R&D Highlights Towards Severe Accident Investigations

P. Chellapandi
Director, Reactor Design Group
Indira Gandhi Centre for Atomic Research
Kalpakkam

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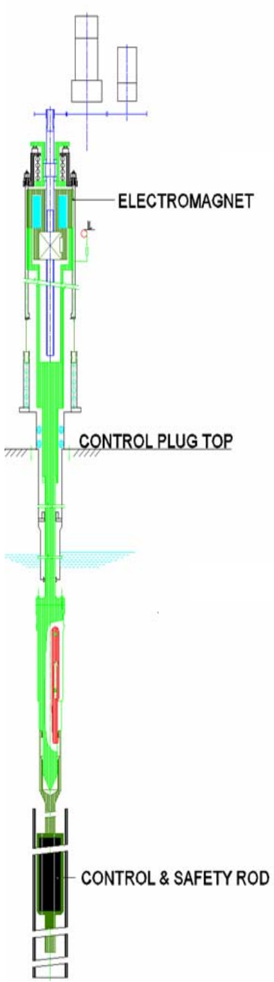
Highlights

- Qualification of reactor shutdown and decay heat removal systems
- Mechanical and thermal consequences of core disruptive accident

Testing of Shutdown Systems of PFBR



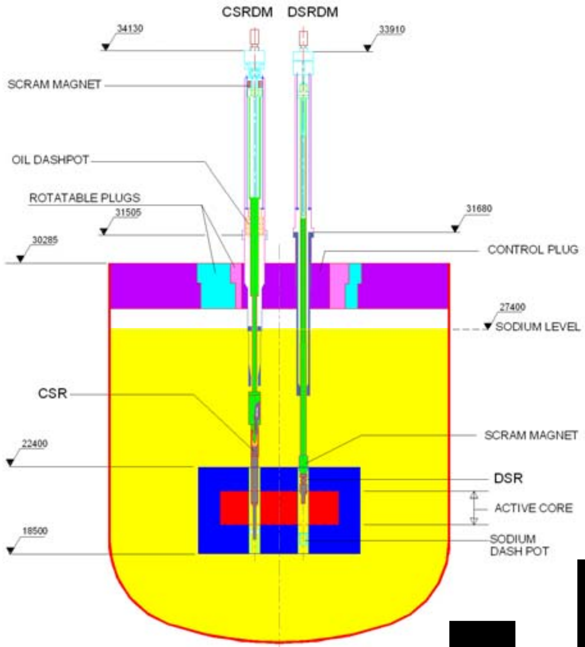
CSR & CSRDM

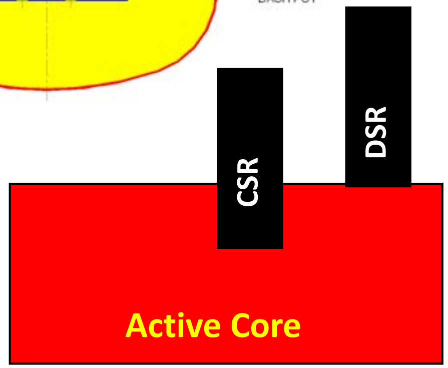
Upper & Lower Parts of CSRDM

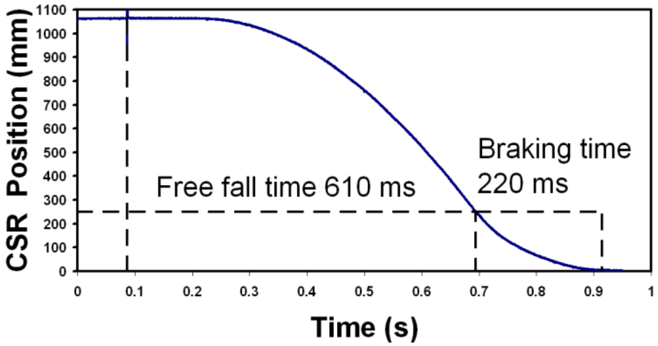
No. of Scram cycles tested in Na

at 803 K : 500

at 823 K : 1093

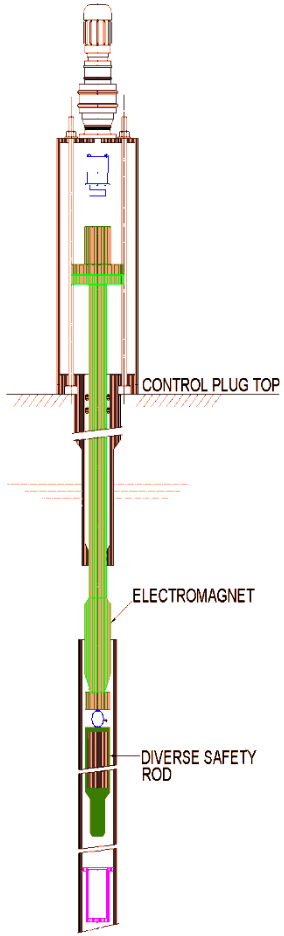






Drop time of CSR : 610 ms < 1 s

Upper & Lower Parts of DSRDM



DSR & DSRDM

No. of cycles tested in Na

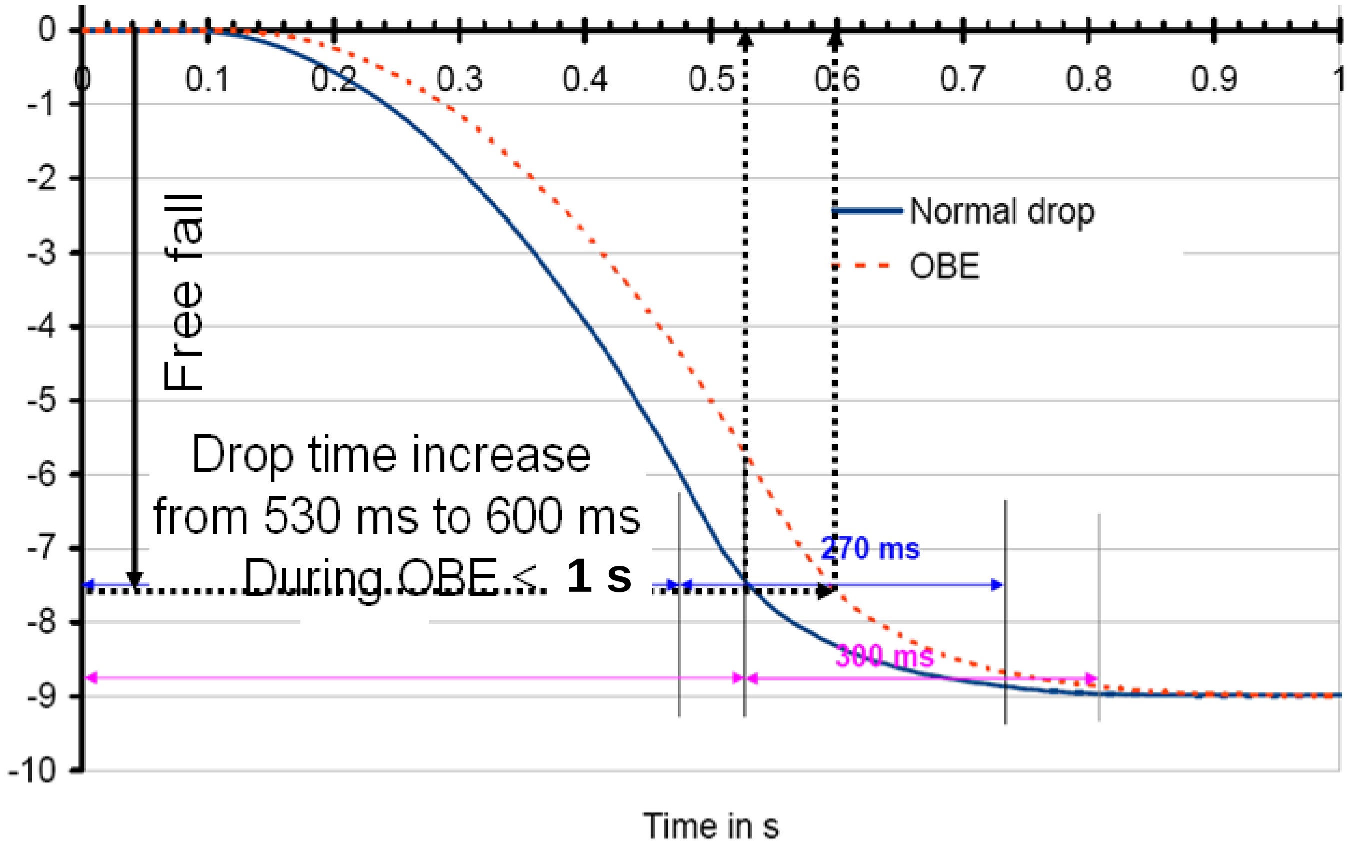
(Scram) at 773 K : 186

(Translation) at 670 K : 986

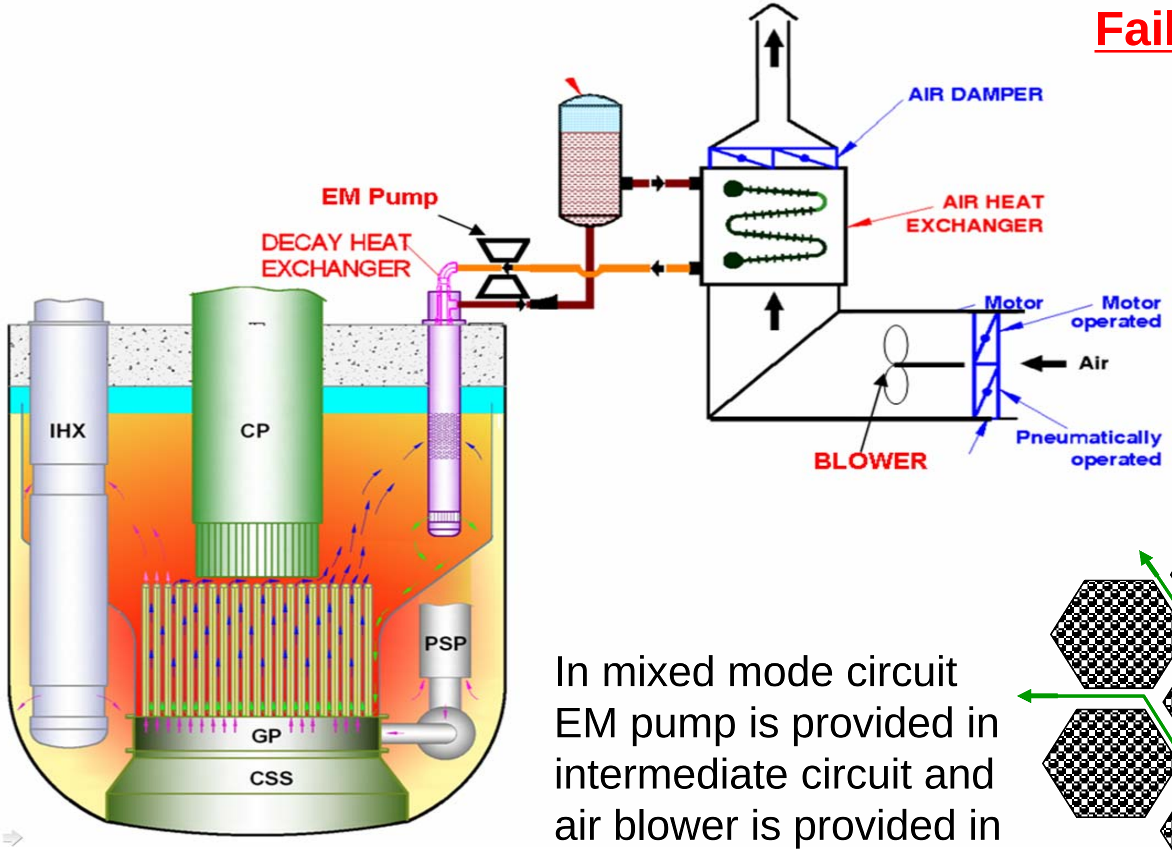
Drop Time of Absorber Rods during EQ

Horizontal excitation is simulated using three actuators at following levels

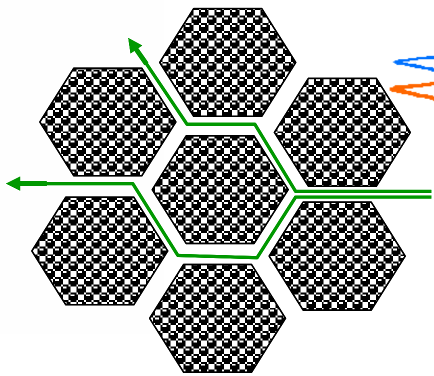
1. Grid plate top level
2. Button level of hexagonal subassembly
3. Control plug top level



Safety Grade Decay Heat Removal System

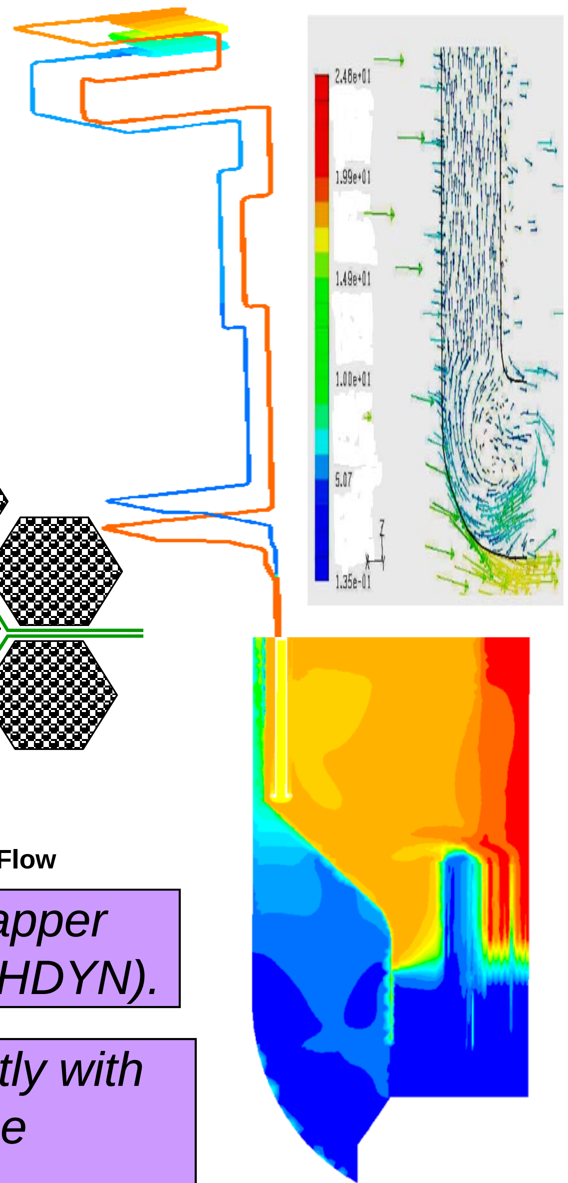


In mixed mode circuit EM pump is provided in intermediate circuit and air blower is provided in air circuit.



Inter Wrapper Flow

Failure of all Pumps



Analysis with multi-dimensional model for pools with inter-wrapper space (StarCD) and 1-D model for equipments and piping (DHDYN).

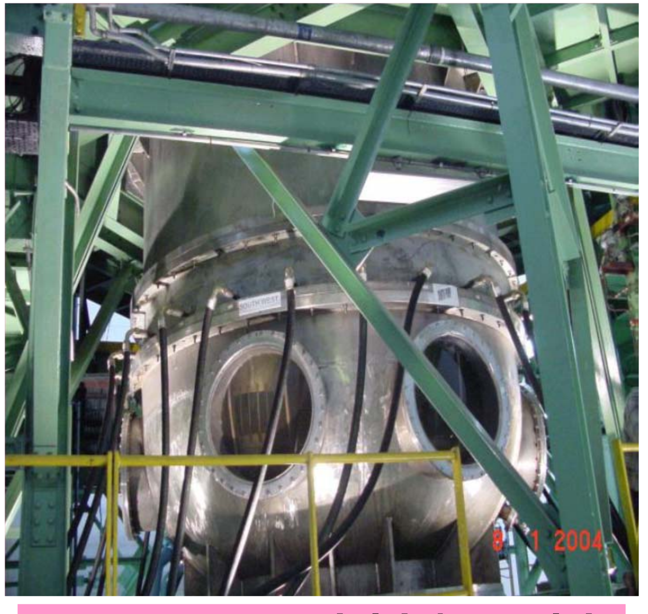
Availability any two circuits for 7 h and one circuit subsequently with primary circuit under natural convection is sufficient to limit the temperatures below category 4 limits

Performance Evaluation of DHR Capability

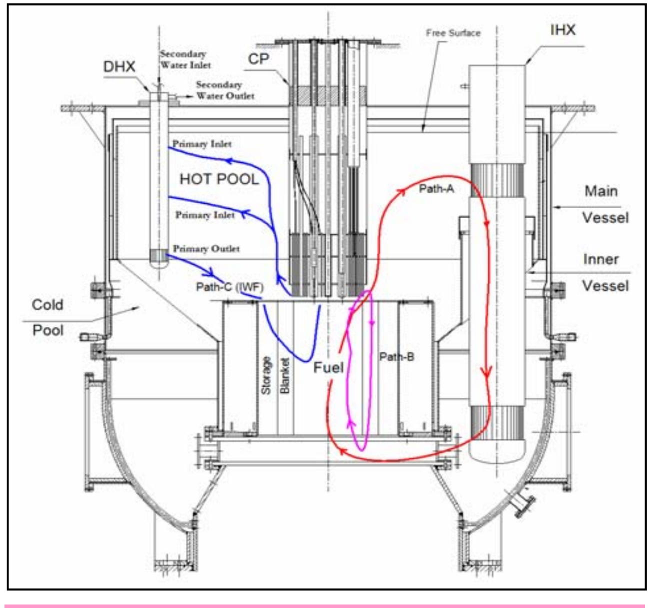
- Temperature & flow distributions in the hot pool
- Confirmation of SGDHR system Performance
- Assessment of Inter Wrapper Flow contribution

<u>Facilities Utilized</u>

FBTR, SAMRAT and SADHANA (1:22)



SAMRAT Model (1/4 scale)



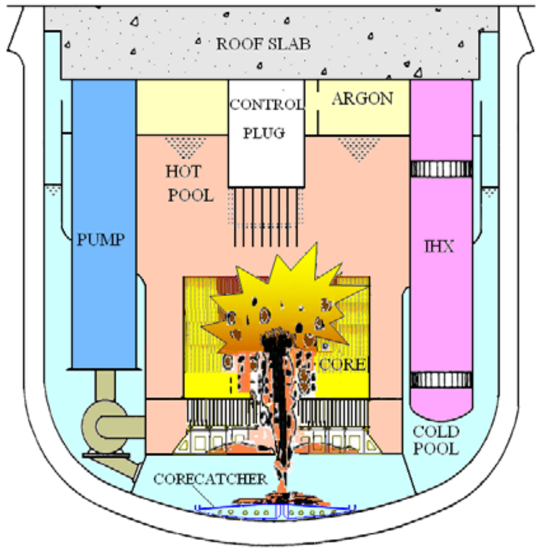
Natural convection flow paths

SADHANA loop

Investigation of CDA Consequences

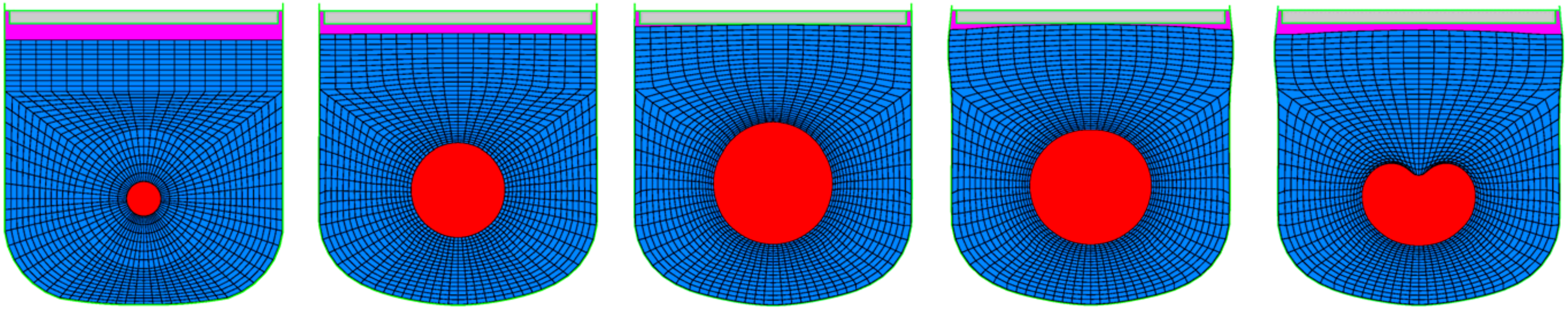
- Structural integrity of primary containment (main vessel with top shield)
- Structural integrity of reactor containment building consequent to sodium fire
- Post Accident Heat Removal Capacity

- Core catcher integrity
- DHX integrity
- Integrity of SGDHR piping
- Debris coolability (debris charcateristics and dispersion pattern) and
- Natural convection path within Na pools



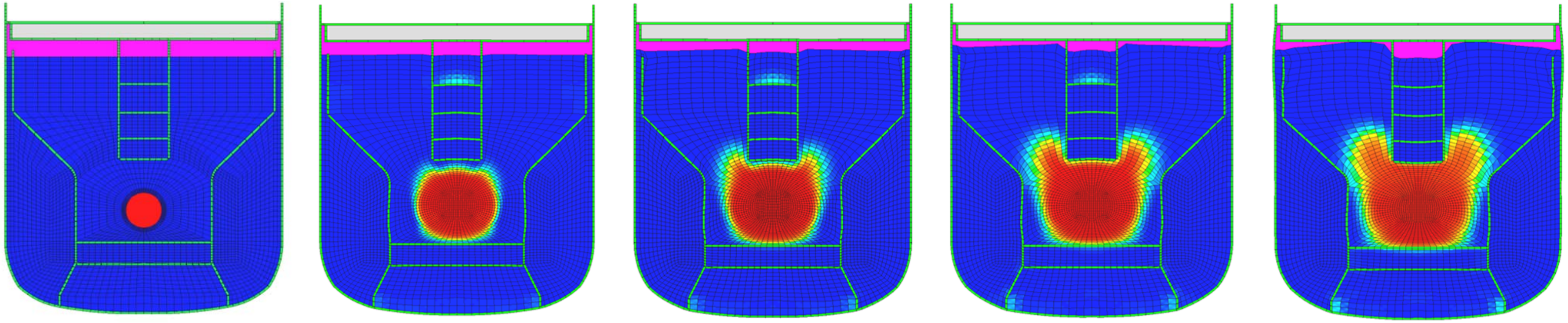
For PFBR, 100 MJ is the mechanical energy release arrived at based on conservative analysis

Transient Response under CDA (100 MJ)



a. 0 ms b. 50 ms c. 100 ms d. 150 ms e. 200 ms

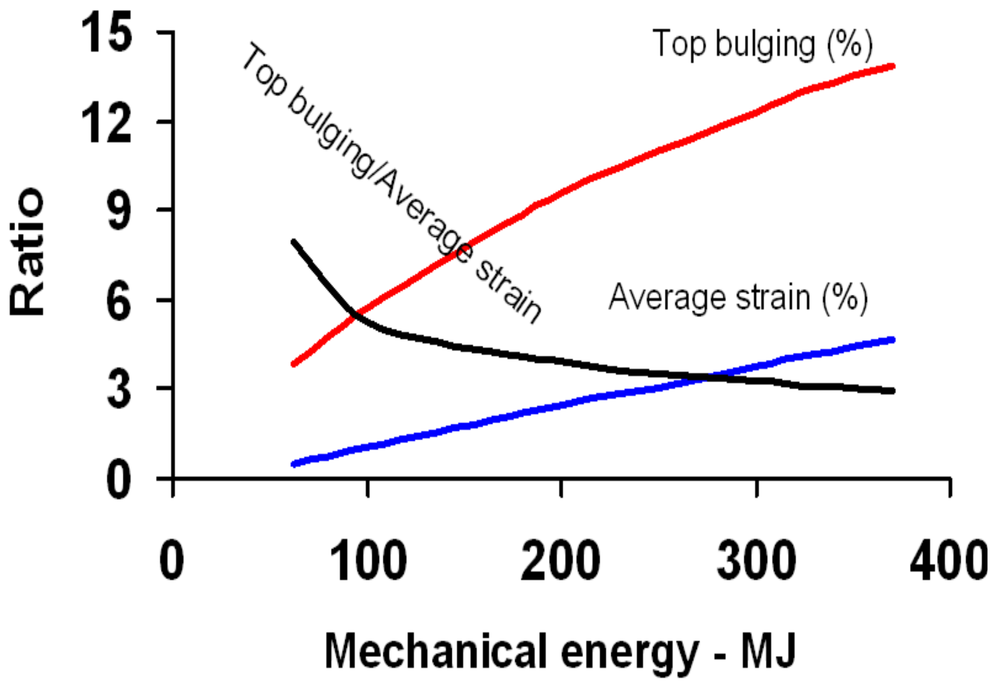
Analysis-1: Main vessel without internals

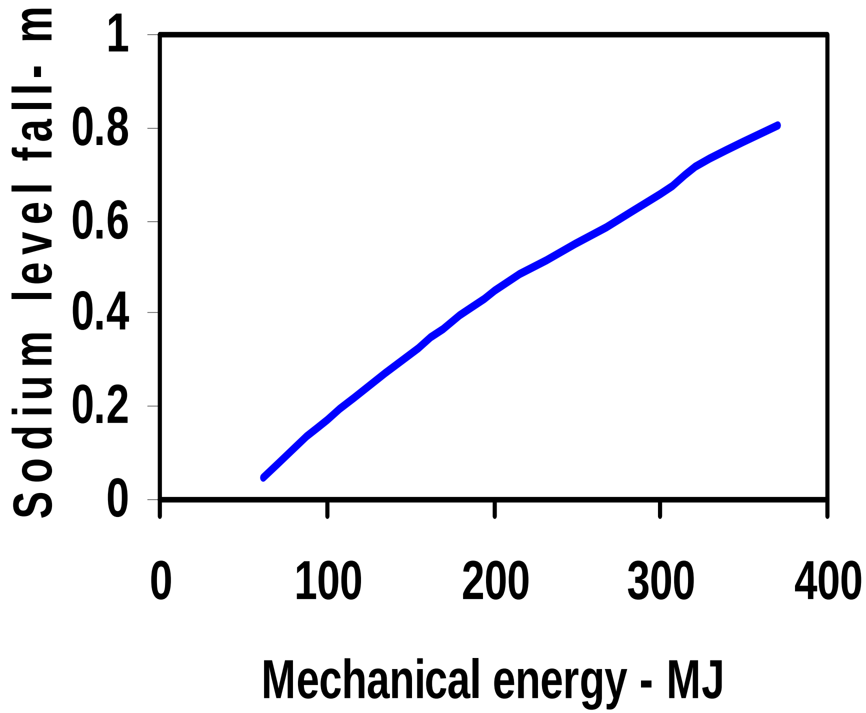


f. 0 ms g. 50 ms h. 100 ms i. 150 ms j. 200 ms

Analysis-2: Main vessel with internals

Effects of Higher Energy Release





Strain tends to become uniform at higher energy, enhancing the energy absorbing potential of main vessel

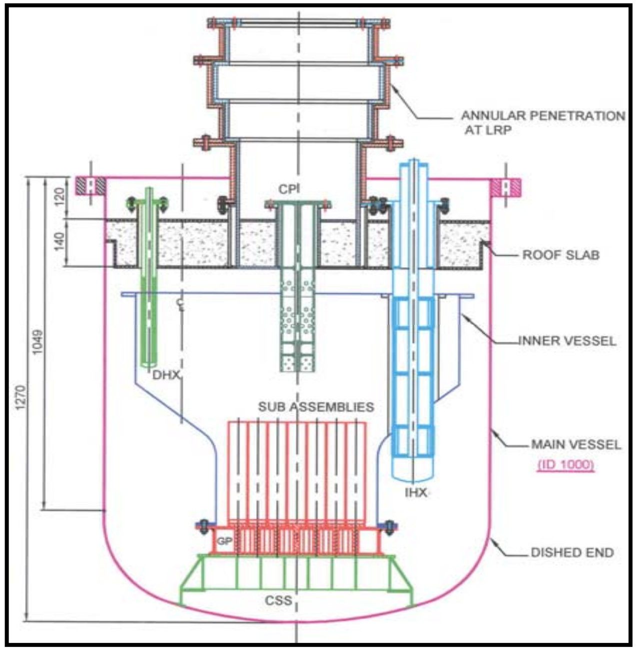
Fall in sodium level within acceptable range w.r.t functionality of DHX

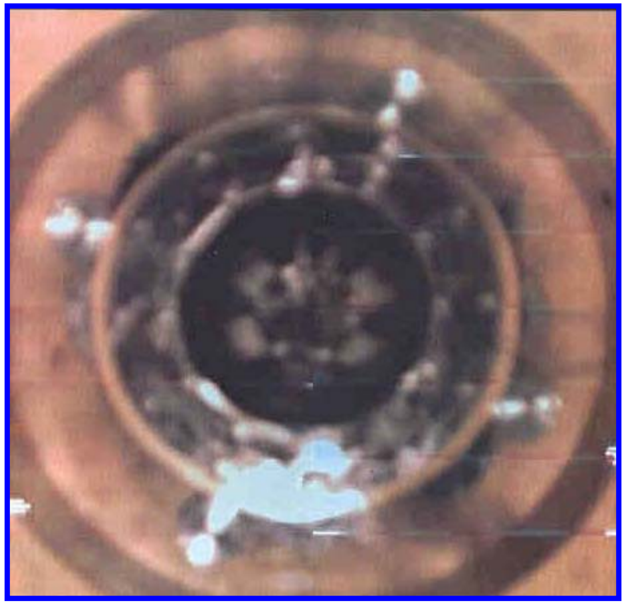
No cliff edge effect even if mechanical energy exceeds about 400 % of design value

Integrity of Main Vessel, Top Shield and DHXs

11 Tests on 1/13th scale mockups to demonstrate the structural integrity of DHX and to simulate sodium leak

Main vessel capacity	=	1200 MJ
DHX capacity	=	500 MJ
Maximum sodium leak	=	275 kg for 100 MJ





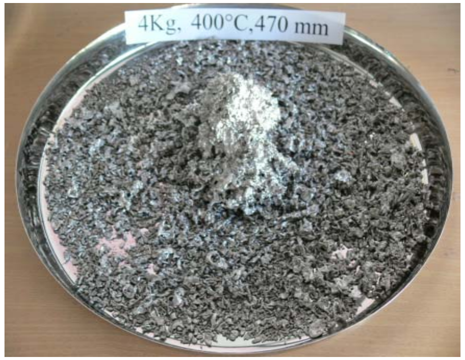
Simulation of Melt though Phenomena

- Woods metal is used to simulate hyrodynamic characteristics of Liquid UO_2.
- Ratio of core excess energy to   energy needed to melt grid plate is simulated
- Result highlights the above phenomena and defines the requirements for realistic modeling of CDA consequences

Melt mass 20 kg

Melting of top GP

Melting of bottom GP

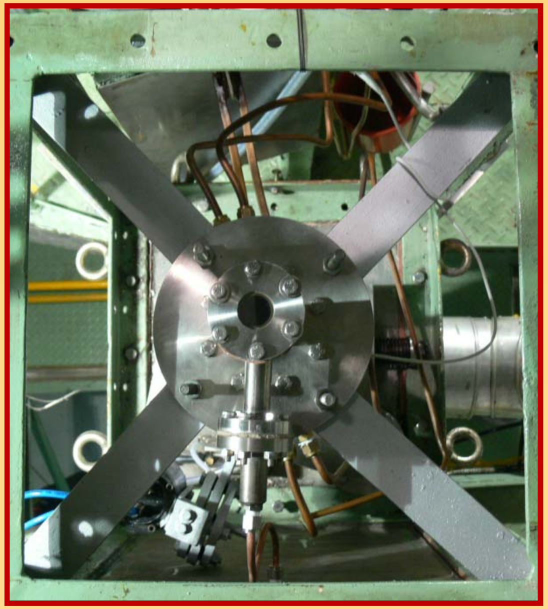


Debris on CC

SOFI Facility – Experimental Program

- **<u>Phase – I</u> (Induction heating of notional mass)**
  - ❑ (*U metal + SS) – Sodium system using melt mass ~ 1 kg*
  - ❑ (*U oxide + SS) – Sodium system using melt mass ~ 1 kg*
- **<u>Phase – II</u> (Induction heating of small mass)**
  - ❑ (*U metal + SS) – Sodium system using melt mass < 20 kg*
  - ❑ (*U oxide + SS) – Sodium system using melt mass < 20 kg*
- **<u>Phase – III</u> (Plasma heating of large mass)**
  - ❑ (*U metal + SS) – Sodium system using melt mass > 20 kg*
  - ❑ (*U oxide + SS) – Sodium system using melt mass > 20 kg*

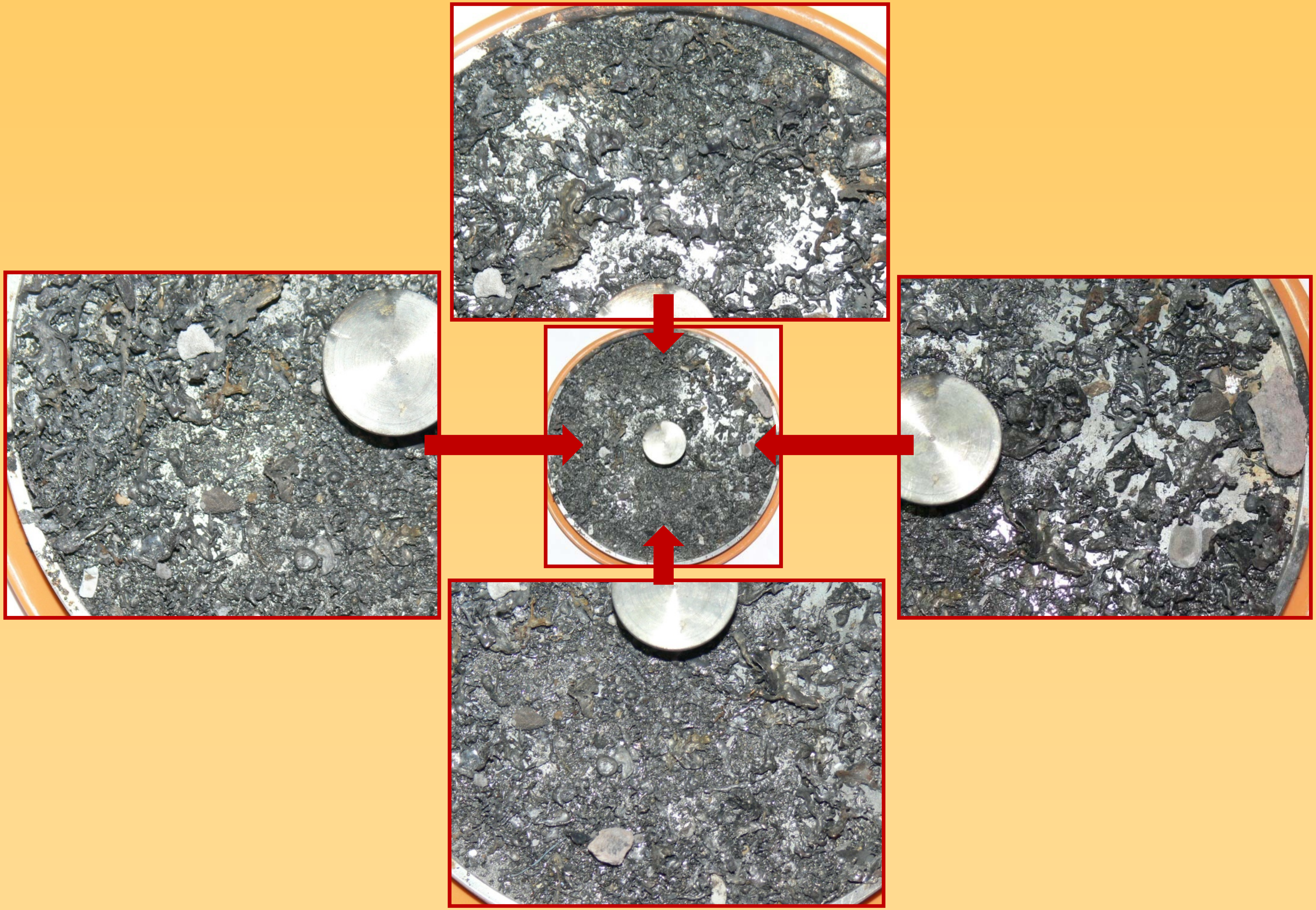
Crucible, coil and release valve



Crucible top assembly

Facility view from control room

Debris bed on Catcher Plate - (U+SS) in Na



Few results from Experiments (else-where) with U and UO_2

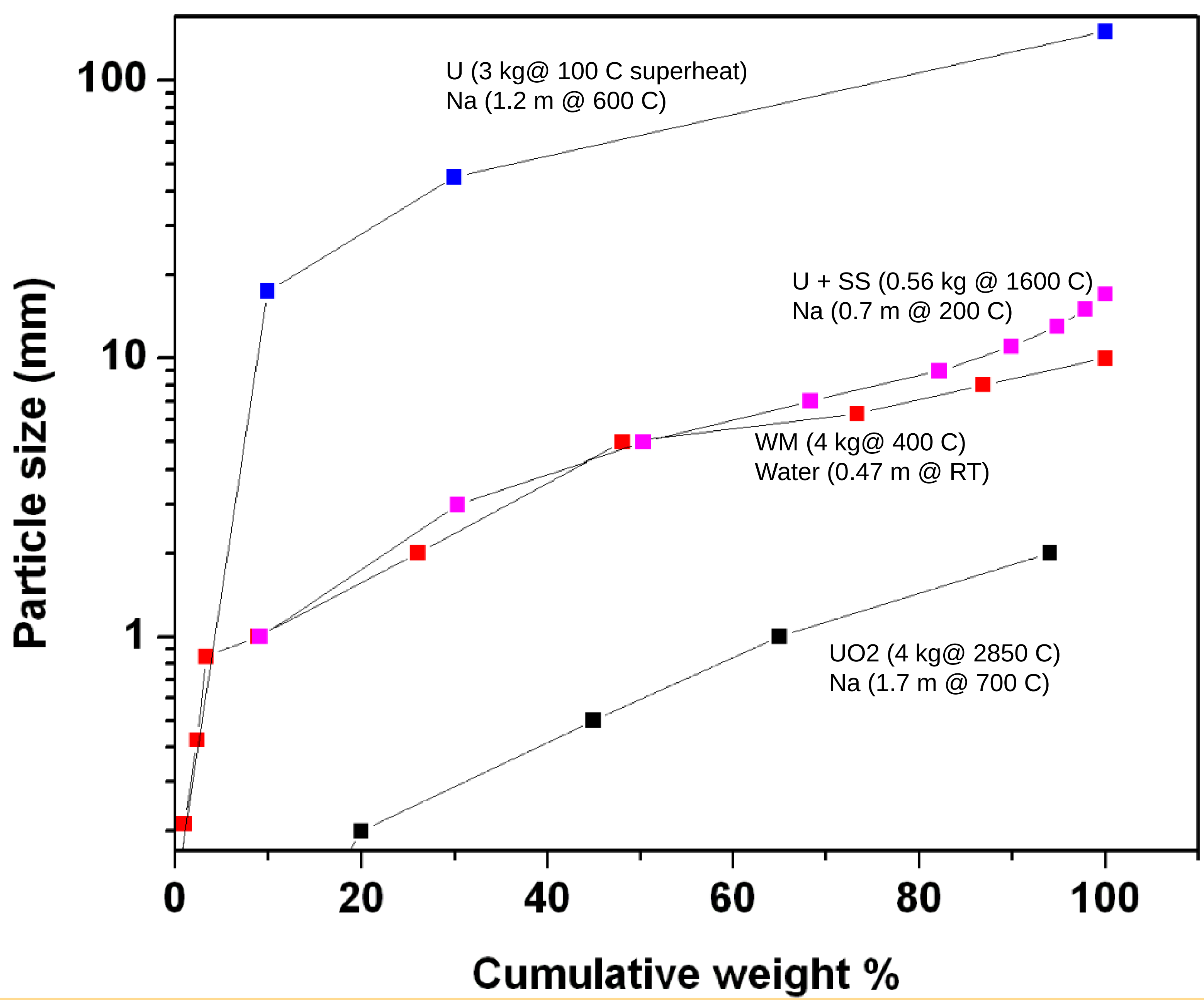
Exp ref	Fuel	Coolant	Objectives	Observations
1	U-Metal 3 kg @ 100 ^{0}C superheat	Sodium 1.2 m ht @ 600 ^{0}C	Break-up behaviour of kilogram quantities of molten uranium, in sodium are studied	-No energetic event -Debris from the meltdown of metal-fuel would be largely coolable by conduction alone
2	UO_2 10 ~ 20 g @ 3020 ^{0}C	Sodium 50 ~ 200 CC vol @ 200~300 ^{0}C	Experiments conducted drop wise to obtain information on the fragmentation of UO2 when dropped in liquid sodium	-Extensive fragmentation of droplets - Only feeble pressure pulses
3	UO_2 4 kg@ 2850 ^{0}C	Sodium 160 kg @ 350 ~ 700 ^{0}C	To study the boiling and fragmentation behaviour during MFCI	-No Energetic FCI - Transition boiling is the initial mechanism for fragmentation

1 - J. D. Gaber at al. 'Breakup and quench of molten metal fuel in sodium',
ANL, ANS Safety Mtg, May 1-5, 1988, Seattle, WA.

2 - Hiroshi MIZUTA, 'Fragmentation of uranium dioxide after molten uranium dioxide-sodium interaction'
Vol 11, P 480-487, Nov – 1974, Journal of Nuclear Science and Technology

3 - H. SCHINS, 'Boiling and fragmentation behaviour during fuel-sodium interactions'
(JRC BETULLA Facility) Vol 91, p 221 – 235 , 1986, Nuclear Engineering Design

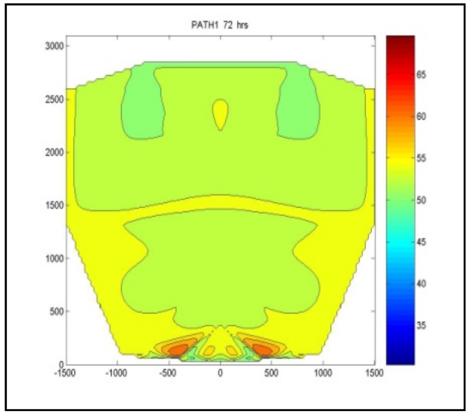
Overall Comparison of various results

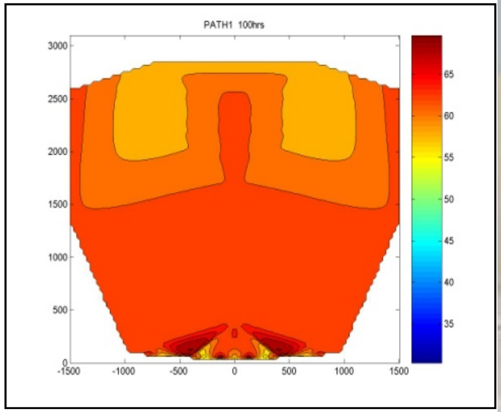


Experimental Studies on PAHR Conditions

- Validation of core catcher and SGDHR concepts
- Confirmation of natural convection flow paths through perforation formed in the grid plate due to melt through of the molten fuel
- Data for the validation of numerical simulation tools

Simulation of natural convection within the 1./4th scaled down water model of RA. Core debris simulated lwith woods metal debris dispersed on the core catcher plate

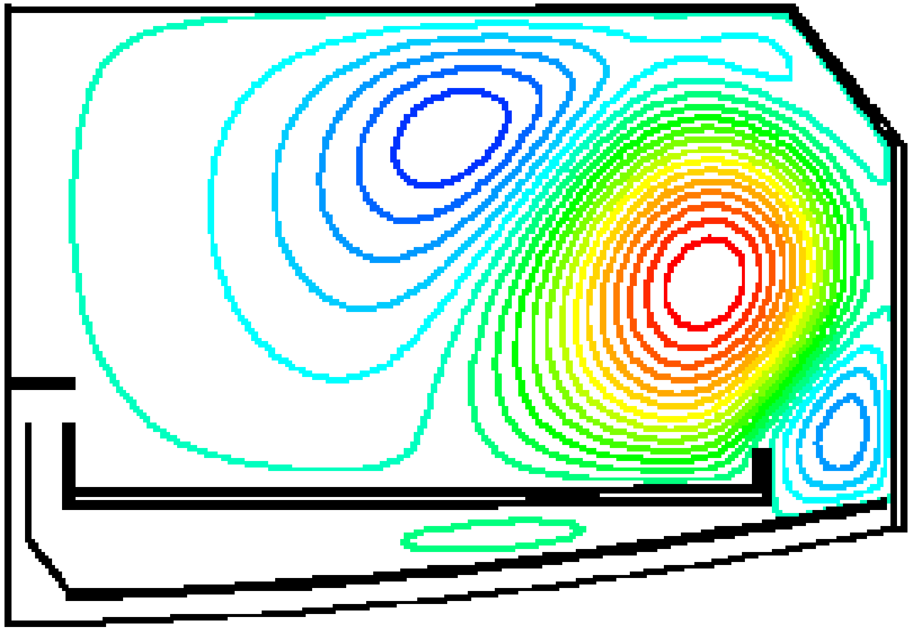




Mapping of temperature evolution

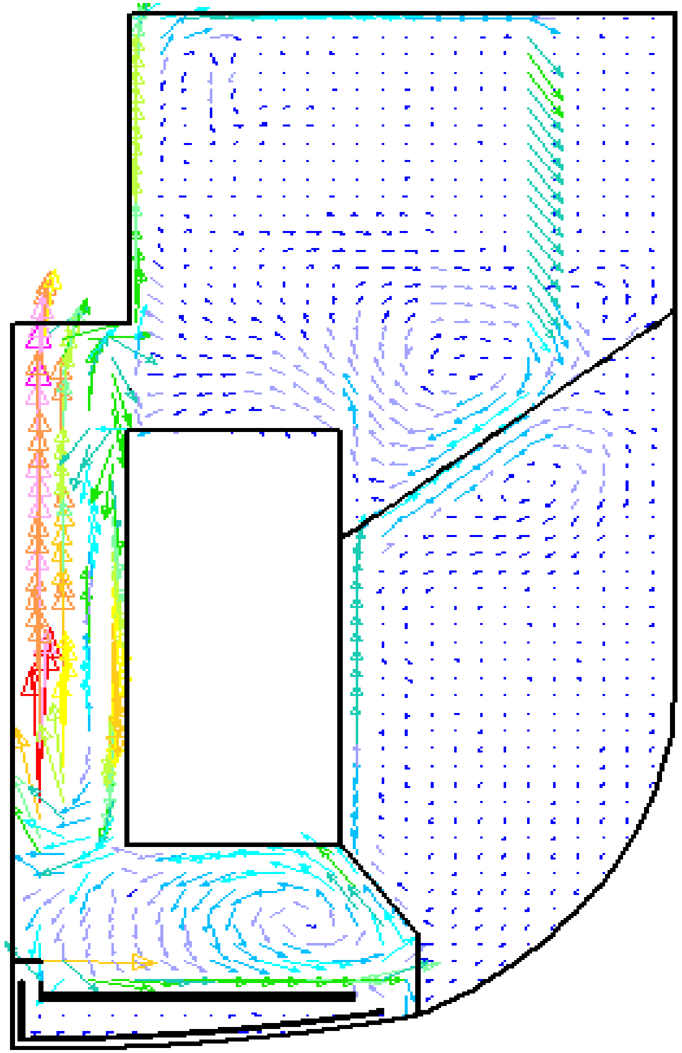
PATH: 1/4th Scaled down model of RA

Post accident scenario



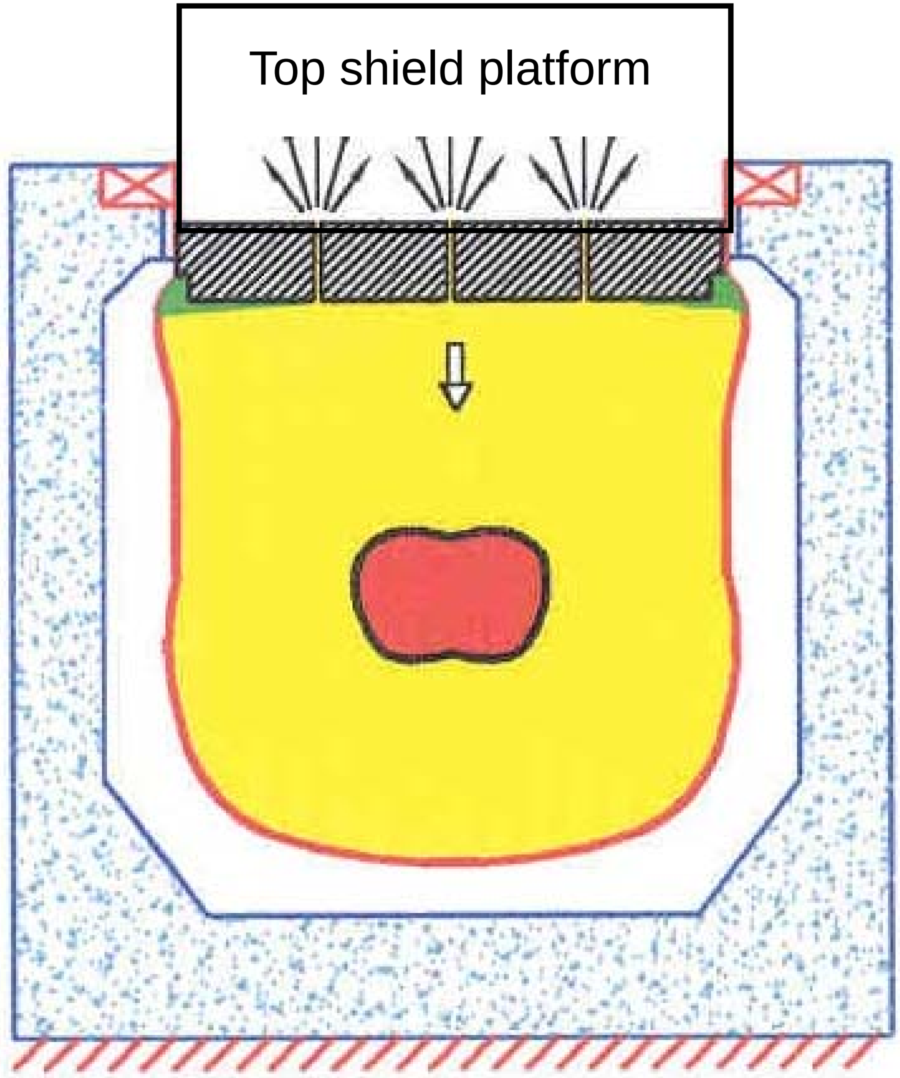
Debris bed cooling

<u>Imp. Aspects</u>
(a) Coolant boiling
(b) Dryout



Heat rejection to DHX through natural convection path

Structural Integrity of SGDHR Piping

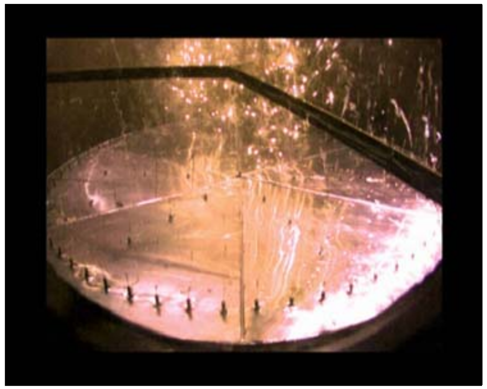


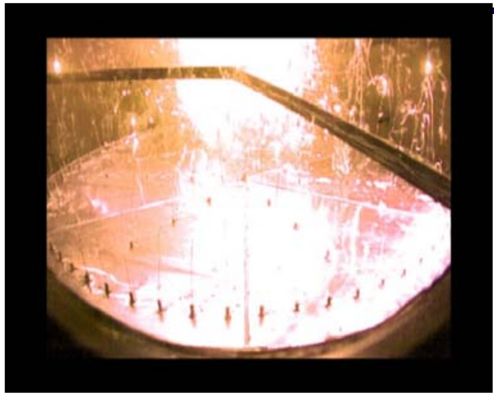
- **Effect of sodium fire followed by cable fire (secondary fire) including insulation materials on the integrity of Safety Grade Decay Heat Exchanger piping passing thro' Top Shield Platform**
- **Theoretical analysis indicates that the maximum temerature rise is about 250o C for the sodium release of 350 kg.**

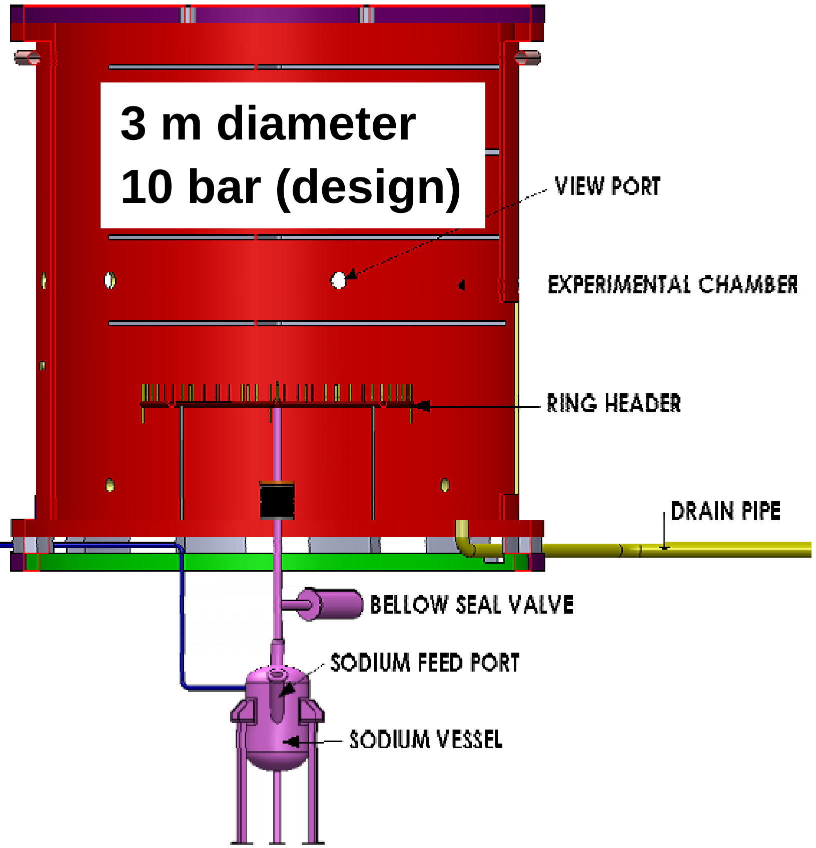
SOCA Facility

Experimental demonstration of structural integrity of SGDHR pipings

The jets of sodium are created by means of a ring header which contains equally distributed nozzles of 1.5 mm dia. along the circumference.







Conclusion

To achieve enhanced safety, emphasis is given on the following aspects

- **Systematic R&D program (short term and long term)**
- **Gaining vast experience**
- **Innovations**
- **Attracting young minds**
- **Developing inter- disciplinary expertise & breakthroughs**

Future Directions

- **Experimental and Numerical Simulation of individual Phenomenon**
- **Coupled Code Development (neutronics, thermal hydraulics, chemical and mechanical)**

Thank you