Experimental Studies Towards SFR Safety

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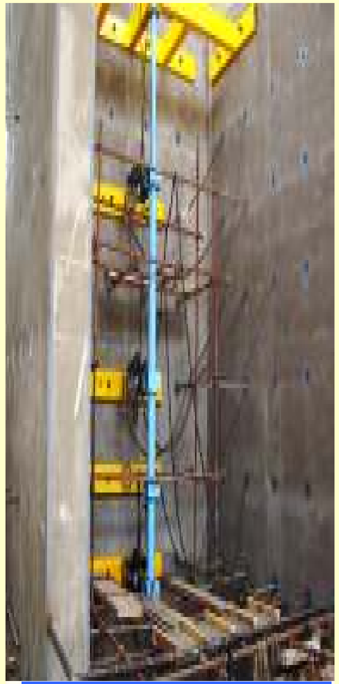
Objectives of Experimental Safety Studies

- Confirmation of Seismic Design Criteria
- Performance Evaluation of DHR Capability
- Recommendation of Design Provisions for Mitigating gas entrainment
- Validation of Mechanical Consequences of CDA
- Simulation of Post Accident Heat Removal Scenarios
- Understanding of Science and Technology of Sodium Fire and Its Effects

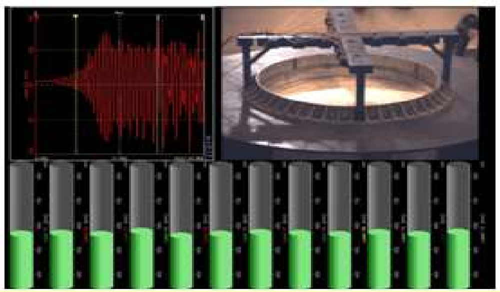
Confirmation of Seismic Design Criteria

Tests completed for PFBR

- **Sloshing of sodium free levels**
- **Dynamic buckling of thin shells (MV, SV, IV and TB)**
- **Dynamics of core SAs including core lift-off tests**
- **Pump instability and seizure**



ARDM model



Sloshing and Dynamic buckling of thin shells

Core lift-off

Pump Seizure

Structural Redundancy Assessment

- **In order to ensure the structural integrity under level D loadings, in the present case under SSE loading, collapse load is estimated with the possible uncertainty.**

Model No.	Firm (Make)	Collapse Load (t)	Load factor for PFBR		
			Normal	OBE	SSE
1.	I – 1	3756	4.08	2.85	2.18
2.	I – 2	4229	4.60	3.20	2.46
3.	II – 5	3020	3.28	2.29	1.76
4.	I – 3	4268	4.64	3.23	2.48
5.	II – 1	2889	3.14	2.19	1.68
6.	I – 4	3231	3.51	2.45	1.88
7.	II – 2	2692	2.93	2.04	1.57
8.	II – 3	2338	2.54	1.77	1.36
9.	II – 4	1642	1.78	1.24	0.95

Minimum required load factor - 1.5 (OBE) and 1.1 (SSE)

For Future SFRs

- Currently tests carried out mainly with 10 t capacity, 3x3m shake table
- 100 t , 6x6 m size shake table is under construction at IGCAR

Integrated Tests for Future SFRS planned

- Simulation of dynamics of Core SAs and Absorber rods drive mechanisms
- Dynamic buckling of thin shells with fluid structural interactions
- Seismic qualification of sodium piping with seismic snubbers

Objectives

- Optimum vessel thickness
- Optimum number of snubbers
- Higher confidence in seismic integrity

Performance Evaluation of DHR Capability

Investigations completed for PFBR

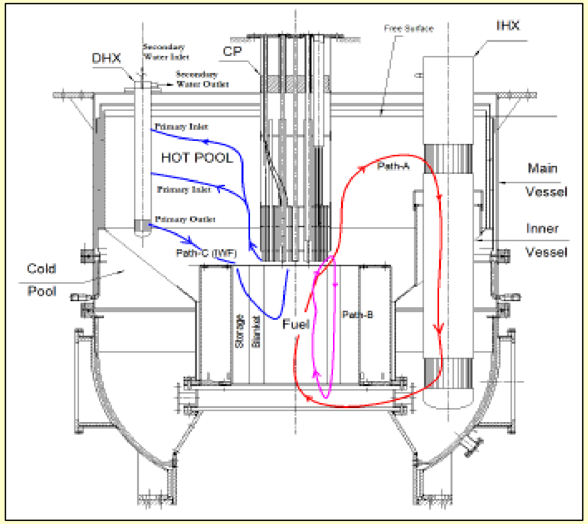
- **Temperature & flow distributions in the hot pool**
- **Confirmation of SGDHR system Performance**
- **Assessment of Inter Wrapper Flow contribution**

Facilities Utilised

FBTR, SAMRAT and SADHANA

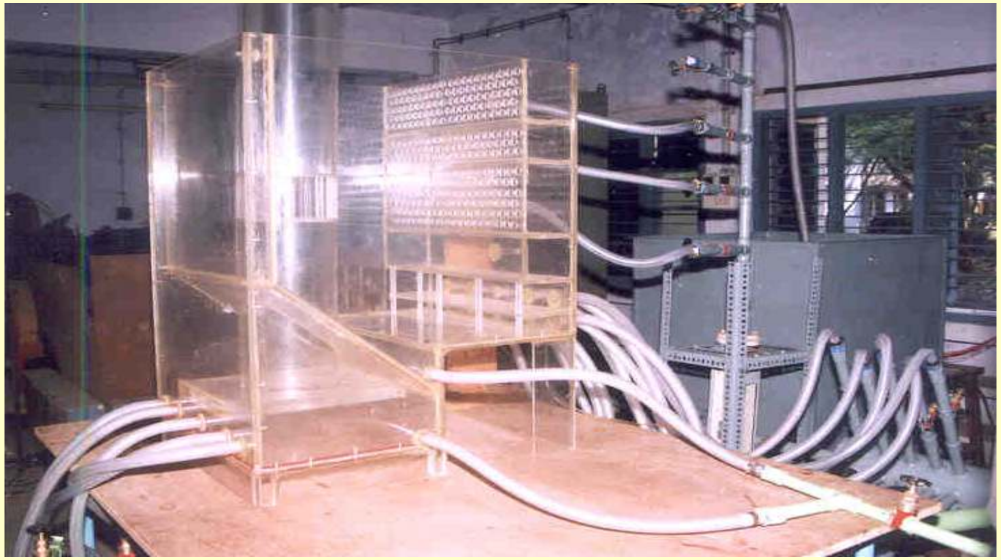
SAMRAT Model (1/4 scale)

SADHANA Loop

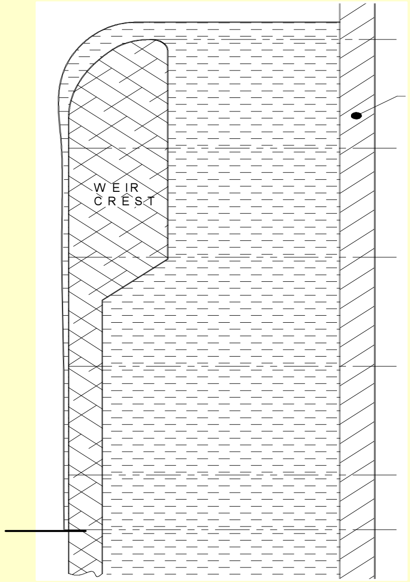


Natural convection flow paths during DHR

Gas Entrainment Mitigation Mechanisms

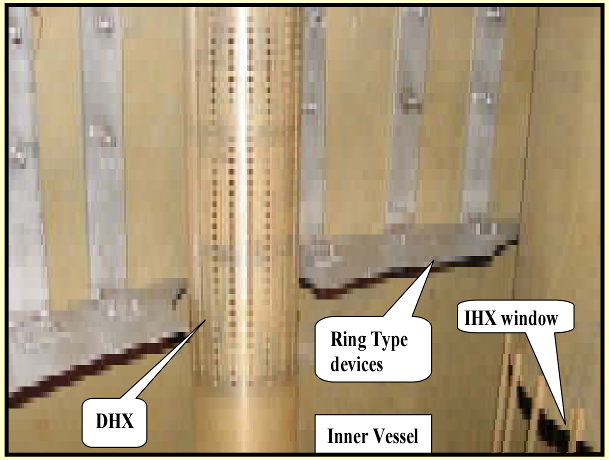


Basic studies to understand the Mechanisms responsible for GE in hot pool (1:27, 1:18 & 1:9 models)

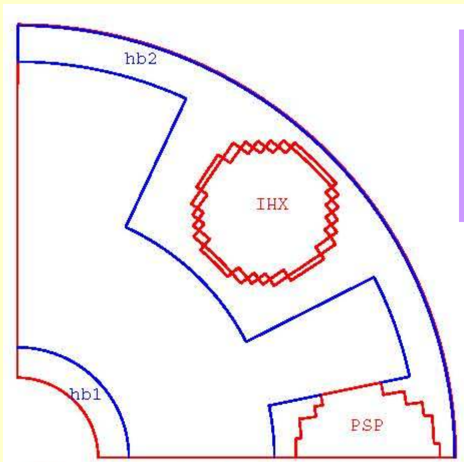


water film thickness over baffle

Gas entrainment at 300 mm fall height



Mitigation of GE in hot pool



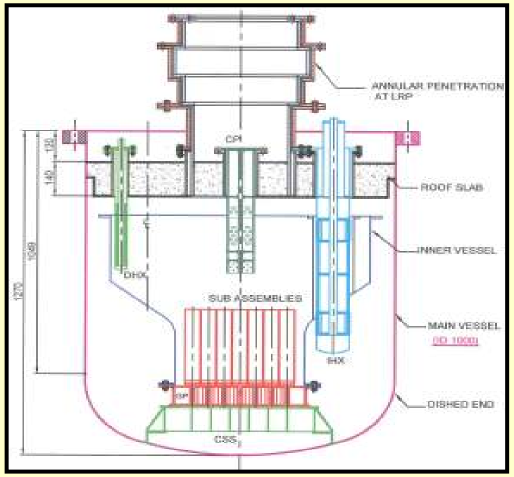
Position of baffles

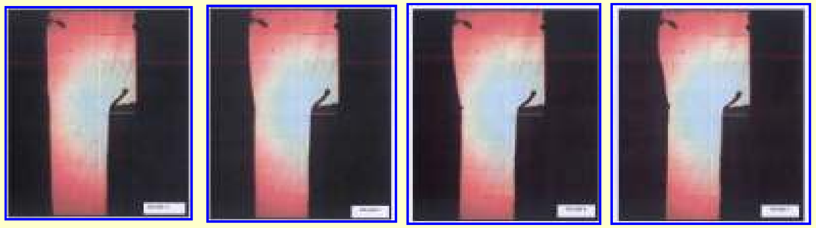
A single horizontal baffle attached to inner vessel upper shell

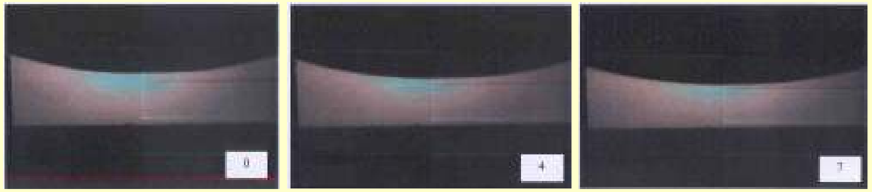
If maximum free surface velocity is < 0.66 m/s, there is no gas entrainment

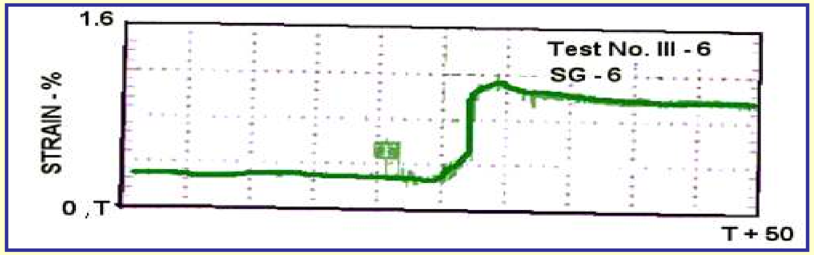
Mechanical Consequences of CDA

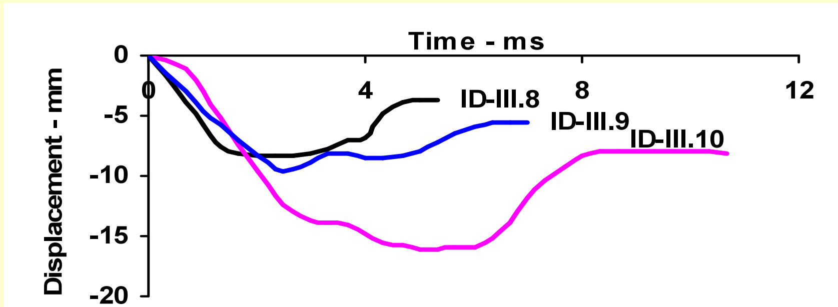
11 Tests on 1/13th scale mockups to demonstrate the structural integrity of IHX and DHX and also to simulate sodium leak









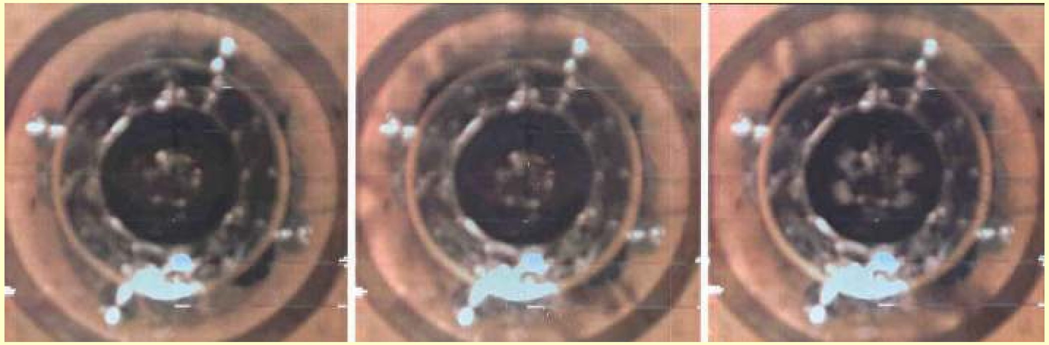


Potential of main vesel is 1200 MJ (Failure at upper portion by radial bulging)

Structural Integrity of IHX & DHX and Sodium Leak

IHX after test

DHX after test



$$Q_p = Q_m \left(\frac{\rho_p}{\rho_m}\right)^{0.5} \left(\frac{A_p}{A_m}\right)^{1.018} \left(\frac{\Delta P_{0-quasi-p}}{\Delta P_{0-quasi-m}}\right)^{0.52} \left(\frac{\Delta T_p}{\Delta T_m}\right)^{1.05}$$

Extrapolation yields:

- **Potential of IHX - 200 MJ and 500 MJ for DHX**
- **Sodium release to RCB is 275 kg**

Future Directions:

- **Experiments with sodium coolant**
- **Simulation of fissile material particles (Pu) accumulated in cover gas space**
- **Use of innovative sensors and instruments to generate data for scientific investigations**

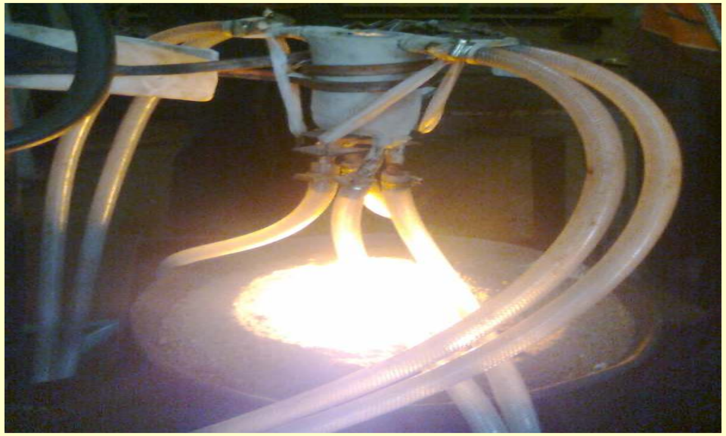
Post Accident Heat Removal Scenarios

Approach

- **Simulation of heat transfer and dispersion characteristics of core debris:**
  Phase-1: Wood metal in water and Phase-2: UO_2 in sodium
- **Thermal hydraulics simulation in water models using the debris bed generated in sodium experiments**
- **Phase-1: 7 SA melting and Phase-2: Melting of larger number of fuel SAs**

Molten Fuel-Coolant Interaction (MFCI) Studies

Simulation of molten-fuel coolant interaction with woods metal



Melting of U fuel pins in ceramic crucible by induction heating

SA Melting Scenarios

- SA blockage mechanisms
- Temperature evolution within blocked SA
- Thermal performance of core catcher while accommodating 7 molten SA

- **Test data were used for validating the numerical simulations**
- **Tests are elaborated to derive the realistic scenario definitions for future SFRs and collaborations**

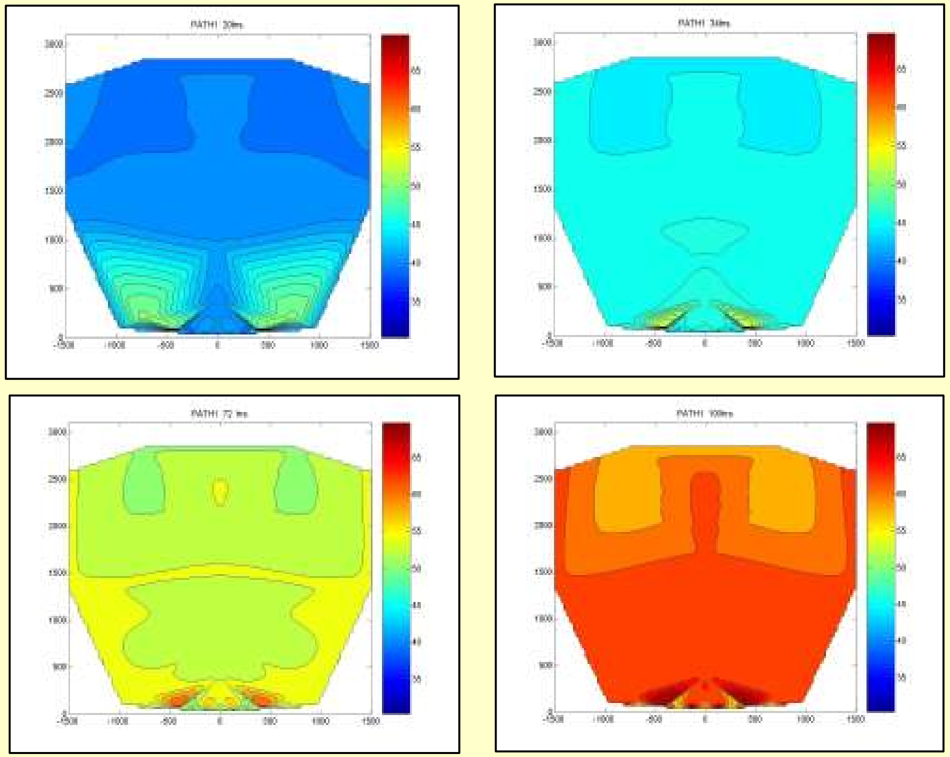
SA blockage Studies

Core catcher model for 7 SA

Thermal hydraulics study on Totally Blocked SA

Post Accident Heat Removal Scenarios

PATH: Post Accident Thermal Hydraulics Studies



Mapping of temperature evolution during PAHR phase

- **1: 4 Scale model studies with accurate temperature mapping, visualization of fluid and data processing possibilities**
- **Potential for studying the possible design option for natural convection cooling of the lower plenum**

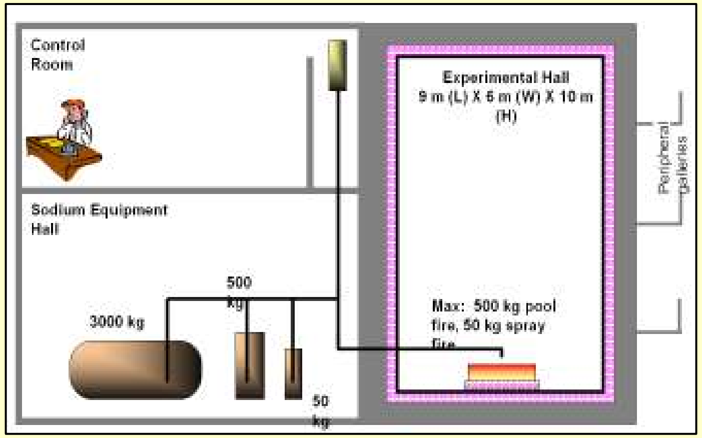
Future direction: Tests with core debris simulated with SOFI test series

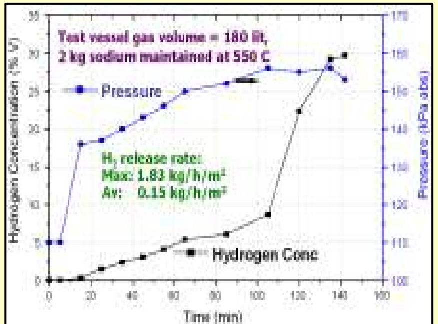
Sodium Fire Studies

Experiments in open fire:
To understand the feasibility of the experiments
Qualification of basic design

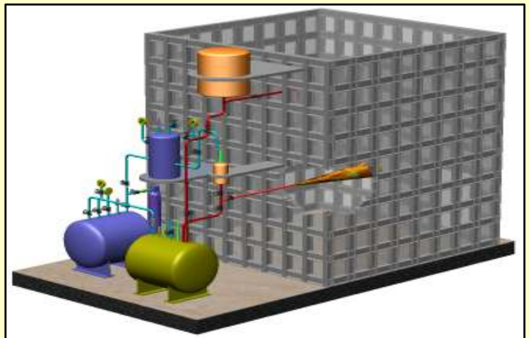
Small scale experiments in Mini Sodium (MINA) experimental facility:
Scientific to engineering scale experiments with variable parameters
Validation of above experiments and sodium fire codes

Large scale experiments in Sodium Fire Experimental Facility (SFEF):
Investigation of design basis experiments and validation
9mx6mx10m hall





Open fire tests for Na-concrete interactions & leak collection tray design confirmation



MINA: Sodium fire scenarios, qualification of innovative fire extinguishers, etc

Sodium Fire Studies – contd..

- *Unique aerosol test facility (generation of sodium and FP aerosols of a few nanometer to micro meter with varying mass concentrations and diagnostic tools for physical and chemical characteristics).*
- *Innovative experiments and enhanced understanding (coagulations of aerosols with the presence of gamma, carbonation, co-agglomeration of Na and FP aerosols).*
- *Qualification of area gamma monitors in sodium aerosol environment for PFBR.*
- *National and International collaborations (BARC, Central Institute of Mining & Fuel research :Dhanbad, Academics, CEA France).*

Real Time Measurements: Mastersizer, QCM , Aerosol spectrometer, ELP impactor, SMPS.
OFF-Line Measurements: Filter paper tech.. Chemical analysis, Conductivity probe,etc.

Sodium Aerosol Studies

Facilities under construction

- **SOCA** – *Sodium and Cable Fire in Top Shield*
- **SOGA** - *Sodium Aerosol in Cover Gas*

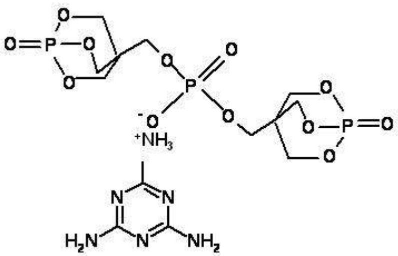
Development of Sodium Fire Extinguishers

- **Commercially used extinguisher $NaHCO_3$ based Dry Chemical Powder has limitations, such as removal and Disposal.**
- **Intumescent Polymer developed at IGCAR expands 200 times in its volume and covers the sodium fire effectively and extinguishes the sodium fire by preventing the oxygen supply**

Current Development: Hallow carbon microspheres and Carbon nano spheres, blankets the sodium fire effectively and extinguishes by limiting the oxygen supply.

Future Direction:

- **Development of nano materials for mitigating the sodium fire**
- **Need of standards for qualifying extinguishers (MINA facility at IGCAR)**



Styrene Divinyl Benzene —(Carbonization at 1123 K, Nitrogen Atmosphere)→ Carbon Microsphere

Summary

- **Innovative experimental techniques for comprehensively addressing the safety issues related to seismic integrity, decay heat removal requirements, severe accident scenarios, post accident heat removal, sodium fire mitigation, development of innovative sodium fire extinguishers, sodium aerosol dispersion studies are the priorities**
- **Experiments are planned to study both science and technology aspects concurrently**
- **High emphasis on involvement of younger scientists & engineers and students from academic institutions**
- **National and international collaborations are encouraged to share the facilities and joint investigations on the basis of challenges and mutual interest**

Thank You