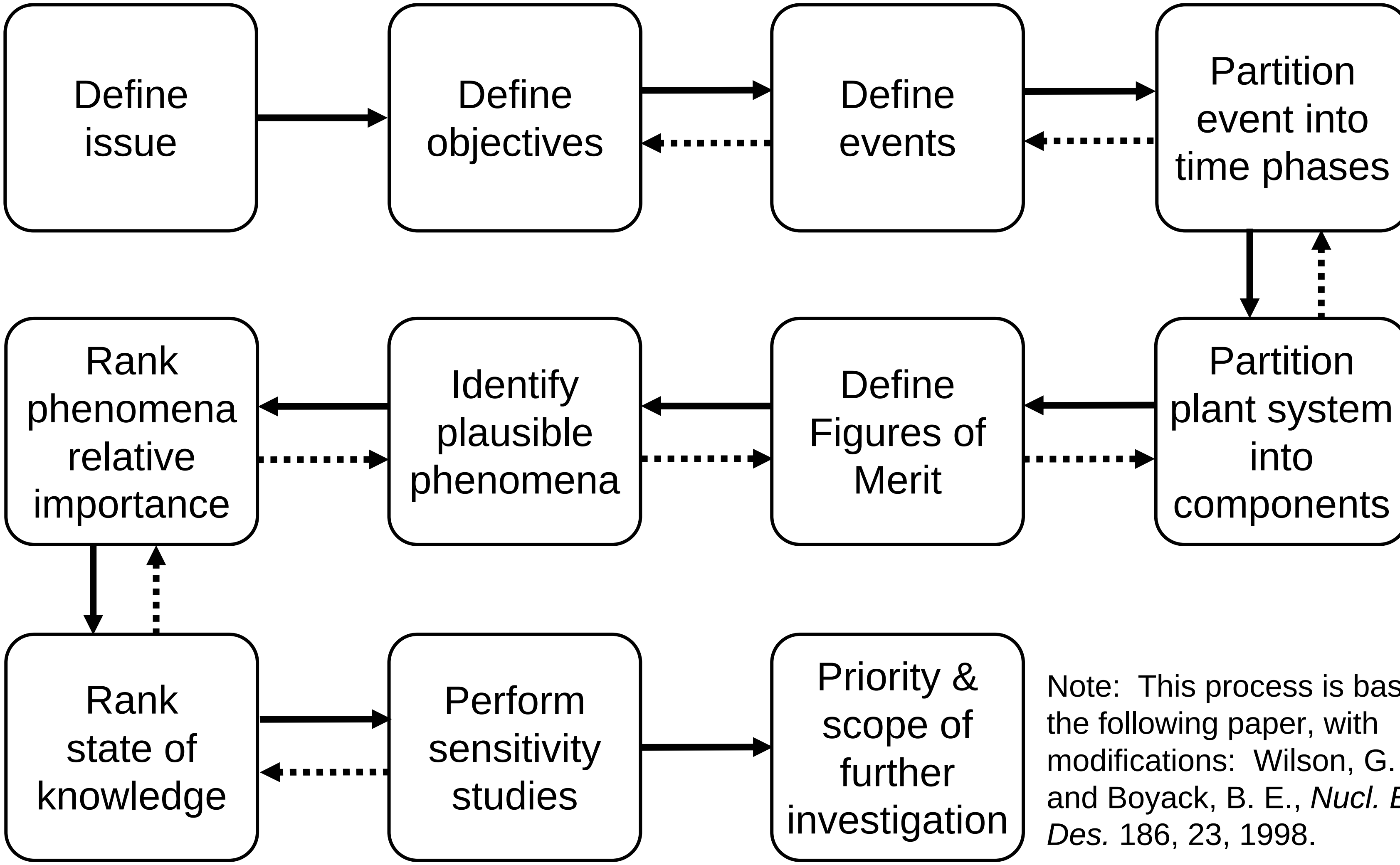
Overview of PIRT Process



Independent PIRT Review and Advisory Panel

- Mario H. Fontana
  (The University of Tennessee)
- Frederick J. Moody
  (Consulting Engineer)
- Hisashi Ninokata
  (Tokyo Institute of Technology)
- Gary E. Wilson
  (KatJon Services Inc.)
- Akira Yamaguchi
  (Osaka University)

11 Steps of the 4S PIRT Process



Note: This process is based on the following paper, with modifications: Wilson, G. E. and Boyack, B. E., *Nucl. Eng. Des.* 186, 23, 1998.

The process is iterative (i.e., recycle through any previous steps as needed)

Issues and Objectives

- Issues
  - Ensure that sufficient state of knowledge (SoK*) exists for important phenomena
  - If the knowledge is insufficient, need to supplement it.
- Objectives of this PIRT
  - This PIRT guides the priority and scope of the theoretical evaluation and test program that should be performed to confirm the state of knowledge of the important safety-related phenomena.
  - This PIRT focuses on confirming our knowledge of the performance of safety-related subsystems and components.

* Extent of knowledge for phenomenon obtained from available data and information; range of what is known and what is unknown.

Event Definition and Partitioning; Plant System Partitioning

- Event definition
  - Select representative events from Design Basis Accidents (DBAs)

- Event partition
  - Consider the time-dependent transient behavior, partitioning event into time phases appropriate to accurate phenomena identification and importance evaluation

- Plant system partition
  - Partition plant system into subsystems that enhance plausible phenomena identification

Figure of Merit and Plausible Phenomena

- Figure of Merit (FoM):
  - *The Figure of Merit is the criterion with which the RELATIVE importance of each "phenomenon" is judged.*

    (Boyack, B. E. and Wilson, G. E., BE-2004 Int. Mtg. on Updates in Best Methods in Nucl. Installations Safety Analysis, Nov. 2004.)

- Plausible phenomena identification
  - Identify phenomena having some influence on the FoM using all currently available information, including expert opinion

Ranking and Sensitivity Studies

- Using all currently available information, including expert opinion:
  - Rank relative importance of plausible phenomena that impact FoM
  - Rank state of knowledge for plausible phenomena
- Perform sensitivity studies to verify/refine preliminary ranking result of phenomena importance
  - Re-evaluate relative importance of phenomena
- Finalize ranking table (PIRT) based on the above considerations

Example of the 4S PIRT Format

Subsystem/ Component	Phenomena	Importance 1st Phase (Early)	Importance 2nd Phase (Late)	SoK
Core/ Fuel Assembly	Pressure loss in core region	M	M	P
	Pressure loss in reflector region	L	L	P
	Natural circulation	L	L	P
	Pressure loss in upper shield region	L	L	P
	Reactivity feedback (fuel, coolant, structures, radial core expansion, core support expansion, Doppler, axial fuel expansion)	L	n/a	P
	Heat transfer between fuel and cladding	L	L	P
	Heat transfer between cladding and coolant	L	L	K
	Flow distribution of the intra- and inter-assembly	H	H	P
	Radial heat transfer between subassemblies (S/A* ←→ Sodium ←→ S/A)	M	H	P

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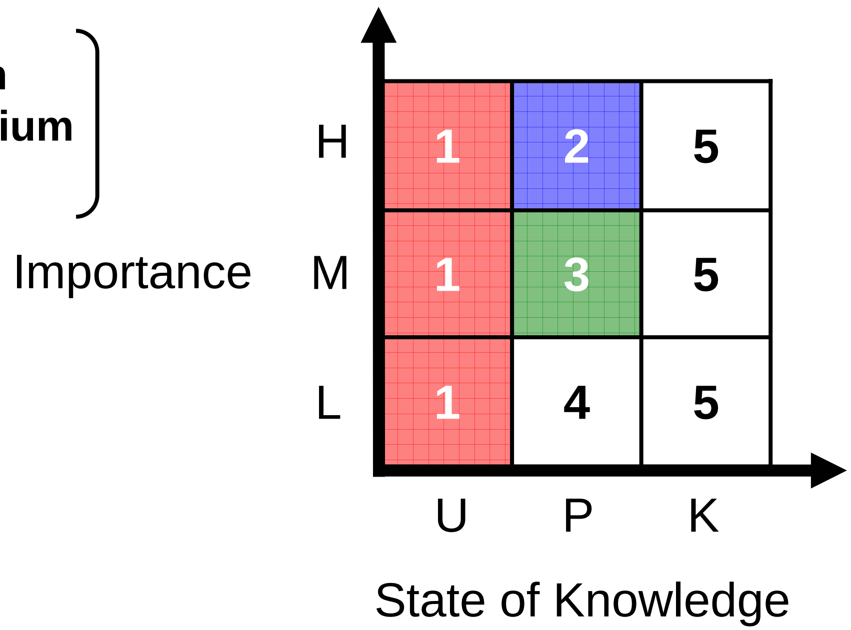
* Subassembly

Priority and Scope of Further Investigation

- Identify phenomena requiring further investigation (theoretical evaluation and test program) based on the results of PIRT

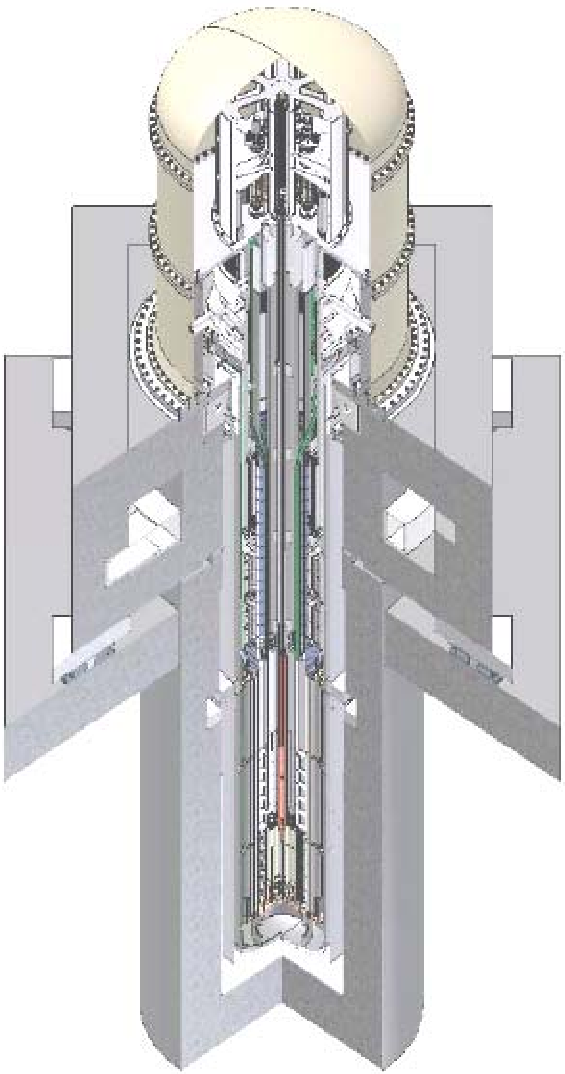
H = High
M = Medium
L = Low



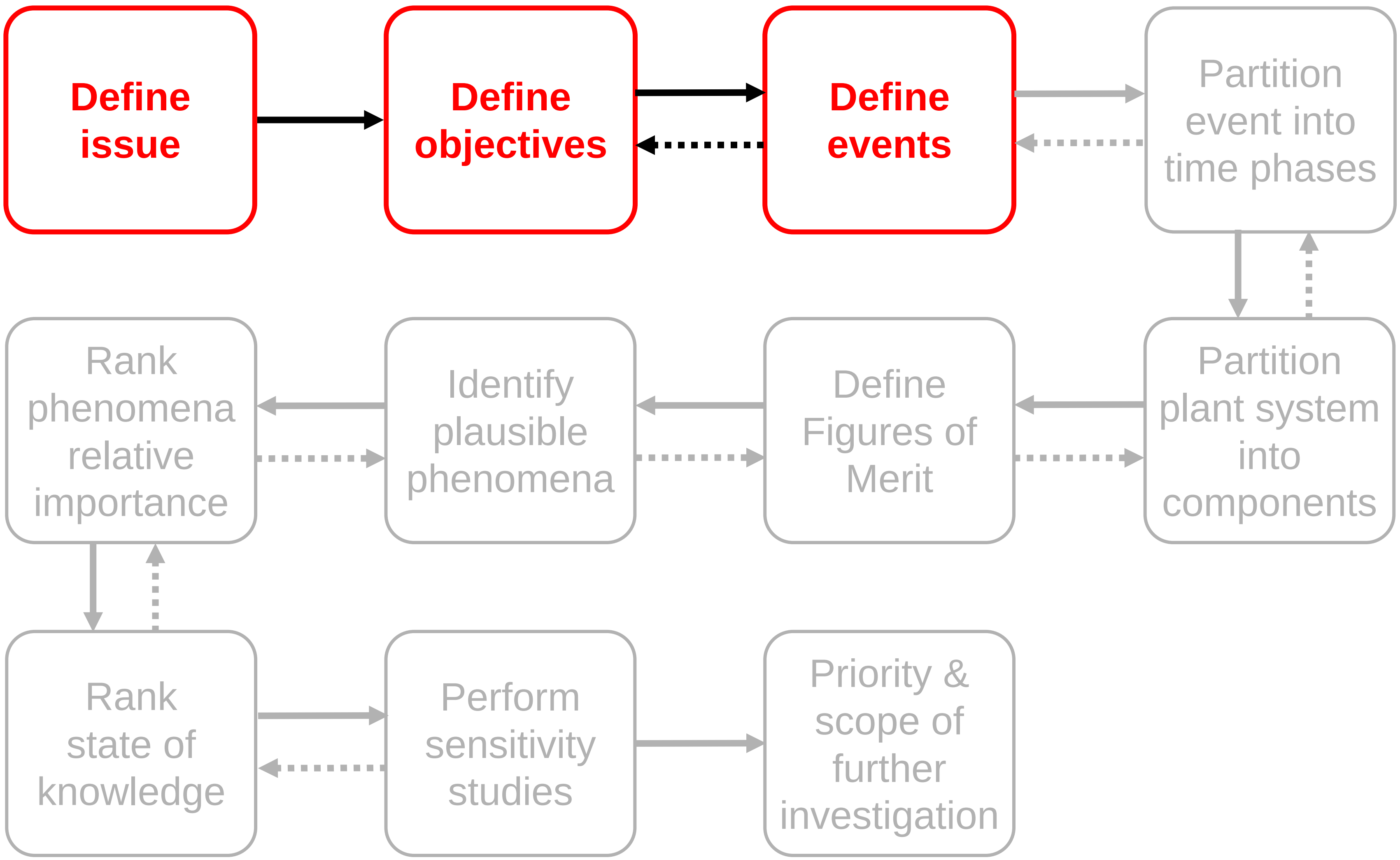
(U = Unknown, P = Partially Known, K = Known)

1 – Highest priority level
2 – 2nd priority level
3 – 3rd priority level
4 – 4th priority level
5 – Lowest priority level

Details of PIRT Process



Issue, Objective and Event Selection



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Issue, Objective and Event Selection

- Issue and Objective
  - Focus on safety-related protection provided by RPS and RHRS

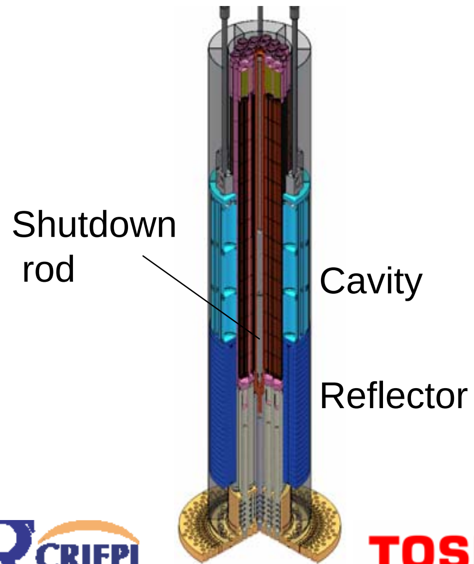
- Event Selection
  - Focus on DBAs; Identification in the 3rd Pre-Application Review Meeting with NRC

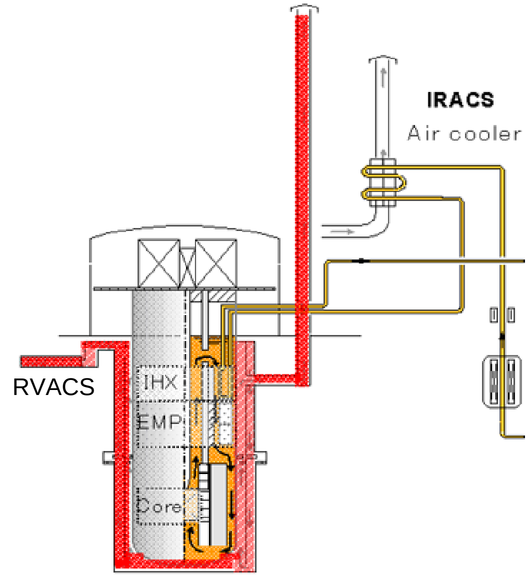
DBAs for RPS

- Rapid motion of reflector at startup
- Failure of a cavity can
- Reactor vessel leakage
- One primary EM pump failure

DBAs for RHRS

- Loss of offsite power
- Sodium leakage from intermediate piping





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Select Representative Events

- Select the events that produce the greatest challenge to the safety systems based on preliminary safety analysis
  - For reactor protection system:
    - Failure of a cavity can
      (Because of maximum reactivity insertion)
  - For residual heat removal system:
    - Loss of offsite power (LOSP)
      (Focus on mainly natural circulation for IRACS)
    - Sodium leakage from intermediate piping (SLIP)
      (Natural circulation for RVACS)

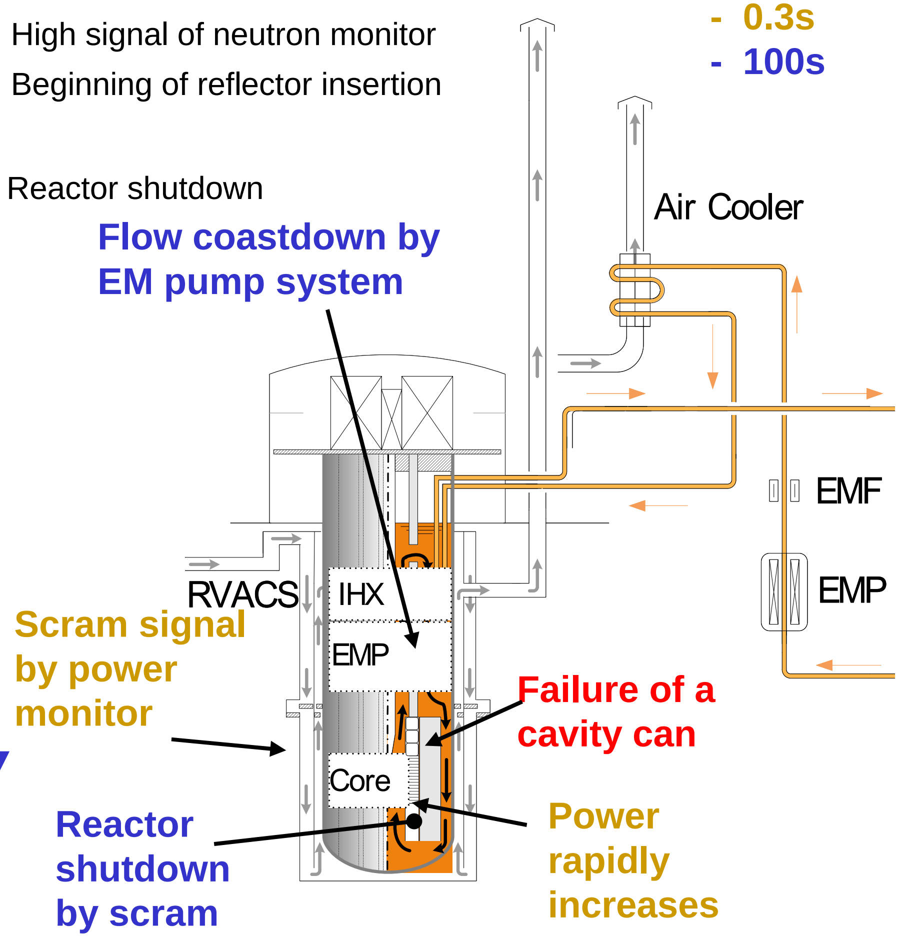
Event Description for Failure of a Cavity Can

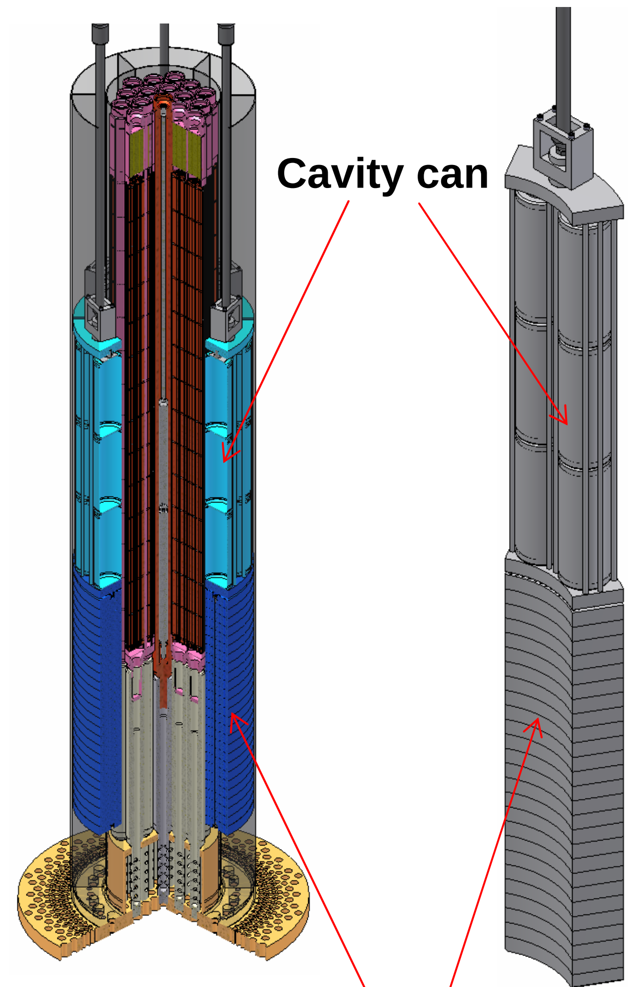
- System response

0.0s Event occurrence
0.3s High signal of neutron monitor
1.3s Beginning of reflector insertion

Reactor shutdown

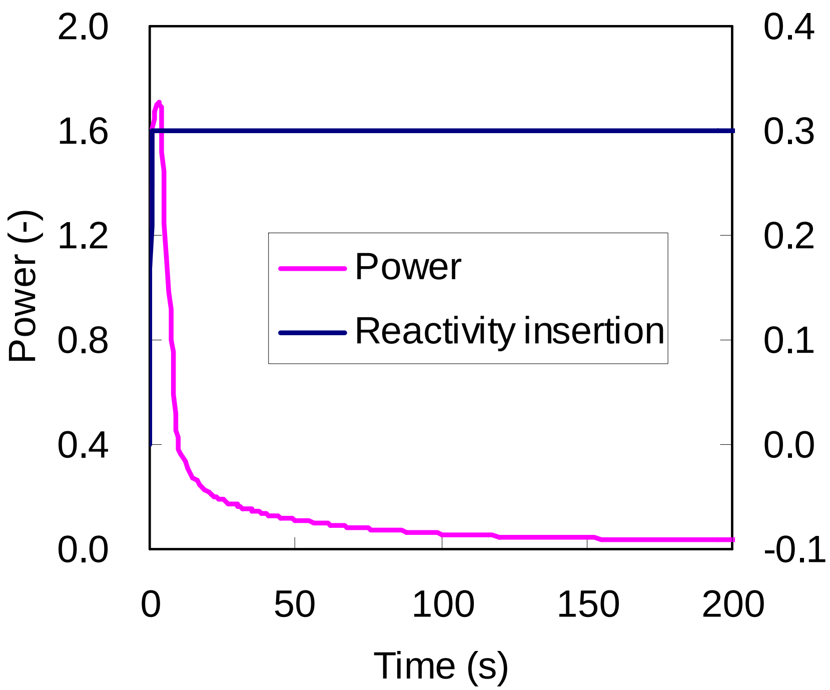
Time: 0s
- 0.3s
- 100s

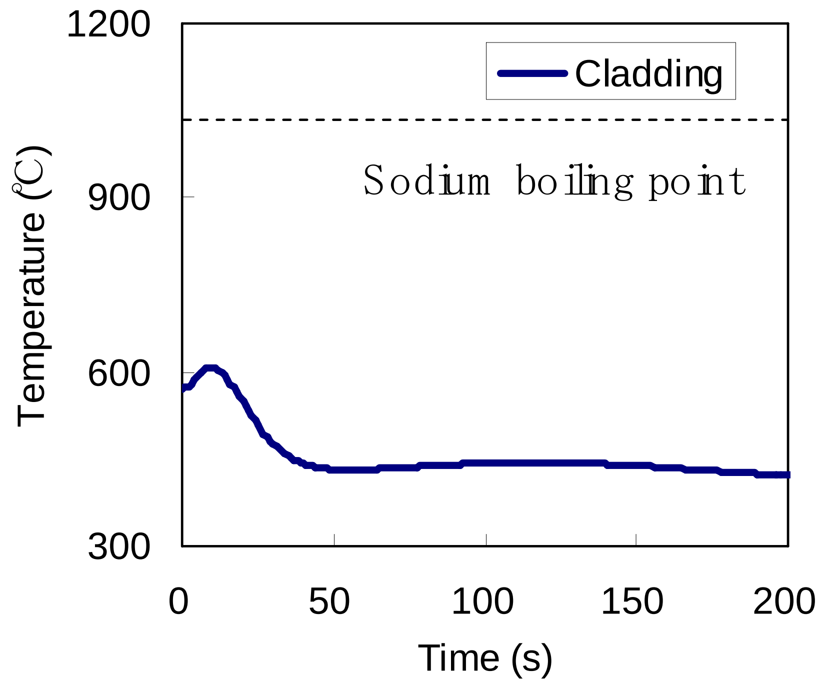




Transient Behavior of Major Parameters

- Failure of a cavity can





Analyses in the PIRT are performed using nominal conditions to identify realistic (best estimate) behaviors.

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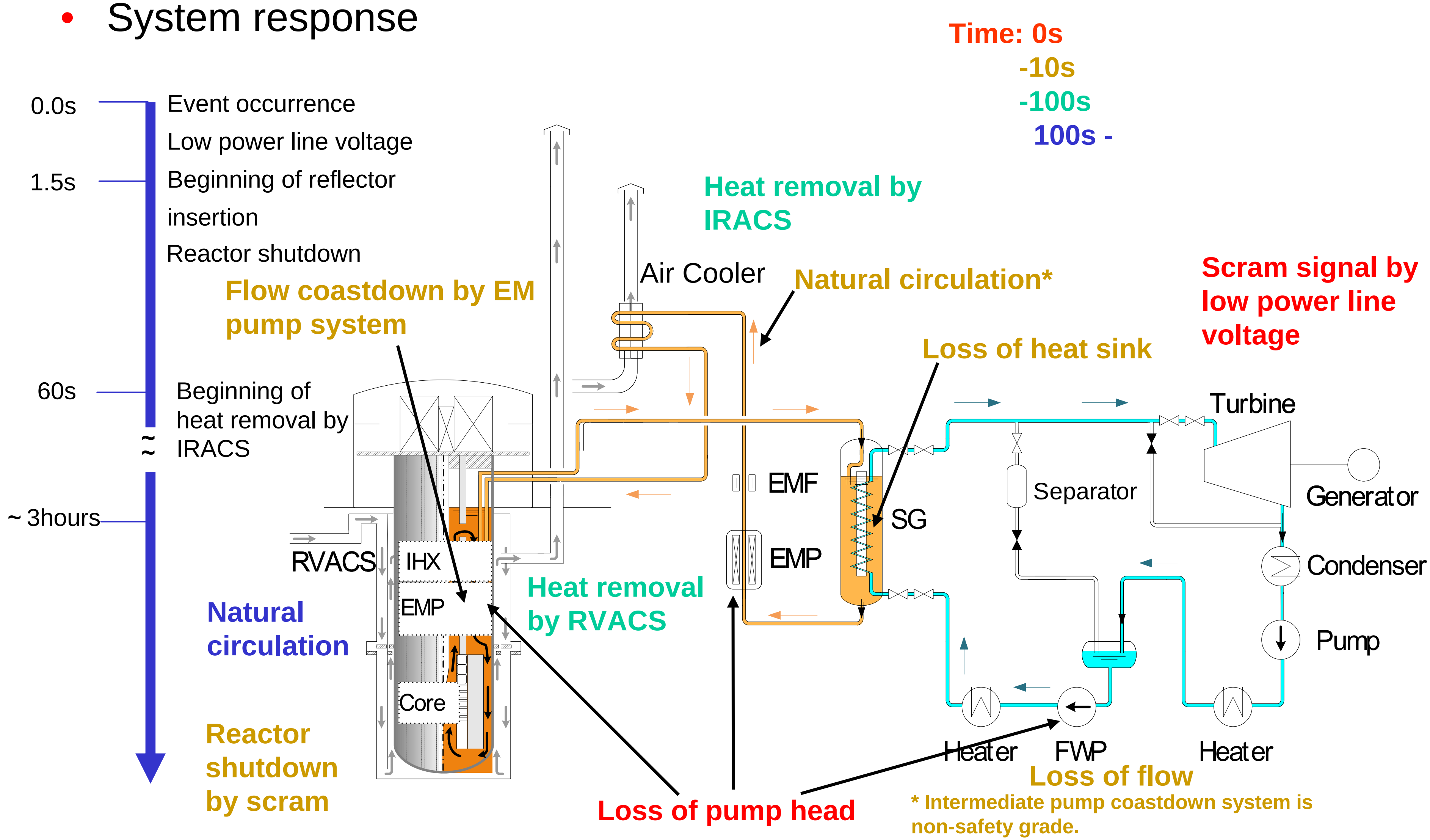
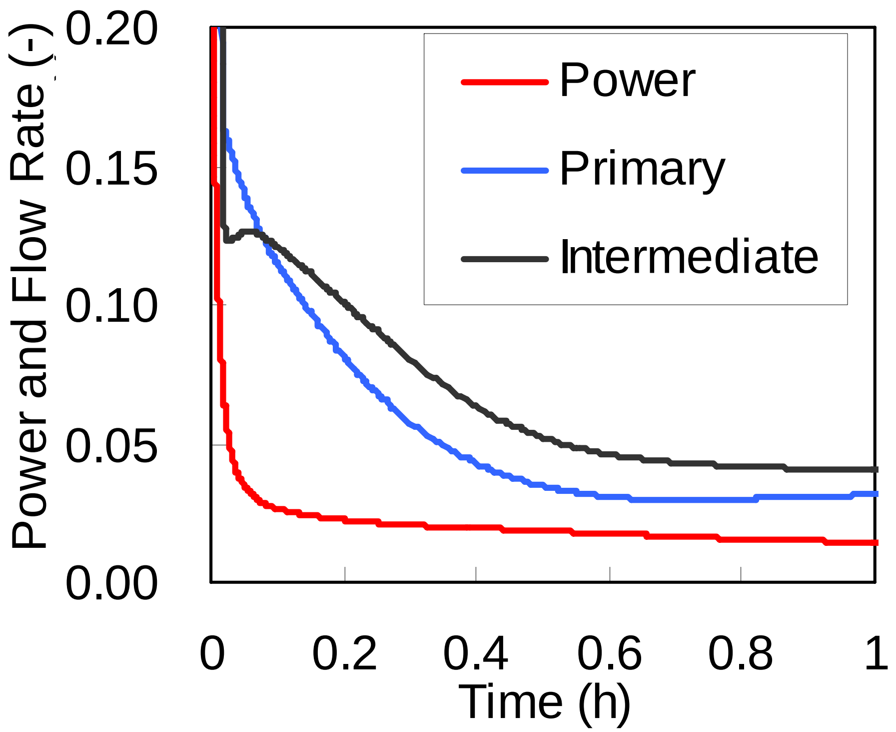
Event Description for LOSP

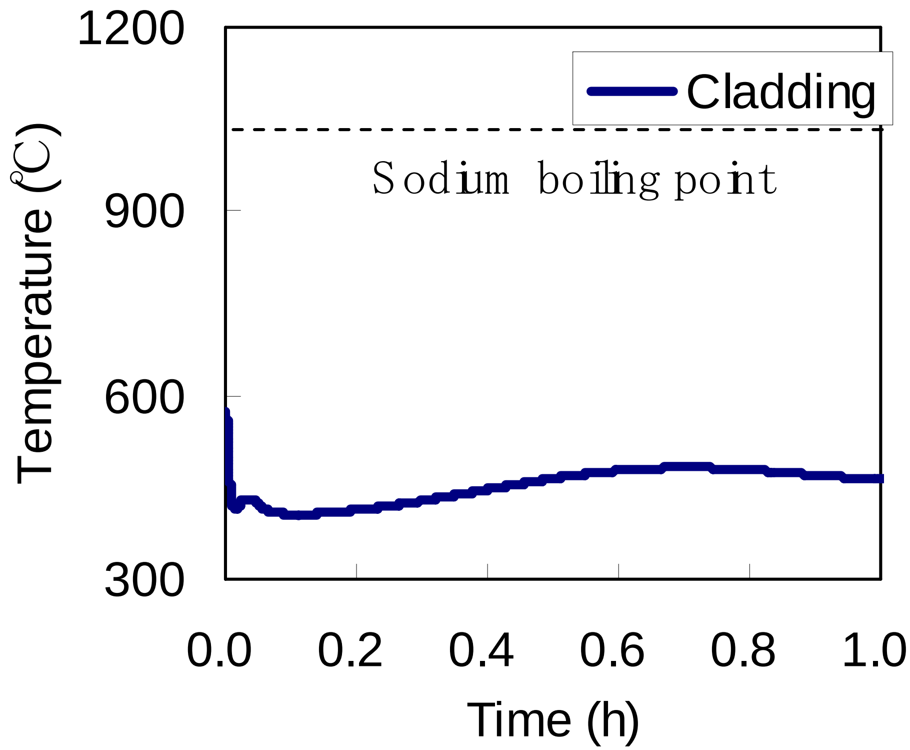
- System response



Transient Behavior of Major Parameters

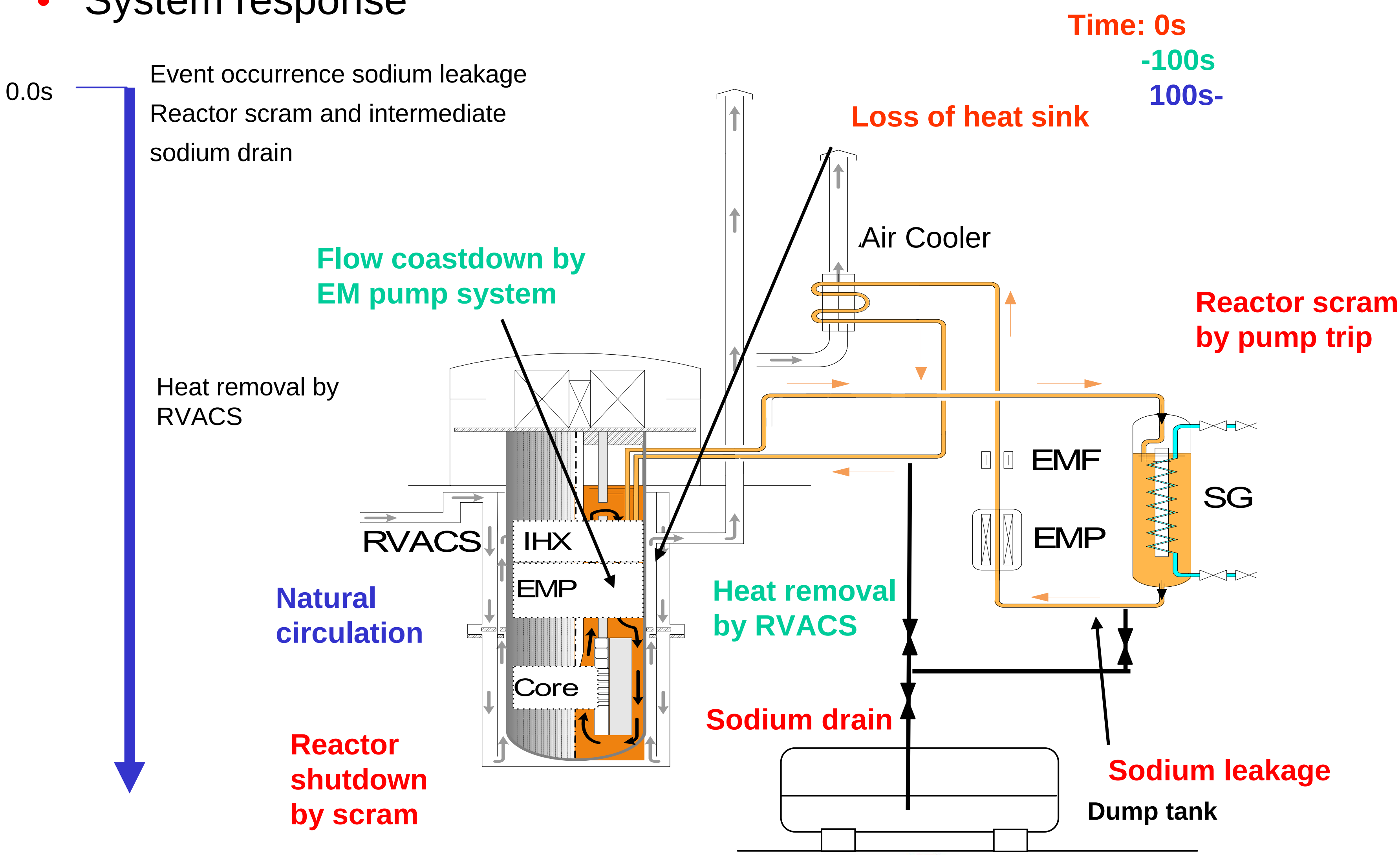
- LOSP





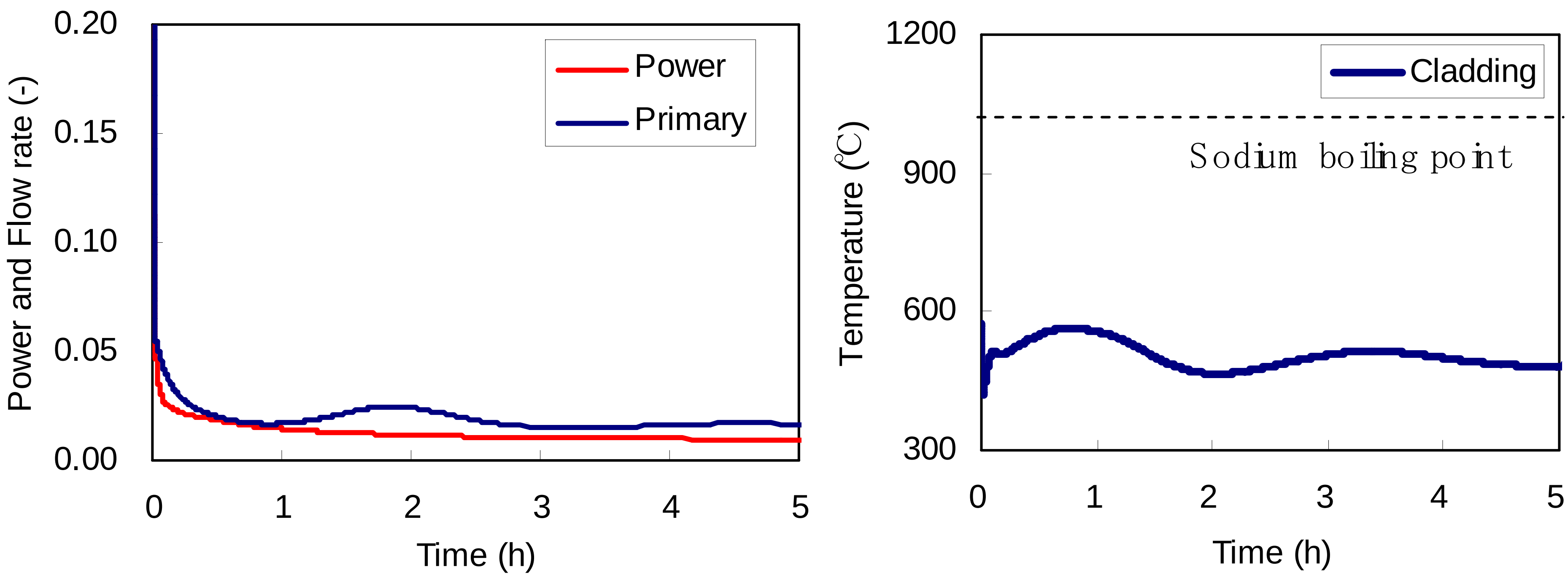
Event Description for SLIP

- System response

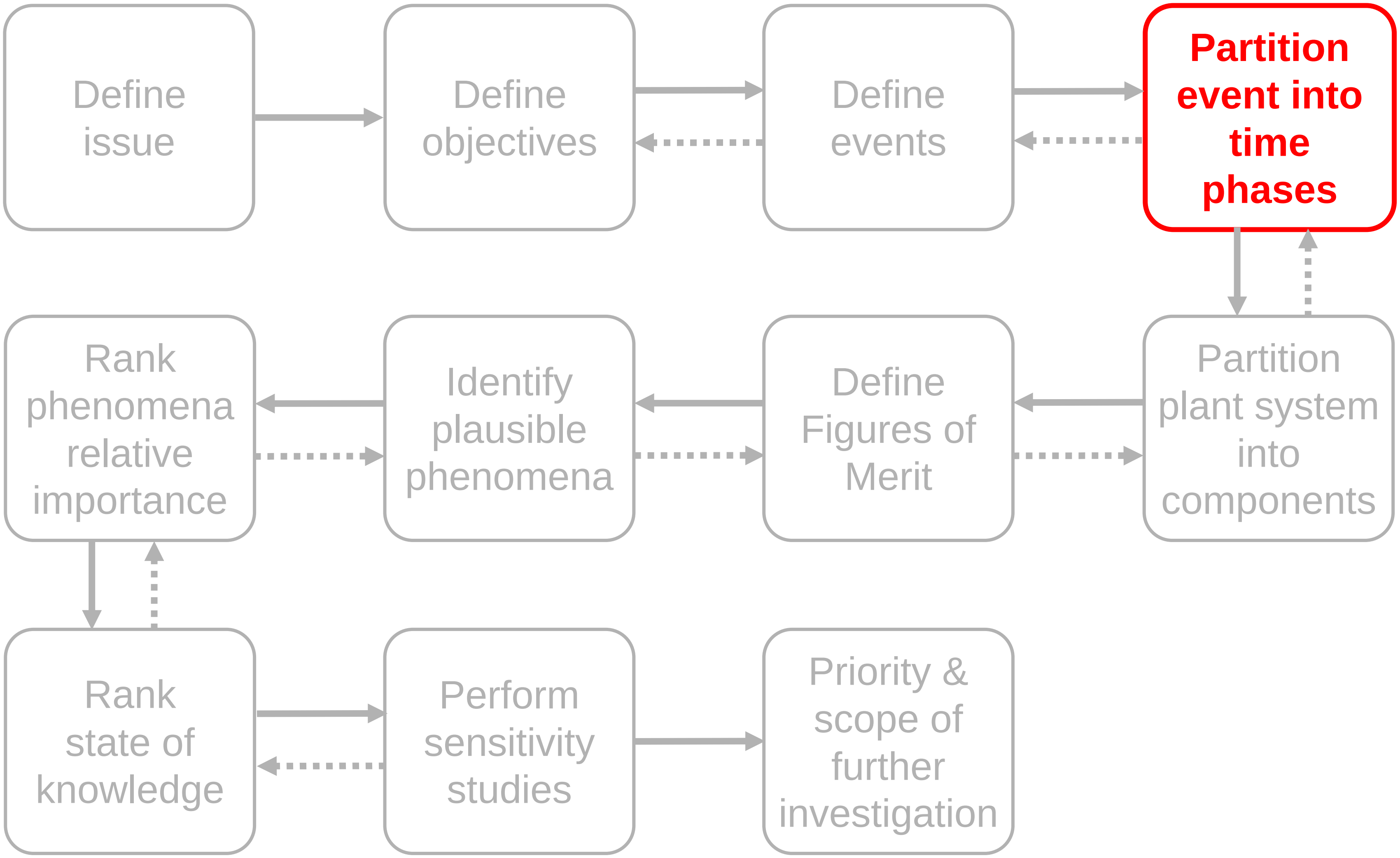


Transient Behavior of Major Parameters

- SLIP



Partition Event into Time Phases



Partition Event into Time Phases

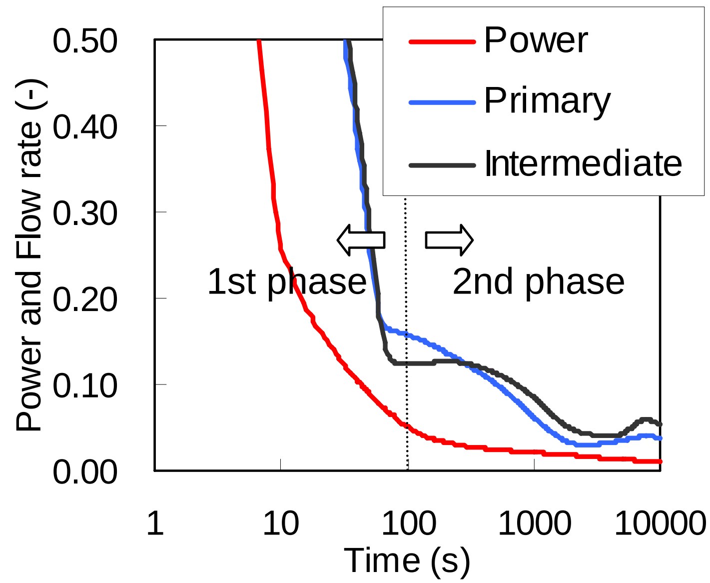
- Relative importance of phenomena is event dependent.
  - Relative importance of phenomena changes during event:
    - Subsystems/components are not always active throughout the entire transient.
    - Dominant phenomena may change as transient progresses.

- Partitioning of an event facilitates understanding of how phenomena importance may change as transient progresses.

Partitioning of Selected Events

- Failure of a cavity can
  - Event initiation until reactor shutdown
    - Partition into time phases is not necessary.

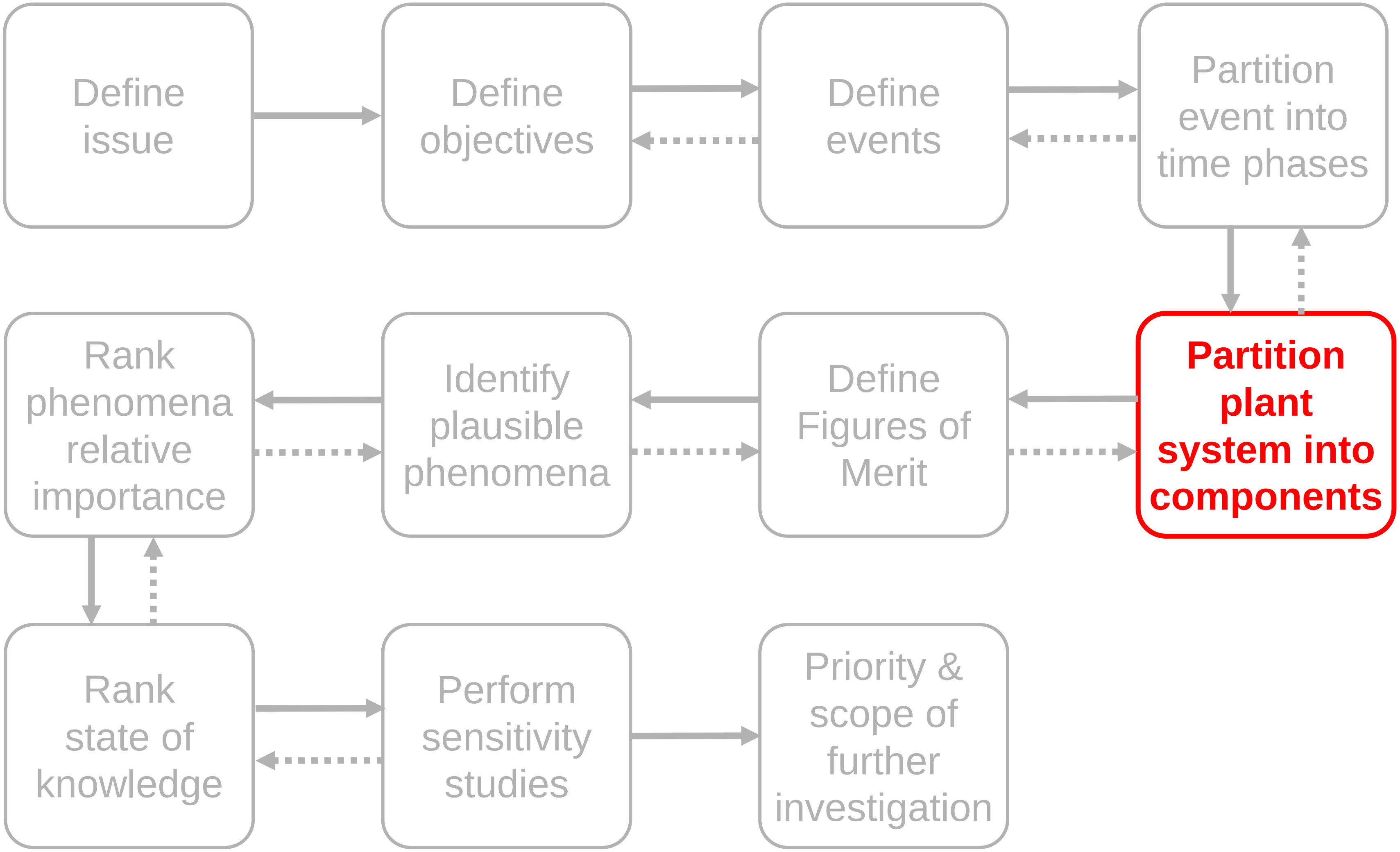
- Loss of offsite power
  - 1st phase: Event initiation until natural circulation is established
  - 2nd phase: Residual heat removal by IRACS



Loss of offsite power

- Sodium leakage from intermediate piping
  - 1st phase: Event initiation until natural circulation is established
  - 2nd phase: Residual heat removal by RVACS

Partition Plant System into Components



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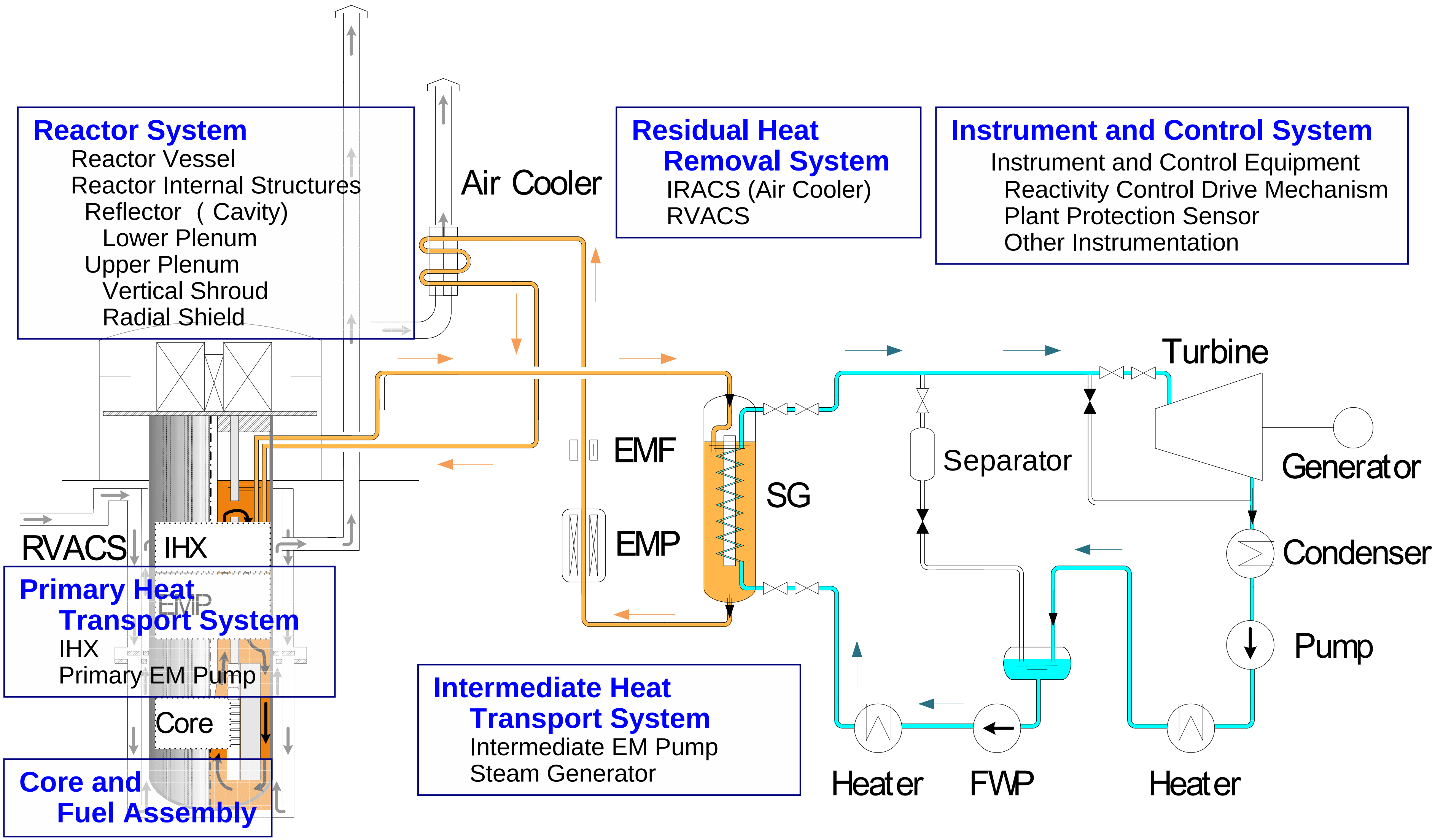
Identification of Key Subsystems and Components

- Identify all the key plant subsystems and their associated components to enhance plausible phenomena identification
- Partition into 5 subsystems from the viewpoint of thermal-hydraulic behavior: "Core and Fuel Assembly," "Reactor System," "Primary Heat Transport System (PHTS)," "Intermediate Heat Transport System (IHTS)" and "Residual Heat Removal System"
- Select one subsystem from the viewpoint of ensuring the performance of the RPS; "Instrument and Control System"
- Partition each subsystem into its components

Partitioning of 4S Plant Systems



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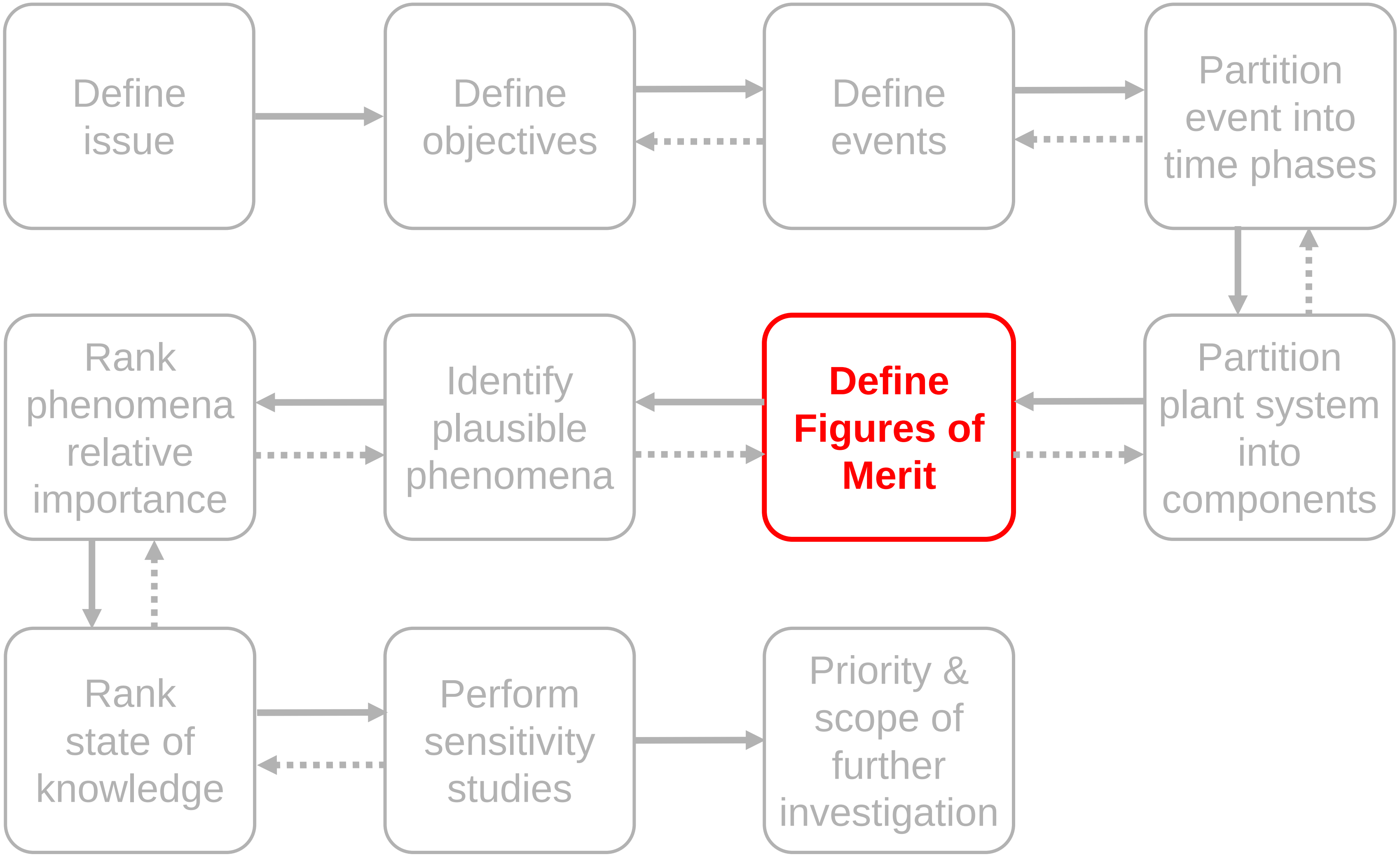
Figures of Merit



Definition of Figures of Merit

- Figure of Merit (FoM):
  - *The Figure of Merit is the criterion with which the RELATIVE importance of each "phenomenon" is judged.*

    (Boyack, B. E. and Wilson, G. E., BE-2004 Int. Mtg. on Updates in Best Methods in Nucl. Installations Safety Analysis, Nov. 2004.)

- Desirable characteristics of FoM
  - Directly related to issue ("issue" means to protect public health and safety)
  - Directly related to phenomena
  - Explicit
  - Easily comprehended
  - Measurable

Example of Figures of Merit Characteristics

Level	Source	Criteria	Directly Related to Issue	Directly Related to Phenomena	Easily Compre-hended	Explicit	Measur-able
1	10 CFR 1.11	Protect public health and safety	Primary Regulatory Issue				
2	10 CFR 100	Limit fission product release	•	•			
3	10 CFR 50 Appendix A	Limit fuel failure and containment breach	•	•			
4	SRP 6.2 Containments	Limit containment pressure, temperature, etc.	•	•	•		
	SRP 15.1.4 to 15.6.1, Non-LOCA	Fuel limits, energy deposition, fuel temperature, etc.	•	•	•	•	•
	10 CFR 50.46 and SRP 15.6.5, LOCA	Peak cladding temperature, hydrogen generation, etc.	•	•	•	•	•
5	AP600: NUREG/CR-6541, INEL-94/0061 Rev. 2	Vessel inventory	•	•	•	•	•
	SBWR: NUREG/CR-6472, BNL-NUREG-52501	Vessel inventory	•	•	•	•	•

(Based on Boyack, B. E. and Wilson, G. E., Int. Mtg. on Updates in Best Methods in Nucl. Installations Safety Analysis, 2004.)

FoM for LMR

- No previous PIRTs for LMRs, but an extensive worldwide LMR knowledge base exists to support PIRT generation.

- Considerations about FoM for 4S
  - Consider the regulatory requirements
    - Protect public health and safety (10 CFR 1.11)
    - Limit fission product release (10 CFR 100)
    - Limit fuel failure (10 CFR 50 Appendix A)
    - Acceptance criteria from 3rd NRC pre-application review meeting based on SRP 15.0 (NUREG-0800)
  - Focus on
    - Integrity of primary coolant boundary
    - Integrity of fuel pin cladding

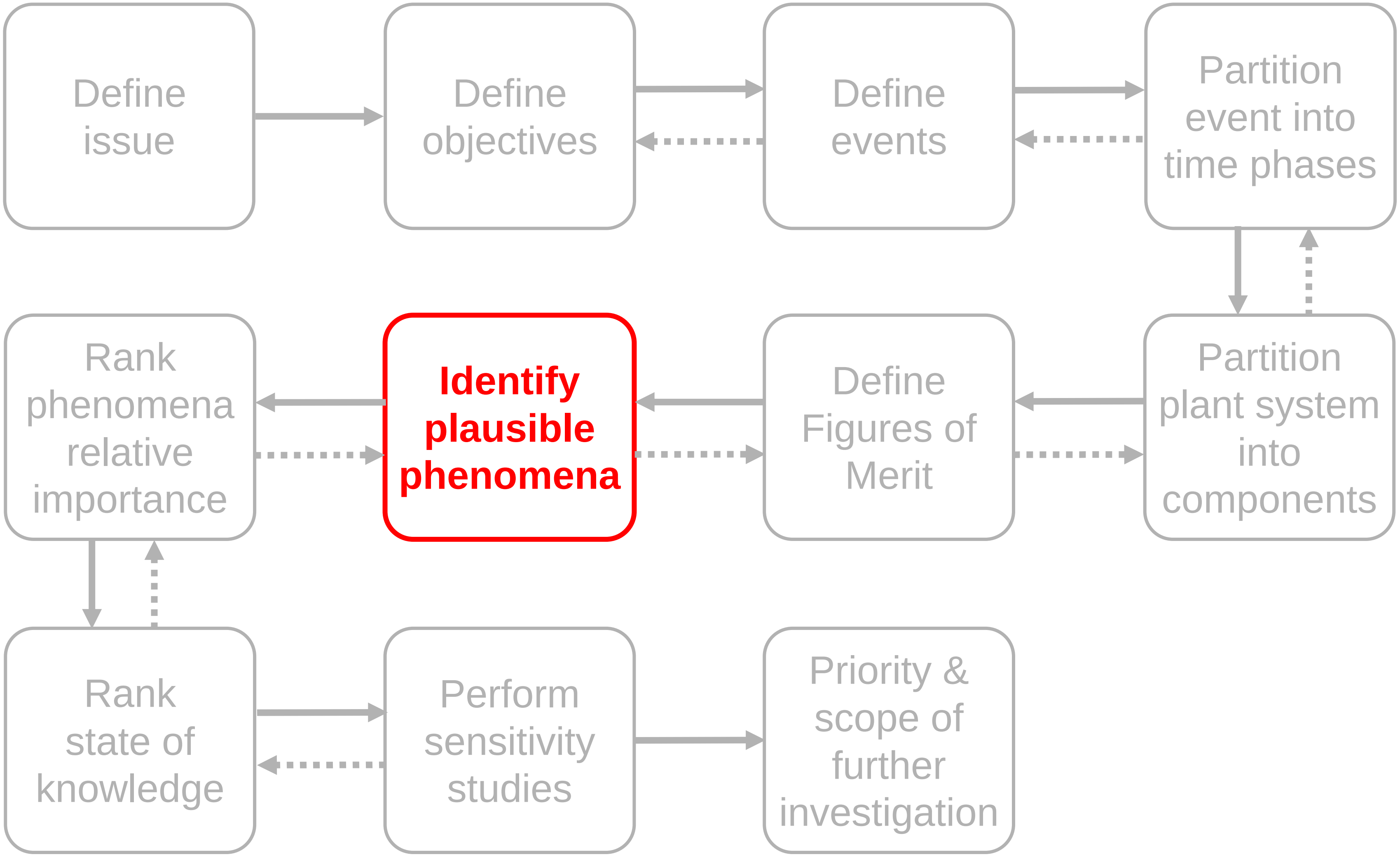
FoM for 4S

- Primary coolant boundary
  - In the long term, cladding temperature will be equal to or exceed the primary coolant boundary temperature.
  - Cladding material has a lower creep strength than the coolant boundary material.
  - Therefore, maintenance of cladding integrity will also ensure the integrity of the primary coolant boundary.

- Cladding temperature can therefore be a surrogate FoM for the integrity of the primary coolant boundary as well as for the integrity of the cladding.

- FoM for 4S: Cladding temperature

Identification of Plausible Phenomena



Rationale for Phenomena Selection

- Procedure for phenomena selection
  - Identify plausible phenomena using all currently available information, including expert opinion
  - In the context of the PIRT process, plausible phenomena are those that may have some influence on the FoM.

Plausible Phenomena of Core/Fuel Assembly

- Core/Fuel Assembly (26 phenomena)
    1. Pressure loss in core region
    2. Pressure loss in reflector region
    3. Natural circulation
    4. Pressure loss in upper shield region
    5. Reactivity feedback: fuel, coolant, structures, radial core expansion, core support expansion, Doppler and axial fuel expansion
    6. Heat transfer between fuel and cladding
    7. Heat transfer between cladding and coolant
    8. Flow distribution of the intra- and inter-assembly
    9. Radial heat transfer between subassemblies (S/A ←→ sodium ←→ S/A)
    10. Heat transfer between cooling path of reflector and reflector
    11. Stored energy of core assemblies including upper shield
    12. Coolant boiling
    13. Core power transient
    14. Decay heat
    15. Heat transfer between core support structure and sodium at lower plenum
    16. Reactivity insertion rate and delay of scram reactivity insertion
    17. Eutectic reaction between fuel and cladding
    18. Temperature dependency of physical properties of materials
    19. Reactivity insertion by cavity failure
    20. FP release in fuel slug and into gas plenum
    21. FP transport from fuel to sodium, and in-sodium
    22. FP transport from sodium to cover gas
    23. Flow-induced vibration in a subassembly
    24. Inter-wrapper flow between wrapper tubes
    25. Generated heat outside core by neutron capture and secondary gamma ray
    26. Maldistribution of the core flow: redistribution of the mass flow in all the core subassemblies

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Plausible Phenomena of Reactor System (1/2)

- Reactor System (22 phenomena)
  - Reactor Vessel
    1. Thermal load of reactor vessel
    2. Bypass flow around IHX primary side
  - Reactor Internal Structures
    - General
      1. Coolant mixing in upper plenum including thermal stratification
      2. Temperature dependency of physical properties of structural materials
      3. Natural circulation
      4. Flow-induced vibration
    - Reflector
      1. Deformation due to thermal effect and irradiation
      2. Local flow behavior in reflector region
    - Lower Plenum
      1. Pressure loss
      2. Heat capacity (coolant and structures)
      3. Mixing behavior of coolant including thermal stratification
      4. Heat loss from reactor vessel

Plausible Phenomena of Reactor System (2/2)

- Reactor System (22 phenomena) (cont.)
  - Reactor Internal Structures
    - Upper Plenum
      1. Pressure loss
      2. Heat capacity (coolant and structure)
      3. Heat transfer between cover gas and sodium
      4. Heat transfer between vertical shroud and sodium
      5. Coolant mixing behavior at core outlet
    - Vertical Shroud
      1. Radial heat transfer between upper plenum to outside region
    - Radial Shield
      1. Local flow behavior in radial shield region
      2. Heat capacity (coolant and structures)
      3. Generated heat effect by neutron capture and secondary gamma rays
      4. Radial heat transfer between core and radial shield

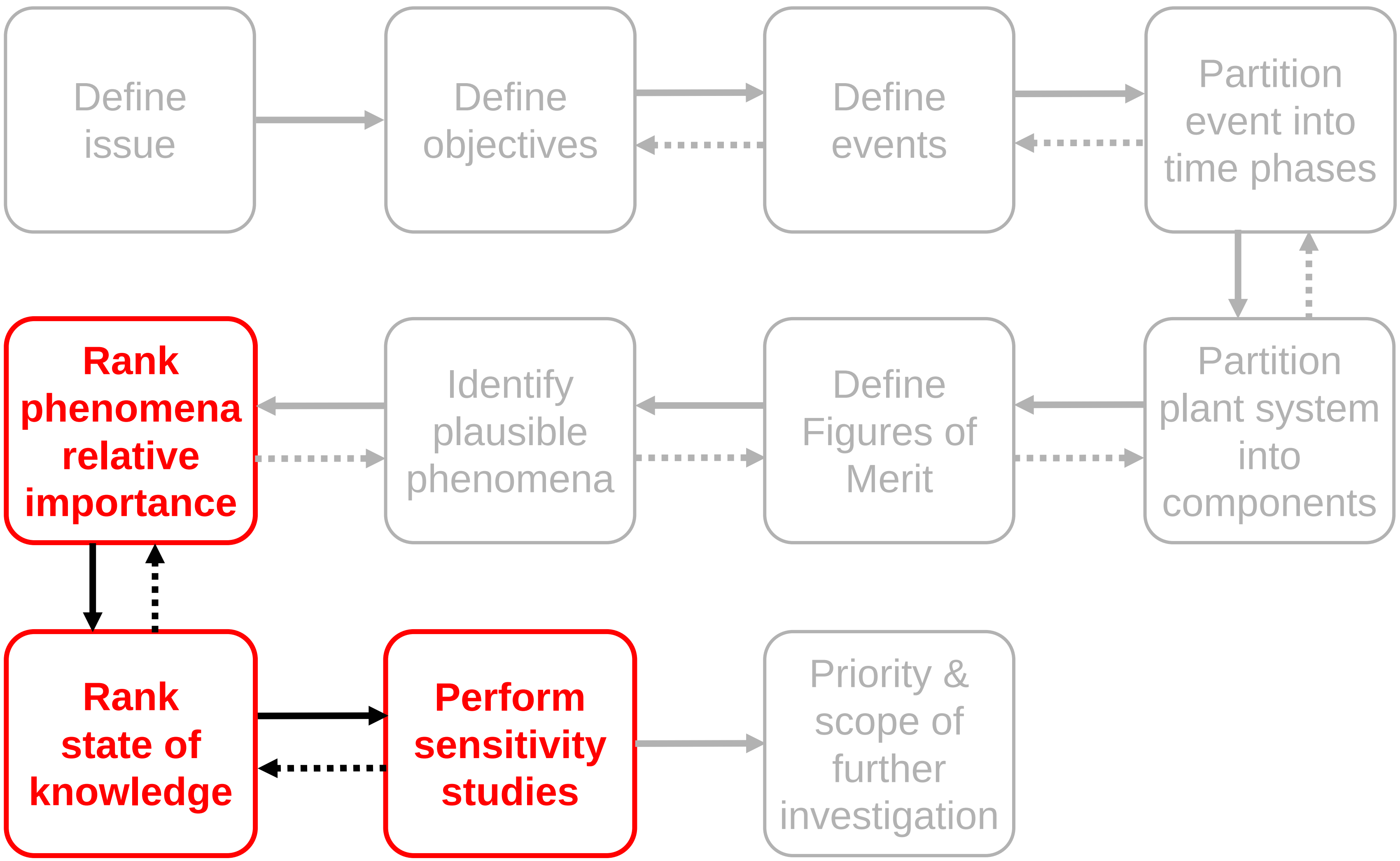
Plausible Phenomena of PHTS and IHTS

- Primary Heat Transport System (13 phenomena)
  - General
    1. Natural circulation head and pressure loss
    2. Sodium inventory
    3. Heat capacity of coolant
  - IHX
    1. Pressure loss
    2. Heat transfer from primary to secondary
    3. Primary flow rate
    4. Intermediate flow rate
    5. Heat capacity of structure
    6. Spatial distribution effect of intermediate flow path in IHX annulus shape
  - Primary EM pump
    1. Flow coastdown performance
    2. Pressure loss
    3. Pump head
    4. Residual heat capacity and joule loss at flow coastdown
- Intermediate Heat Transport System (8 phenomena)
  - General
    1. Pressure loss
    2. Natural circulation head
    3. Heat removal from SG
    4. Heat transfer between upper plenum and intermediate coolant external to IHX
  - Intermediate EM pump
    1. Flow coastdown performance
    2. Pressure loss
    3. Pump head
  - Steam Generator System
    1. Heat capacity of structure, sodium, water and steam

Plausible Phenomena of RHRS/ Instrument and Control System

- Residual Heat Removal System (15 phenomena)
  - IRACS (Air Cooler)
    1. Pressure loss of sodium side
    2. Pressure loss of air side
    3. Heat transfer between tube and air
    4. Heat transfer between tube and sodium
    5. Inlet air temperature range
    6. Heat capacity of structure
  - RVACS
    1. Pressure loss in air flow path
    2. Heat transfer between GV wall and air
    3. Heat transfer between collector wall and air
    4. Heat transfer between concrete wall and air
    5. Thermal radiation between RV wall and GV wall
    6. Thermal radiation between GV wall and collector wall
    7. Thermal radiation between collector wall and concrete wall
    8. Asymmetric air flow
    9. Inlet air temperature range
- Instrument and Control System (7 phenomena)
  - Instrument and Control Equipment
    - Reactivity Control Drive Mechanism
      1. Shutdown speed of reflector
      2. Shutdown speed of shutdown rod
    - Plant Protection Sensor
      1. Delay of scram signal of primary EM pump voltage and current
      2. Delay of scram signal of low power line voltage
      3. Delay of scram signal of instrumentation of neutron flux
      4. Delay of scram signal of instrumentation of IHX primary outlet temperature
    - Other instrumentation
      1. Delay of scram signal of instrumentation of SG outlet temperature

Ranking and Sensitivity Study



Objectives of PIRT Ranking

- Ranking of results, from combination of “relative importance” and “state of knowledge” of phenomena, determines the priority and scope of continued theoretical evaluation and test program.

- Ranking process is the heart of the PIRT.

Ranking Scale of Phenomena Importance

- Ranking scale of phenomena importance
  - Level of influence on FoMs
    - High (H): High impact on FoM
    - Medium (M): Moderate impact on FoM
    - Low (L): Low impact on FoM
    - Insignificant (n/a): No or insignificant impact on FoM
  - Ranks are initially determined using all currently available information, including expert opinion, then refined using the results of sensitivity studies.

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Example of Importance Ranking of Phenomena

- Example of initial ranking of phenomena importance
  - Event: Loss of offsite power

Subsystem/ Component	Phenomena	1st Phase (Early)	2nd Phase (Late)
Core/Fuel Assembly	Pressure loss in core region	L	L
	Pressure loss in reflector region	L	L
	Natural circulation	L	M
	Pressure loss in upper shield region	L	L
	Reactivity feedback (fuel, coolant, structures, radial core expansion, core support expansion, Doppler, axial fuel expansion)	L	L
	Heat transfer between fuel and cladding	L	L
	Heat transfer between cladding and coolant	L	L
	Flow distribution of the intra- and inter-assembly	H	M
	Radial heat transfer between subassemblies (S/A ←→ Sodium ←→ S/A)	M	M

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Ranking Scale of State of Knowledge

- Ranking scale of state of knowledge
  - State of knowledge regarding each phenomenon
    - Known (K):
      Small uncertainty in test data and analytical modeling
    - Partially Known (P):
      Moderate uncertainty in test data and analytical modeling
    - Unknown (U):
      Very limited or no knowledge, large uncertainty in test data and analytical modeling

  - Ranks are determined using all currently available information, including expert opinion.

Example of State of Knowledge of Phenomena

- Example of state of knowledge of phenomena
  - Event: Loss of offsite power

Subsystem/Component	Phenomena	SoK
Core/Fuel Assembly	Pressure loss in core region	P
	Pressure loss in reflector region	P
	Natural circulation	P
	Pressure loss in upper shield region	P
	Reactivity feedback (fuel, coolant, structures, radial core expansion, core support expansion, Doppler, axial fuel expansion)	P
	Heat transfer between fuel and cladding	P
	Heat transfer between cladding and coolant	K
	Flow distribution of the intra- and inter-assembly	P
	Radial heat transfer between subassemblies (S/A ←→ Sodium ←→ S/A)	P

⋮

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Example of State of Knowledge Rationale

- Example of rationale

  Ranking result: Partially known

  - There is extensive experimental knowledge regarding natural circulation. However, experimental knowledge is limited to a simpler geometry. Therefore, actual plant systems with more complicated geometry are difficult to fully understand.

Event	Loss of offsite power		
Component	B:Reactor System		
Sub-component	B3:Reactor Internal Structure / General		
Phenomenon	b09: Natural circulation		
Code	RK_b09	Rank	P
Rationale	There are some correlations made on the basis of simple and ideal geometry. However, natural circulation is significantly dependent on the geometrical shape and scale. Accordingly, the characteristics of natural circulation must be analyzed by theoretical investigation using CFD code etc. or testing.		
Reference	[1] Mohr, D. et al., "Natural-Convection Behavior of EBR-II: A Comparison of CONVECT Analysis with Test Results," Trans. Am. Nucl. Soc. (1975) [2] Singer, R.M. et al., "Steady State Natural Circulation Performance of the Experimental Breeder Reactor II Primary Heat Transfer Circuit," Nuclear Science and Engineering (1977) [3] Baumann, W.L. et al., "EBR-II In-Vessel Natural-Circulation Analysis," NUREG/CR-2821, ANL-82-66 (1982) [4] Foust, O.J., Sodium-NaK Engineering Book Vol. II.		

Prioritization of Sensitivity Studies

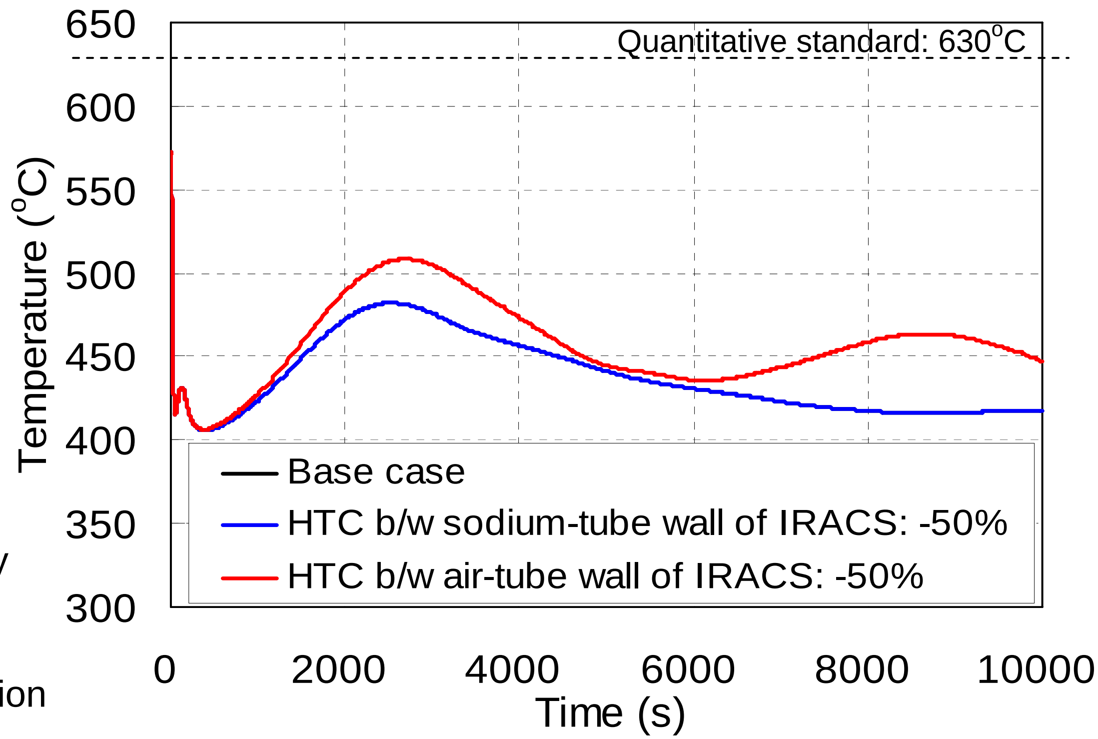
- Prioritize phenomena to perform sensitivity studies based on the initial ranking results
  - High importance: 1st priority
  - Medium importance: 2nd priority
  - Low importance: 3rd priority

Quantitative Standard for FoM

- Quantitative standard for FoM is different from safety acceptance criteria.
- Quantitative standard for FoM is the metric for sensitivity analysis.
- Quantitative standard for cladding temperature is determined to be 630^{o}C as a result of sensitivity studies.
  - Calculations assume contact between the fuel and cladding at the highest temperature region at the top of the fuel early in life.
  - Results using cladding temperatures up to 630^{o}C show no violation of the design criteria.

Example of Sensitivity Analysis

- Example of sensitivity analysis
  - Event: Loss of offsite power
  - Phenomena: Heat transfer between tube and air (IRACS)
    Heat transfer between tube and sodium (IRACS)
  - Parameters*: HTC** between air and tube wall
    HTC between sodium and tube wall



Cladding temperature

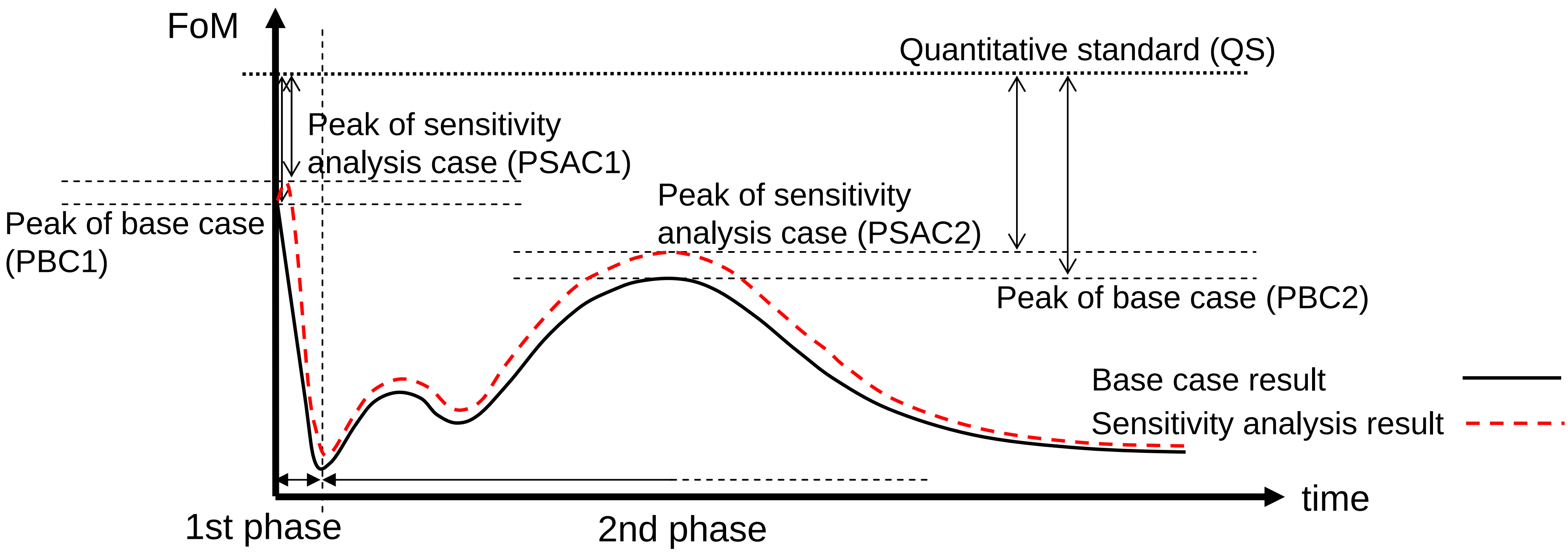
* Analysis parameter used in safety analysis code “ARGO***”

** Heat transfer coefficient

***Refer to 1st and 3rd Pre-Application Review Meetings with NRC

Evaluation Method to Determine Sensitivity of FoM to Phenomenon

- Compare margin to standard between base case and sensitivity analysis



- Sensitivity of FoM to phenomenon in each time phase

$$\text{Sensitivity} = 1 - \frac{\text{FoM}_{QS} - \text{FoM}_{PSACn}}{\text{FoM}_{QS} - \text{FoM}_{PBCn}}$$

where n indicates the number of time phases

- Sensitivity analysis guides expert re-evaluation of phenomena importance.

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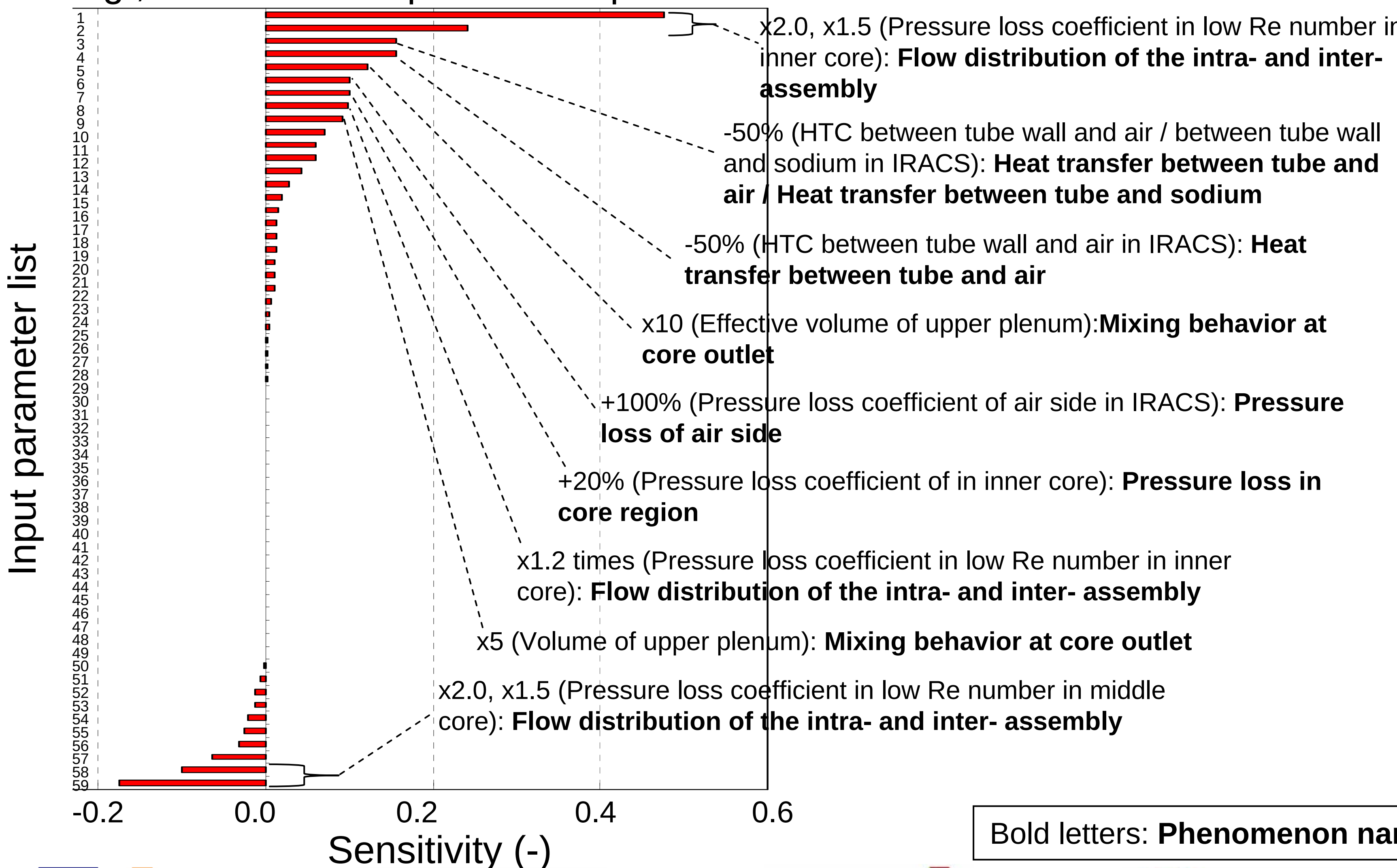
Summary of Result of Sensitivity Study

- e.g., Loss of offsite power: 2nd phase



Bold letters: **Phenomenon name**

Example of Phenomena Importance Rationale

- Example of rationale
  Ranking: High in both phases
  - In 2nd phase:
    - For extremely low Re number, the knowledge of the pressure loss of the core part has not obtained enough.
    - The uncertainty is relatively larger.
    - The result of sensitivity analysis shows that a factor of the flow distribution has a considerable effect on FoM.
    - The very tight pin spacing in the core part has a large influence not only on the ratio of flow distribution in the 1st phase but also on that in the 2nd phase, according to experts.

<table>
<tr><td>Event</td><td colspan="5">Loss of offsite power</td></tr>
<tr><td>Component</td><td colspan="5">A: Core/Fuel Assembly</td></tr>
<tr><td>Sub-component</td><td colspan="5">–</td></tr>
<tr><td>Phenomenon</td><td colspan="5">a08: Flow distribution of the intra- and inter-assembly</td></tr>
<tr><td>Code</td><td>RK_a08</td><td>Rank (1st)</td><td>H</td><td>Rank (2nd)</td><td>H</td></tr>
<tr><td>Rationale (1st phase)</td><td colspan="5">The core in the 4S reactor has very tight pin spacing. Hence, the change of the ratio of flow distribution in the core, which is caused by deformation of the geometry, may have a considerable effect on cladding temperature during flow coastdown of EM pump.
Therefore, this phenomenon is ranked as “H”.</td></tr>
<tr><td>Rationale (2nd phase)</td><td colspan="5">In the 2nd phase, for extremely low Re number, the knowledge of the pressure loss of the core part has not obtained enough. Hence, the uncertainty is considered to be relatively larger. Actually, setting the ratio of the flow distribution as parameter, the result of sensitivity analysis shows that it has a considerable effect on FOM. Therefore, this phenomenon is ranked as “H”.</td></tr>
<tr><td>Reference/ Note</td><td colspan="5"></td></tr>
</table>

Example of Ranking Result

- Example of post-sensitivity study ranking of phenomena
  - Event: Loss of offsite power

*Arrow indicates change from initial ranking

Subsystem/ Component	Phenomena	Importance: 1st Phase (Early)	Importance: 2nd Phase (Late)	SoK
Core/ Fuel Assembly	Pressure loss in core region	L→M	L→M	P
	Pressure loss in reflector region	L	L	P
	Natural circulation	L	M	P
	Pressure loss in upper shield region	L	L	P
	Reactivity feedback (fuel, coolant, structures, radial core expansion, core support expansion, Doppler, axial fuel expansion)	L	L→n/a	P
	Heat transfer between fuel and cladding	L	L	P
	Heat transfer between cladding and coolant	L	L	K
	Flow distribution of the intra- and inter-assembly	H	M→H	P
	Radial heat transfer between subassemblies (S/A ←→ Sodium ←→ S/A)	M	M→H	P

⋮

PIRT Results

- PIRT Ranking results

Importance \ SoK →	U	P	K
H	None currently identified	- Flow distribution of the intra- and inter- assembly - Maldistribution of the core flow: redistribution of the mass flow in all the core subassemblies - Natural circulation (in core/fuel assembly) - Natural circulation (in reactor internal structure) - Natural circulation head and pressure loss (in PHTS) - Radial heat transfer between subassemblies - Coolant mixing in upper plenum including thermal stratification - Thermal radiation between RV wall and GV wall - Thermal radiation between GV wall and collector wall - Thermal radiation between collector wall and concrete wall - Asymmetric air flow (in RVACS)	8 phenomena
M	None currently identified	- Pressure loss in core region - Reactivity insertion rate and delay of scram reactivity insertion - Eutectic reaction between fuel and cladding - Pressure loss of air flow path (in RVACS) - Reactivity insertion by cavity failure	6 phenomena
L	None currently identified	36 phenomena	16 phenomena

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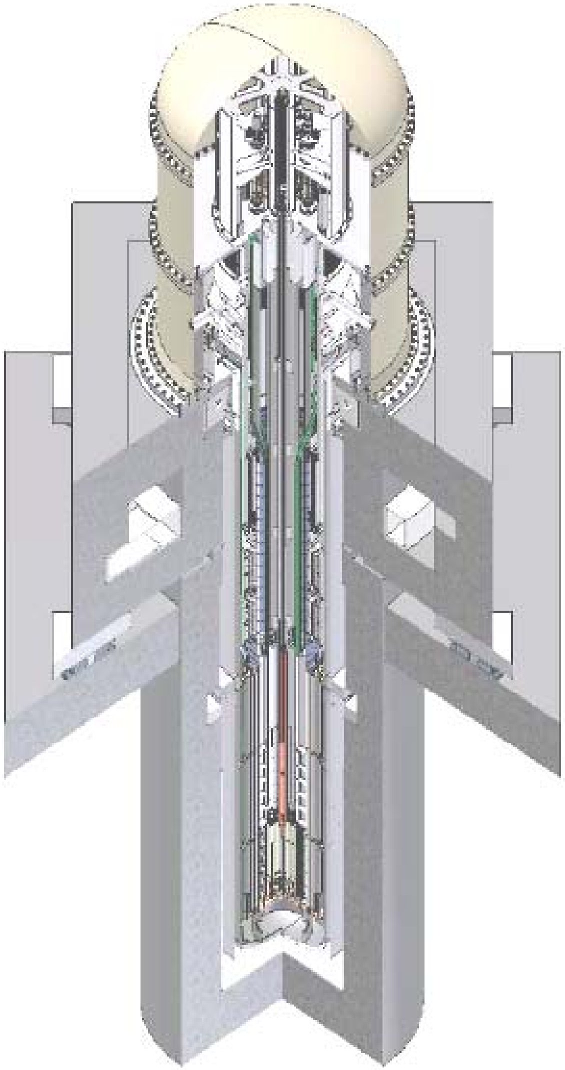
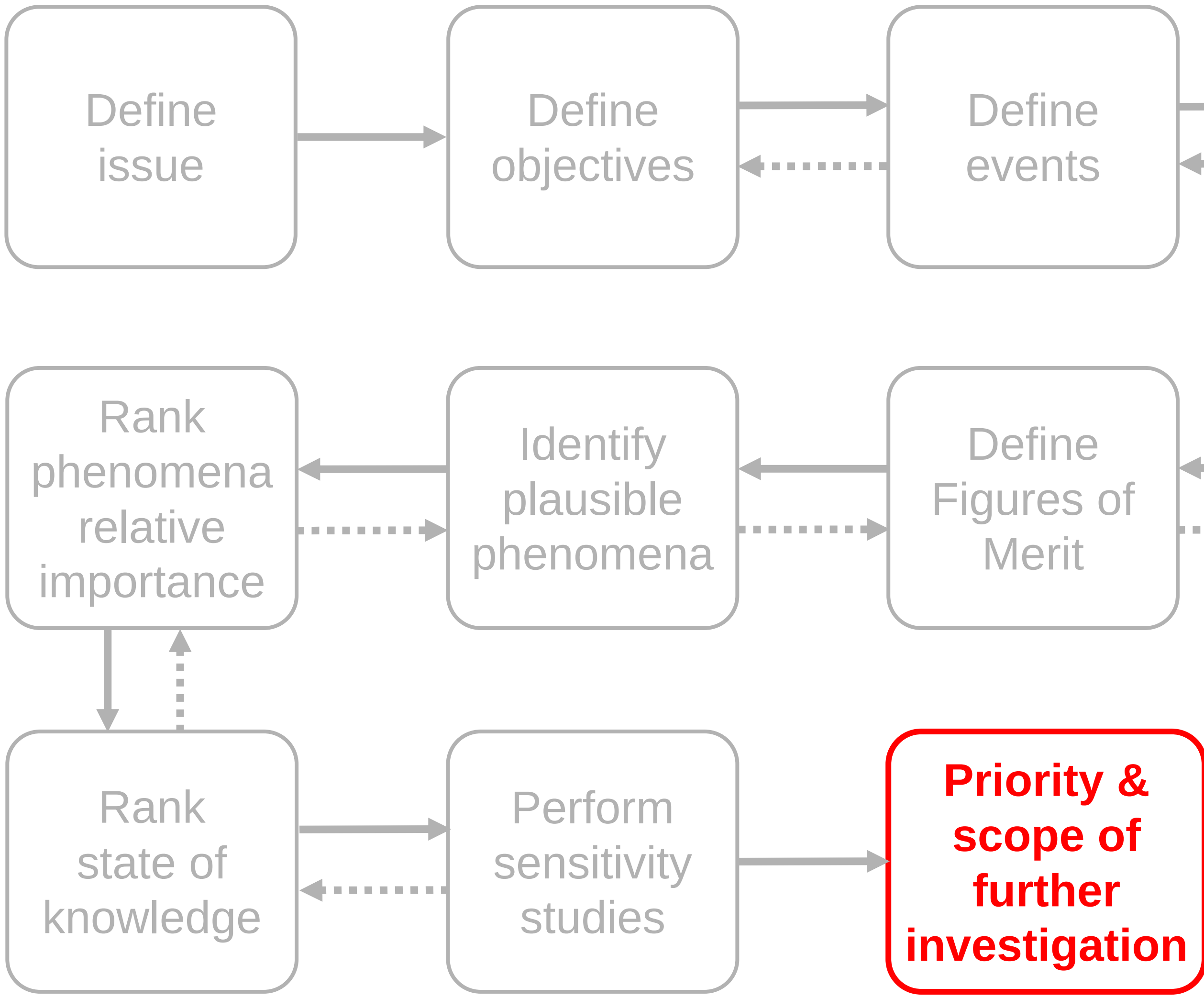
Development of Priority and Scope for Further Investigation

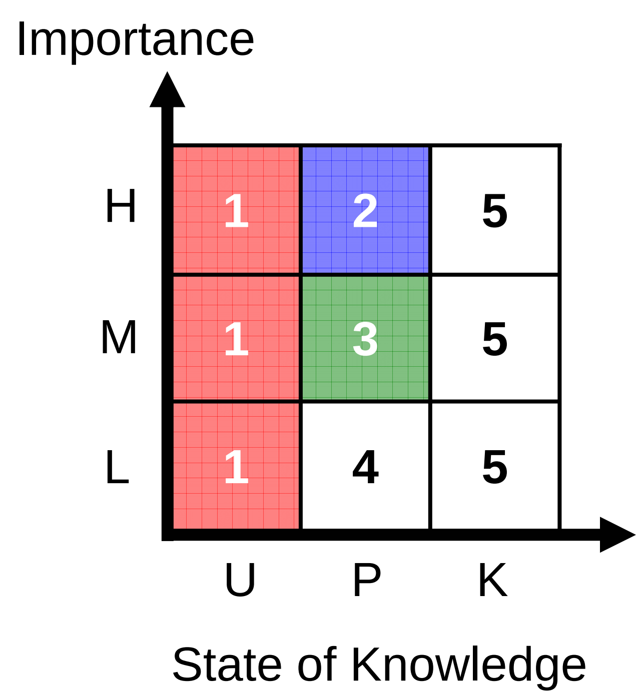


Priority and Scope of Test Programs



Priority for Further Investigation

- Priority 1: Unknown
- Priority 2: High importance and partially known
- Priority 3: Medium importance and partially known
- Priority 4: Low importance and partially known
- Priority 5: Known



Guideline for Further Investigation

	Theoretical evaluation	Test
Priority 1 (None currently identified)	Test planning ➡	✓
Priority 2 and **Priority 3**	✓ ➡	Depends on results of theoretical evaluation
Priority 4 and Priority 5	None	None

List of Further Investigation

	Theoretical Evaluation	Test
Priority 1	None currently identified	
Priority 2 and Priority 3	– Flow distribution of the intra- and inter- assembly – Maldistribution of the core flow: redistribution of the mass flow in all the core subassemblies – Natural circulation (in core/fuel assembly) – Natural circulation (in reactor internal structure) – Natural circulation head and pressure loss (in PHTS) – Radial heat transfer between subassemblies – Coolant mixing in upper plenum including thermal stratification – Thermal radiation between RV wall and GV wall – Thermal radiation between GV wall and collector wall – Thermal radiation between collector wall and concrete wall – Asymmetric air flow (in RVACS) – Pressure loss in core region – Reactivity insertion rate and delay of scram reactivity insertion – Eutectic reaction between fuel and cladding – Pressure loss of air flow path (in RVACS) – Reactivity insertion by cavity failure	Depends on results of theoretical evaluation
Priority 4 and Priority 5	65 phenomena currently are identified. However, further investigation is not planned.	

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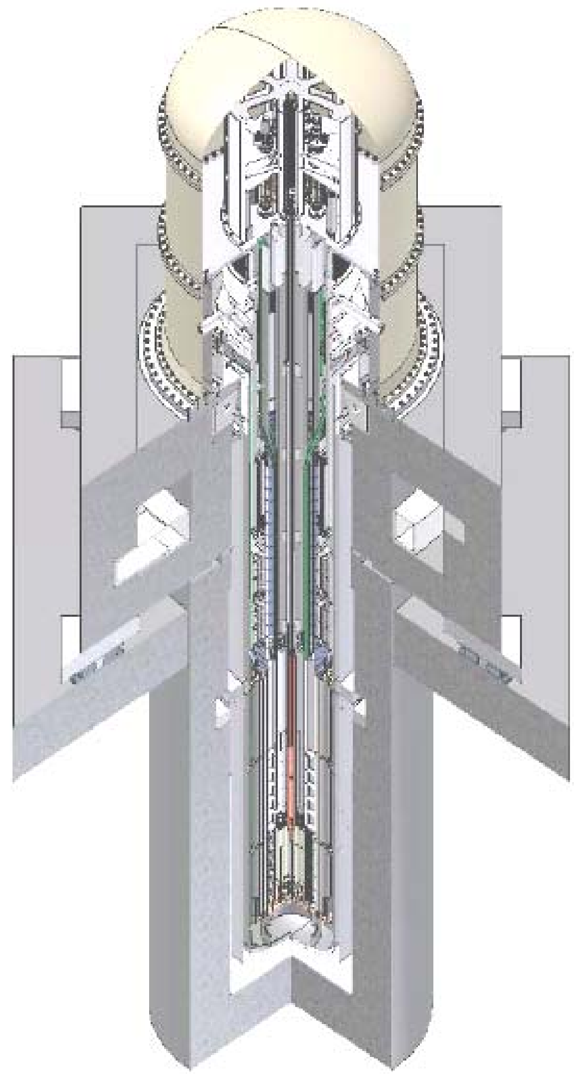
Summary

- PIRT process has been applied to 4S
  – Use of independent, expert review and advisory panels to help ensure quality
  – Use of classic 11-step PIRT process
  – Selection of 3 events that capture event spectrum
  – Plant partitioned into 6 subsystems that capture the necessary reactor response
  – Sensitivity studies performed to refine phenomena importance and state of knowledge

- Final PIRT results provide guidance for the priority and the scope of further investigation, that is:
  - Priority 1: No phenomena
  - Priority 2: 11 phenomena
  - Priority 3: 5 phenomena

Design Conformance to Draft Policy Statement on Regulation of Advanced Nuclear Power Plants



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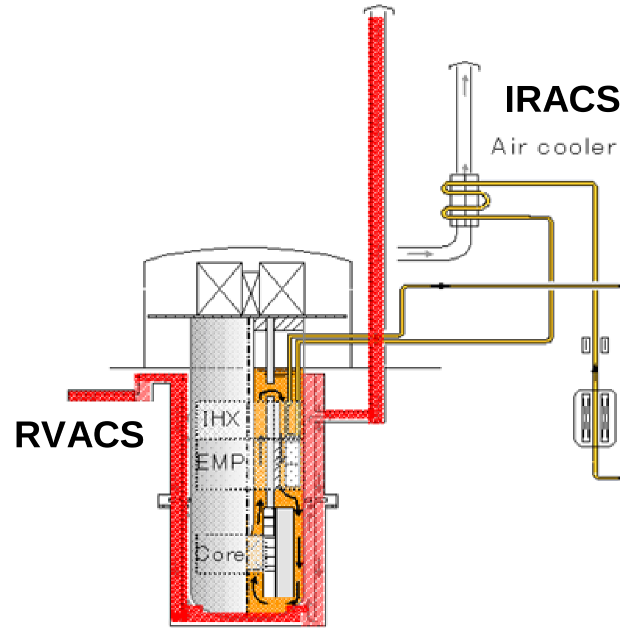
Design Conformance to Attribute 1

[Attribute 1]

- *Highly reliable and less complex shutdown and decay heat removal systems.*
- *The use of inherent or passive means to accomplish this objective is encouraged (negative temperature coefficient, natural circulation, etc.).*

[Design]

- Redundant and diverse residual heat removal using natural circulation



- Reactivity temperature coefficients are negative; minimize need for fast shutdown
- Redundant and diverse shutdown systems

Design Conformance to Attribute 2

[Attribute 2]

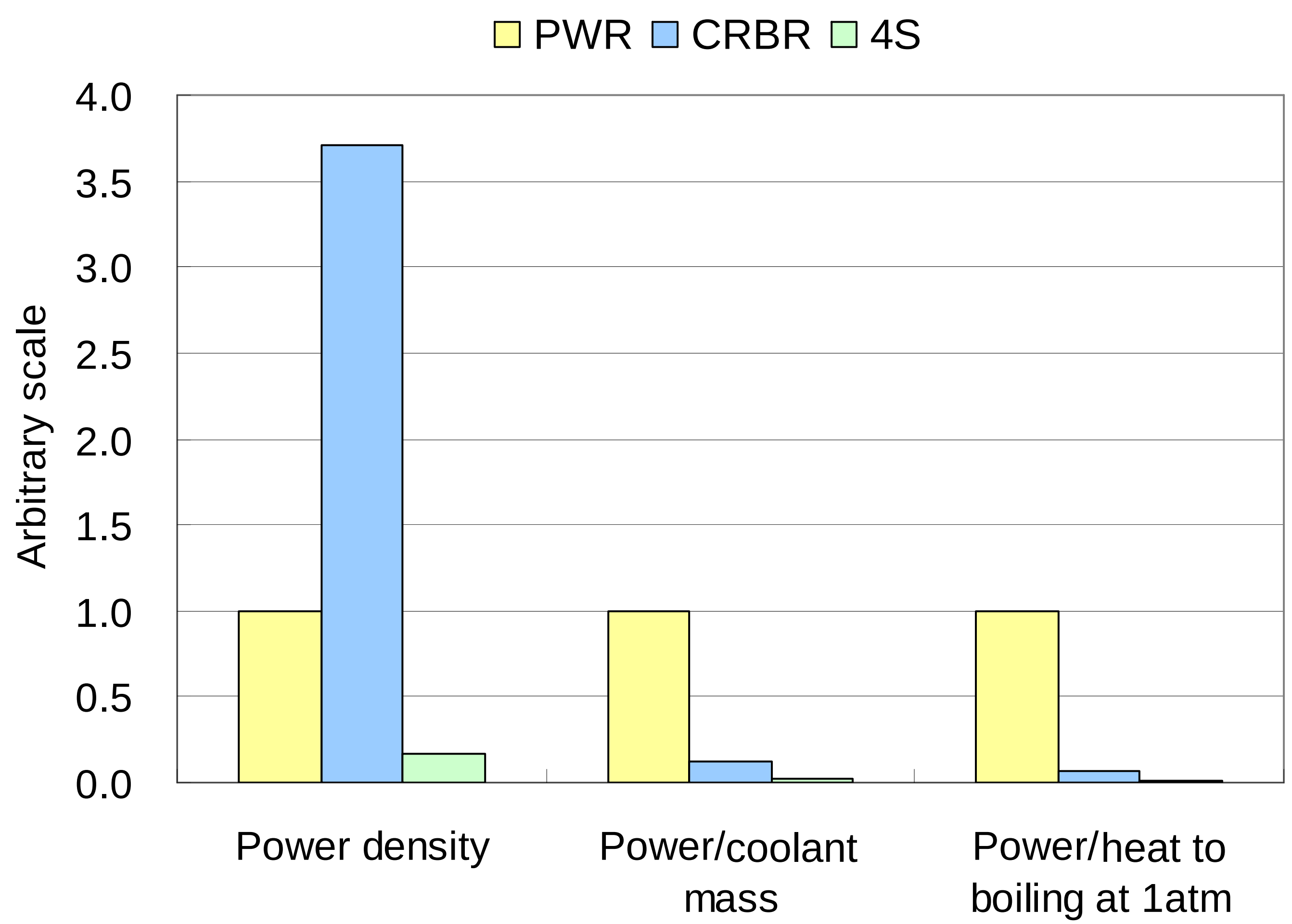
- *Longer time constants and sufficient instrumentation to allow for more diagnosis and management before reaching safety systems challenge and/or exposure of vital equipment to adverse conditions.*

[Design]

- 4S has a large thermal inertia due to small power density and large coolant mass leading to long time constants.
- 4S has extensive instrumentation and is operated conservatively relative to any limits.
- Monitoring and mitigation of sodium/ steam generator leakage precludes sodium fires or sodium/water reaction.

Comparison of Design Features

- Comparison of design features for PWR, CRBR and 4S



Design Conformance to Attribute 3

[Attribute 3]

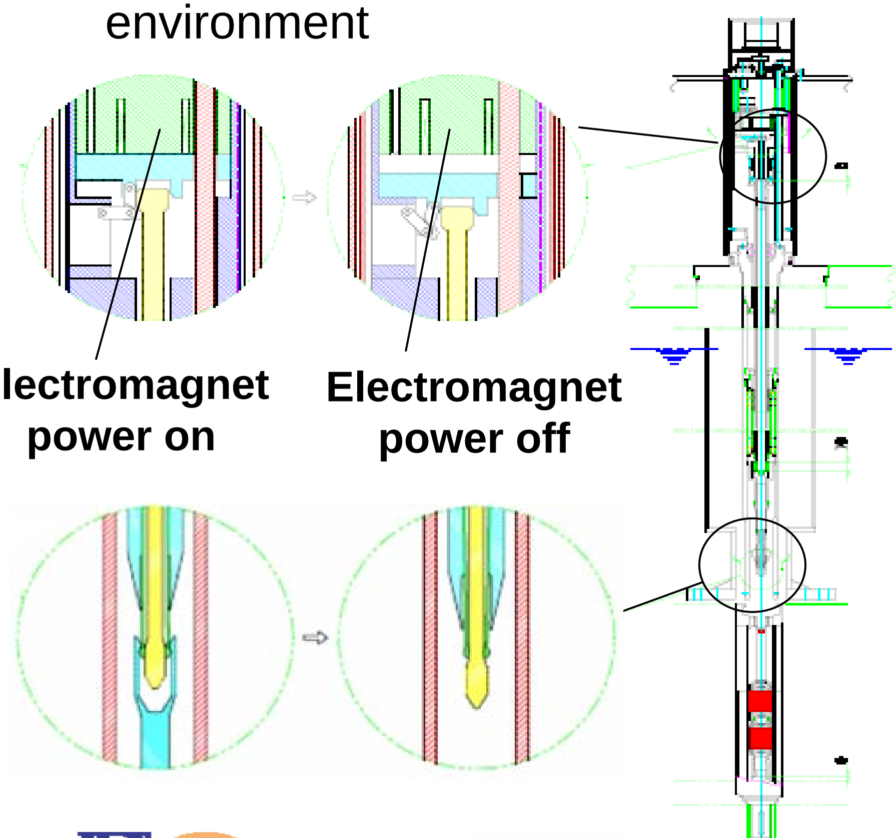
- *Simplified safety systems that, where possible, reduce required operator actions, equipment subjected to severe environmental conditions, and components needed for maintaining safe shutdown conditions.*
- *Such simplified systems should facilitate operator comprehension, reliable system function, and more straightforward engineering analysis.*

[Design]

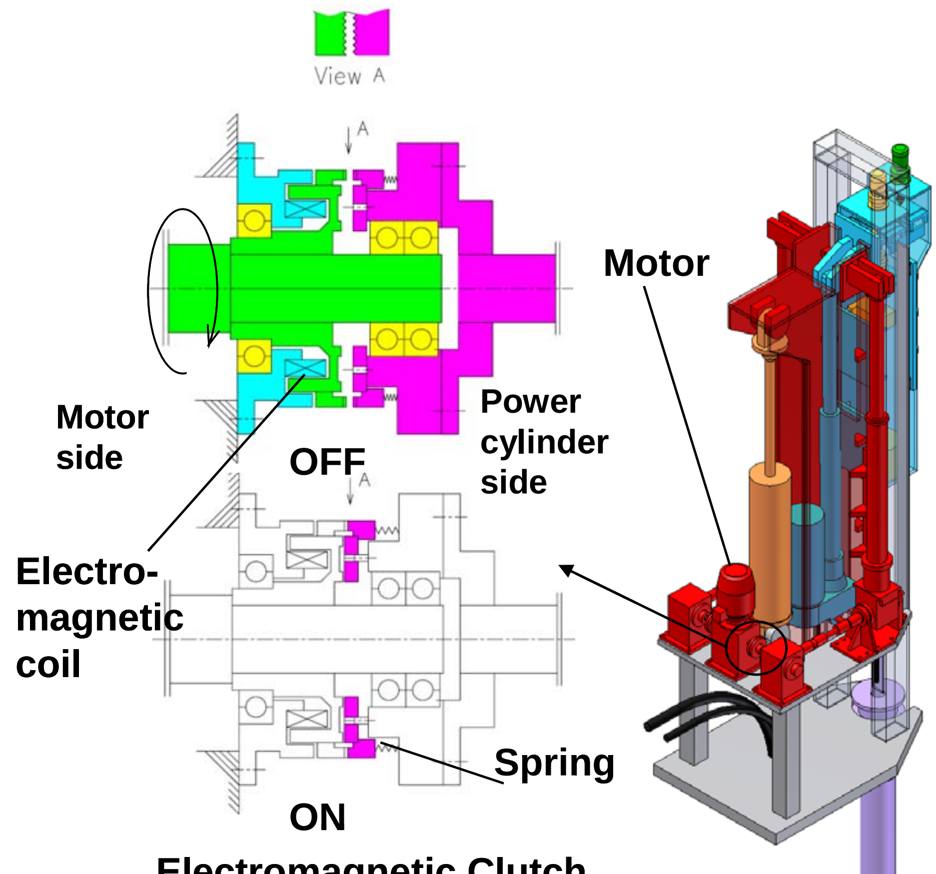
- Safety systems are simple and do not require operator action
  - Fail-safe reactor shutdown
    - Shutdown rod drive system
    - Reflector drive system
  - Fail-safe residual heat removal systems (RHRS)
    - IRACS with fail-safe damper
    - RVACS with no active components
- Severe environmental conditions are inherently less likely due to 4S design (e.g., minimal essential equipment in containment, sealed reactor vessel, guard vessel).
- Human factors considerations have been incorporated to facilitate operator comprehension.

Fail-Safe Reactor Shutdown Systems

- Fail-safe shutdown rod drive system
  - Loss of power to electromagnet results in release and gravity insertion to negative reactivity position.
  - Sealed against effects of adverse environment



- Fail-safe reflector drive system
  - Loss of power to clutch results in release and gravity drop to negative reactivity position.



Electromagnetic Clutch

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Design Conformance to Attribute 4

[Attribute 4]

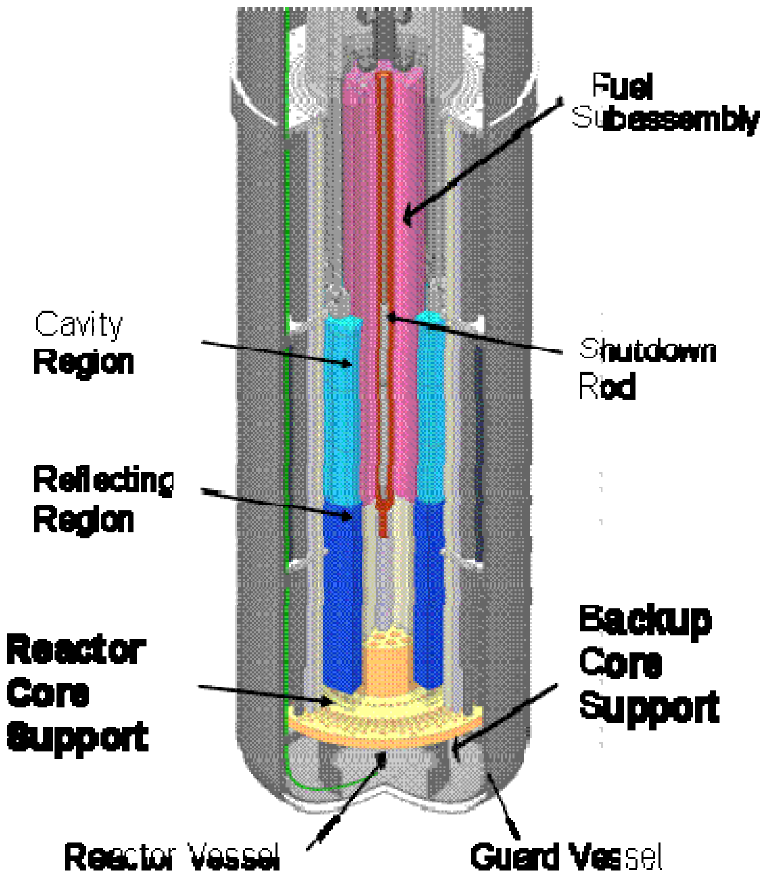
- *Designs that minimize the potential for severe accidents and their consequences by providing sufficient inherent safety, reliability, redundancy, diversity, and independence in safety systems.*

[Design]

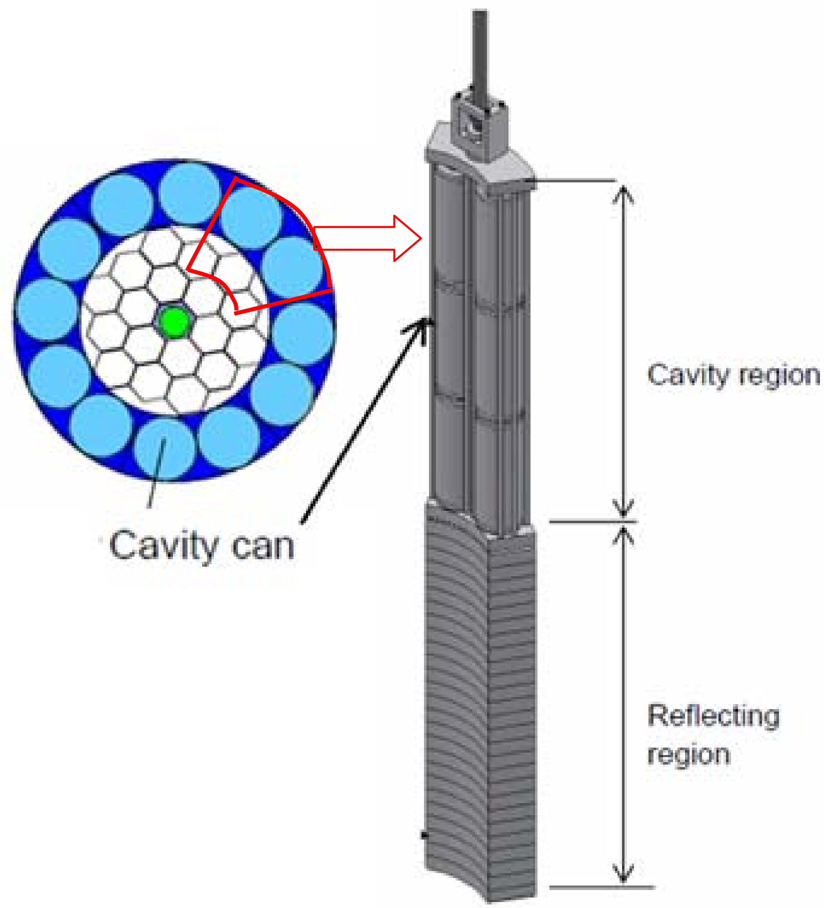
- Risk reduction by passive safety
  - Metallic fuel
  - Negative reactivity temperature coefficients
  - Natural circulation
  - Sodium affinity for fission products
- Risk reduction by innovative design
  - No refueling core
  - EM pump
  - Redundant flow path of inlet assembly module
  - Backup redundant and diverse systems for residual heat removal system
  - Double-walled steam generator tubes with leak detection
  - Minimal containment penetrations
  - Backup core support structure
  - Multiple redundant cavity cans
- 4S can safely accommodate ATWS and significant blockage of RVACS.

Measures against Severe Accidents

- Backup core support structure



- Multiple redundant cavity cans



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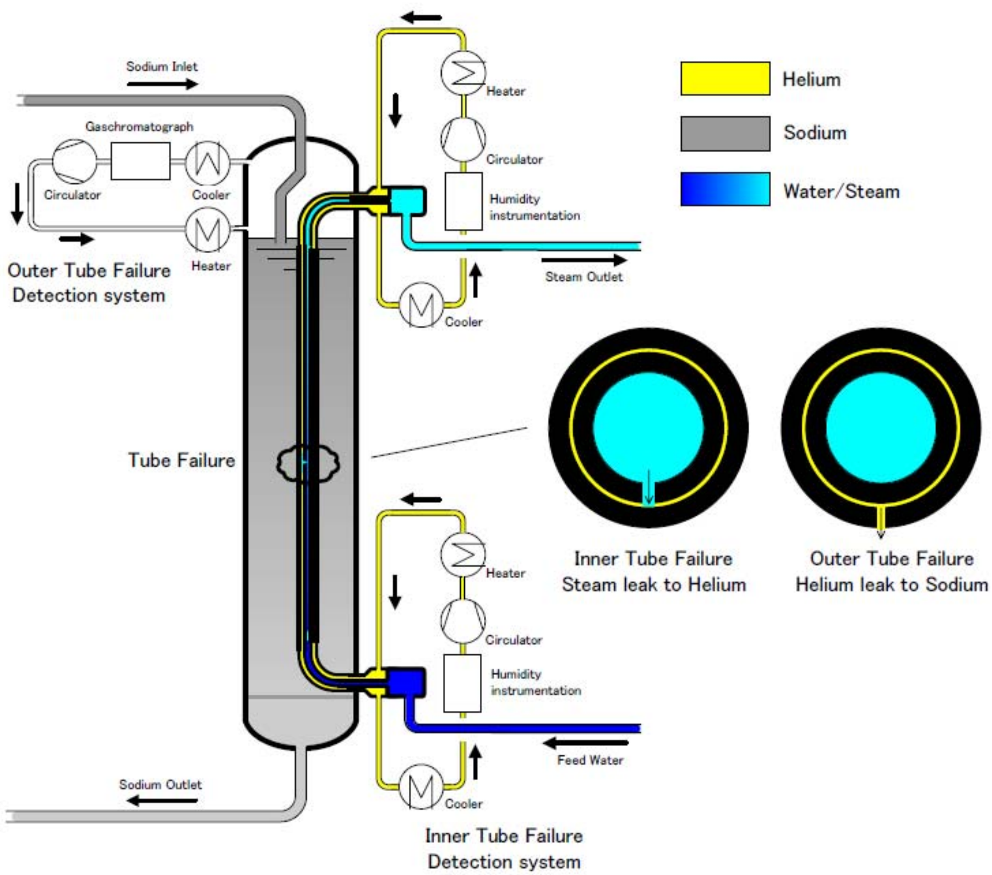
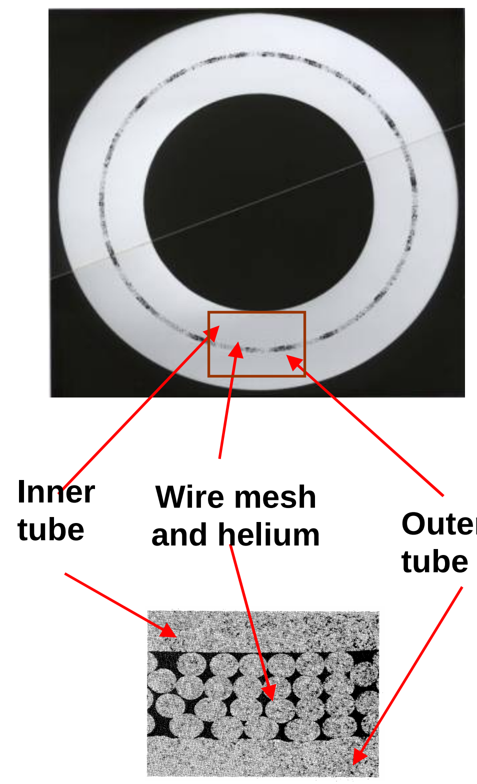
Measures against Severe Accidents (cont.)

- Detection for double-walled SG tube leak





Enlarged view of DWSG tube

Note: This R&D has been performed as a part of joint R&D projects under sponsorship of the nine Japanese electric power companies, Electric Power Development Co., Ltd. and the Japan Atomic Power Company (JAPC).

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Design Conformance to Attribute 5

[Attribute 5]

- *Designs that provide reliable equipment in the balance of plant (BOP) (or safety system independence from BOP) to reduce the number of challenges to safety systems.*

[Design]

- Adopt safety system independence from BOP
  - RHRSs do not rely on BOP
    - IRACS and RVACS
  - Use of immersion-type EM pump for primary cooling system; no BOP cooling
  - Use of heat-resistant type EM pump for intermediate cooling system; no BOP cooling
  - HVAC system does not rely on cooling water; uses atmospheric heat sink

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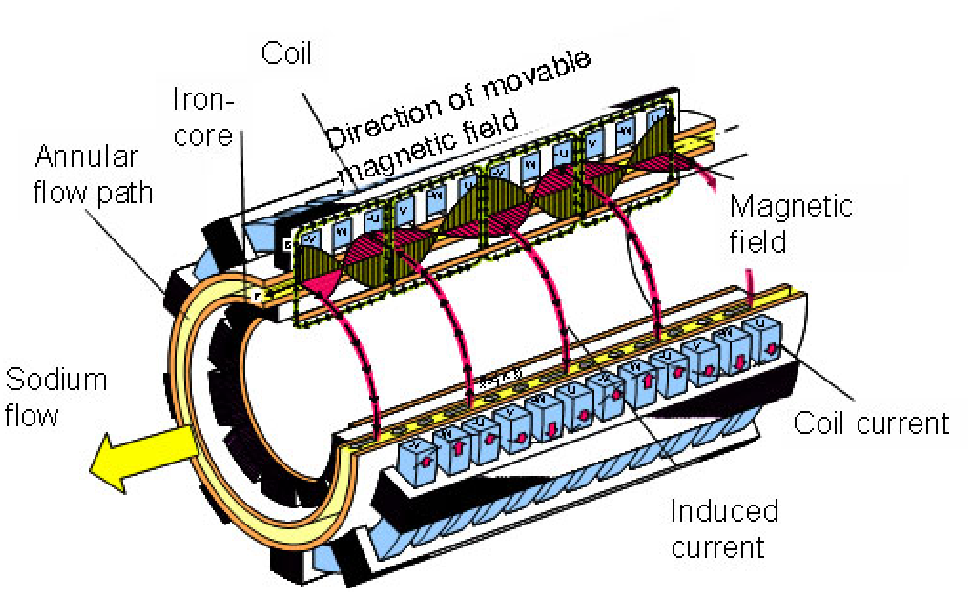
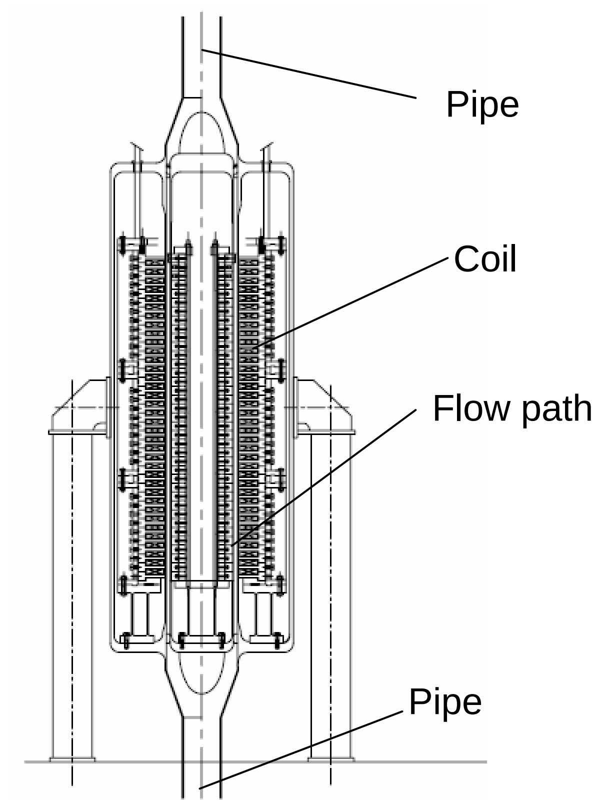
EM pump Cooling

- Immersion-type EM pump for primary cooling system
- Heat-resistant EM pump used in intermediate cooling system





Design Conformance to Attribute 6

[Attribute 6]

- *Designs that provide easily maintainable equipment and components.*

[Design]

- No refueling
- Minimal active components in reactor system
  - EM pump
  - No rotating plug
- Minimal electrical and electronic components
- Low (or no) maintenance primary components
  - Integrated EM pump and IHX can be removed for maintenance if necessary
  - No moving parts, non-corrosive environment

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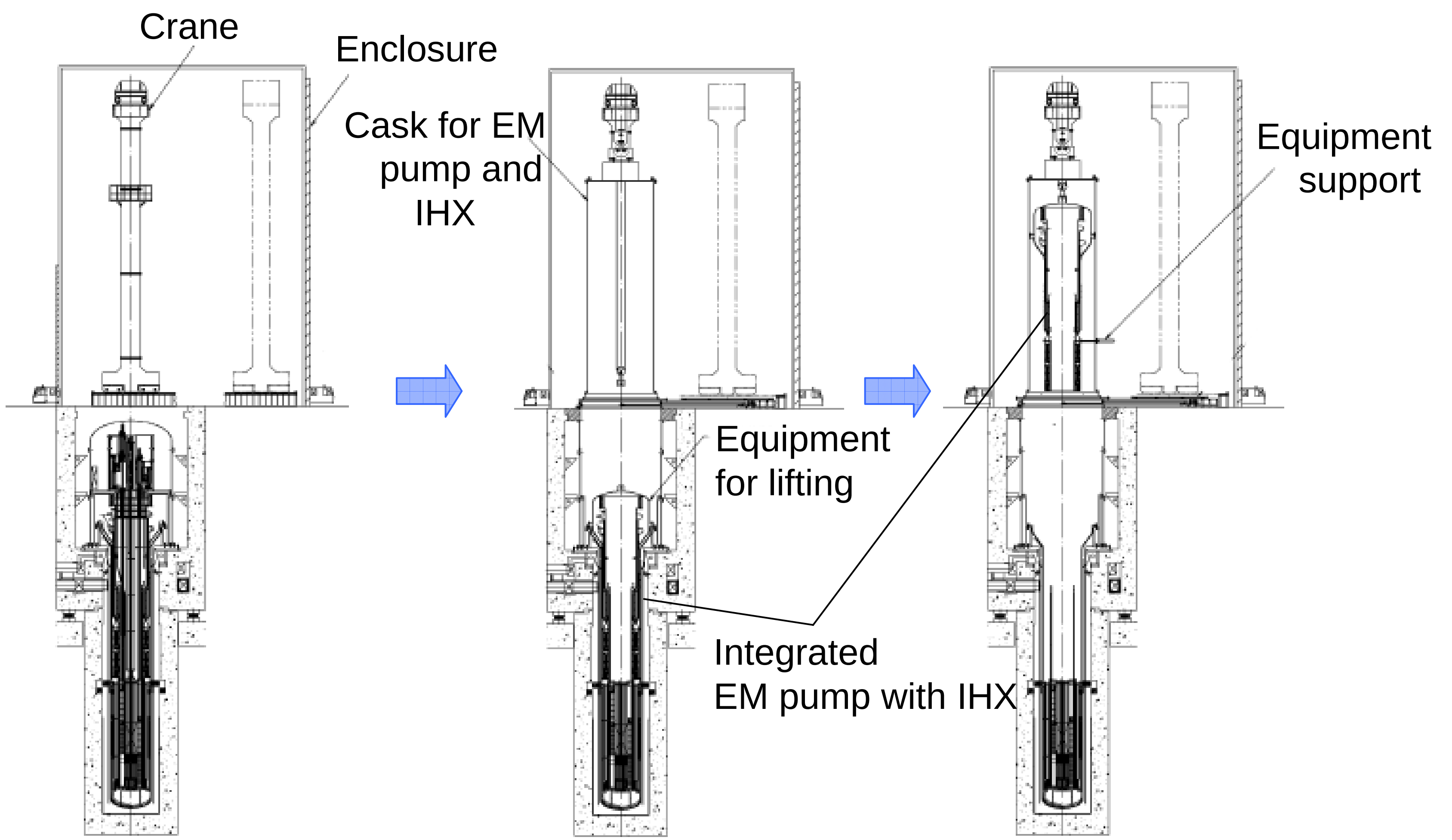
Maintainable Primary Components

- Procedure for removal/replacement of integrated EM pump and IHX



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Design Conformance to Attribute 7

[Attribute 7]

- *Designs that reduce potential radiation exposures to plant personnel.*

[Design]

- Minimize possibility of exposure during maintenance, inspection and repair
  - No refueling
  - Sealed reactor vessel
  - Small radioactivity inventory
  - Minimally activated intermediate loop sodium
  - No routine maintenance required in reactor silo
  - Remote in-service inspection
  - Area radiation monitoring

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Design Conformance to Attribute 8

[Attribute 8]

- *Designs that incorporate the defense-in-depth philosophy by maintaining multiple barriers against radiation release, and by reducing the potential for, and consequences of, severe accidents.*

[Design]

- Physical barriers
  - Fuel cladding
  - Primary coolant boundary
  - Containment boundary
- Functional barriers
  - Prevention
  - Protection
  - Mitigation
- Samples of specific design features were identified with Attribute 4.

Design Conformance to Attribute 9

[Attribute 9]

- *Design features that can be proven by citation of existing technology, or that can be satisfactorily established by commitment to a suitable technology development program.*

[Design]

- Citation of existing technology
  - Previously performed tests
  - Worldwide LMR technology base
- Commitment to fill important knowledge gaps by a suitable technology development program based on the 4S PIRT

Tests to Support 4S Design

Design Feature	Verification Item	Required Testing	Status
Long cylindrical core with small diameter	Nuclear design method of reflector control core with metallic fuel	Critical experiment	**Done**
Reflector controlled core			
High volume fraction metallic fuel core	Confirmation of pressure drop in fuel subassembly	Fuel hydraulic test	**Done**
Reflector	Reflector drive mechanism with fine movement	Test of reflector drive mechanism	**Done**
RVACS	Heat transfer characteristics between vessel and air	Heat transfer test of RVACS	**Done**
EM pump	Structural integrity Stable characteristics	Sodium test of EM pump	**Done and Planned**
Steam generator (Double-wall tubes)	Structural integrity Heat transfer characteristics Leak detection	Sodium test of steam generator Leak detection test	**Done and Planned**
Seismic isolation	Applicability to nuclear plant	Test of seismic isolator	**Done**
Important phenomena	Dependent on results of theoretical evaluation		**Pending**

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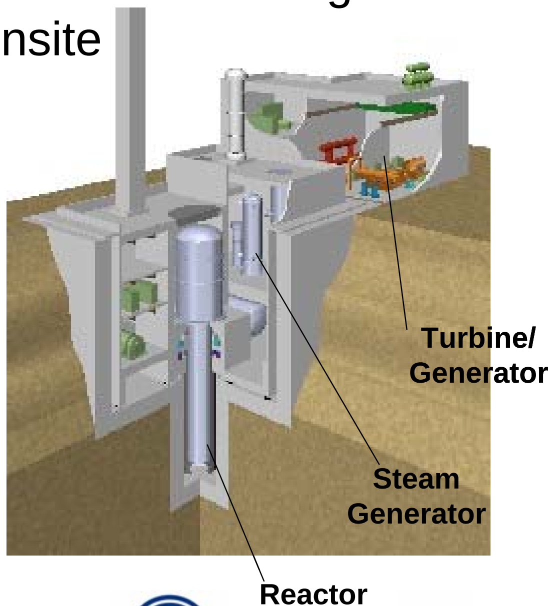
Design Conformance to Attribute 10

[Attribute 10]

- *Designs that include considerations for safety and security requirements together in the design process such that security issues (e.g., newly identified threats of terrorist attacks) can be effectively resolved through facility design and engineered security features, and formulation of mitigation measures, with reduced reliance on human actions.*

[Design]

- Threats of terrorist attacks
  - Below-grade siting
  - Remote control room
  - Passive safety systems
  - Security systems
- Theft of nuclear fuel
  - Sealed reactor vessel
  - No other fuel or fuel handling equipment onsite



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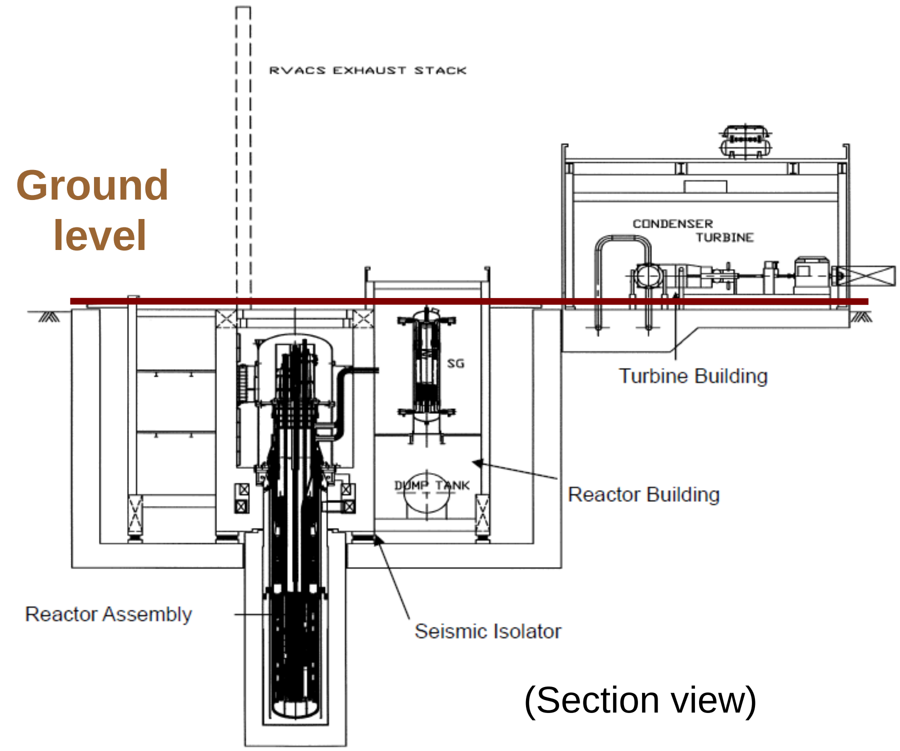
Design Conformance to Attribute 11

[Attribute 11]

- *Designs with features to prevent a simultaneous loss of containment integrity (including situations where the containment is bypassed), and the ability to maintain core cooling as a result of an aircraft impact, or identification of system designs that would provide inherent delay in radiological releases (if prevention of release is not possible).*

[Design]

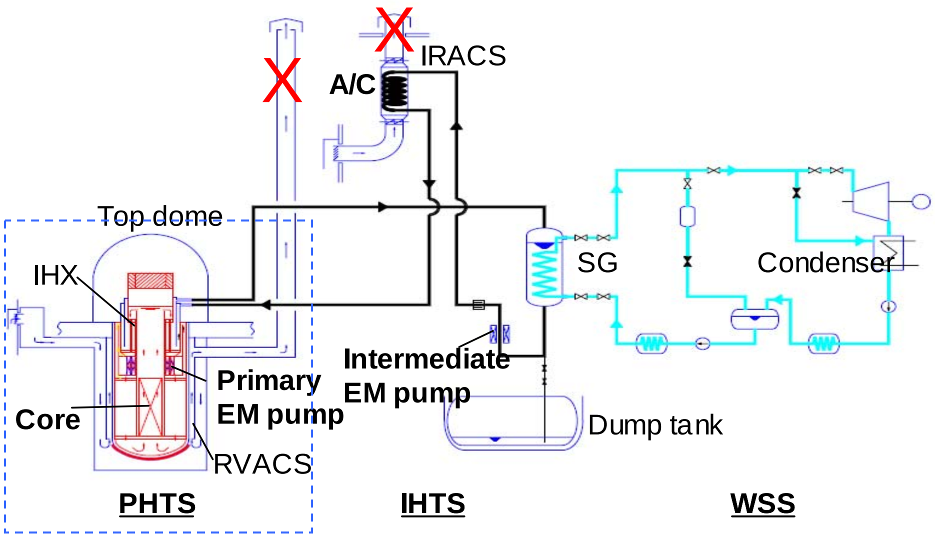
- Below-grade siting
- Heat removal after aircraft crash
  - RVACS maintains natural circulation without stacks

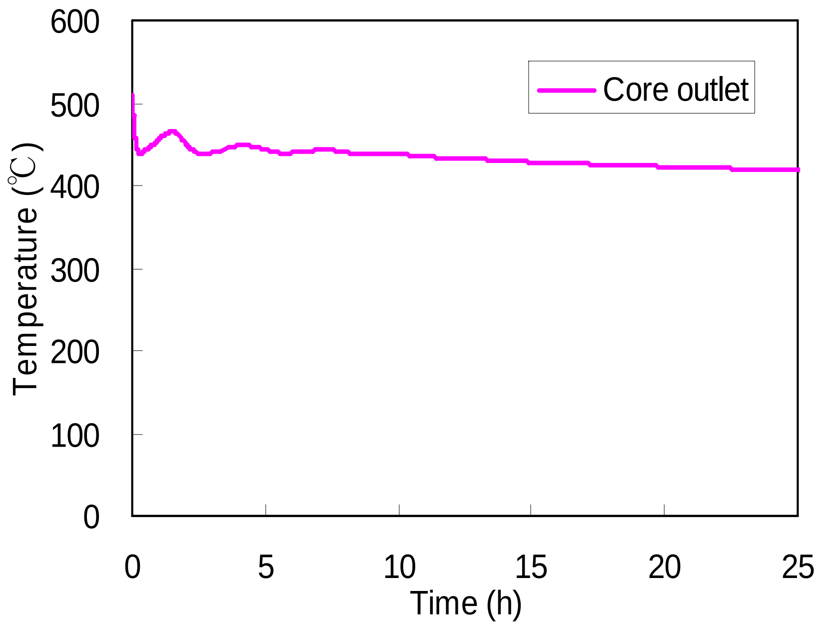


(Section view)

Core Cooling after Aircraft Crash

- Analysis results of heat removal after aircraft crash
  - RVACS and IRACS stacks destroyed by crash of aircraft
  - Intermediate and feedwater pumps trip
  - Reactor shuts down
  - IRACS not available
  - For RVACS, 50% of the cross-section of air flow path blocked





Core outlet temperature

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Design Conformance to Attribute 12

[Attribute 12]

- *Designs with features to prevent loss of spent fuel pool integrity as a result of an aircraft impact.*

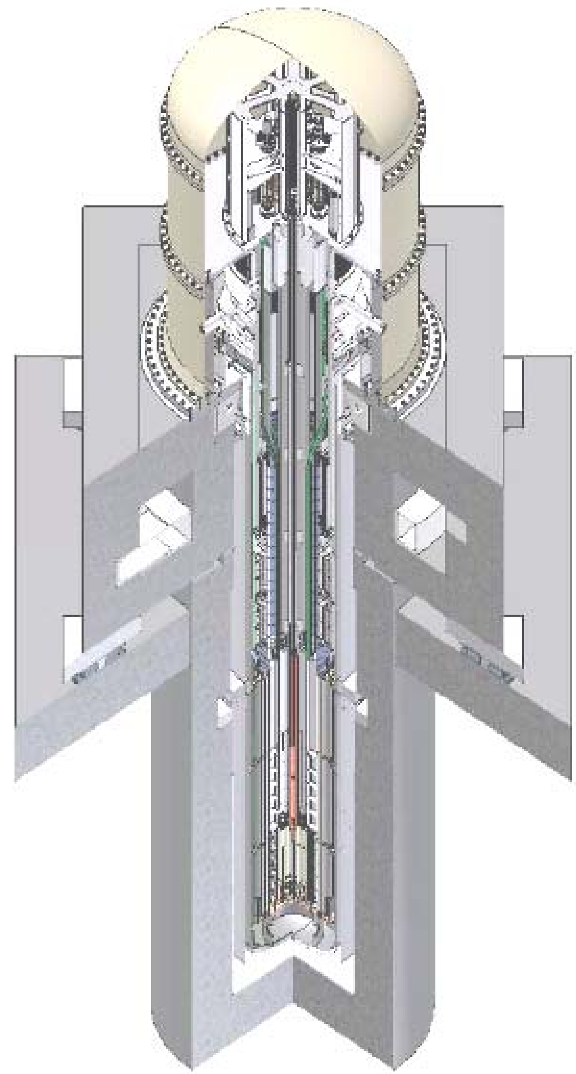
[Design]

- No spent fuel pool
- No refueling
- Minimal exposure of spent fuel at end of life

Summary of Application to 4S

4S Design			Conformance to attributes											
			1	2	3	4	5	6	7	8	9	10	11	12
Reactor and core	Core		✓	✓		✓		✓	✓	✓		✓		✓
	Reactivity control and shutdown system		✓		✓	✓				✓				
Reactor coolant system and connected systems	Reactor vessel				✓				✓	✓		✓		
	Shielding plug					✓		✓	✓	✓		✓		
	Guard vessel				✓					✓				
	Top dome				✓	✓			✓	✓				
	Reactor internal structure					✓		✓						
	Primary heat transport system	General		✓		✓		✓	✓	✓				
		EM pump				✓	✓	✓		✓				
		IHX						✓						
	Intermediate heat transport system	General		✓		✓			✓					
		EM pump					✓							
	Residual heat removal systems	IRACS	✓		✓	✓	✓			✓		✓		
		RVACS	✓		✓	✓	✓			✓		✓	✓	
Instrumentation and control	Reactor protection system			✓				✓						
Auxiliary systems							✓							
Steam and power conversion system	DWSG			✓		✓				✓				
Building												✓	✓	
Reactor general	Human factors considerations have been incorporated to facilitate operator comprehension				✓									
	Minimal electrical and electronic components							✓						
	Low (or no) maintenance primary components							✓						
	Remote in-service inspection								✓					
	Designs to satisfy DID philosophy									✓				
	Citation of existing technology										✓			
	Suitable technology development program based on the 4S PIRT										✓			
	No other fuel or fuel handling equipment onsite											✓		
	No spent fuel pool													✓
	Minimal exposure of spent fuel at end of life													✓

Conclusions

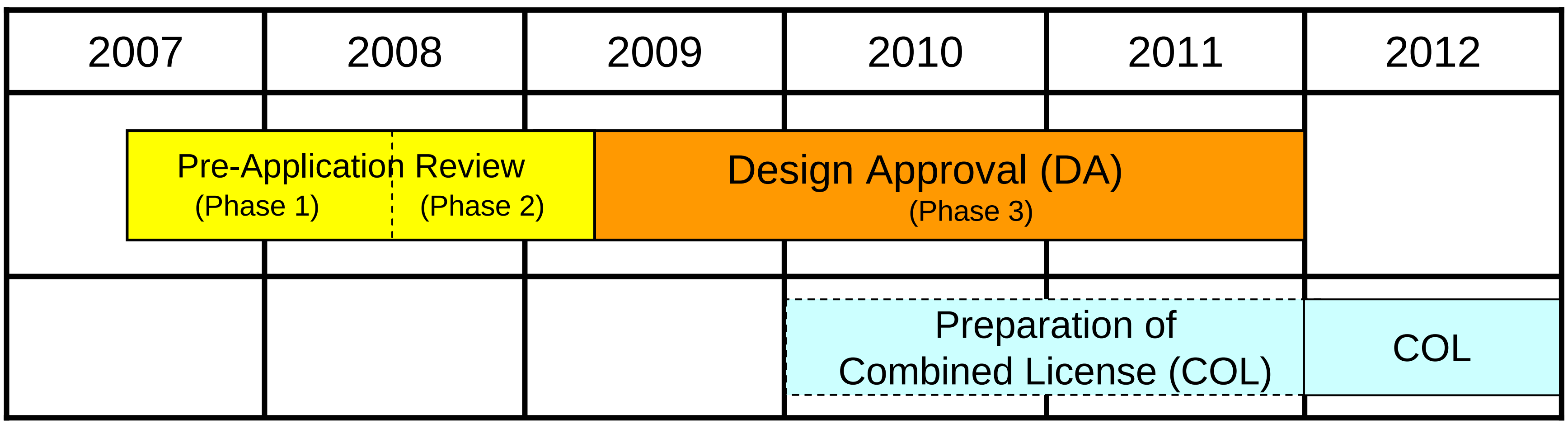


Conclusions

- PIRT process has been applied to 4S.
- Final PIRT results provide guidance for the priority and the scope of further investigation.
- 4S design team has evaluated conformance of the design to the draft policy statement.
- 4S design conforms to the twelve attributes of the draft policy statement.

Proposed Licensing Approach

- **Submit Design Approval application in 2009**
  - **Phase 1:** Complete a series of meetings with NRC to identify issues to be addressed before Design Approval application
  - **Phase 2:** Submit technical reports and obtain NRC feedback to address the issues identified in Phase 1
  - **Phase 3:** Submit Design Approval application and obtain FSER
- **Toshiba expects a U.S. customer will submit a COL application referencing Design Approval.**



Phase 2 – Proposed Licensing Approach

- **Schedule of technical reports for NRC review**

– Long-life metallic fuel		
• Analysis methodology		
• Fuel performance	June 30	2008
– Safety design and safety analysis		
• Principal design criteria		
• Evaluation criteria		
• Analysis methodology		
• Safety analysis results	October	2008
– PIRT and test program	November	2008
– Seismic isolation	December	2008
– Responses to NRC questions	December	2008

End