Program for Assessment of Calandria as an Ultimate Barrier to Corium Relocation for PHWRs

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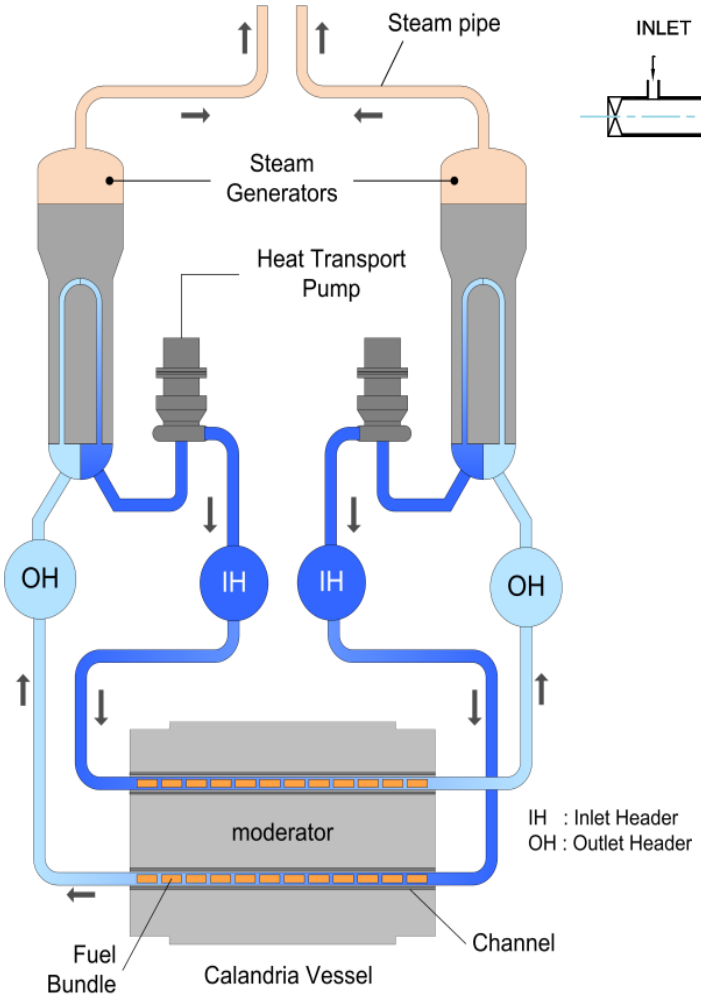
Program Objectives

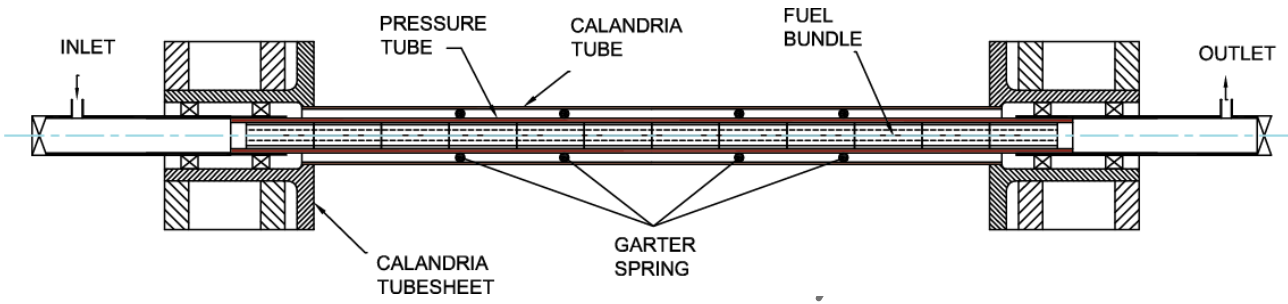
- Assessment of Calandria Integrity under Severe Accident Management Guidelines (SAMGs).
- The Assessment will strengthen further “Technical Basis Document’ for SAMGs as Implemented for PHWRs
- The Assessment will also helpful for PARS (Passive Auto Catalytic Recombiners) deployment and CFVS (Containment Filtered Venting System)

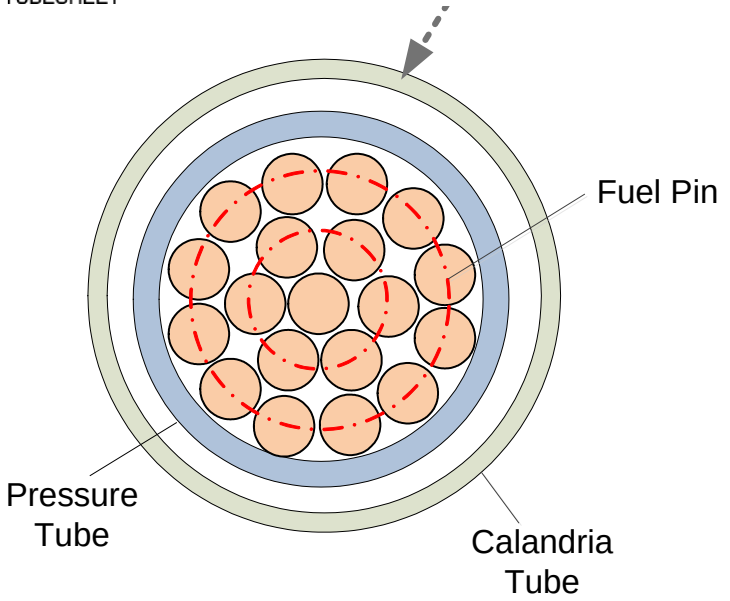
A Brief on PHWR Design

PHWR Schematic



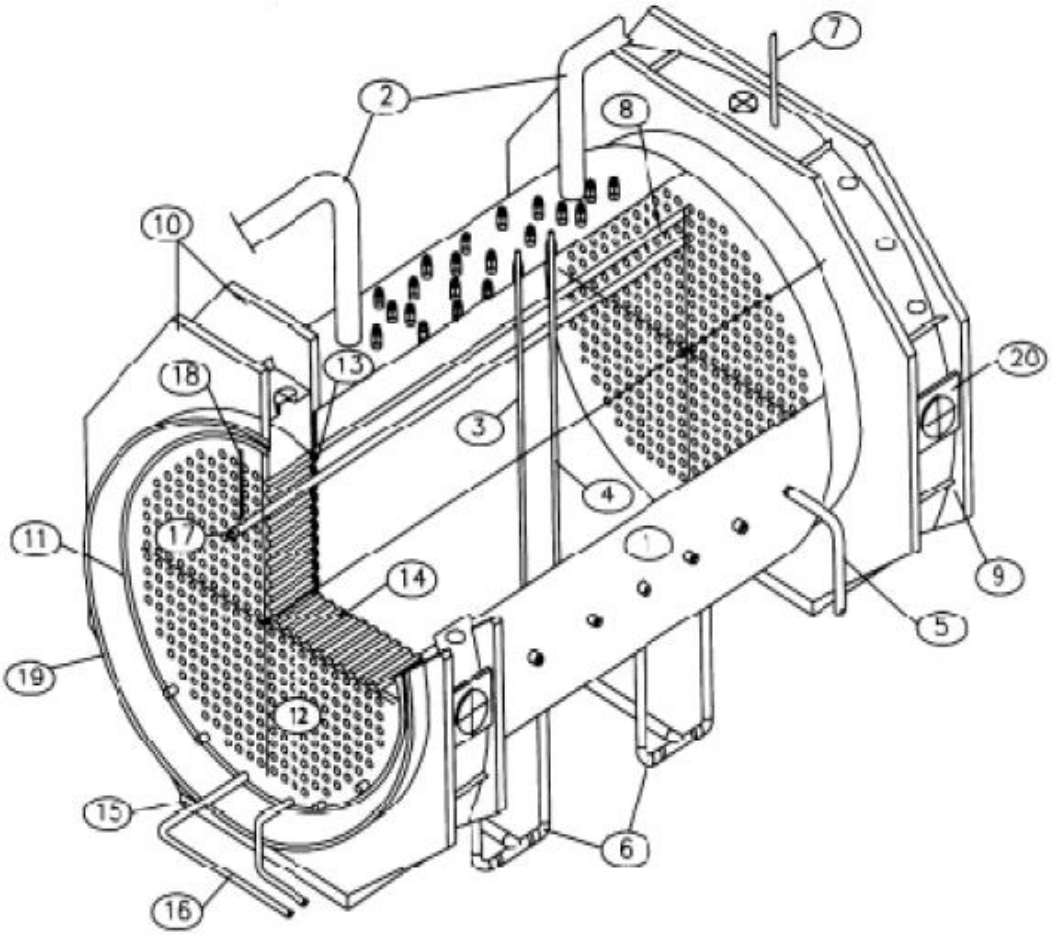
Reactor Channel





Channel cross-section

A Brief on PHWR



Schematic of Calandria with all components

No.	Component description
1	Calandria Shell
2	Over pressure relief device
3& 4	Shutdown rods
5 & 6	Moderator Inlet and outlet
7	Vent pipe
8	Reactor Channel Assembly
9	End Shield (ES)
10	ES support
11	Main Shell Assembly
12	Tube Sheet Fuelling Machine
13	Tube Sheet Cal side
14	Lattice Tube (end part of reactor channel)
15	ES support plate

Anticipated SBO Scenario under Unmitigated Severe Accident

- Deceleration of SBO [Unavailability: Class IV and III power (DG supply)]
- Primary Circulating Pump Trips
- Reactor Trips
- Main Steam Isolation Valve closure and SG feed isolation
- Manual Action Requirement 1: Steam Generator Crash Cooling and Addition of Fire Fighting Water (FFW) addition in Steam Generator Secondary Side

Action Fulfillment (Success or Failed) Status: Failed

- SG secondary side dryout
- Primary pressure rises and safety relief valve (SRV) opens
- Channels becomes dry due to devoid of coolant
- High Power Channel burst due to high pressure (SRV set point) and high temp.
- Modertaor expulsion through Calandria Relief Devices
- Top Three rows of channel get exposed

Anticipated SBO Scenario under Unmitigated Severe Accident

- **Manual Action Requirement 2: Addition of Fire Fighting Water (FFW) to Calandria Through OPRD Lines**

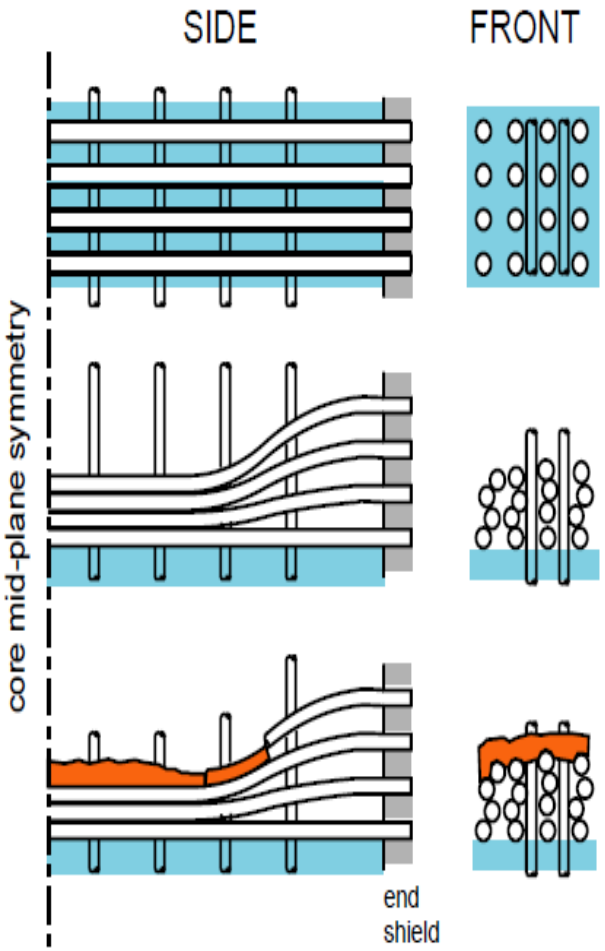
  Action Fulfillment (Success or Failed) Status: Failed

- Moderator Boil-off leads to More Number of Channels Exposed
- Exposed channels sags and disassembled from end connections and pileup to form suspended debris bed
- Suspended debris weight increases and rest on still submerged channels
- After the exceedence of load bearing capacity of submerged channels a total core collapse is anticipated.
- The collapsed core forms a terminal debris bed at Calandria Bottom
- The Vault Water Boil of Initiates from terminal Debris bed
- **Manual Action Requirement 3: Addition of Fire Fighting Water (FFW) to Vault Through Relief Lines**

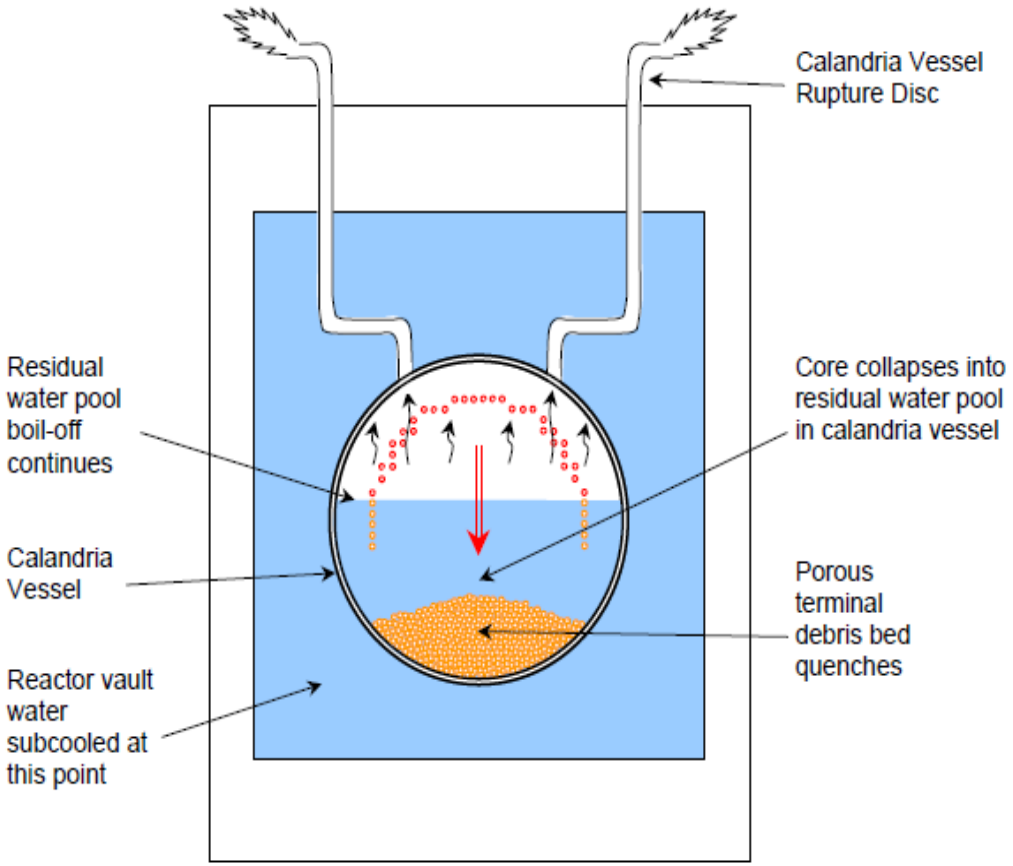
  Action Fulfillment (Success or Failed) Status: Failed

- Vault water boils-off and Calandria gets exposed and fails, leading to MFCI from the discharge Zr rich Corium with remaining vault water and MCCI with vault concrete

Conceptual Schematic of Suspended and Terminal Debris Bed



A Schematic of showing suspended debris bed made from sagged disassembled exposed reactor channels



A schematic showing the collapsed core forming a terminal debris bed

Failure Criteria for Calandria Under SA

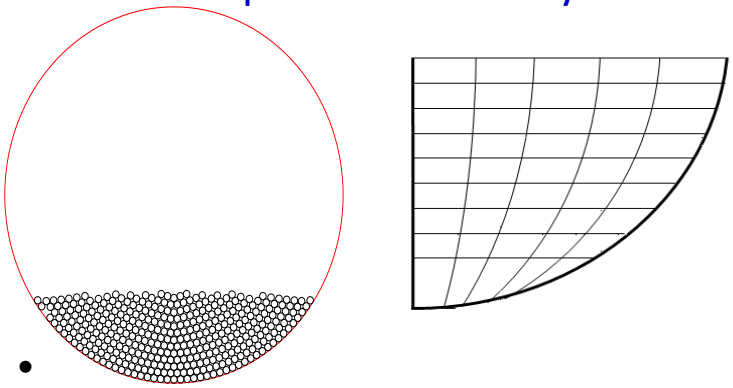
- The integrity of Calandria is of importance to retain the debris/melt in case of unmitigated beyond design basis accidents like SBO.
- During such situation Calandria may experience different kind of loads and can fail.
- An international consensus considers following failure modes of Calandria:
  - Failure due to corium molten layer attack
  - Failure by high temperature creep
  - Failure due to inadequate external cooling leading to CHF
  - Failure of Calandria bottom drain line
  - Failure by high pressure (around 2.2 MPa)
  - Failure due to debris impingement

Remark: Currently the program examines the five criteria

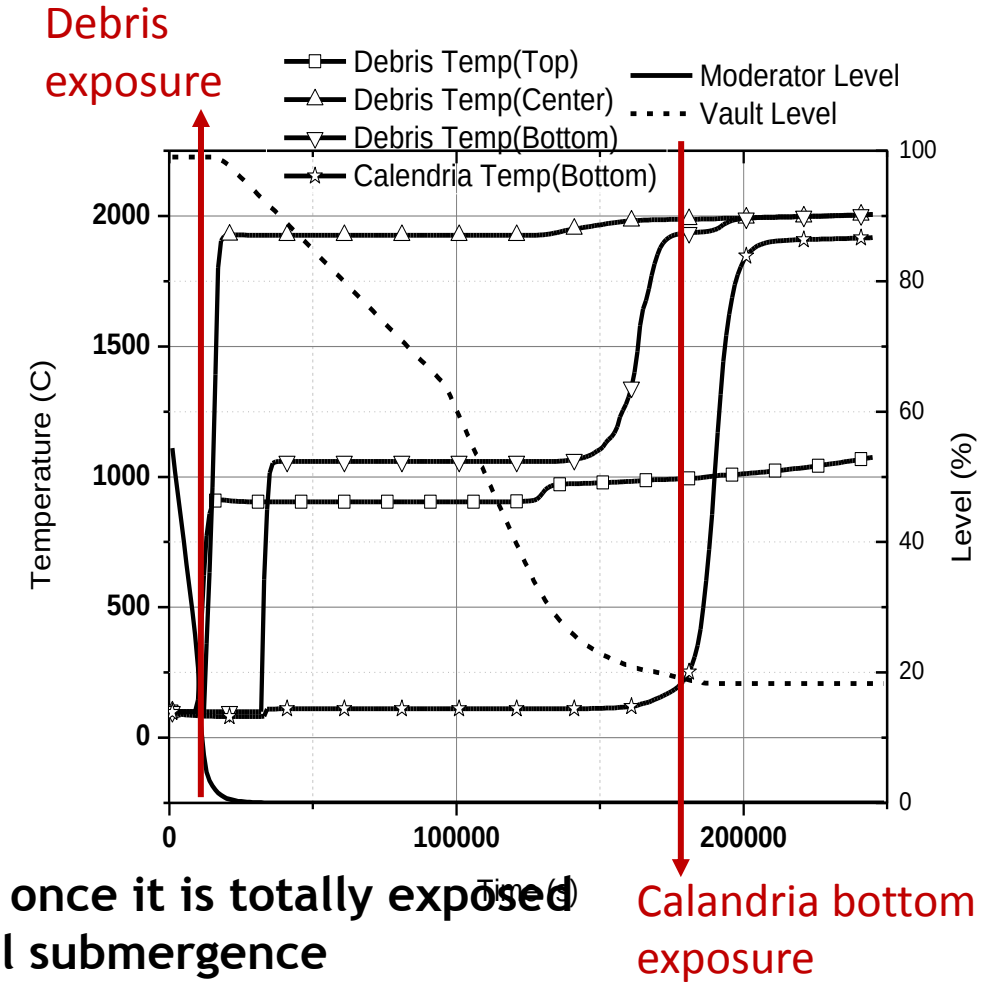
Program: Analytical Approach (1)

Calandria Heatup Prediction with Code Debris Bed Heat Up Analysis (DBHUA) for 540 MWe PHWR

- **Code Features:**
- Specifically Developed for PHWR specific
- debris bed
- The classical debris bed models as used for PWRS are adopted and suitably modified



Debris configuration and mesh for debris bed



Analysis Conclusion :

(i) Debris bed heatup only gets initiated once it is totally exposed

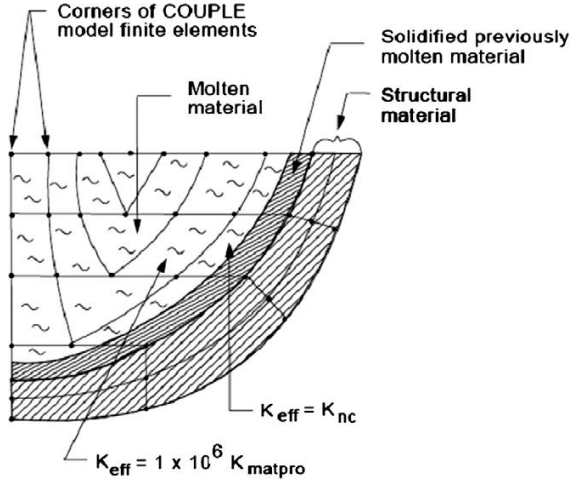
(i) Calandria Integrity is maintained still submergence

(ii) Calandria wall ablation takes place once it is exposed from Vault Water and no creep failure is noticed

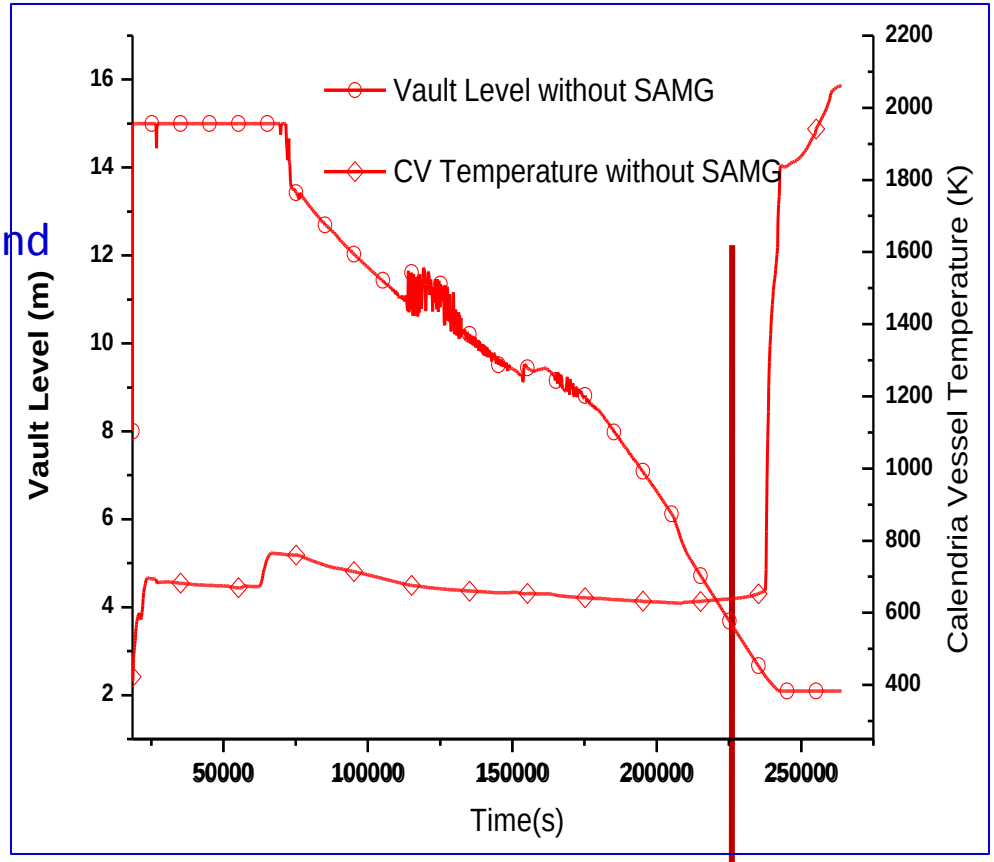
Program: Analytical Approach (2)

Calandria Heatup Prediction with Code RELAP5/SCDAP for 540 MWw PHWR

- **Code Features:**
- Specifically Developed for PWR specific debris bed and applied for PHWR
- Debris particle size of 120 mm (spherical) and 0.4 porosity has been considered



COUPLE mesh for debris bed



Calandria bottom exposure

Analysis Conclusion :

(i) Calandria Integrity is maintained still submergence

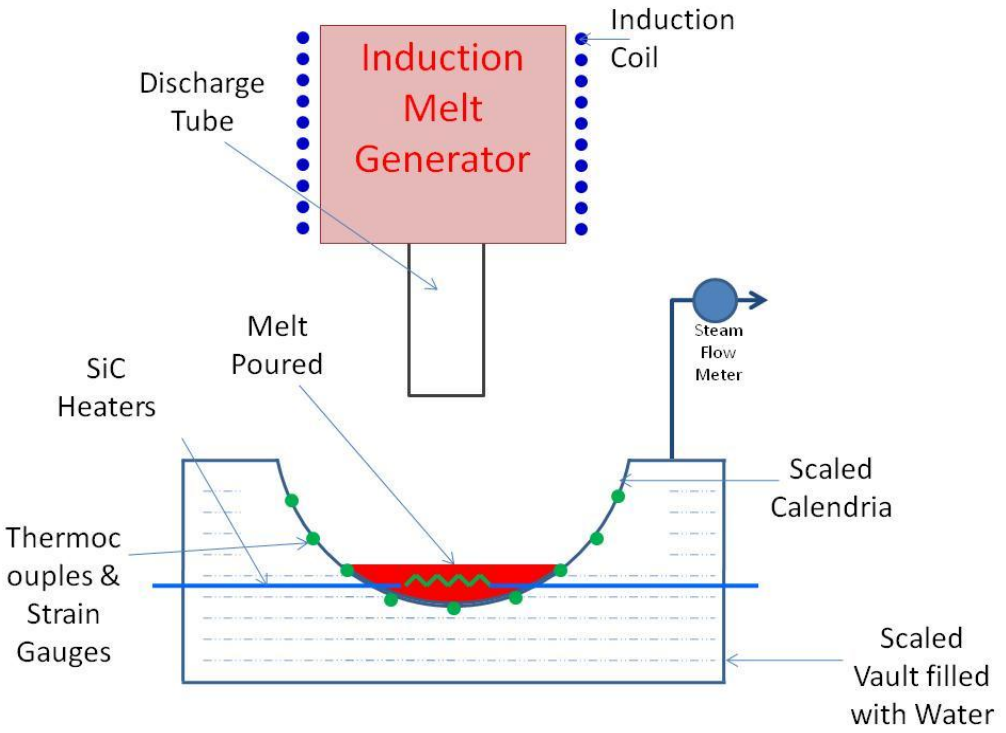
(ii) Calandria wall ablation takes place once it is exposed from Vault Water

(iii) No creep failure of Calandria is noticed

Program: Experimental Approach

Experimental Plan for Establishment of Calandria as a Core Catcher:

- 1:6 Power to Volume Scaling with conservation of decay power through SiC heaters
- CHF and Vessel Strain Behaviour will studied
- Molten Material (Cao +WO3) at 2500°C



Schematic of Test Setup for External Cooling of Calandria for PHWRs

Measurements
Temperature at Calandria Outer Surface and at different thicknesses
Calandria outer surface strain measurements
Melt temperature by pyrometers
Steam exit temperature
Generated steam flow rate
Water level in the Calandria Vault
Photography of the Calandria outer surface for determination of boiling regimes
Power input to SiC heaters.

Conclusion

Analytical Approach:

- Through Analytical Studies Calandria Integrity is Ensured till its submerged
- Lower power density of the PHWR core and large bottom surface of the Calandria leads to a lower heat flux than required for Critical Heat Flux to occur
- The loading, debris weight per unit surface area of calandria and lower Calandria temperature (300°C) does not lead to any material creep till Calandria is submerged.
- SAMG Action : Addition of water into Vault will be able to hold the core within Calandria, thus the component acts as a core catcher

•Experimental Approach:

- The fabrication Setup is on way. Setup will be commissioned in 2017