Closing the Fuel Cycle with Fast Reactors: Indian experience and perspectives

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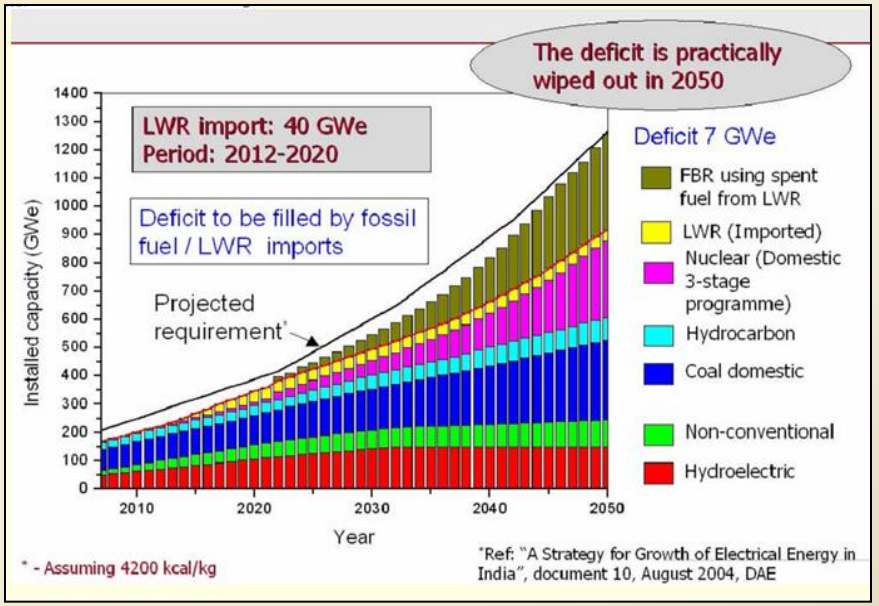
Energy Scenario for India

Energy Resource	Amount	Electricity Potential* GWe-yr
Coal	53.3 -BT	10,660
Hydrocarbon	12 –BT#	5,833
Uranium-Metal	94,000-T	
- In PHWR		490
- In Fast Breeders		64700
Thorium-Metal (In Breeders)	2,25,000 –T	155,000
Hydro	150 -GWe	69 GWe-yr / yr
Renewables	100 GW(e)	



Nuclear Power Scenario

Stage – I PHWRs

- 15- Operating
- 3 - Under construction
- Several others planned
- Construction planned for 700 MWe units
- Gestation period being reduced
- POWER POTENTIAL ≅ 10,000 MWe

LWRs

- 2 BWRs Operating
- 2 VVERs under construction

Stage - II Fast Breeder Reactors

- 40 MWth FBTR – 24 years of successful operation
- (U,Pu)C fuel burn up 165 GWd/t achieved in FBTR
- Sodium Technology mastered - Na pumps operate more than 1,50,000 h
- 500 MWe Commercial FBR – Advanced stage of construction
- Power potential – Minimum 530 GWe

Stage – III and Beyond Thorium Based Reactors

- 30 kWth KAMINI – Operating
- 300 Mwe AHWR – Regulatory Evaluation
- Power Potential = 155,000 GWe-y
- Availability of ADS can enable early and enhanced introduction of Thorium Fuel Cycle
- Participation in ITER towards development of fusion technology

Energy sustainability with closing the fuel cycle is the policy; Growth limited by our ability to expand in a robust manner

FBR Programme in India

- India started FBR programme with the construction of FBTR
- FBTR is a 40 MWt (13.5 MWe) loop type reactor. The design is same as that of Rapsodie-Fortissimo except for incorporation of SG and TG (agreement signed with CEA, France in 1969).
- FBTR is in operation since 1985.
- 500 MWe Fast Breeder Reactor Project (PFBR) through Indigenous design and construction
- Govt. granted financial sanction for construction in Sep 2003.
- Construction of PFBR has been undertaken by BHAVINI.
- PFBR will be commissioned by Sep. 2011.
- Beyond PFBR: 6 units of 500 MWe FBR (twin unit concept) similar to PFBR with improved economy and enhanced safety by 2020.
- Subsequent reactors would be 1000 MWe units with metallic fuel

Fuel Cycle of FBTR

FBTR is in operation since 1985,

It uses a unique U, Pu mixed carbide fuel with high Pu content (Mark I 70 %, Mark II 55 %)

The fuel has set an international record in burn-up (165 GWd/t) without any fuel pin failure in the core

- **The fuel has been fabricated at BARC**
- **Comprehensive post–irradiation examination of the fuel has been carried out in hot cells at various stages of burn-up**
- **The fuel discharged at a burn up of up to 150 GWd/t has been reprocessed in CORAL facility**
- ***The recovered Pu has been used to fabricate the fuel, which has been loaded in the FBTR core, thus closing the fuel cycle***
- **Demonstration Facility to reprocess FBTR fuel on regular basis to be commissioned by end 2011**

Prototype Fast Breeder Reactor (PFBR)

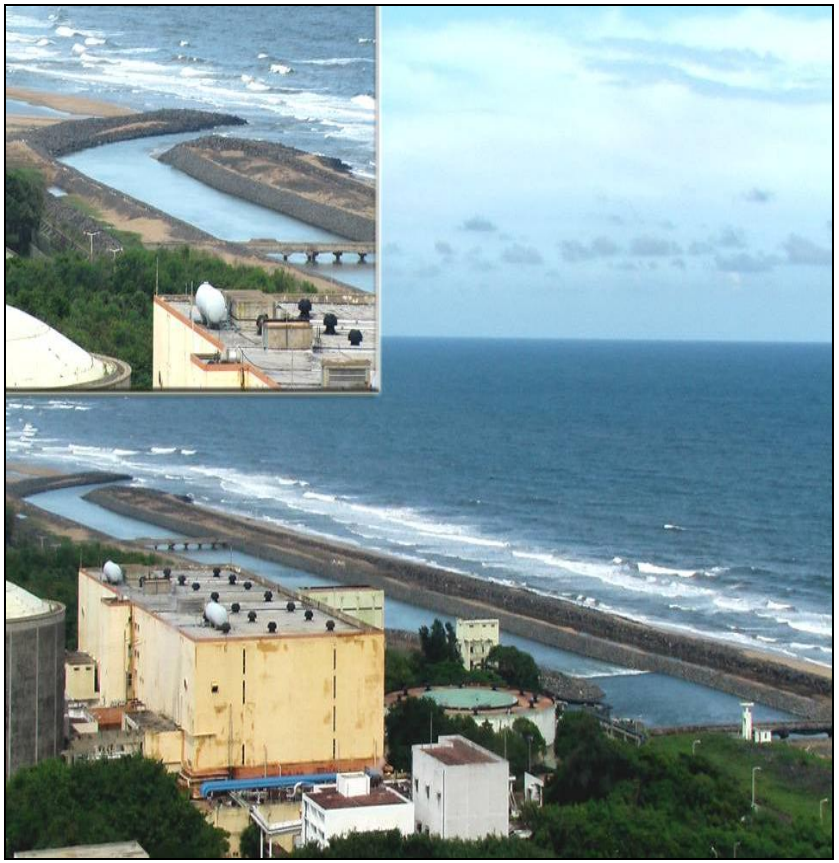
Designed by IGCAR and constructed by BHAVINI.

PFBR fuel under irradiation in FBTR has already crossed 100000 MWd/t

- **Power : 500 MWe**
- **Fuel: U,Pu Mixed Oxide (21 & 28 %)**
- **Peak burn up: 100,000 MWd/t (proposed to be enhanced to 150 GWd/t and subsequently to 200 GWd/t)**
- **Initial cores to be fabricated in Advanced Fuel Fabrication Facility (Tarapur) and subsequent cores in Fast Reactor Fuel Cycle facility (FRFCF) being set up at Kalpakkam, colocated with PFBR**
- **Fuel to be reprocessed in FRFCF**

PFBR: Civil Works Nearing Completion

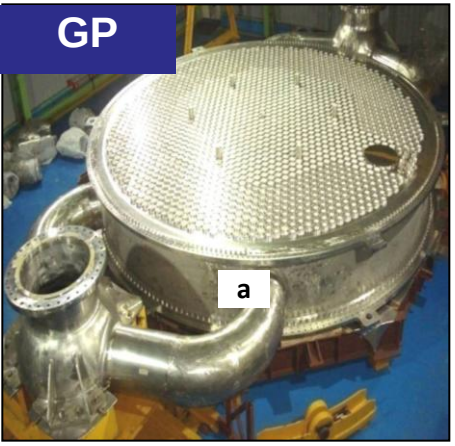
RCB Roof Truss construction



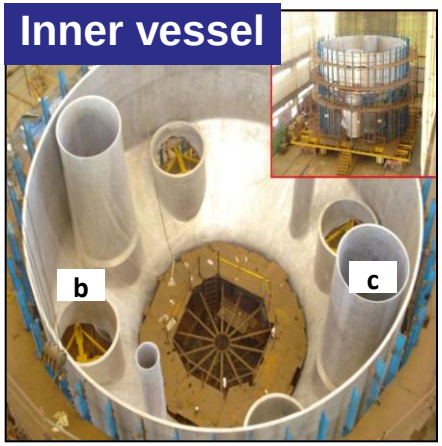
Sea water outfall channel

PFBR: Components manufacture in advanced stage

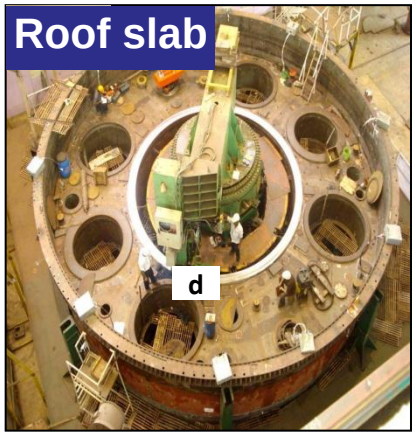
GP



Inner vessel



Roof slab



IHX

DHX

Horton spheres

LRP/SRP

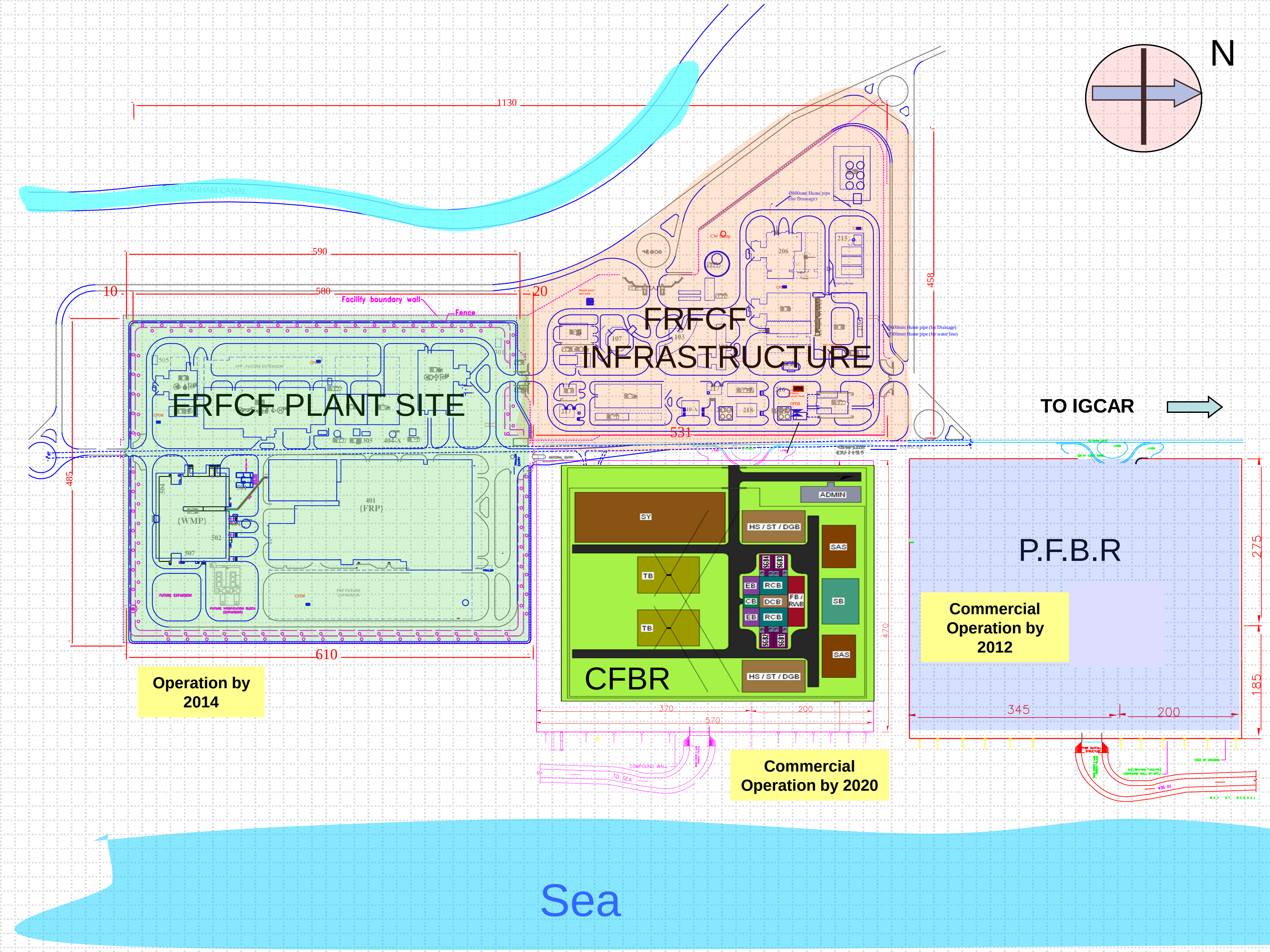
Erection of PFBR Components

Main Vessel Erection

Dec 2009

Erection of thermal baffles

May 2010


N
TO IGCAR
1130
590
580
10
20
458
485
610
531
FRFCF PLANT SITE
FRFCF INFRASTRUCTURE
Facility boundary wall
Fence
{WMP}
401
{FRP}
Operation by 2014
CFBR
SY
ADMIN
HS / ST / DGB
SAS
TB
SB
EB
RCB
CB
DCB
FB / RWB
370
200
570
470
Commercial Operation by 2020
P.F.B.R
Commercial Operation by 2012
345
200
275
185
Sea

Artist's impression of FRFCF

Fast reactor Fuel Cycle facility (FRFCF)

This facility will be self contained and have all facilities for recycling the fuel from PFBR, including fuel fabrication & assembly plants, reprocessing and waste management facility

Layout of FRFCF planned in such a way that future expansion would be possible to meet the requirements of two more 500 MWe FBRs that would be built at Kalpakkam site at later date.

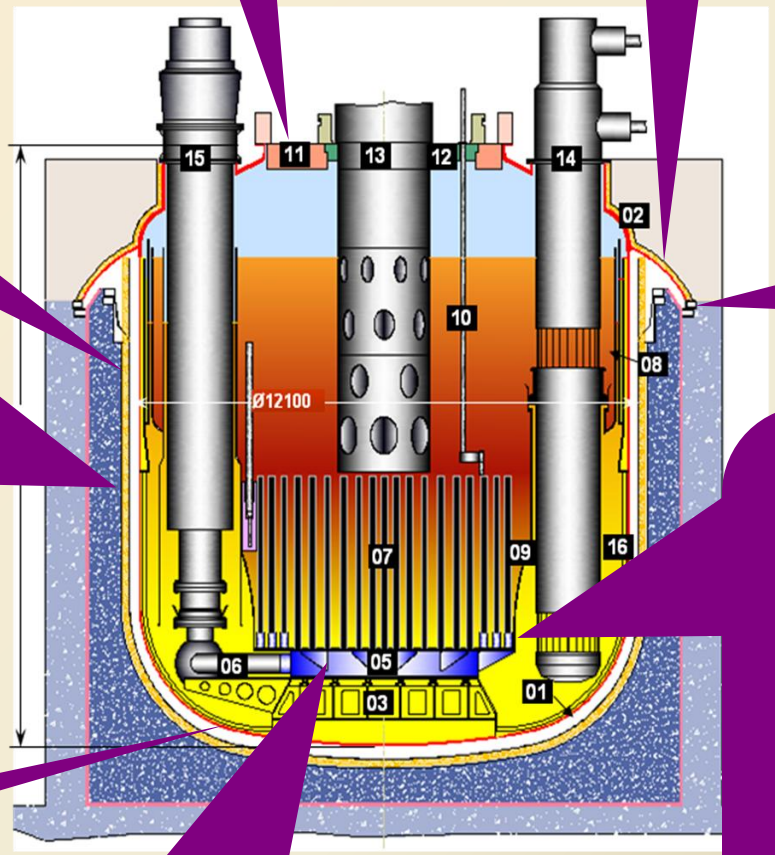
Facility will be commissioned in 2014

Innovations in Reactor Assembly Design Features for Future FBRs

Thick plate Top shield

Dome shaped roof slab

Integrated liner and safety vessel with thermal insulation arrangement



Conical shell for reactor assembly support

Optimization of vessel thickness on OBE elimination Seismic design based on SSE as design basis event

Inner vessel with single toroidal shell (redan) directly connecting grid plate with the upper cylindrical shell

Eight primary pipes

Welded grid plate with reduced height

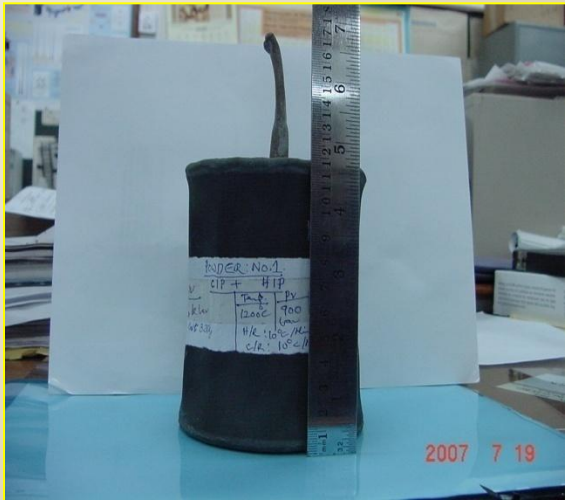
25% weight reduction

Other Improvements

- Shut down systems with improved reliability : $< 10^{-7}$ / reactor year
- Improved Safety Grade Decay Heat Removal Systems
- Steam generator with increased tube length, reduced weld joints: 27 % savings in construction material
- Reduction in construction time

Fast Reactor Fuel Cycle: thrust areas

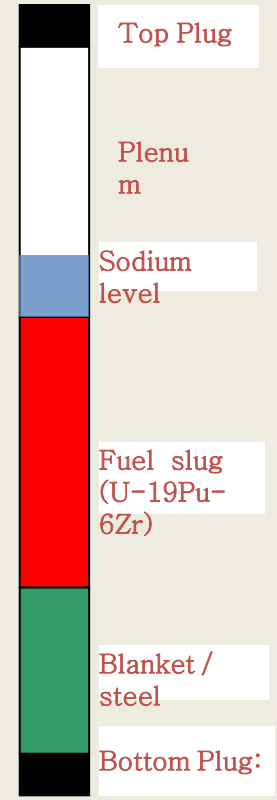
- Enhanced recovery of U and Pu with reduced concern on third phase formation: alternate trialkyl phosphates and amides under development
- Development of materials for process equipment and tanks to enhance plant life: Ti-Ta-Nb and Zr alloys developed
- Partitioning of minor actinides: process demonstrated in hot cells; studies with HLW from CORAL plant in progress
- Pd recovery: extraction-electrodeposition process
- Ceramic and glass waste forms for enhanced loading of fast reactor waste: High loading of Cs with resistance to leaching demonstrated in FPG glass



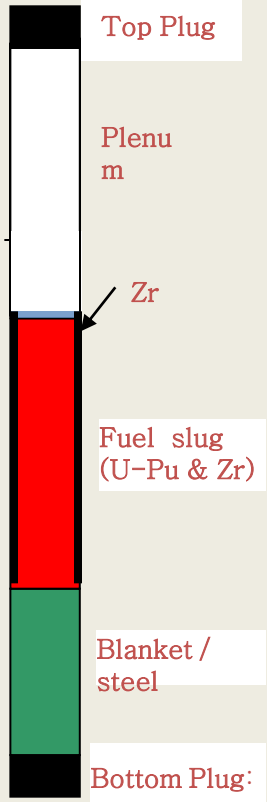
Metallic Fuel Development

Doubling time : 30 y for oxide , 10 y for metal and 7 ys for improved metal (without Zr)

- Pin Irradiation in FBTR
- Subassembly Irradiation in FBTR
- Full Core Metallic Fuel in FBTR
- Flexible Oxide & Metal 500 MWe Design
- Metallic Fuel Design 1000 MWe Units



Na bonded



Mechanical bonded

Mechanical bonding under development at BARC and sodium bonding at IGCAR

Development of Metal fuelled reactor and associated fuel cycle

- Physics design of metal core for 1000 MWe FBR completed; breeding potential (BR = 1.5) and actinide burning potential confirmed
- Fuel fabrication route through co-swaging established at BARC; sodium bonding facility commissioned at IGCAR
- Test fuel pin irradiation followed subassembly level irradiation in FBTR
- Pilot plant for fuel fabrication being constructed at Kalpakkam, colocated with FBTR; pyroprocess plant to established in same complex

Pyroprocess Development

- Engineering scale test facility commissioned in April 2010
- Molten salt electrorefining of Uranium being studied at kg scale
- Materials development for enhanced life
- Engineering of advanced electrorefiners and cathode processors
- Studies in progress on waste salt treatment and development of waste forms

Pyroprocess Development

Lab scale facility for Pu studies

Engineering Scale Facility for process equipment development

Fast Reactor Fuel Cycle : Enabling programmes

- ✓ **Programmes with breakthrough potential: applications of room temperature ionic liquids as solvents, diluents and electrolysis media, supercritical fluid extraction as waste management tool**

- ✓ **Collaborations with academic and research institutions towards basic understanding of processes, development of new processes and equipment, and realising innovations with breakthrough potential**

- ✓ **Human resource development: Advanced courses under the auspices of Homi Bhabha National Institute in fuel cycle related subjects to train and empower young generation for taking up challenging programmes**

- ✓ **Advanced R & D facilities being planned in XII five year plan period to develop and demonstrate processes such as sol-gel fuel fabrication, partitioning of minor actinide separations and waste form production in engineering scale**

Closed Fuel Cycle with FBRs: International Collaborations

- PSA methodologies for fuel cycle plants
- Materials development and testing for plant life enhancement
- On-line tracking of fissile material in process streams and equipment
- Development of alternate extractants and waste forms

Thank You