Improvement of Severe Accident Management for Indian NPPs

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Improvement of Severe Accident Management for Indian NPPs

- Post Fukushima Accident safety re-assessment of all Indian NPPs was carried out by the utility in cooperation with regulatory body and research centres. These assessments brought out the requirements for further enhancement in safety, especially against severe external events.

The approach adopted for these safety enhancements is outlined below:

- Re-confirmation of capability to withstand currently defined site specific design / review basis levels of external events for individual plants.

- Assessment of margins available for beyond the design / review bases levels of external events.

- Enhancing the capability of the plants to perform the safety functions under extended SBO / extended loss of heat sink through the design provisions

Improvement of Severe Accident Management for Indian NPPs

- The measures being incorporated based on the above assessments include:

Alternate provisions for core cooling and cooling of reactor components including identification / creation of alternate water sources and providing hookup points to transfer water for long term core cooling,

- Provision of portable DGs / power packs
- Battery operated devices for plant status monitoring
- Additional hook up points for adding up water to spent fuel storage pools
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– Review and strengthening of severe accident management provisions particularly with respect to:

- Hydrogen Management
- Containment venting
- Availability of key parameters for monitoring even under most extreme conditions

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- The measures being incorporated based on the above assessments include:

- Review of adequacy of SAM programme following a severe external event, with the possibility of destruction of support facilities, both inside the plant and the surroundings; and affecting multiple units.

– Creation of an On-site Severe Accident Management Support Facility at each NPP site which should remain functional under extreme events including radiological, with adequate provisions of communication, monitor plant status and having capacity for housing essential personnel for a minimum period of one week.

Significant progress has been made in all the areas identified for post Fukushima upgrades for each of the operating NPP in the country.

Improvement of Severe Accident Management for Indian NPPs

▪ Strike an appropriate balance for SAMGs between explicit procedural steps and more flexible guidance

• During the accident conditions when EOP actions are not able to satisfying the safety functions, operators require both kind of instructions i,e explicit procedures based on symptoms and also flexible guidance so that if the symptom does not fall explicitly in line with the laid down procedure

• Following steps may be followed for strike a balance for preserving the "safety functions"

Step -1 :Each explicit procedural steps should be backed by a flexible guidance to fulfill the objective intended in the procedural step

e.g. : Explicit step : Inject ion of water into RPV at 650°C (outer plenum temperature)

Objective : Establishment of core cooling

Action Status : Failed due to some reason (Mobile DGs could not be brought to start pumps)

Flexible guidance : Core cooling to be achieved to arrest core degradation

Other options listed to operator as a flexible guidance: SG crash cooling and FFW injection to SG/ Activation of shutdown decay heat removal system

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- Strike an appropriate balance for SAMGs between explicit procedural steps and more flexible guidance

Step -2 : Evaluation of the core/containment state arise from the failure of a strategy to achieve the objectives at one phase, should still leave options for achieving the objectives at subsequent phases as a part of flexible guidance

This step helps to understand that if the explicit procedure is not followed the next procedure should not be detrimental to safety

e.g Hydrogen risk from flooding of highly degraded core

Hydrogen risk from late containment spray

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- **Necessary steps required to formulate an adequate technical basis for SAMGs, and it's up gradation with improvements of further understanding of severe Accidents phenomena**

Step-1 : PSA Level-2 studies (Internal & external events) to find out the weakness in Design and proposed/existing SAMG s and strengthening those system/equipment weakness

Step-2: Continued severe accident research and synthesis of generated information

Step-3: Improvements of Severe Accident related physical models used in SA analysis codes. The improvements to be based on the periodic update from research generated information

Step-4: Periodic SA analysis considering plant modification and ageing to redefine (if necessary) SAMG

Step-5 : Up gradation of knowledge base from Candidate accident management strategies from other sources (international collaboration etc.)

Step-6 : Different Industry studies on severe accident management guidance for certain type of plants

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- **Necessary steps required to formulate an adequate technical basis for SAMGs, and it's up gradation with improvements of further understanding of severe Accidents phenomena**

Step-2: Continued severe accident research and synthesis of generated information – example PHWR

EXAMPLE OF THE DEVELOPMENT OF SEVERE ACCIDENT MANAGEMENT INSIGHTS FOR A PHWR

1	steam explosion	in-vessel: (high pressure steam explosion in calandria vessel is highly unlikely) ex-vessel: will or will not fail containment
3.	core concrete interaction	can/cannot lead to containment overpressurization can lead to combustible gas (CO) will/will not continue after flooding of debris
5.	in-vessel debris cooling	submerging debris will/will not keep debris in-vessel
6.	external vessel cooling	will/will not retain debris in-vessel
7.	ex-vessel debris cooling	Not applicable for PHWRs
8.	hydrogen generation	hydrogen deflagration may/may not occur deflagration may/may not challenge the containment integrity
10	determination of accident progression	onset of core melting will/will not be observed by control room relocation of debris to calandria vault/shield tank will/will not be identified by control room calandria breach will/will not be observed by control room

Enhancements to Severe Accident Management Guidelines – Technical Basis

- Analysis of a potential beyond design basis accident or severe accident sequence typically has one of the following objectives [Safety Guide: No. NS-G-2.15]

(1) Formulation of the technical basis* for development of strategies, procedures or guidance;

(2) Demonstration of the acceptability of design solutions to support the selected strategies, procedures and guidelines in accordance with the established criteria;

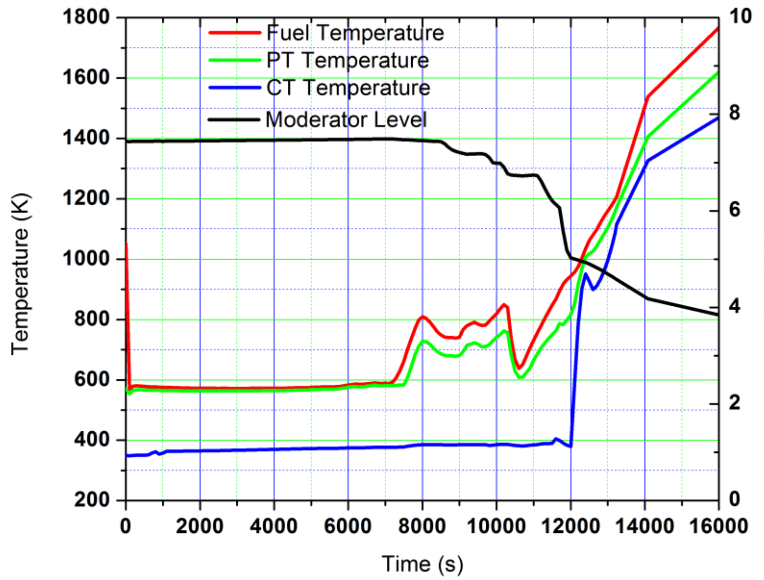
(3) Determination of the reference source terms for emergency plans.

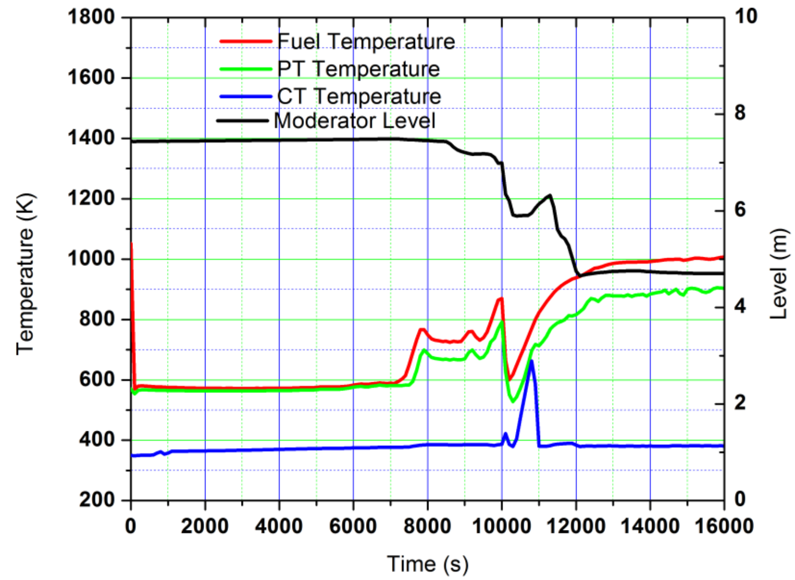
* A technical basis includes analyses, evaluations, assessments and engineering judgment

Severe Accident Analysis to Evolve SAMG for 540 MWe PHWR –Technical Basis

Water Injection into Calendria Vessel post OPRD Rupture

SBO: Without Injection into Moderator	SBO: With Water Injection into Moderator



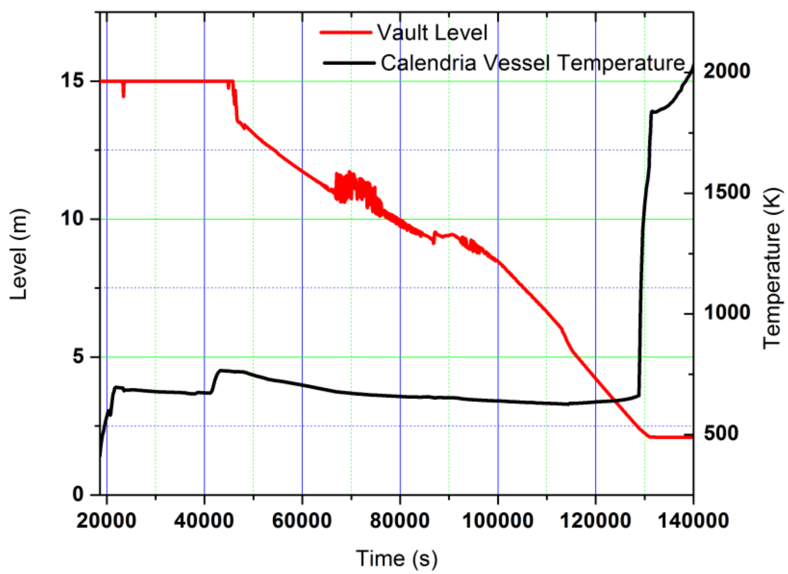
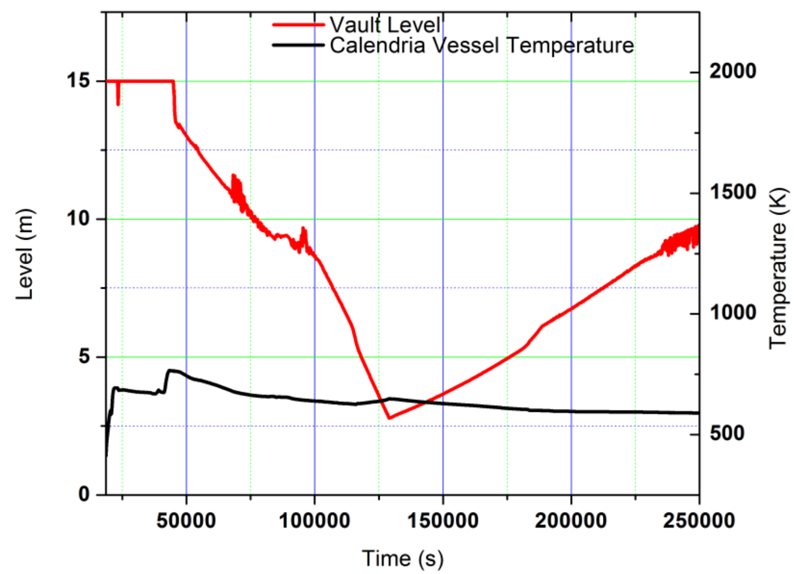


Channel uncovery due to moderator boil-off causes sharp rise in CT temperature followed by rise in Pt and fuel temperature.

Water injection into Calendria post OPRD rupture within 2 hours arrests the temperature rise.

Severe Accident Analysis to Evolve SAMG for 540 MWe PHWR – Technical Basis

Water Injection into Calendria Vault post Vault RD Rupture

SBO: Without Injection into Vault	SBO: With Water Injection into Vault
	
Vault water boi-off causes exposure of calendria vessel from outer side leading to sharp rise in its temperature	Addition of water into calendria vault 1 day after the channel disassembly helps in maintaining calendria integrity

Enhancements to Severe Accident Management Guidelines –Betterment of Technical Basis

- Major Experimental Activities under progress/planned to enhance severe accident management

(1) PHWR specific Large Scale Molten Fuel Coolant Interaction Experiment at ITFSS to resolve the issue of LCDA (single channel event) propagation to SCDA (multiple channel failure)

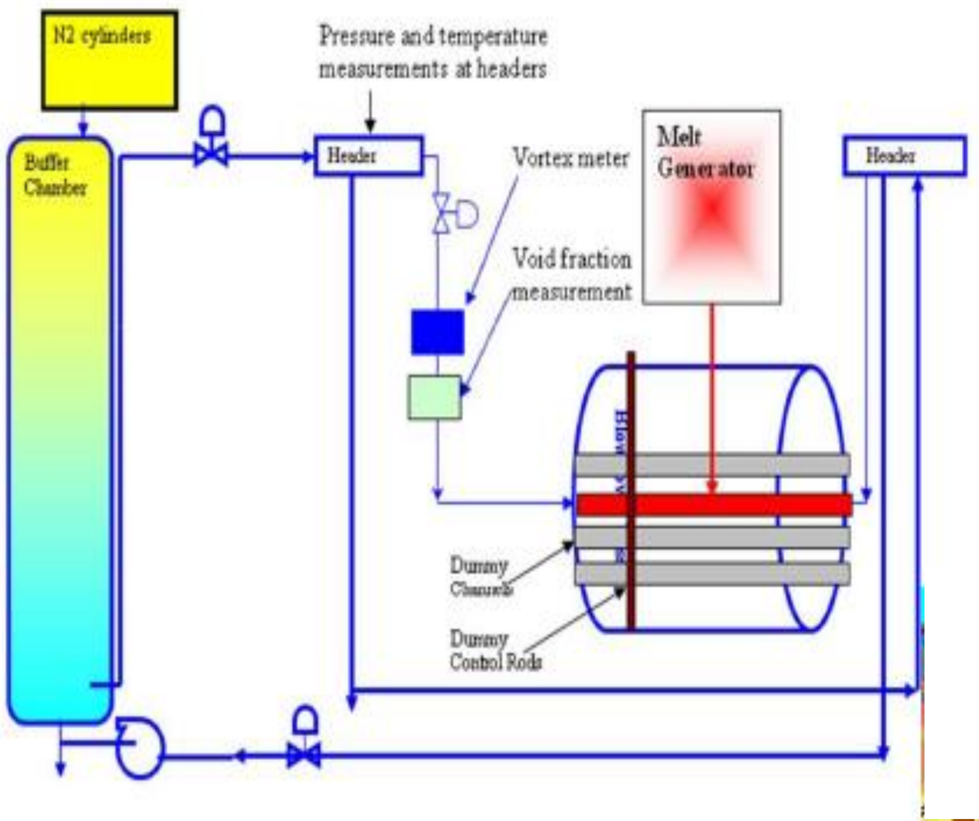
(2) Calandria as a Core Catcher for PHWR – Establishing the external cooling adequacy

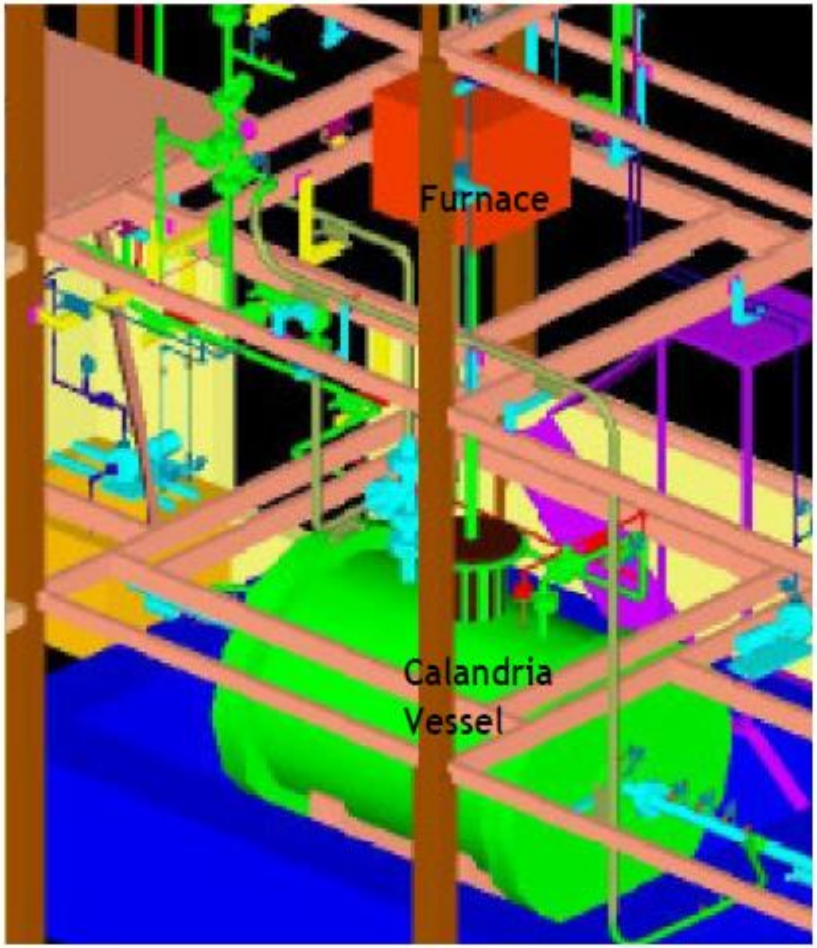
(3) Hydrogen Generation estimation from Molten corium concrete (hematite type) interaction

(3) Design establishment of Hard Venting and recombiner at CONSISTs facility

Experiment: MFCI Study Planned at ITFSS

• **Large Scale Study at Integral Test facility at Safety Studies (ITFSS)**



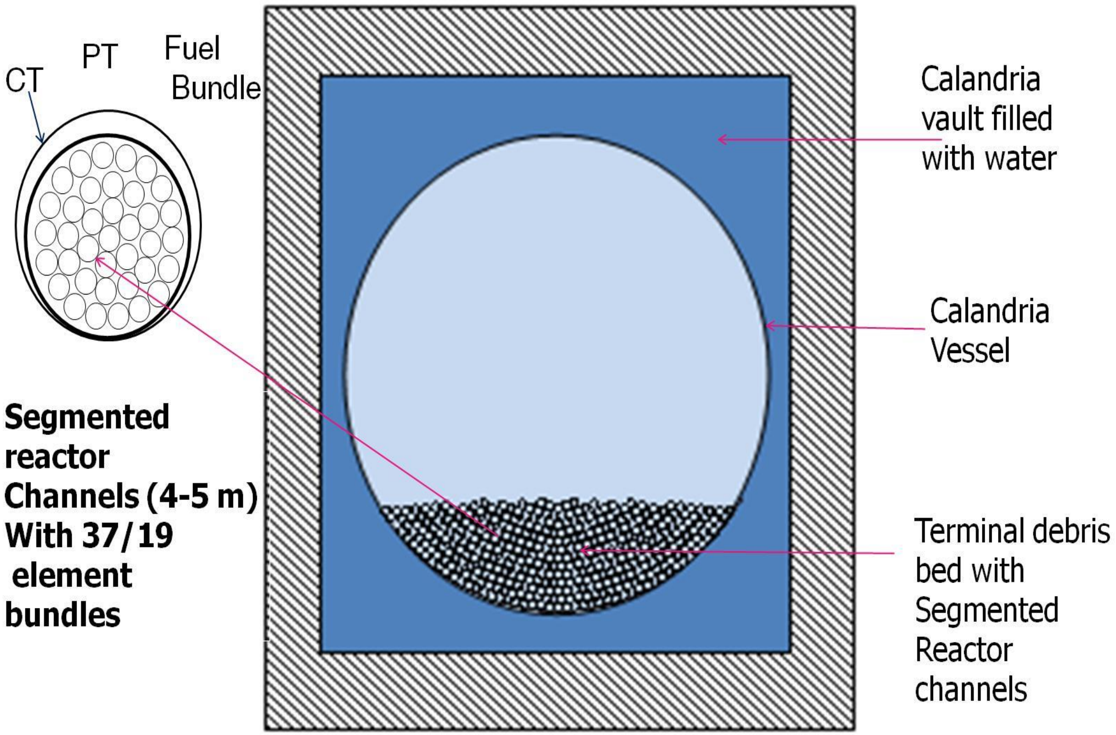


Molten material : Alumina at 2400°C
Material Amount : 25 kg

Calandria Vessel As a Core Catcher - Analytical Study & Experimental Program

Calandria Failure Criteria [IAEA TECDOC 1594]

- failure due to molten layer attack
- failure by high temperature creep
- failure due to inadequate external cooling
- failure by high pressure (around 2.2 MPa)
- failure due to debris impingement
- failure of CV bottom drain line



Calandria Vessel with terminal debris bed

Calandria Vessel As a Core Catcher
- Analytical Study & Experimental Program

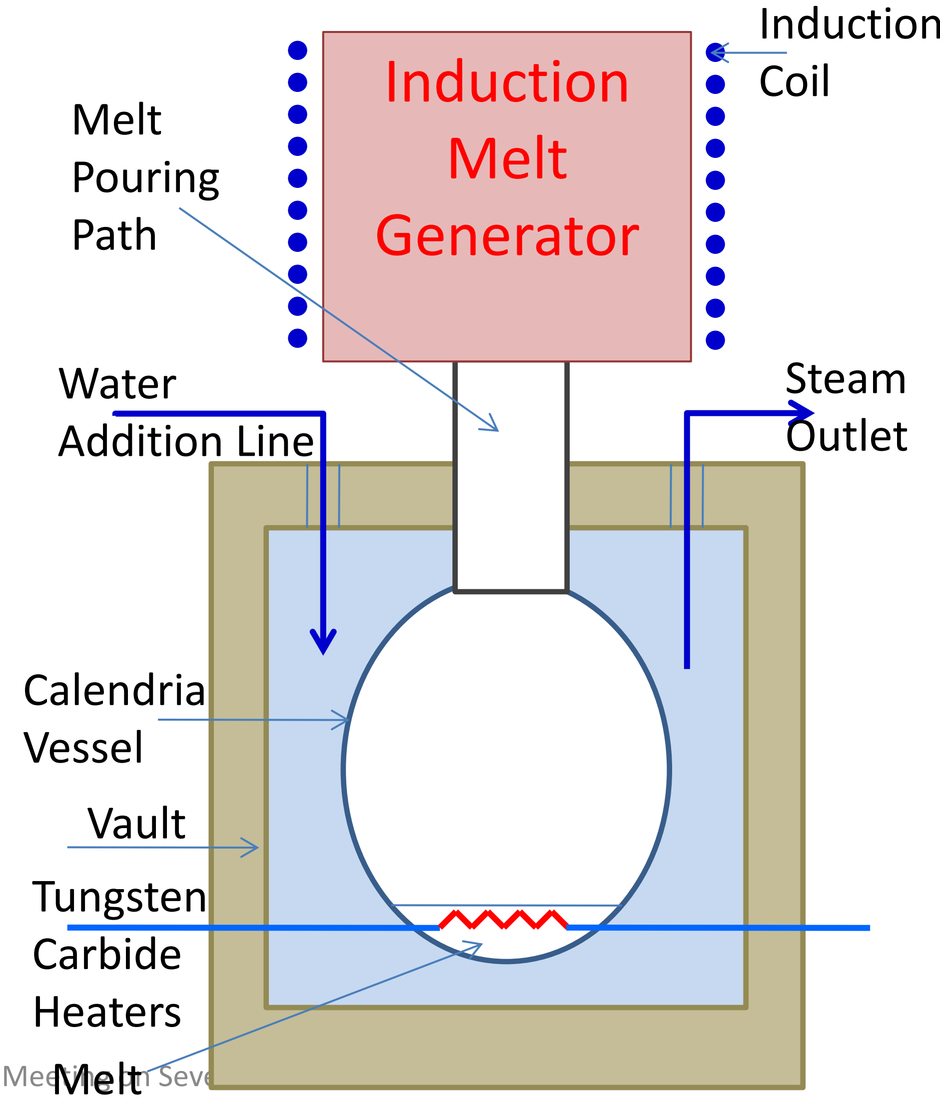
- A setup is planned with1:6 Scaled Down model of Calandria and Vault

- 80 kg CaO and 20 kg WO3 melt generated in an induction furnace (100 kW) will be released Into calandria submerged into vault water

- Decay Heat of the melt will be simulated with tungsten carbide heaters

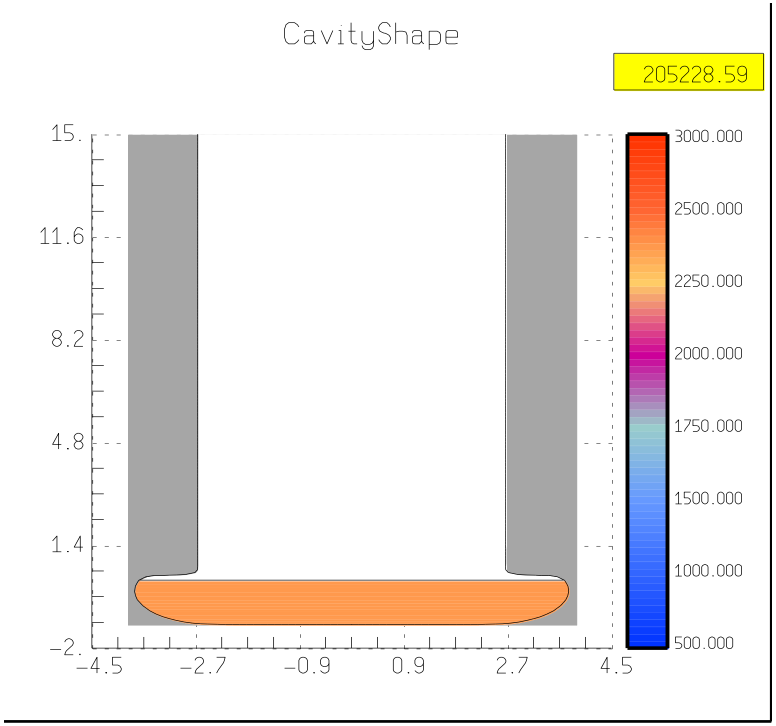
- Measurements
 Temperature: Melt, Calandria & Vault
 Steam generation, level, strains
 are the other measurements

- Vessel deformation will be studied with exposure



Experiments under Plan: Molten Corium Concrete Interaction

- **Study of MCCI for PHWR Specific Concrete (Hematite Type)**



Results (ASTEC) showing Vault Concrete Ablation for CANDU

Experimental Validation Plan

- **A setup is planned with1:6 Scaled Dry Vault with SS line**
- **75 kg Alumina melt generated in an induction furnace (100 kW) will be released into Vault**
- **Measurements**
  Melt and Concrete temperature and Evolved Gas composition
- **Study of water addition from top**

Containment System Integral Simulation Test (CONSIST) Facility

AHWR design incorporates the containment with various passive and FOAK safety features, the performance of containment and its associated systems will be demonstrated in a simulated integral test facility.

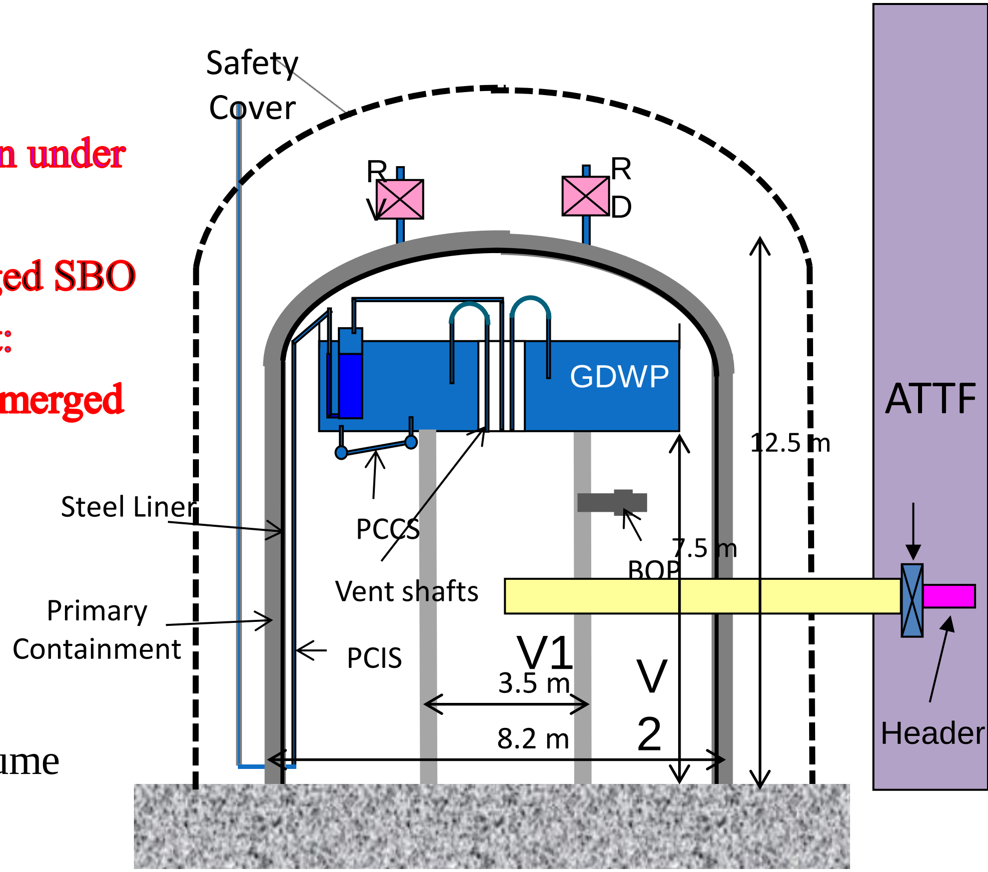
The CONSIST Facility is designed for integration with ATTF

Objectives:

- Containment thermal-hydraulic design validation under LOCA conditions
- Demonstrate the capability to withstand Prolonged SBO
- Capability to withstand Fukushima like accident:
  - Efficacy of cooling of the AHWR core by submerged feeders and tail pipes when the GDWP cracks.
  - Validation of Hard vent design for AHWR
  - Validation of Hydrogen mitigation by PARCS

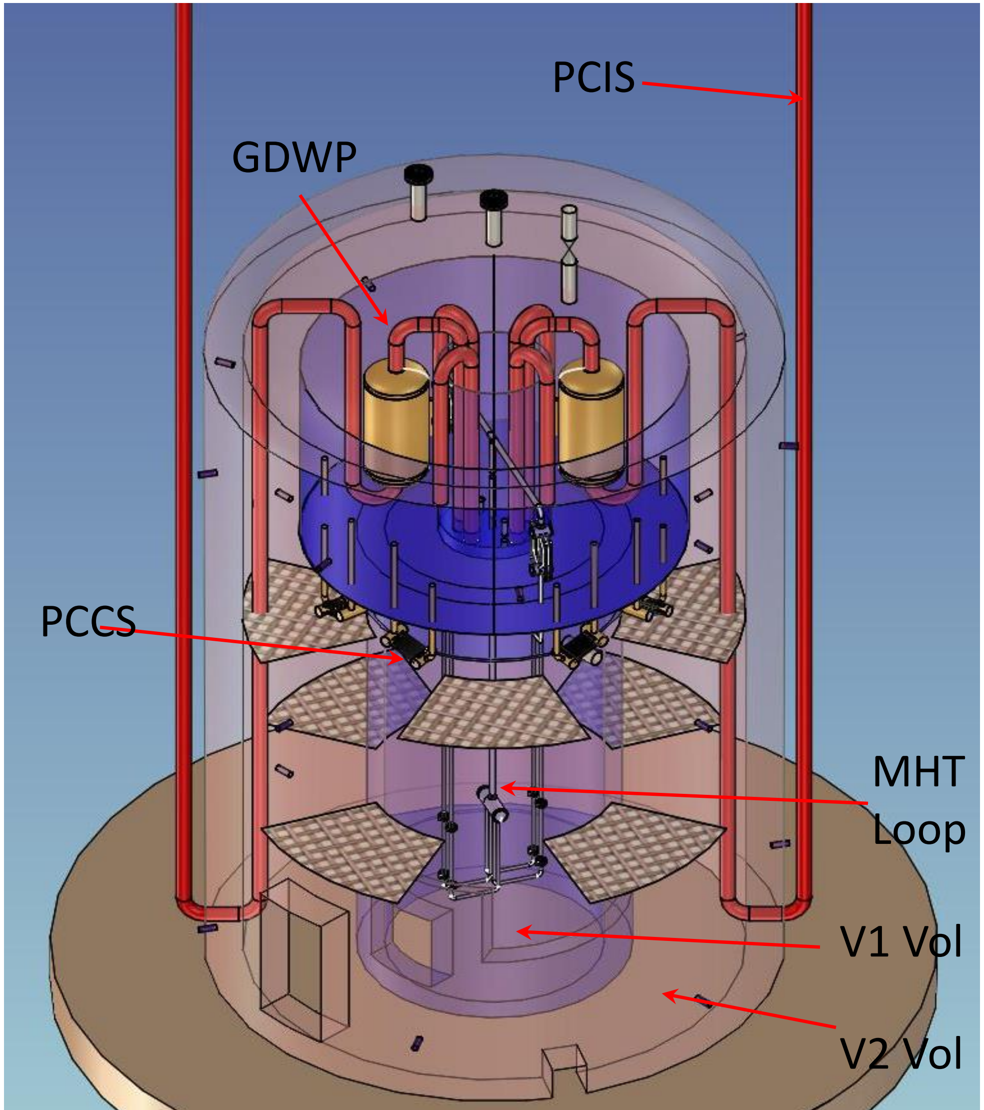
Scaling Philosophy:

- The CONSIST facility is based on power to volume scaling.



Schematic of CONSIST Facility

CONSIST Facility



3-D Model of CONSIST

Systems Simulated:

- V1 & V2 Volumes
- GDWP
- PCCS
- PCIS
- MHTS Loop with ICS
- PARS
- Hardened Vent System

Facility Dimension:

- Height - 12.5 m
- Diameter - 8.2 m
- Material - RCC

Improvement of Severe Accident Management for Indian NPPs

- **Prioritizations of SAMG scope (all reactor power levels, multi-unit sites, spent fuel pools) while developing the SAMG for a site.**

- Step-1: SA analysis support is extensively required to evaluate the plant state at different power levels and burnup conditions followed by testing of adequacy of mitigating action plan . SAMG scope should address the worst possible power & burnup state for building up strategies

- Step-2 : Multiple unit site SAMG strategy planning is very complex as evident in Fukushima event. Power restoration (in case of SBO) is the most prioritized job as managing the safety system and monitoring the safety functions need power so that all the units could be monitored and cooled. With this achievement containment failure risk and radiation risk is very much reduced

- Step-3 : Provision of Passive Cooling through atmospheric cooling is an alternative options of decay heat removal from reactor core/containment and spent fuel bay for multi unit site as they are helpful to reduce SAMG actions for maintaining the safety functions

- Step-4: Prioritization to attend reactor core versus spent fuel cooling entirely depends on the age of the spent fuel. For freshly dumped spent fuel the priority is as good as the reactor core due to it's high decay power. The management strategy need to be formulated on the decay power state of spent fuel pool.

Improvement of Severe Accident Management for Indian NPPs

- Betterment of interface between SAMGs and emergency operating (or other) procedures to facilitate timely entry and response

- Step -1 : Identification of inadequacy of EOP action through plant parameters (not only one) at an much early stage of accident

e.g for LOCA with loss of ECCS : accumulator pressure & level, Reactor pressure, level, Class IV and III availability, moderator level low etc.

Step -2 : Overlapping phase should be formulated between EOPs and SAMGs and Candidate High Level Actions could be poised much before recognition of plant damage states or after certain parameters exceed their safety thresholds,

Step-3: Operator training on full plant simulator covering both EOP and SAMGs with various combinations of failures of availability of provision

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Example: Need for multiple entry point : EOP to SAMG transition for PHWRs

Condition	Parameter	Measurement device
1. Loss of core cooling	No subcooling margin in inlet headers for several minutes	Heat transport system temperature and pressure instrumentation
AND either		
2. Loss of moderator cooling to fuel channels OR 3. Excessive release of fission products from fuel	Moderator level below highest channels Plant radiation levels	Moderator level instrumentation In-containment fixed area gamma monitors or field surveys

And Miles to go Before We Sleep