Newsletter PRABHAVINI

प्रोग्राम-आण्विक भट्टी अपकर्ष एवं विकिरण निर्धारण

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PRABHAVINI is an integral safety analysis code being developed to address Design Basis Accidents (DBA) and Beyond Design Basis Accidents (BDBA) in nuclear reactors. It would allow calculations from the initiating event up to the fission product release to the atmosphere. Currently version 2.0 is available. PRABHAVINI development is being carried out under the purview of DAE Steering Committee of Coordinated Safety Research with contributions from BARC, NPCIL, AERB, and IGCAR. This newsletter is intended to highlight on-going activities for code development on quarterly basis.

IN THIS ISSUE

- The module of ABHA has been improved by providing PT/CT contact conductance, Pool boiling curve, user defined body temperature and user defined initial axial variation of component temperature.
- VIKIRAN module is developed and implemented in the code. The module estimates atmospheric dispersion of radionuclides and external and internal dose to member of public.
- The ABHA has been validated against the ICSP floated by IAEA to assess the capabilities of computer codes used in predicting sub-cooling requirements for an overheated pressure tube, plastically deforming and contacting the calandria tube during a postulated large break loss of coolant accident.
- The wall boiling and wall heat flux apportionment model used in heat transfer module of PRAVAH is assessed using the data from Christensen sub-cooled nucleate boiling experiment.
- The containment thermal-hydraulic model of PARIRODHAN is assessed against the data from CSF experiment.

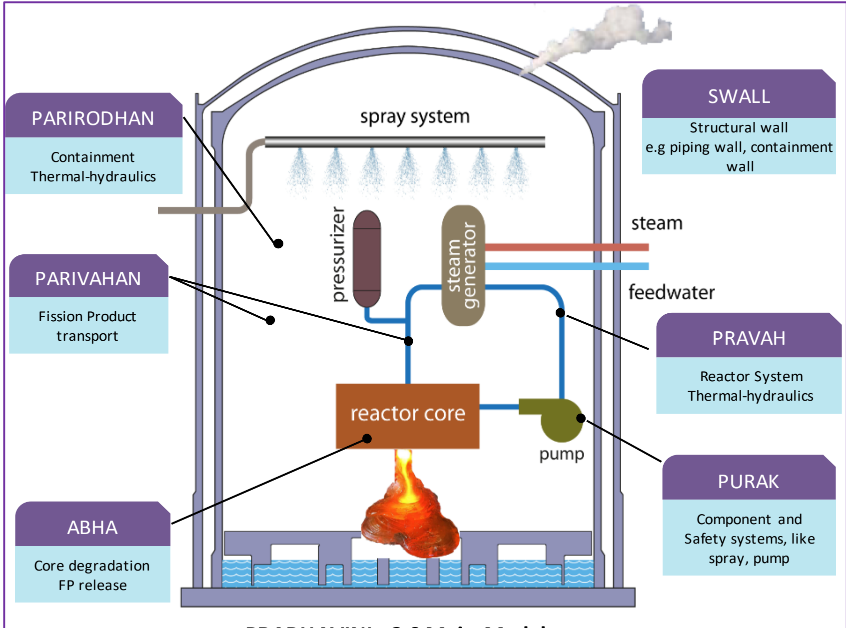
The released version 2.0 has five major modules namely PRAVAH (thermal-hydraulics), ABHA (Core Degradation), PARIVAHAN (fission-product transport), PARIRODHAN (Containment phenomena) and PURAK (system components). ABHA contains sub-modules SHAKTI (Point Kinetics), PARIRODHAN contains two sub-modules VAHITI (Containment thermal-hydraulics) and DAHAN (hydrogen combustion).
New features are added as well as modifications are done in the existing modules. Those are discussed in following sections.

ENGINEERING MODULES

ABHA

Important inclusions in this quarter in the ABHA module are listed below

- ***PT/CT contact conductance***: At high temperature PT would thermally sag or balloon and contact the CT partially or fully along the circumference. A semi-analytical formulation of the contact conductance based on Yovanovich model has been implemented. In the code, the model is tuned to work specifically with the PHWR PT/CT material properties. For



PRABHAVINI v2.0 Main Modules

HBNI M. Tech and Ph.D. Projects linked to Code Development Program

1. *Computational Model Development for Fuel Dispersion from Corium Jet and Associated Heat Transfer*, Shri Srijon Guha, AERB, M.Tech – ongoing
2. *Development and Validation of Reflood Model for Deformed LWR core*, Shri Vivek Singla, LWR-Directorate, NPCIL, M.Tech – ongoing
3. *Computational Model Development for Reactor Pressure Vessel Lower Head Heat Transfer, Shri* Aviral Chauhan, NPCIL, M.Tech – ongoing
4. *Study of PHWR Degraded Core Heat Transfer*, Shri Rajaganesh, DGFS- Ph.D., HBNI – ongoing

ballooning contact, the model predicts a PT/CT contact zone or distance within which the contact pressure is assumed to vary linearly from 1 atm pressure to the PT internal pressure. The model has been validated against experimental finding as described in validation and verification section.

- ***Pool boiling curve:*** In ABHA standalone mode, the user has the option to activate pool boiling around a structural component as a boundary condition. The model has the ability to predict heat transfer coefficient based on the surface temperature, encompassing the regime from single phase to film boiling.
- ***UDBT block*** *(User Defined Body Temperature):* User may define constant body temperature of a component using this block.
- User now can define initial axial variation of temperature of a component in the input deck. This helps in convergence and achieving faster steady state solution.

VIKIRAN

A new module VIKIRAN is introduced to estimate atmospheric dispersion of radionuclides and estimation of external and internal doses to member of public. Gaussian Plume model is used to evaluate the atmospheric dispersion of radionuclides using joint frequency distribution of wind data. One calendar year data (continuous hourly data) of wind speed classes, wind directions and stability classes A to F are used in calculation. External doses arise from cloud immersion of airborne radionuclides, plume shine, ground shine and internal doses arise from inhalation, ingestion of contaminated food are included in the estimation. Three routes are considered in estimation of ingestion dose viz. doses from food crop, meat and milk.

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VALIDATION & VERIFICATION ACTIVITY (V&V)

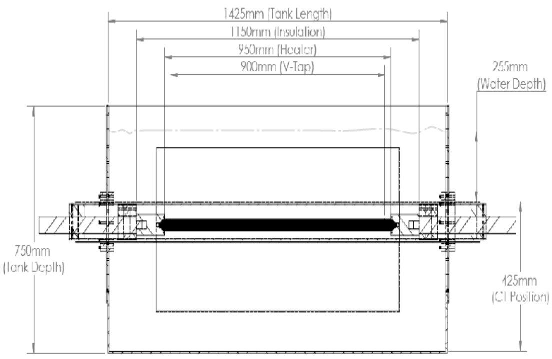
ABHA Module Benchmarking

The ABHA module of PRABHAVINI has been validated against the ICSP exercise (IAEA-TECDOC-1890)[1] which was floated by IAEA to assess the capabilities of computer codes used in predicting sub-cooling requirements for an overheated pressure tube, plastically deforming and contacting the calandria tube during a postulated large break loss of coolant accident. The experiment setup (shown in Figure titled schematic of the Test Section) comprised a short section of Zr-2.5Nb pressure tube mounted concentrically inside a Zircaloy-2 calandria tube. Both the pressure tube and calandria tube were free to expand during heating. The test section was submerged in distilled light water in an open tank. A graphite rod heater was placed inside PT to heat the PT through radiation mode. Argon was supplied inside the pressure tube and Carbon dioxide in the PT/CT annulus. During the test, the pressure tube was pressurized to 3.5 MPa and heated with a power of 164 kW/m. The power is maintained till pressure tube contacted the calandria tube.

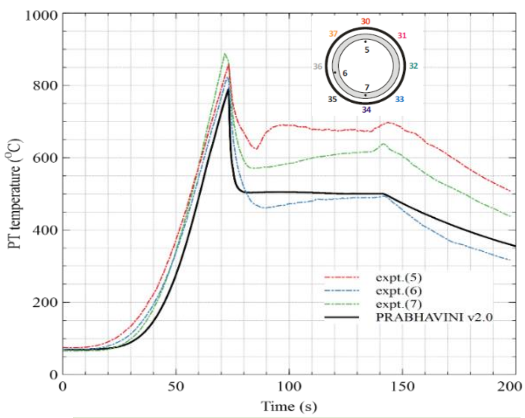
Data relevant to following phenomena were measured for assessment of computer codes - a) radiation heat transfer to the pressure tube, b) pressure tube deformation or failure, c) pressure tube to calandria tube heat transfer, d) Calandria tube to moderator heat transfer, and e) Calandria tube deformation or failure. PT/CT contact conductance obtained from inverse calculation was also provided for comparison. Sequence of events as observed in the analysis and in the experiment are shown in Table 1. PT temperature at mid-section is plotted in Figure titled PT Temperature Evaluation. PT contacts the CT at time t = 75.23 s and at temperature of 790 °C. It is observed that the code predicted lower PT/CT contact temperature in comparison to the experiment. This deviation is attributed to the eccentric placement of graphite heater in the experiment which could not be simulated in the code due to limitations in the existing model. After PT/CT contact, the pressure tube temperature reduced sharply and the calandria tube temperature showed a momentary rise to a peak value of 358 °C and dropped to 117 °C. Calandria tube temperature is plotted in Figure titled CT Temperature Evaluation. During contact, CT surface entered into transition boiling and later it remained in nucleate boiling till the end of analysis. In the experiment, the CT temperature measurements show large variation along the circumference from the bottom to the top which could not be captured by PRABHAVINI code as it evaluates temperature in 'r-z' direction only. The calculated and the experimentally derived contact conductance between PT and CT are shown in Figure titled Calculated PT/CT Contact Conductance. The peak conductance of 21.7 kW/m²/K predicted by the analysis is in good agreement with the experimental value of 20 kW/m²/K. After the first PT/CT contact, the CT expanded and the PT shrinked due to sudden change in temperature. This lead to the release of contact and drop in the contact conductance.

Table 1: Sequence of events

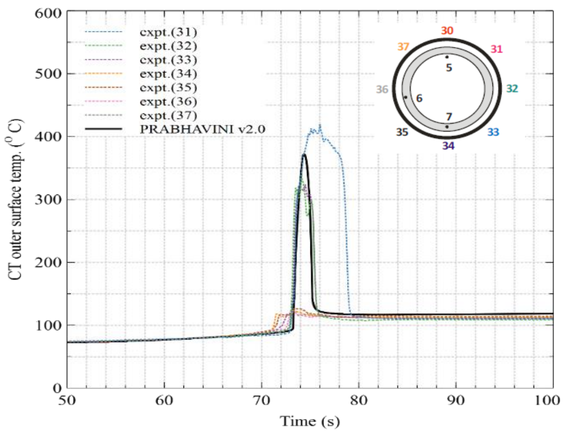
Events	Experiment	PRABHAVINI
Initiation of transient	0. s	0. s
Time to reach 142 kW	20. s	20. s
Depressurization started	135.4 s	135.4 s
Power off	140.8 s	140.8 s
Depressurization complete	179.0 s	179.0 s
End of transient	200.0 s	200.0 s
First PT/CT contact (TC5/TC6/TC7)	73/72.6/71.4	73.25 s
PT contact temperature (TC5/TC6/TC7)	858/823/889	787 °C
Peak CT temperature (TC30/TC31/TC32/TC33/TC34 /TC35 /TC36 /TC37)	540/411/326/320/123/126/120/124	365 °C
Maximum value of Contact conductance	20 kW/m²/K	21.7 kW/m²/K



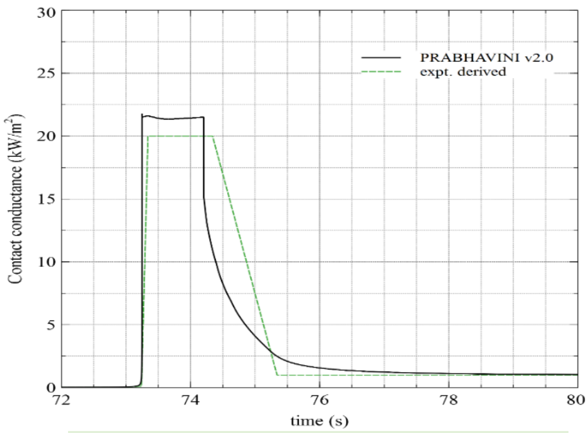
Schematic of the Test Section



PT Temperature Evolution



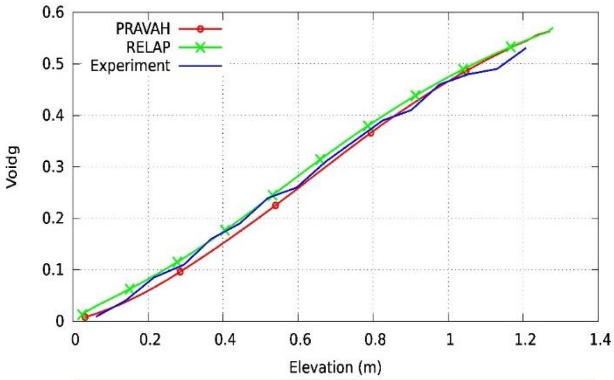
CT Temperature Evolution



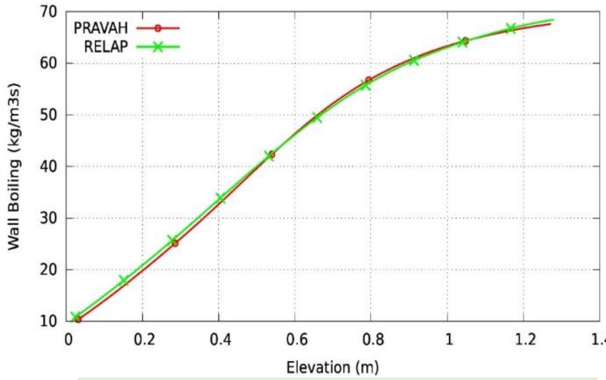
Calculated PT/CT Contact Conductance

PRAVAH Module Benchmarking

The wall boiling and wall heat flux apportionment model used in Heat Transfer Module of PRAVAH is assessed using the data from a separate-effects, sub-cooled nucleate boiling experiment conducted by Christensen[2]. The test section used for Christensen's problem consists of a vertical rectangular tube with 1.11 x 4.44 cm internal dimensions, wall thickness of 0.9 mm and 127 cm height[2]. The tube is heated by passing an AC current through the tube walls to produce 70 kW power. The test section is maintained under a pressure of 5.512 MPa and water is injected into the test section from bottom at a constant mass flux of 907.3 kg/m^2s with 12.5 K of sub-cooling. The void fraction along the length of the test section was measured by a gamma ray densitometer.



Void Fraction Variation for Christensen Boiling Problem

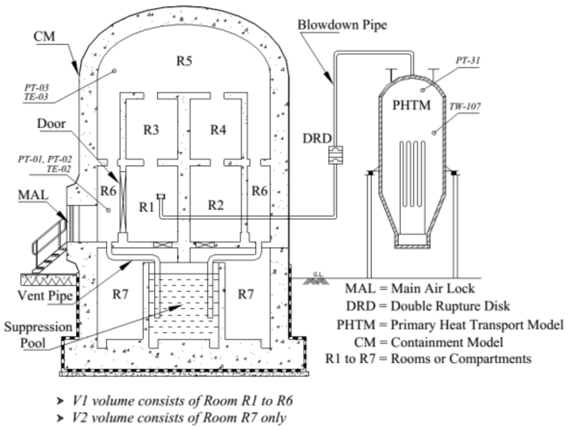


Wall boiling for Christensen Boiling Problem

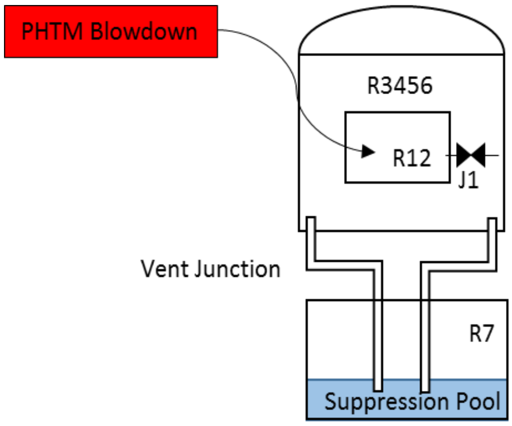
Figure titled void fraction variation for Christensen Boiling Problem shows the prediction of void fraction variation along the elevation of test section by PRAVAH module and its comparison with Christensen's experimental data and RELAP5[3] simulations. PRAVAH is able to capture the evolution of void fraction accurately. Figure titled Wall boiling for Christensen Boiling Problem shows a good agreement between predictions of wall boiling rate by PRAVAH with that of RELAP5.

PARIRODHAN Module Benchmarking

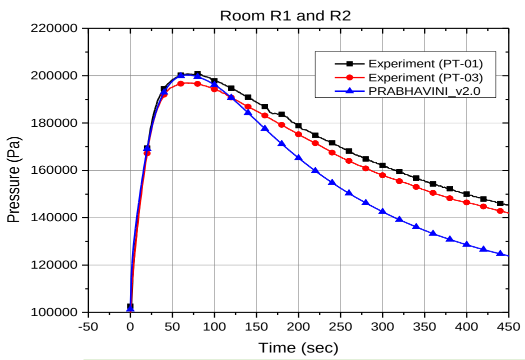
Validation of the PARIRODHAN module is carried out against Containment Studies Facility (CSF) developed by Containment Studies Section, RSD, BARC[4]. The facility (shown in Figure titled Schematic of Containment Studies Facility) consists of a) Containment model: The facility is 1:250 (approx.) volumetrically scaled down model of the prototype standardized 220MWe Pressurized Heavy Water Reactor (PHWR). The containment model consists of two floors and a basement. The two floors constitute volume V1 which contains 6 rooms and the basement forms the volume V2. The suppression pool is also a part of volume V2. Both volumes V1 & V2 are connected by vent system with down comers which are partially submerged in the suppression pool. b) Primary Heat Transport Model system (PHTM): PHTM system is provided to simulate the blow-down mass and energy discharge into the containment model during postulated accident scenario. The validation exercise has been carried out for 75 bar blow-down case where the pressure and temperature transient of Volume V1 and V2 are compared. The peak pressure and time of occurrence in containment model for V1 and V2 volumes are in good agreement with the experimental result. Figures titled room R12 (room 1 & 2) pressure and temperature shows the validation exercise. Similar trend is observed using other codes such as CONTRAN and ASTEC[5] for the analysis.



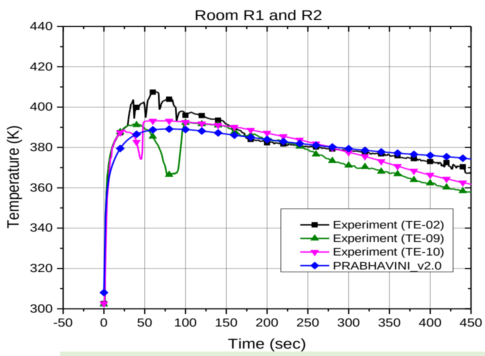
Schematic of Containment Studies Facility



Nodalization of Containment Studies Facility



Pressure Transient of COMPARTMENT - R12



Temperature Transient of COMPARTMENT-R12

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3. RELAP5/Mod3 Code Manual: Developmental Assessment Problems, Volume 3, NUREG/CR-5535, 1990.
4. Thangamani, I., Dutta, A., Shanware, V. M., Verma, V., & Singh, R. K. (2014). Analysis of the CSF model for simulated loss of coolant accident conditions. Kerntechnik, 79(2), 111-122.
5. Dutta A, Thangamani I, Shanware VM, Rao KS, Gera B, Kiran AR, Goyal P, Verma V, Sharma PK, Agrawal MK, Ganju S. Experiments and analytical studies related to blowdown and containment thermal hydraulics on CSF. Nuclear Engineering and Design. 2015 Dec 1; 294:233-41.