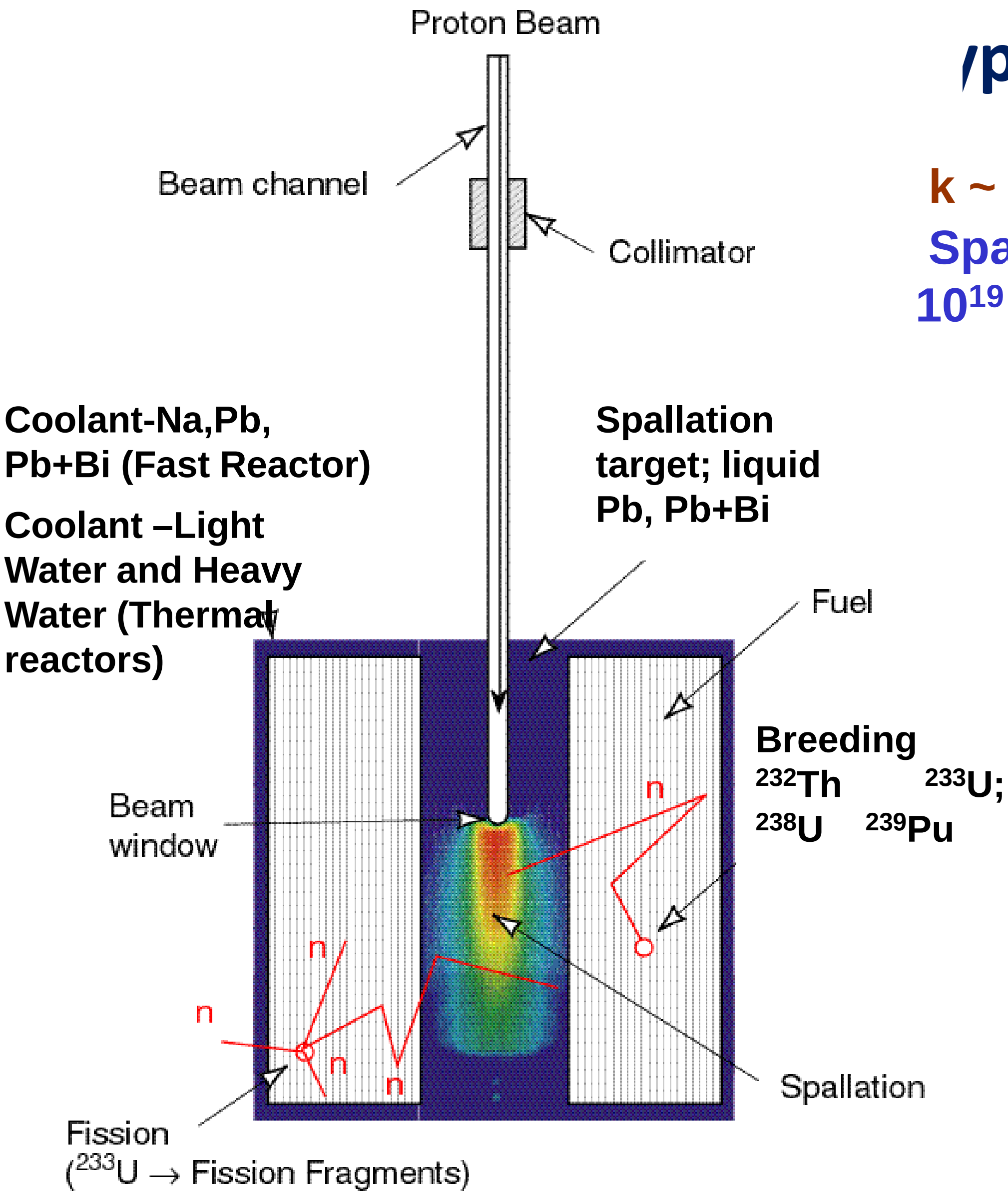
Indian Programme on the Development of Neutron Sources for ADS

P. Satyamurthy
BARC

ypical ADS Reactor



k ~ 0.95 to 0.98

Spallation Neutrons ~ 10^{18} - 10^{19} per second

-Inherent safety

-Transmutation of Nuclear Waste

-Utilization of Thorium

-High Resistance to Proliferation

Why Liquid Target?

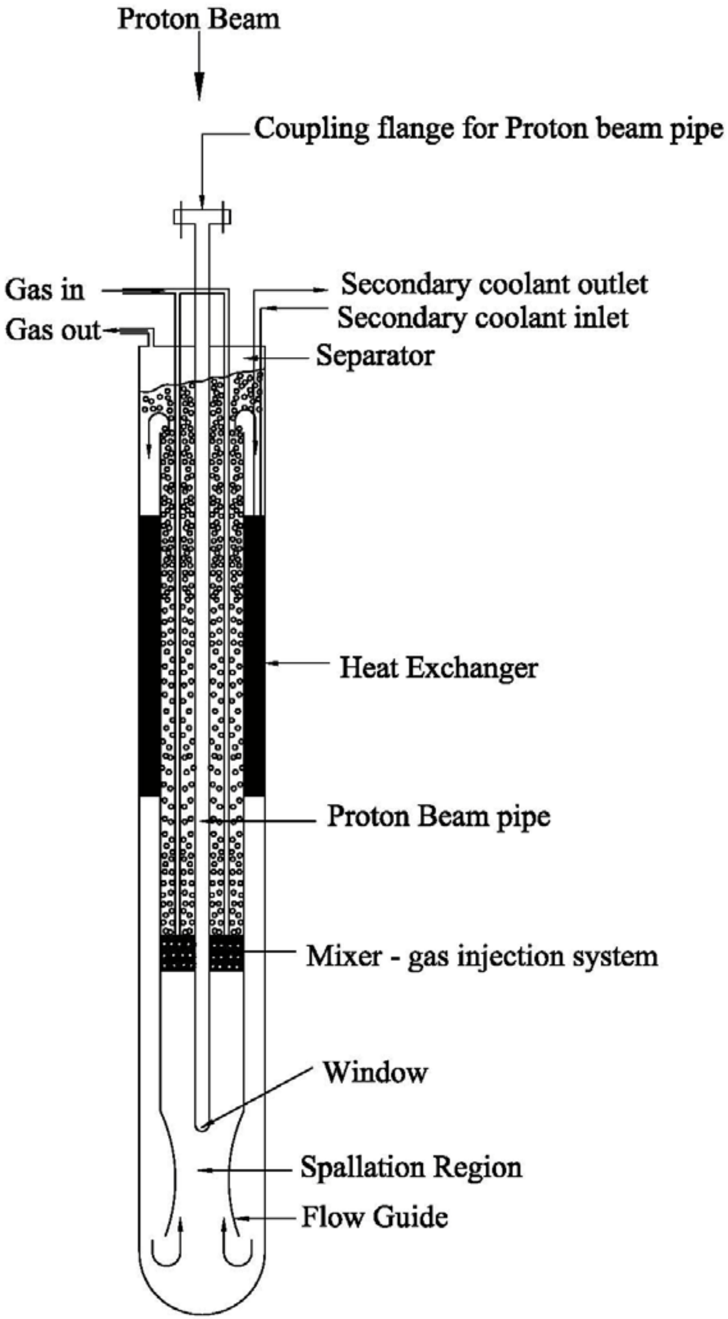
-Very High Heat Deposition Density by proton beam

~ kW/cm^3

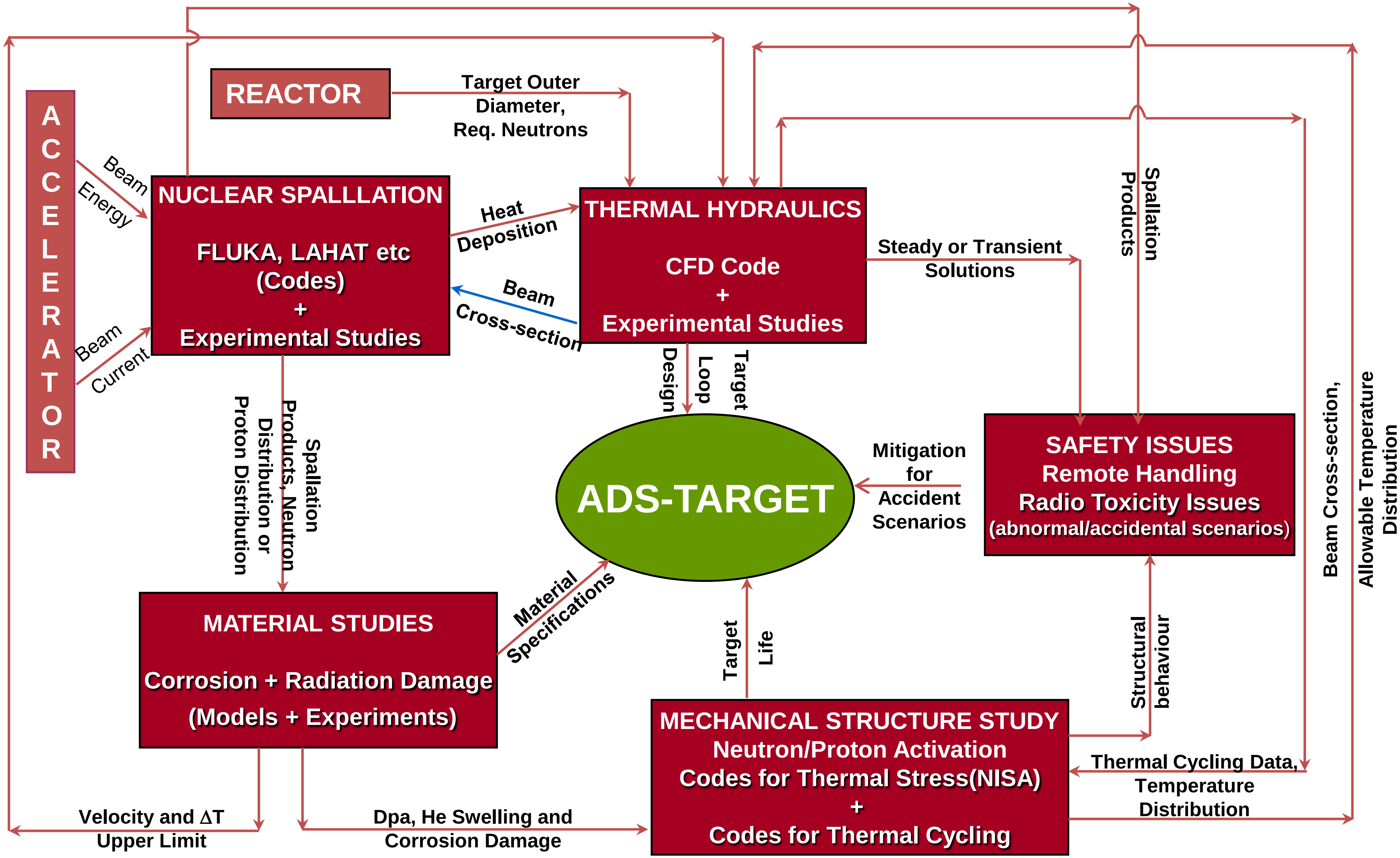
-Very High Radiation Damage ~100 DPA or more/year

Embrittlement
Irradiation Creep
Void Swelling
Hydrogen Generation
Helium Generation
Transmutation

Solution for both these issues – Use circulating liquid target



Typical Gas Driven Liquid Metal LBE (Lead-Bismuth-Eutectic) Neutron Spallation Target Module

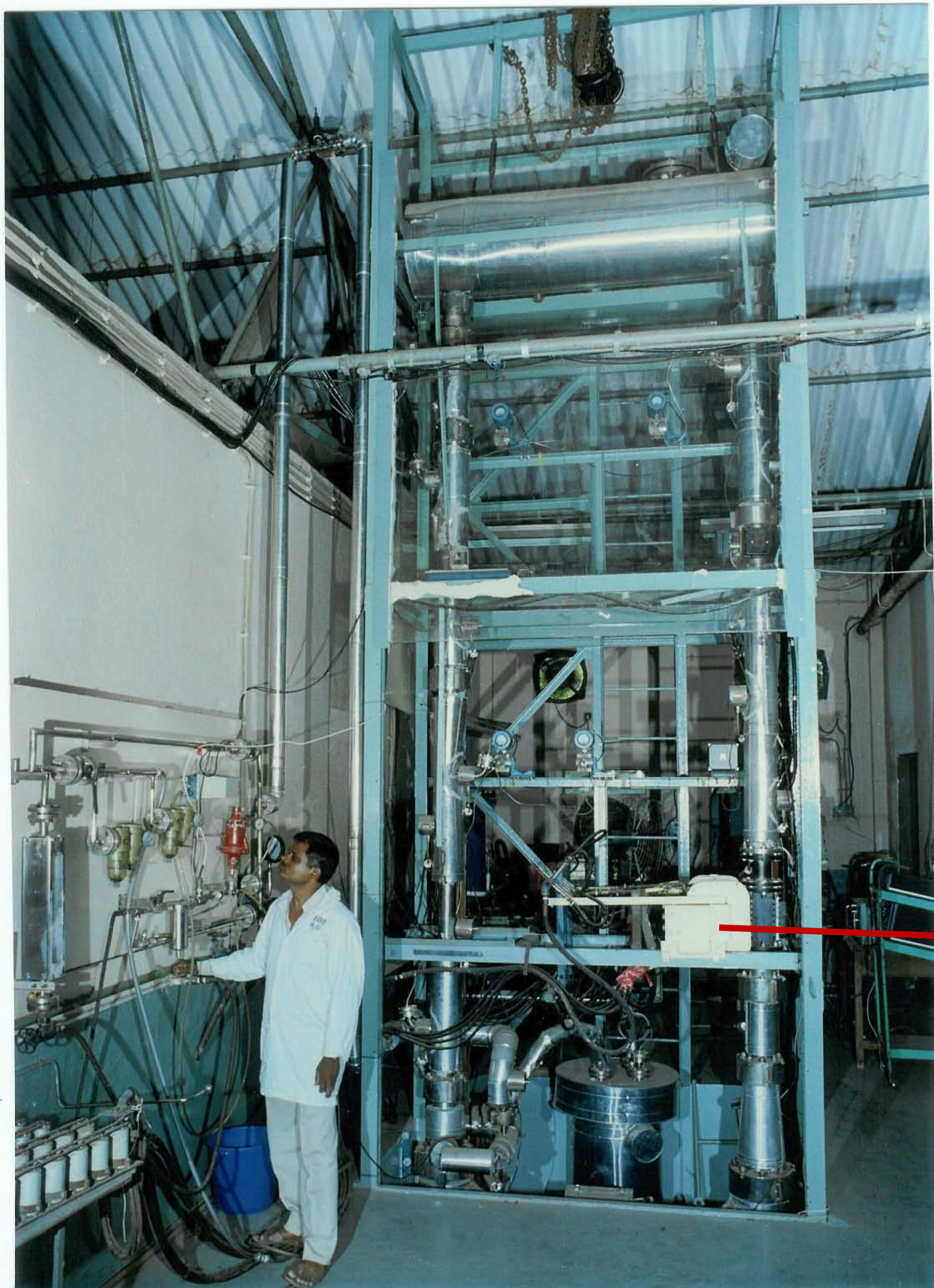


ADS TARGET DEVELOPMENT

INTER-LINKED TECHNOLOGY ISSUES

Indian R&D Road Map for Liquid Metal Spallation Target development

1) **Setting up of Multiple Liquid metal Experimental facilities for R&D Studies**
   - -Thermal-hydraulic simulation
   - -Gas driven circulation (two-phase flow studies)
   - -Component development
   - -Diagnostic development
   - -Design codes validation
   - -Corrosion studies and mitigation technologies
2) **Development of design codes and analysis using existing codes** (FLUKA-High energy Particle code by CERN, 3D CFD codes, Two-phase flows, etc)
3) **Experimental Facilities for Coupling of Target module with proton beam**
4) **Setting up of demo ADS reactor**



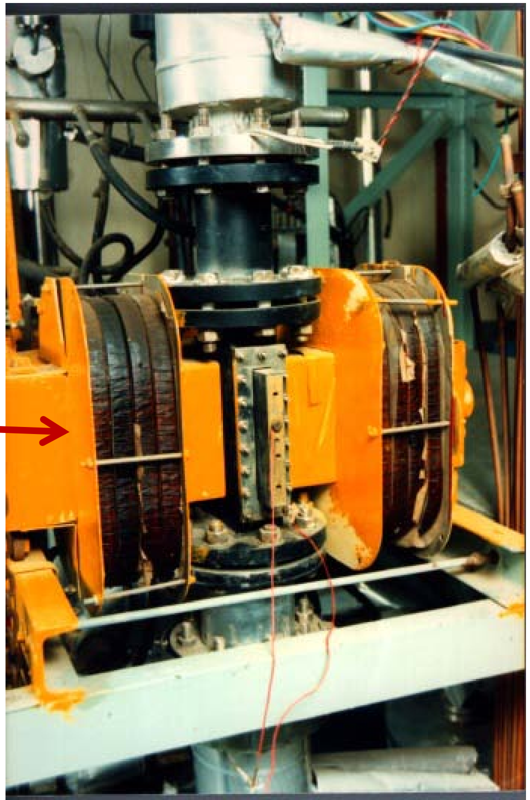
Mercury-MHD Experimental Facility –BARC

Height – 6m

Inventory – 1.5 t

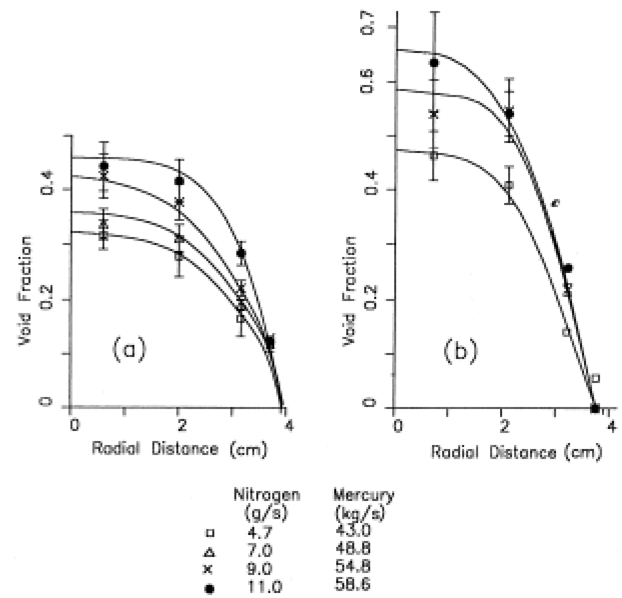
Mercury Flow Rate – 60 kg/s

Magnetic Field – 1T



Gamma ray void fraction measurement systems

Parallel and Rotational Single Beam Scanning Gamma Ray System (^{60}Co of 50 mCi)

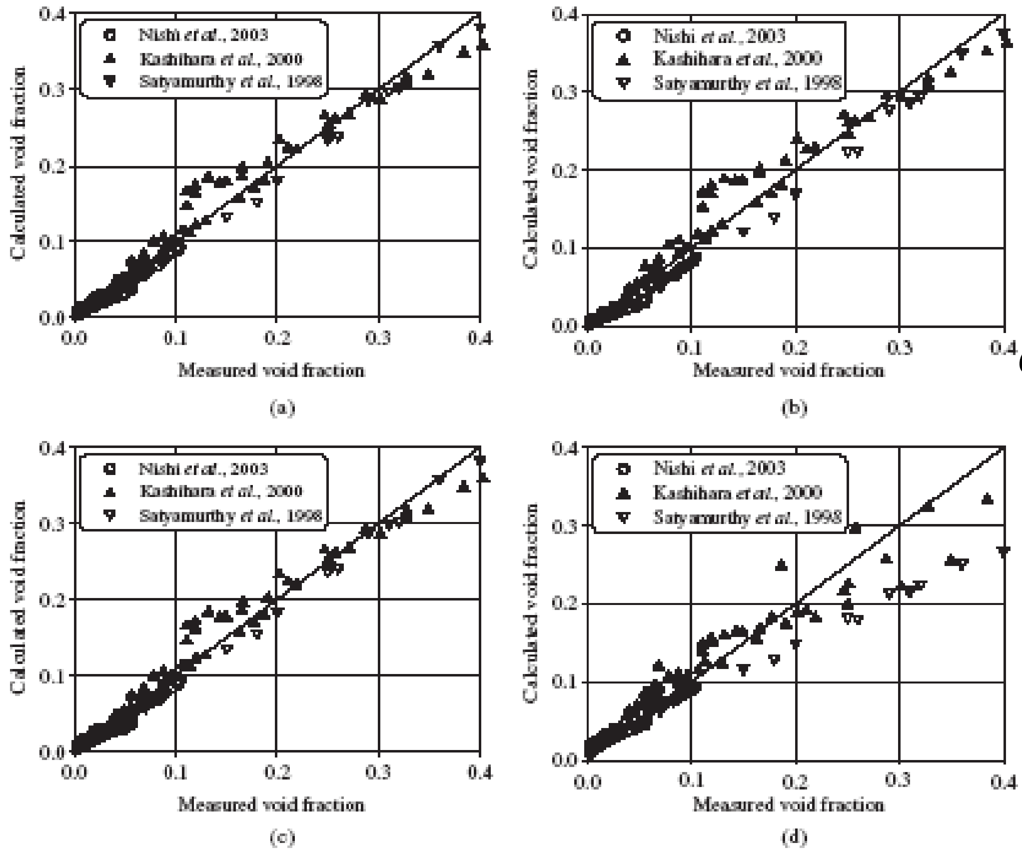


Multi Detector High Energy Gamma Ray System for the Measurement of Void Distribution

Int. J of Multi-phase flow (24) 1998

Drift flux model for heavy liquid metal two-phase flows

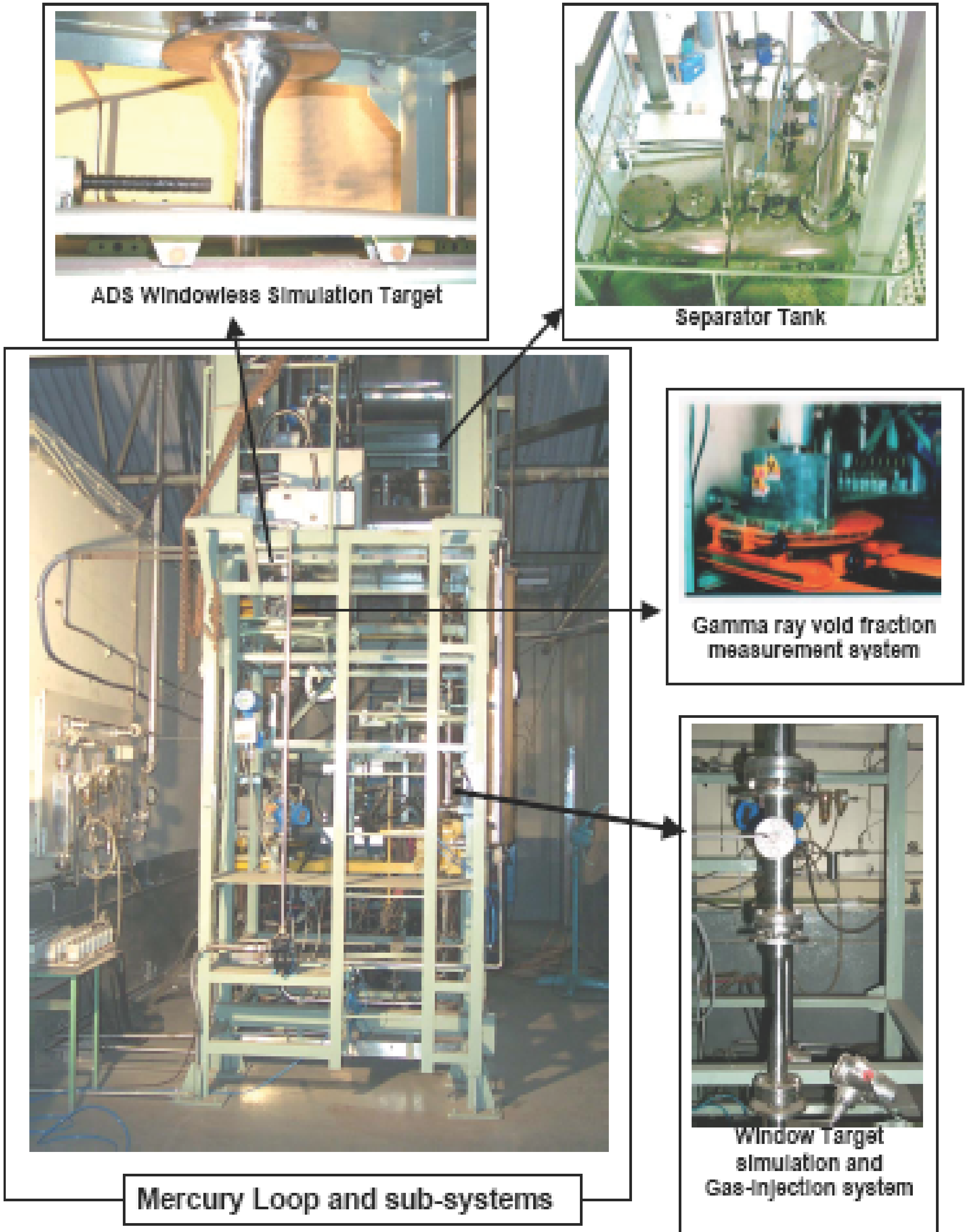
Development of a Drift-flux Model for Heavy Liquid Metal/Gas Flow 605



$$\alpha = \frac{j_g}{0.9\left(j_g + j_l\right) + 2.33\left(g\sigma_l\Delta\rho_l / \rho_l^2\right)^{\frac{1}{4}}}$$

Fig. 5 Comparison with loop test data[6–8] of (a), (b), (c) drift-flux model results using u_{gl} formalisms of types a, b, c (see Table 2), respectively, and (d) Brannover correlation[11] predictions

Mikityuk et al, J. Nu. Sc. & Tech., Vol.42, no.7, july 2005



Mercury Loop for Diagnostic Studies

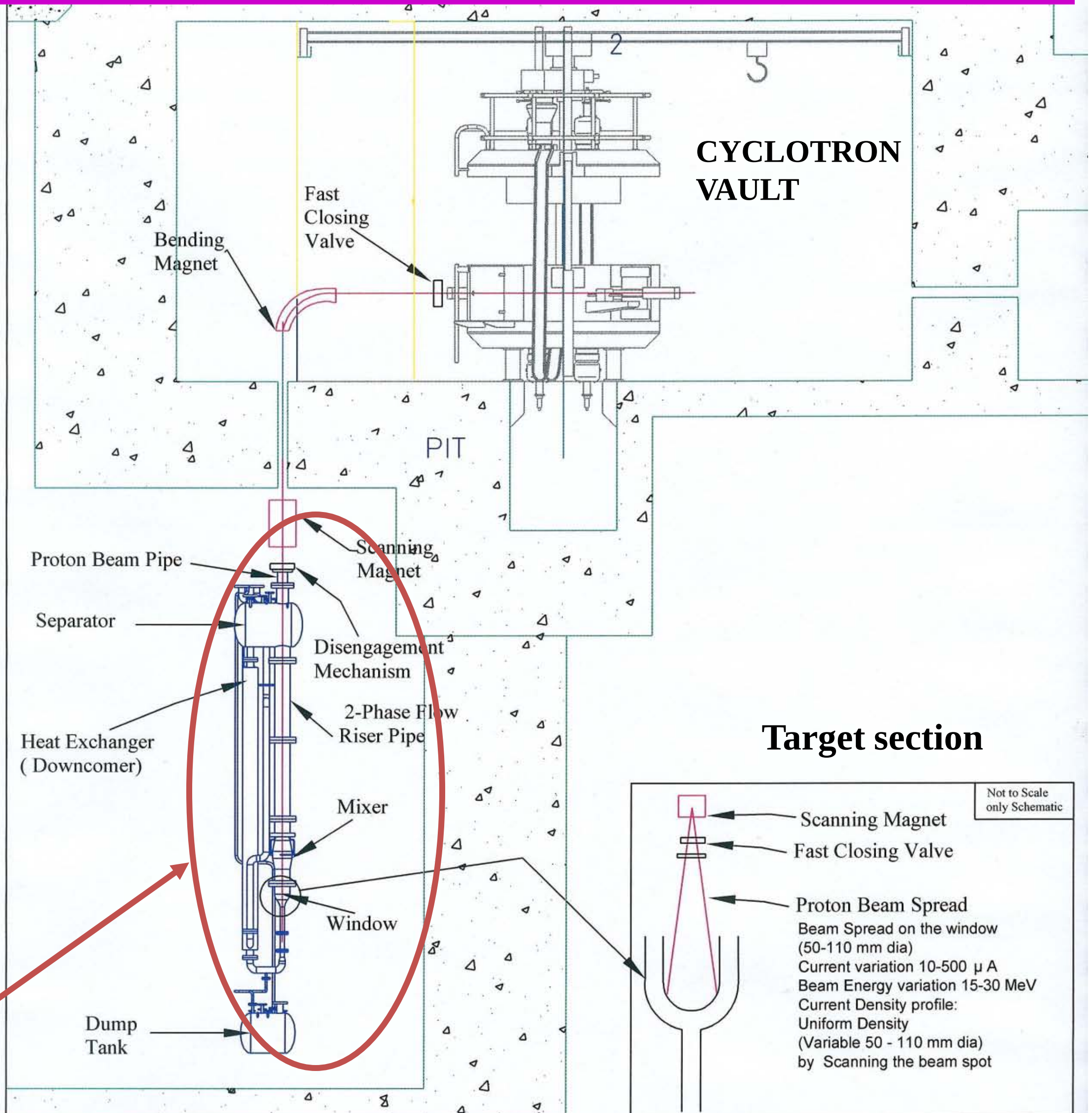
(setup in 2005)

- -Velocity field mapping
- -Two-phase flow studies
- -Window Simulation
- - Windowless target simulation
- -Carry under

Target Experiments - Coupling With Proton Beam 30 MeV and 500 micro A (CW)

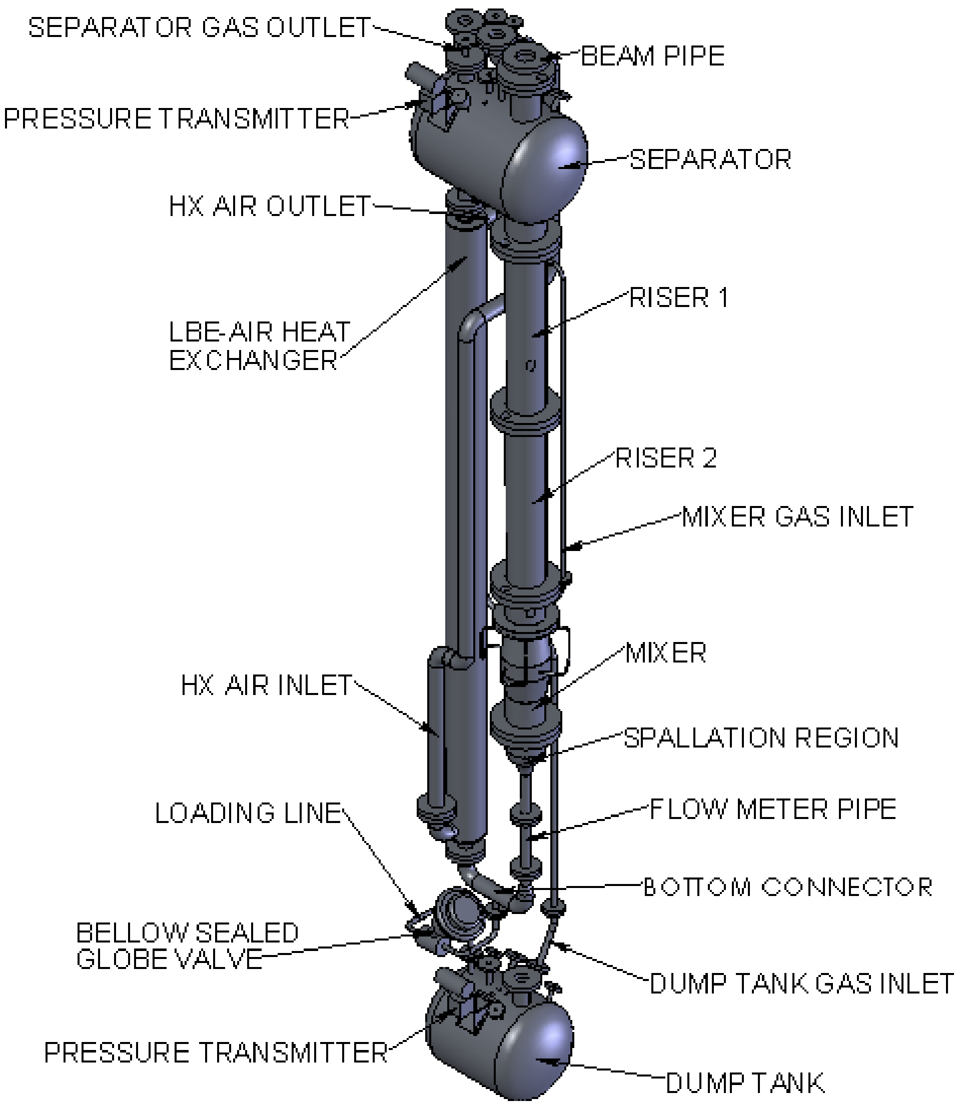
- -Coupling of Beam with Target Module
- -Window heat extraction
- -Radioactivity Issues
- -Gas handling
- -Irradiation studies
- -Combined Control & Instrumentation
- -Remote Operation
- -Remote Dismantling

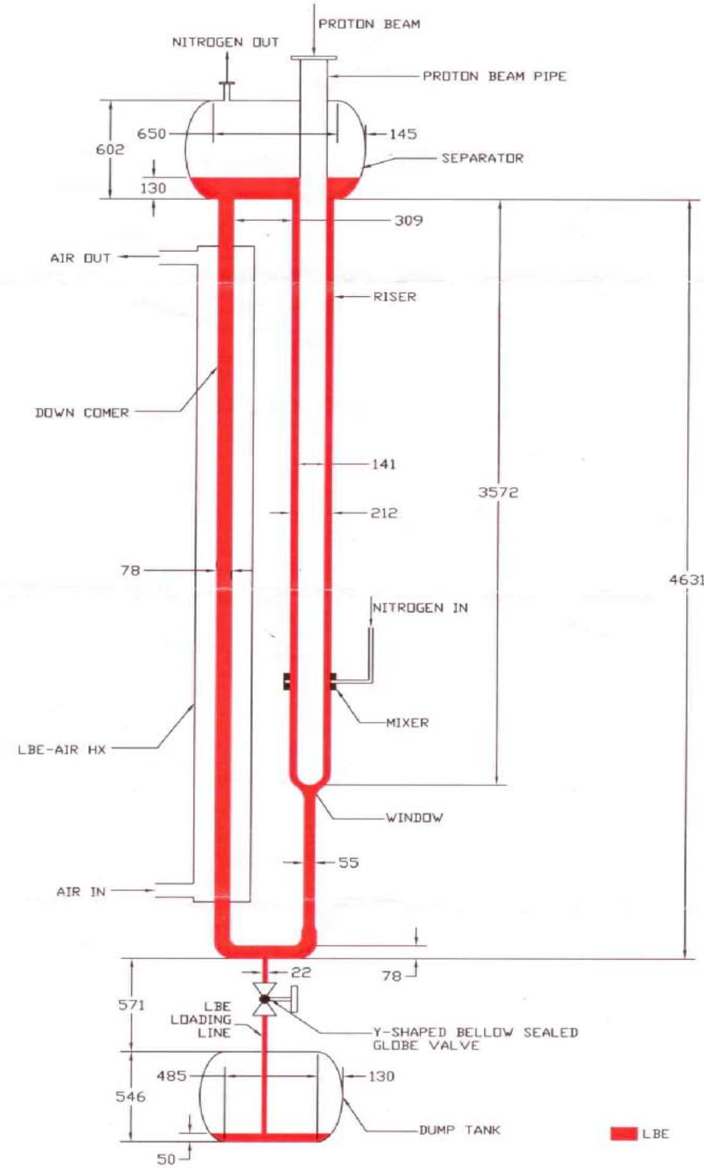
LBE Target Module



Medical Cyclotron -LBE Test Target Facility

Target Module for Coupling to 30MeV & 0.5mA proton Beam





ADS-workshop-BARC-12,13,14-12-11

Special features of Window

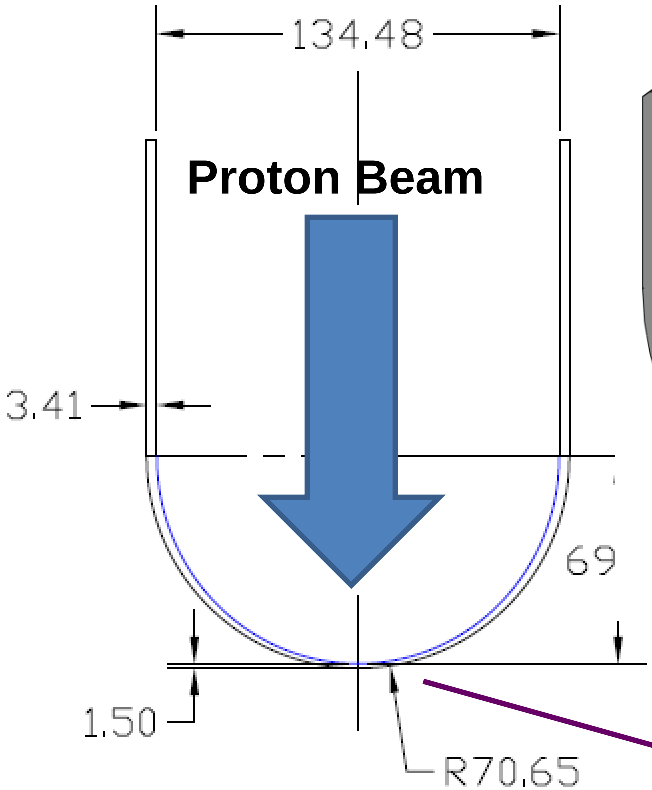
P91 – Ferritic-martensitic Steel

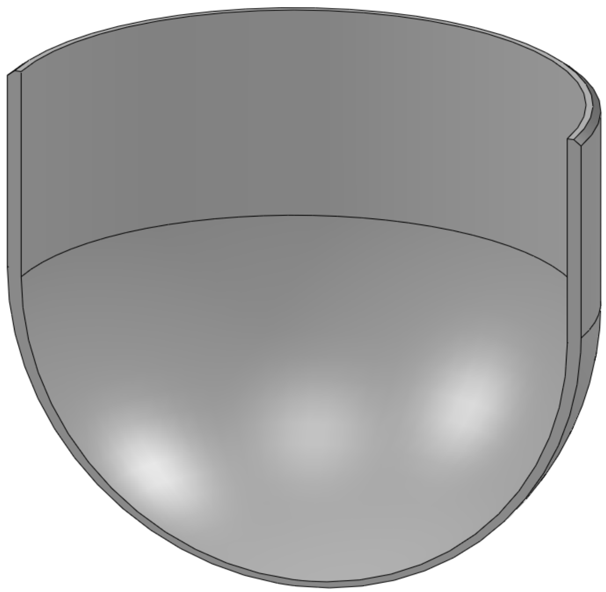
(Ni:0.13,Cr:8.26,Mn:0.38,Mo:0.95,Si:0.43,Ti:0.014, V:0.2,C:0.105,P:0.009,S:0.003,Nb:0.08,N:0.055, Al:0.024,Cu:0.08,As:0.02,Sn:0.008,Fe:balance)

-High Thermal conductivity coupled with low thermal expansion-can accommodate higher thermal loads

-Radiation Resistance-Longer life in radiation environments

-Indigenously developed



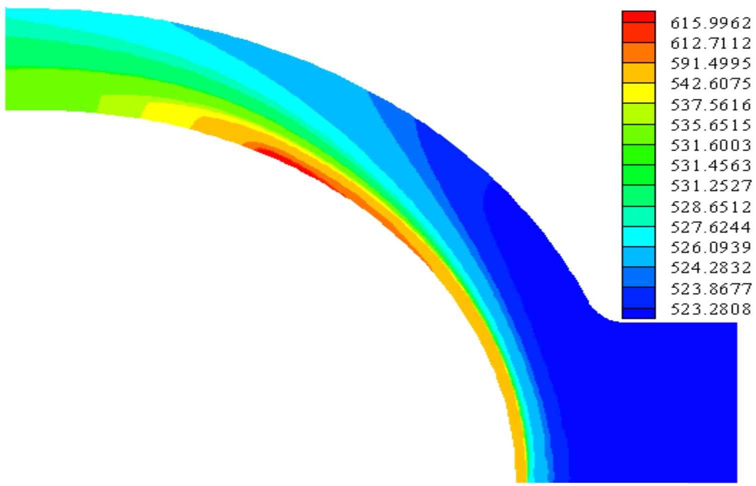


Optimization between mechanical and thermo-mechanical strength, compactness and minimum beam energy deposition

Variable thickness

Thermal & Thermo-mechanical Analysis of Window

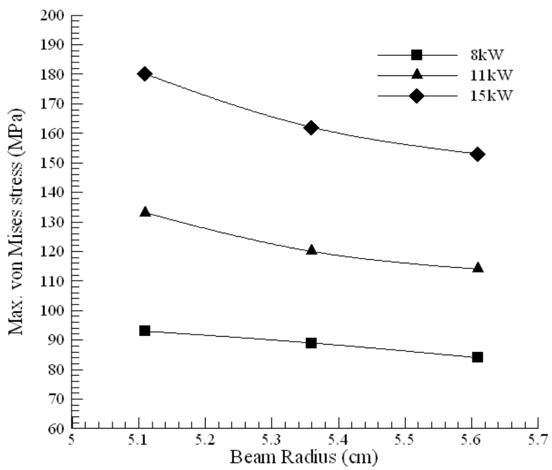
Optimisation Studies



Temperature Contour plots for 15kW with 5.61cm beam radius, flat beam profile and 15 kg/s LBE flow rate.

T window- max <350 C ,

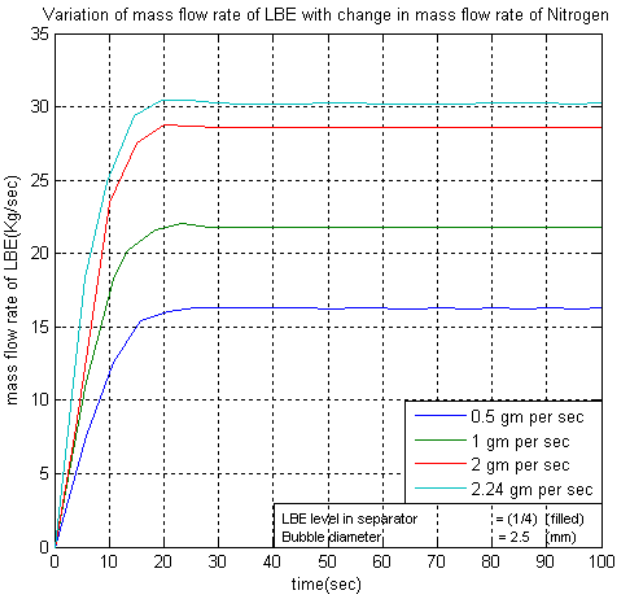
Beam Radius (scanned) = 5.6 cm



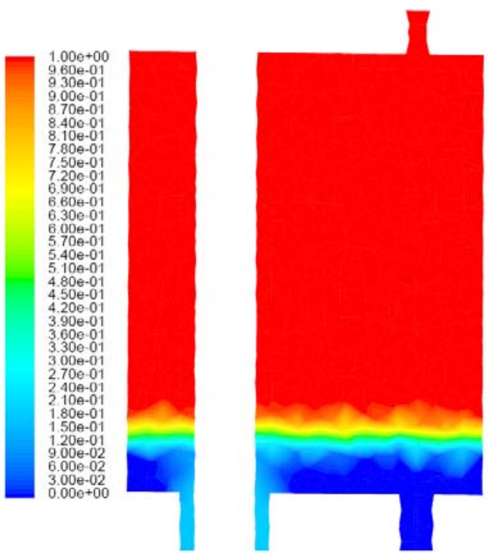
Effect of Beam scanned area on stresses

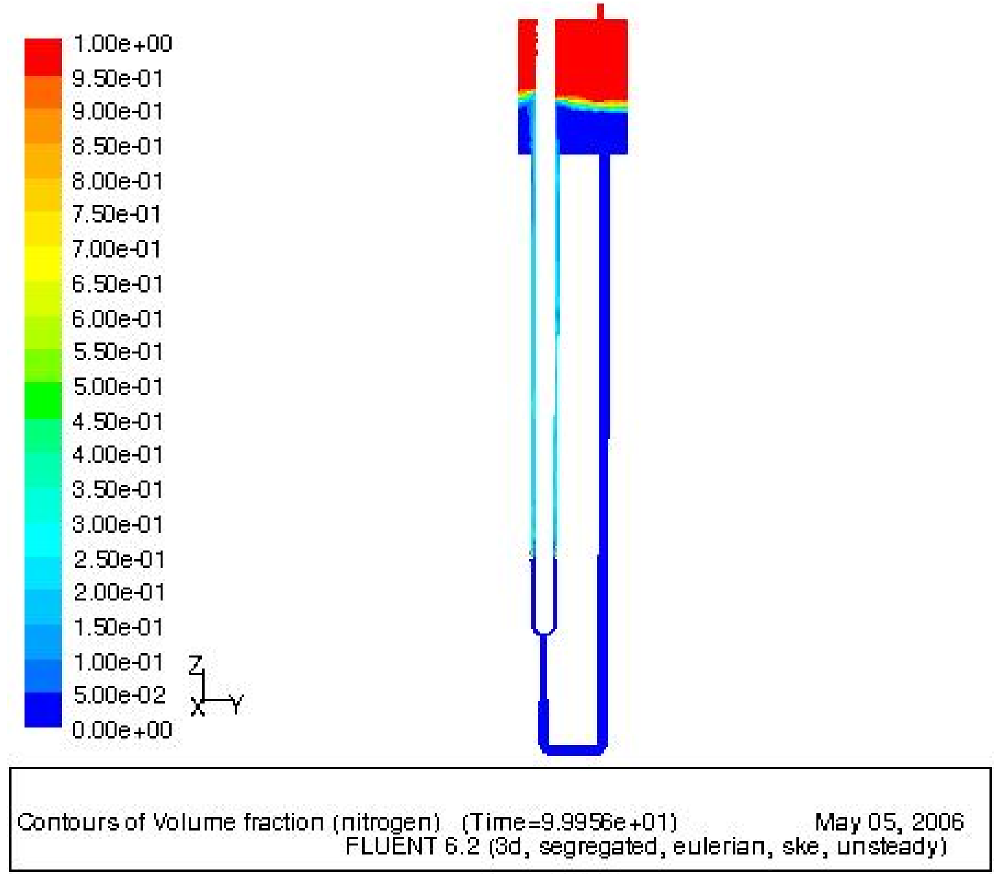
5mm gap, 15kg/s (5.61 cm beam scanned radius)				
Loading conditions	Hoop Stress (MPa)		Max von Mises Stress (MPa)	Allowable Stress (MPa)
	-ve	+ve		
Thermal	-162	97.6	146	603
Mechanical	-11.2	2.23	13.1	201
Thermo-mechanical	-169	89.7	153	603

Two Phase Flow Analysis-Target Module for coupling with proton beam



LBE flow rate as function of time for various flow rates

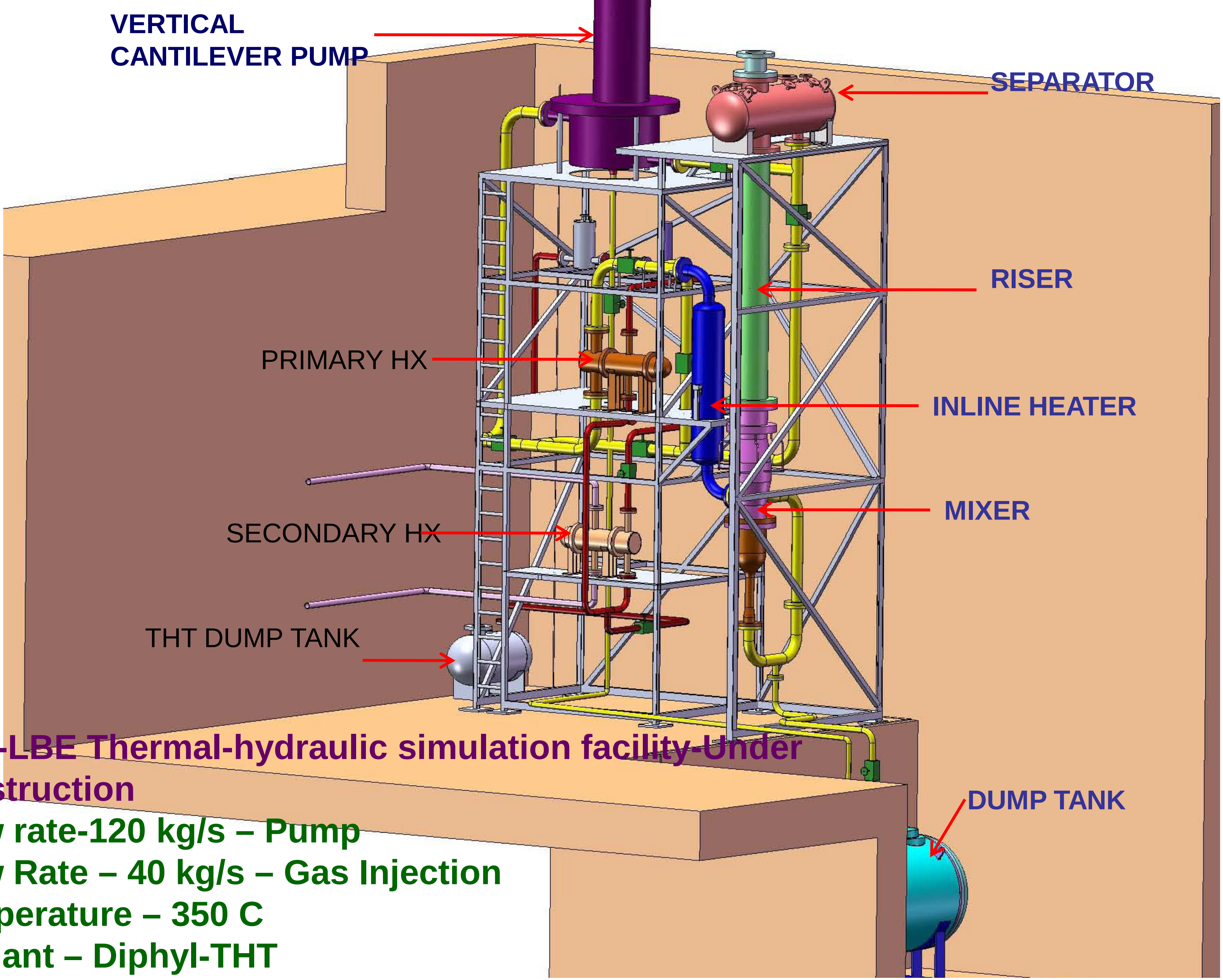




Liquid Carry over estimated 3.8 x 10^{-11}kg/s.
No carry under observed

Prototype ADS target Module for Medical Cyclotron with provision to remotely dismantle from cyclotron beam line, utility lines, power cables etc and transport to Cask

During fabrication & assembly at the Vendor site



CFB-LBE Thermal-hydraulic simulation facility-Under construction

Flow rate-120 kg/s – Pump

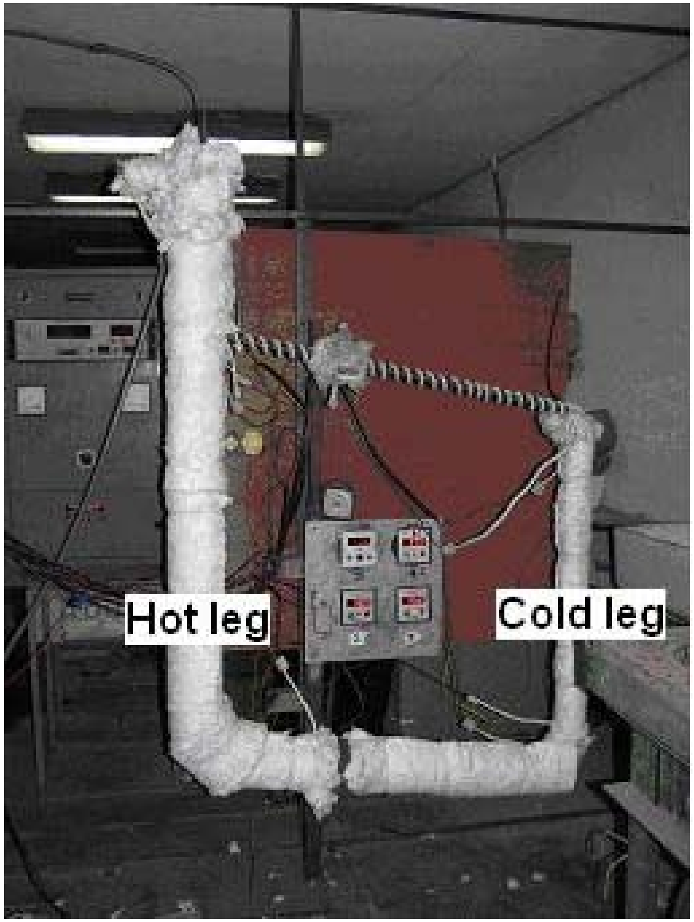
Flow Rate – 40 kg/s – Gas Injection

Temperature – 350 C

Coolant – Diphyl-THT

Window Heat simulation-Electron source

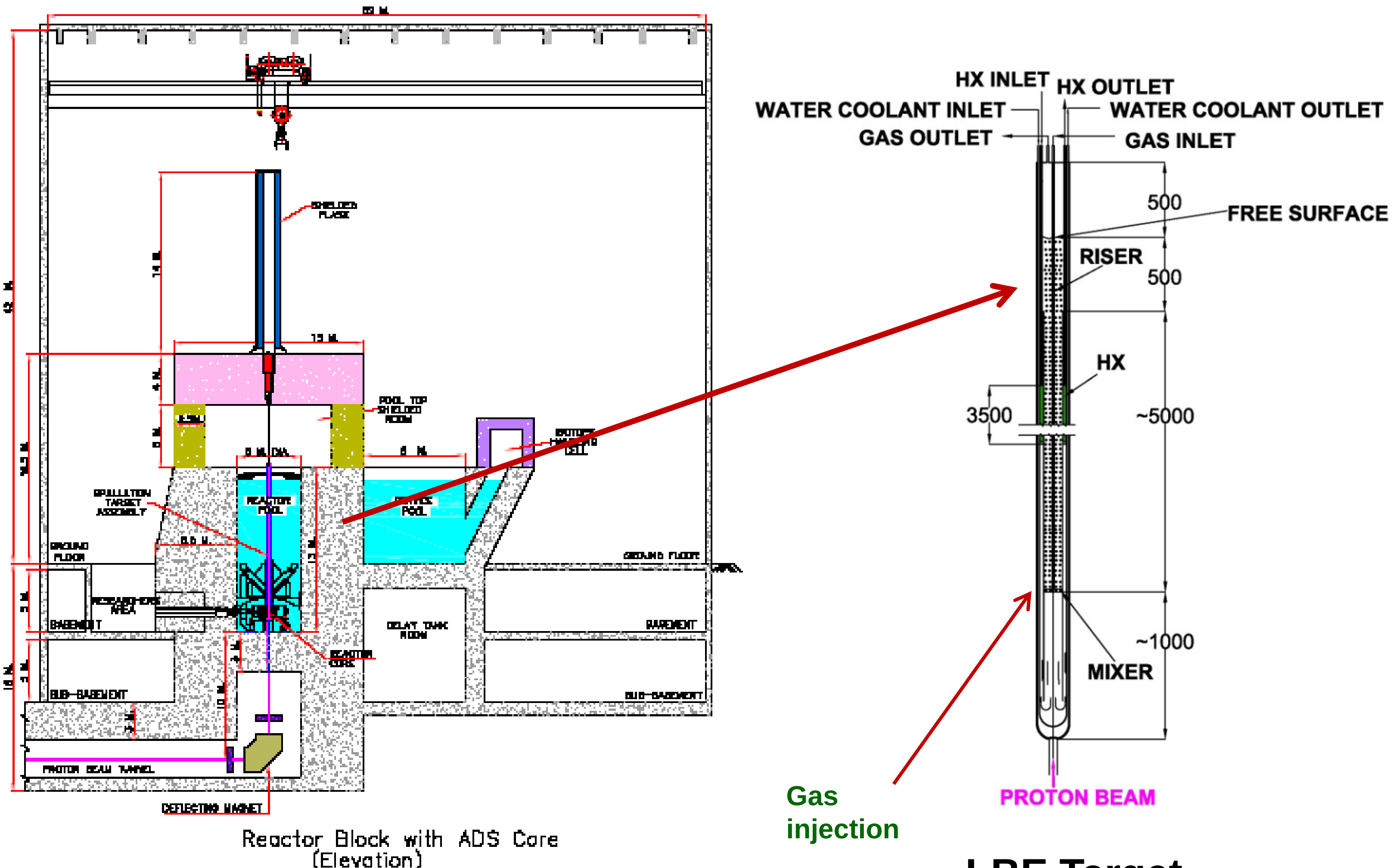
LBE Loop for Corrosion Studies



For Corrosion Studies on Structural Materials-SS304L, SS316L, T91
- Non-isothermal loop under active oxygen control

Lead-bismuth eutectic thermo-buoyancy loop

Proposed ADS Target for Experimental Reactor
Proton : Energy – 650 MeV, Current : 0.9mA-Design stage



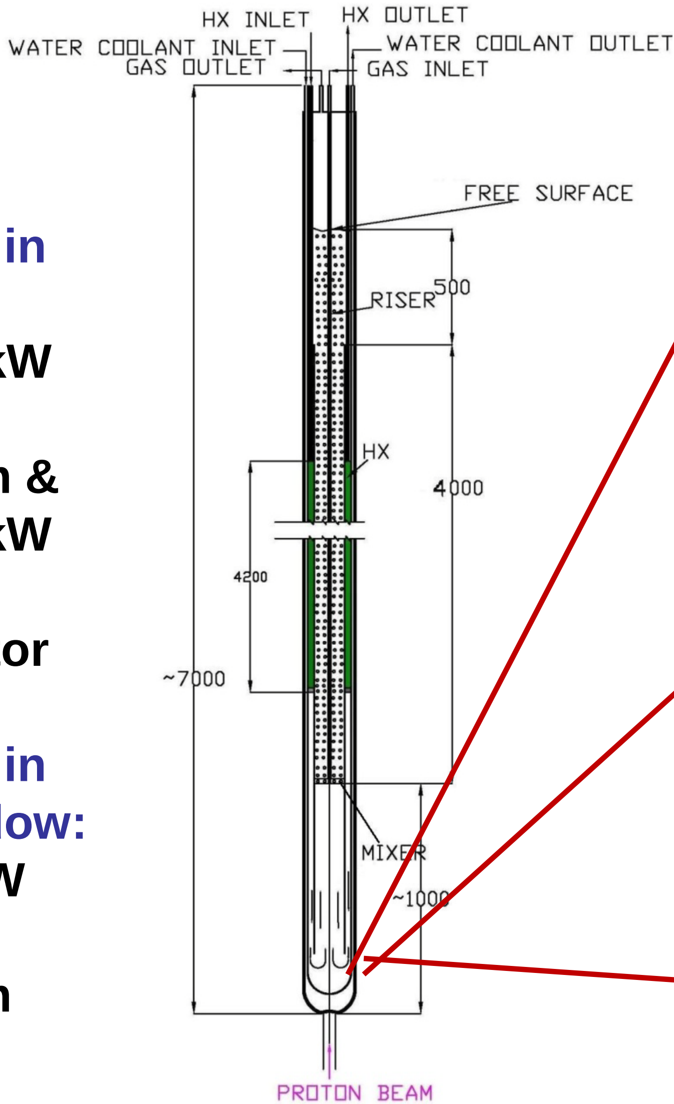
Reactor **LBE Target**

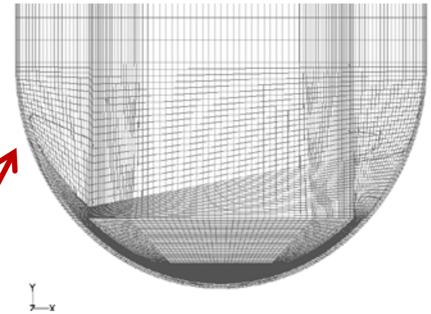
Target- Heat Extraction Studies -3D flow Analysis-

Proposed ADS Target for High Flux Research Reactor

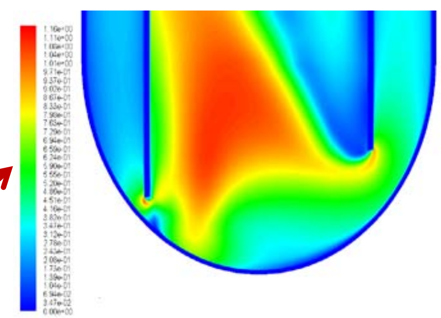
Heat in LBE:
390 kW from beam & 370 kW from reactor

Heat in Window:
3.7kW from beam

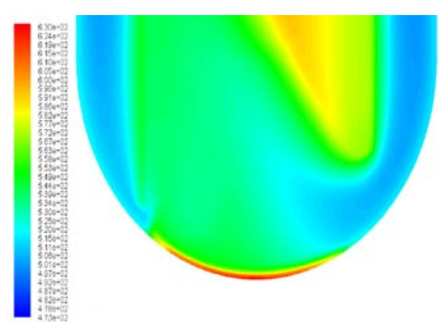




Grids-12 lakhs



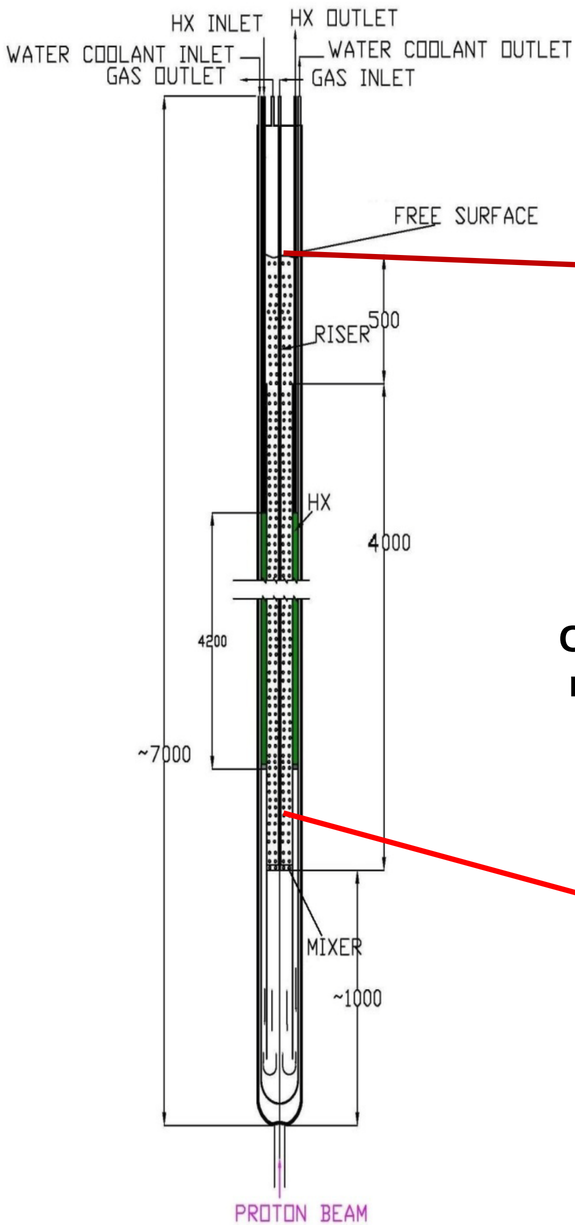
Velocity contours for 50 kg/s Max. Vel – 1.16 m/s)

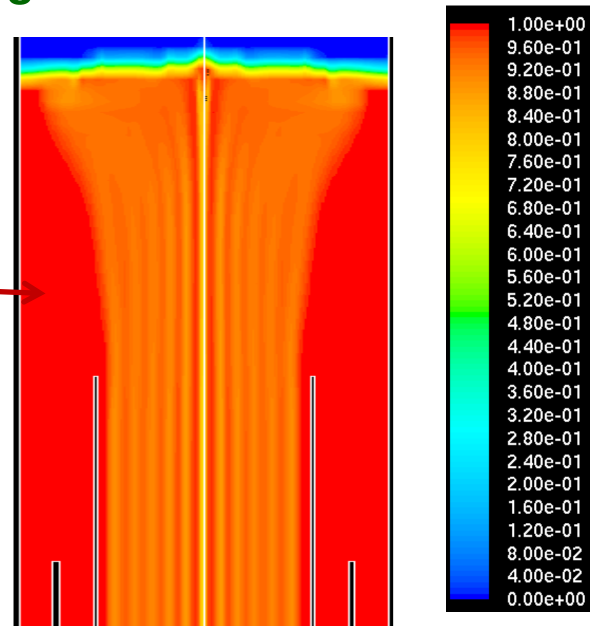


Temperature contours (Max Temp of LBE < 335K , Max. Window Temp < 360 C

CFD Analysis of two-phase flow – Gas lift studies

Proposed ADS Target for High Flux Research Reactor

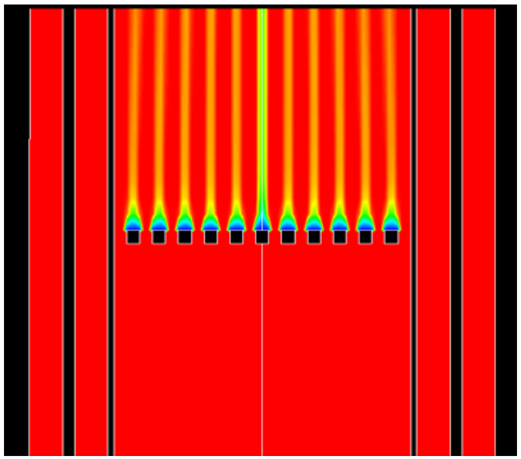


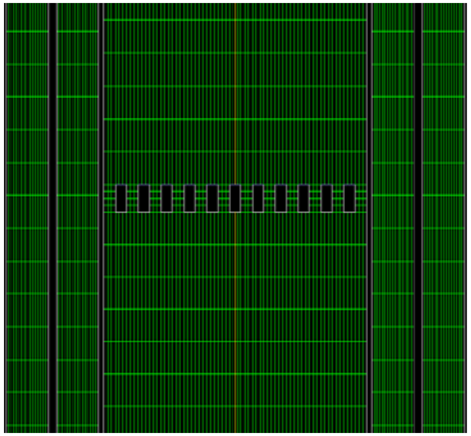


Gas flow rate - 0.7 g/s

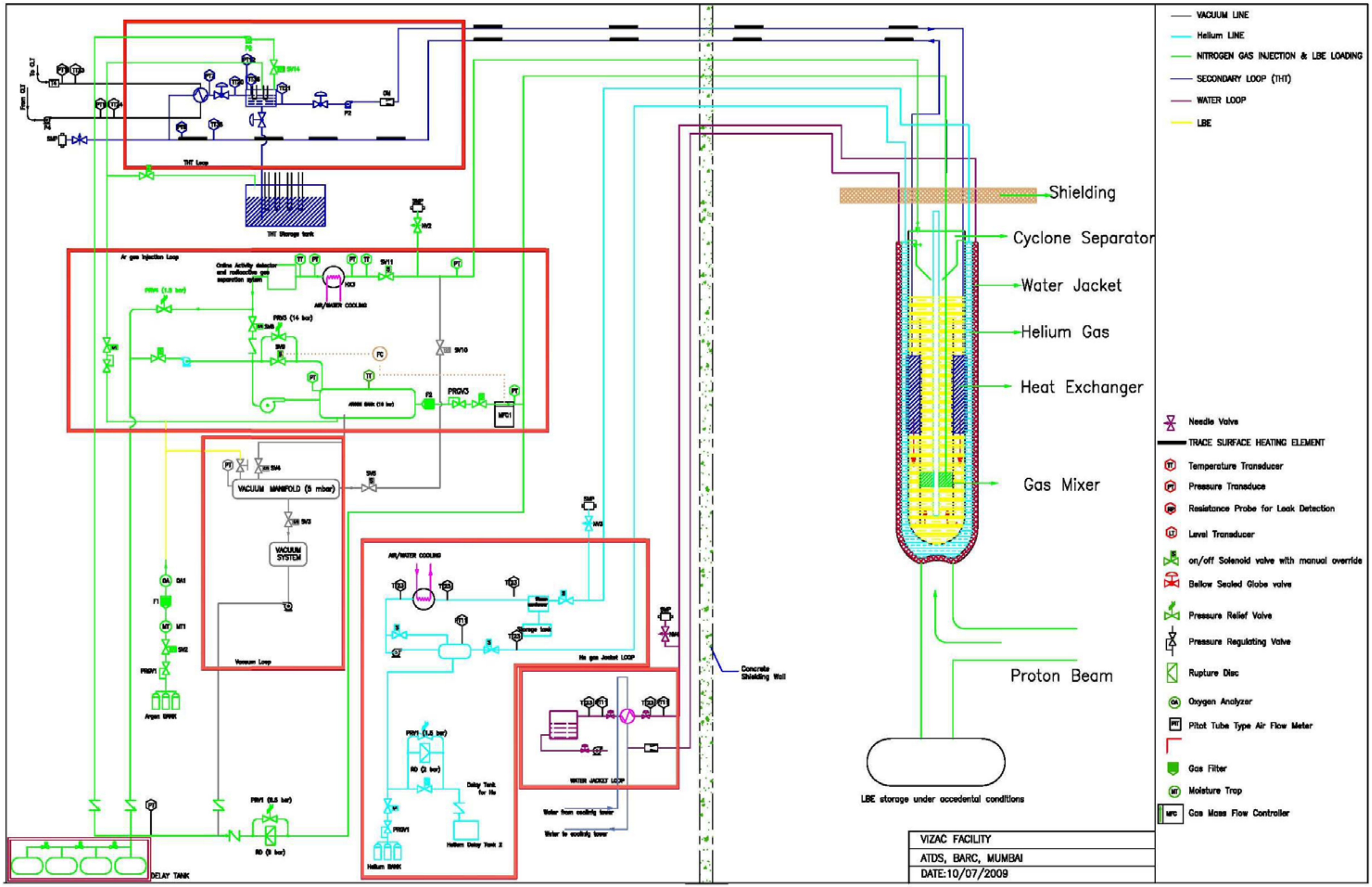
LBE Flow rate – 54kg/s

Contours of volume fraction of LBE near Top region (red – LBE & Blue –Gas)





Grid Details near the Mixer



VACUUM LINE
Helium LINE
NITROGEN GAS INJECTION & LBE LOADING
SECONDARY LOOP (THT)
WATER LOOP
LBE
Shielding
Cyclone Separator
Water Jacket
Helium Gas
Heat Exchanger
Gas Mixer
Proton Beam
LBE storage under accidental conditions
Concrete Shielding Wall
Needle Valve
TRACE SURFACE HEATING ELEMENT
Temperature Transducer
Pressure Transducer
Resistance Probe for Leak Detection
Level Transducer
on/off Solenoid valve with manual override
Bellow Sealed Globe valve
Pressure Relief Valve
Pressure Regulating Valve
Rupture Disc
Oxygen Analyzer
Pitot Tube Type Air Flow Meter
Gas Filter
Moisture Trap
Gas Mass Flow Controller
VACUUM MANIFOLD (5 mbar)
VACUUM SYSTEM
Vacuum Loop
THT Loop
THT Storage tank
Ar gas Injection Loop
AIR/WATER COOLING
He gas Jacket Loop
WATER JACKET LOOP
Water from cooling tower
Water to cooling tower
Helium BANK
Argon BANK
DELAY TANK
VIZAC FACILITY
ATDS, BARC, MUMBAI
DATE:10/07/2009

Electron Photo-neutron target:

Tantalum/U Nat./U Enriched cooled by H_2O

Beam Parameters:

Dia: 30 mm

- **Energy 100 MeV**
- **Power: 100 kW**
- **Duty cycle: 400 Hz**
- **Pulse duration: 10 µs.**

Photo-neutron target:

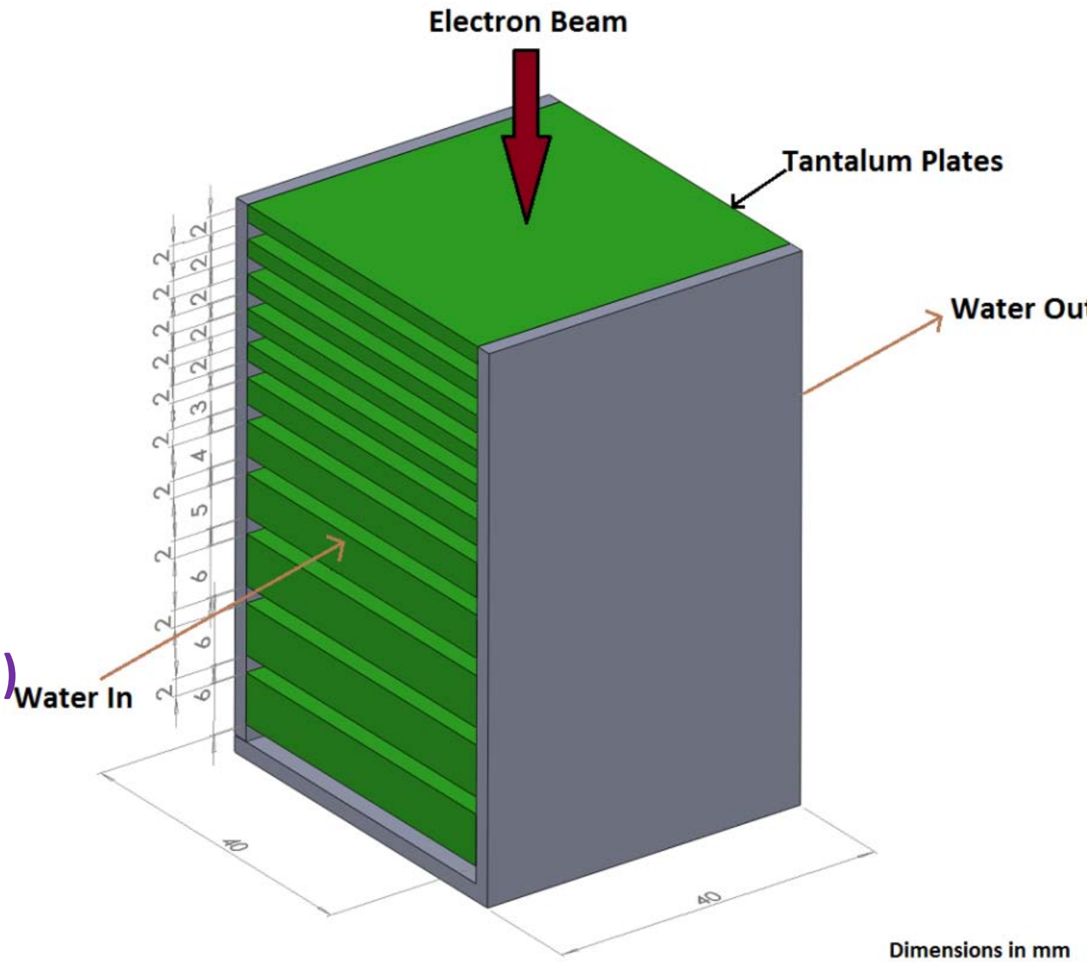
Tantalum/U Nat./U Enriched cooled by H_2O

Beam Parameters:

- Beam Dia: 30 mm
- Beam Energy 100 MeV
- Beam power: 100 kW
- Duty cycle: 400 Hz
- Pulse duration: 10 µs.

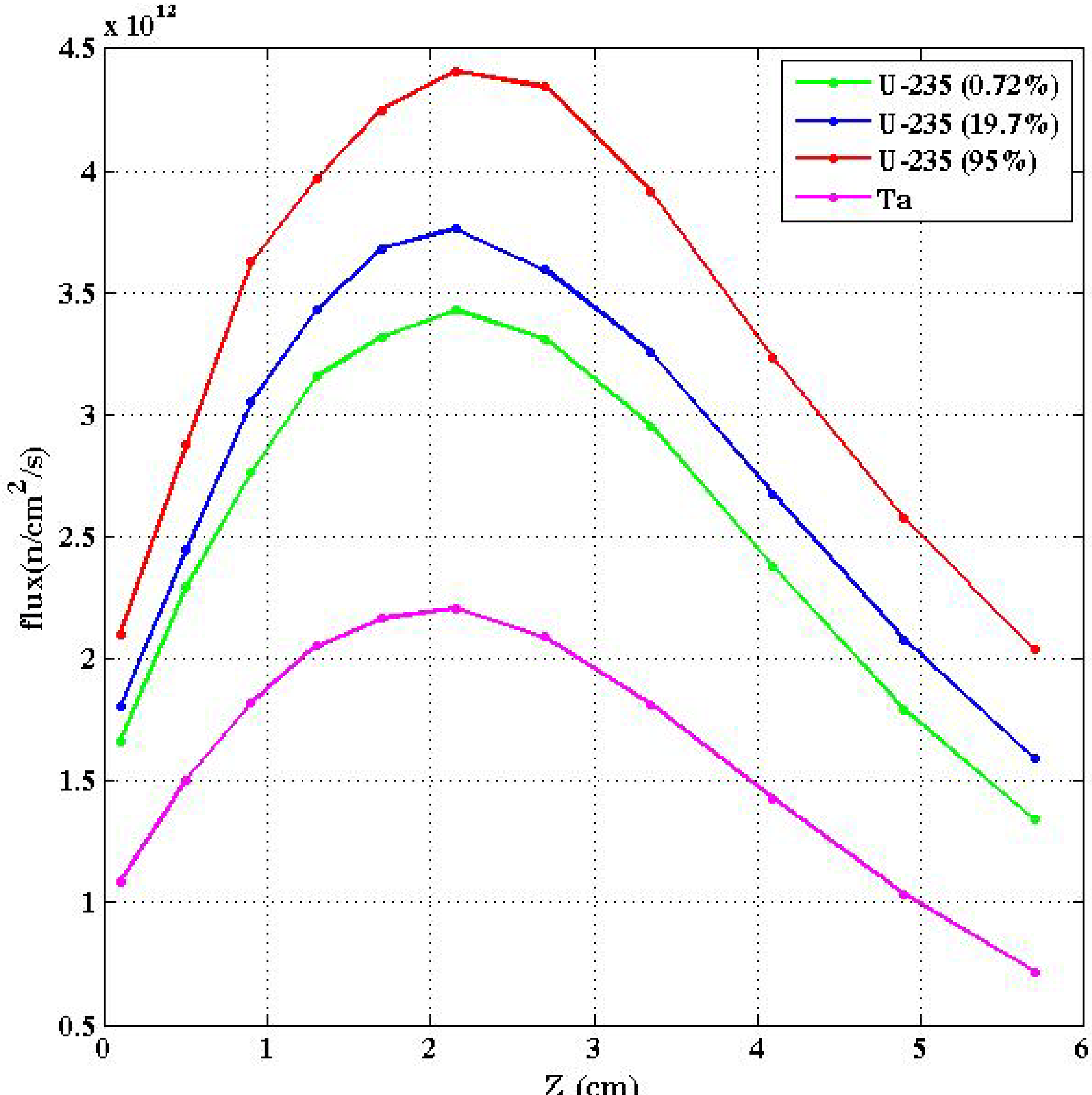
Target Geometry:

- Rectangular plates (4 cm× 4cm)
- Number of plates: 11
- Thickness : 0.2 – 0.6 cm
- Water channel width: 0.2 cm



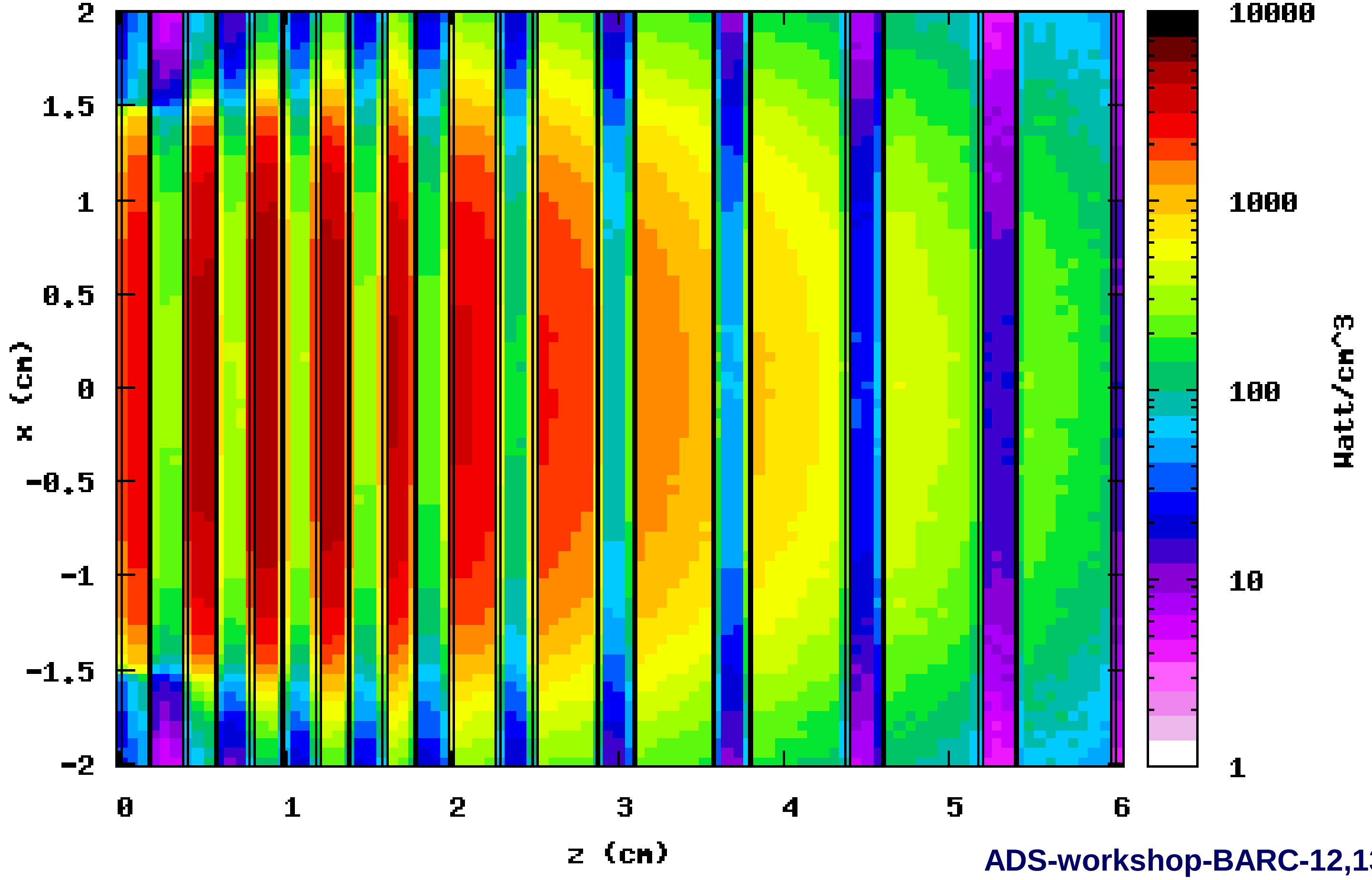
Schematic of Target configuration

Neutron flux distribution

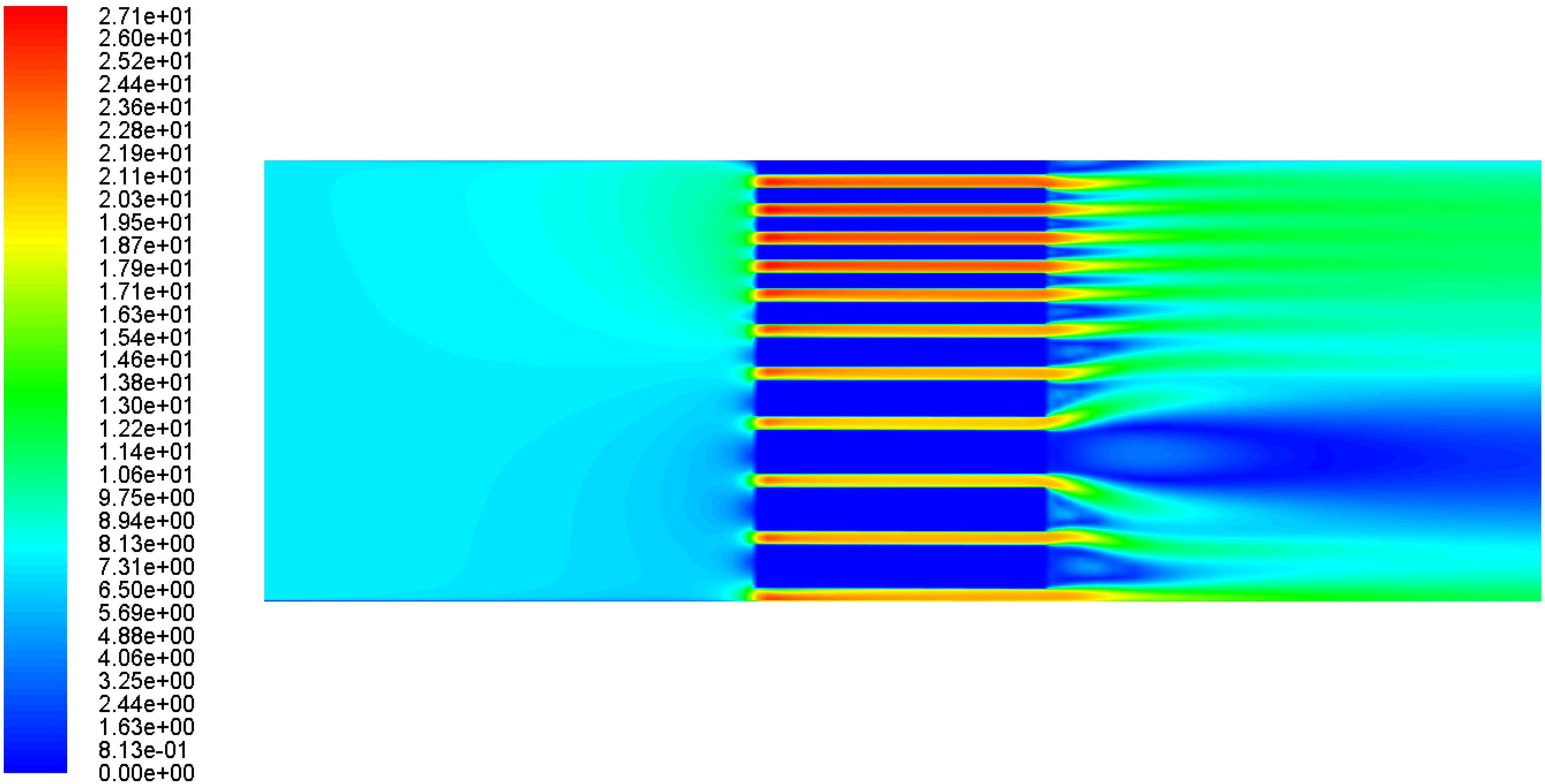


Target Material studied	Number of neutron produced per electron	Maximum neutron flux at the target surface
Ta	3.36E-2	2.206E+12
U^{235}(0.72%)+U^{238}	4.41E-2	3.428E+12
U^{235}(19.7%)+U^{238}	4.42E-2	3.761E+12
U^{235}(95%)+U^{238}	4.43E-2	4.405E+12

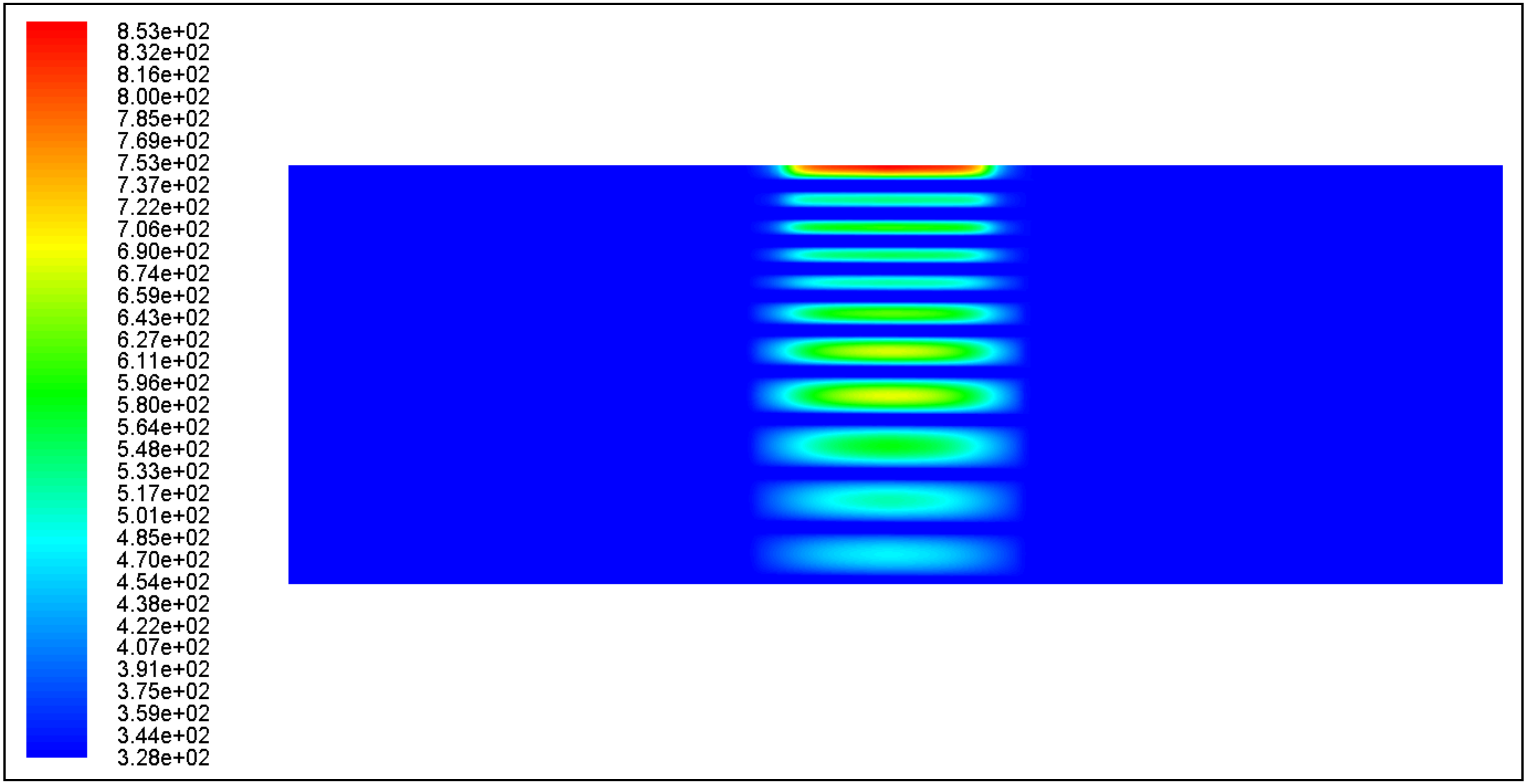
Time averaged heat density deposited by the electron beam

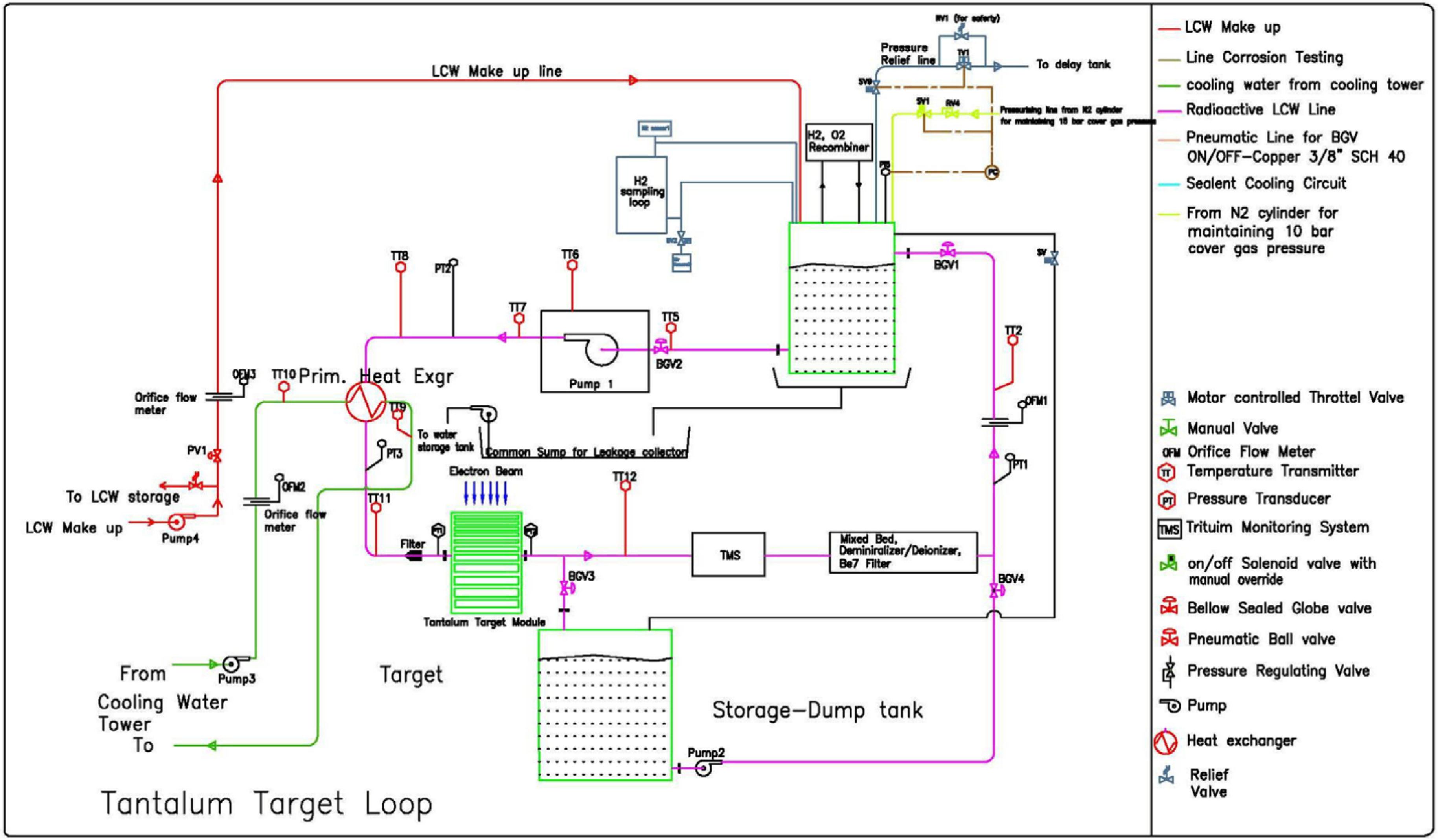


Velocity field in the target module (mass flow rate:18.56 kg/s)



Temperature distribution in the Target module (Water inlet temperature: 55^0 C, Maximum temperature of solid target: 580^0C-1st Plate, Maximum temperature of water: 195^0 C)





Preliminary process flow of target loop

Thank you