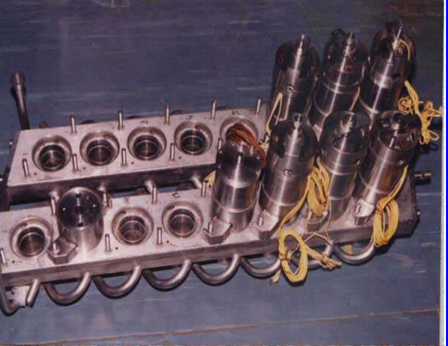
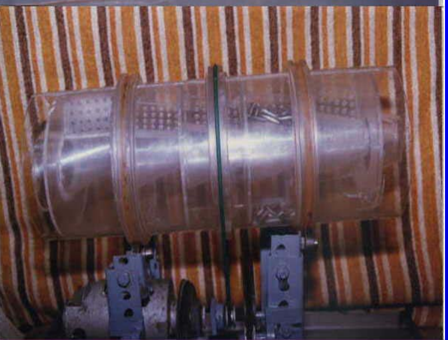
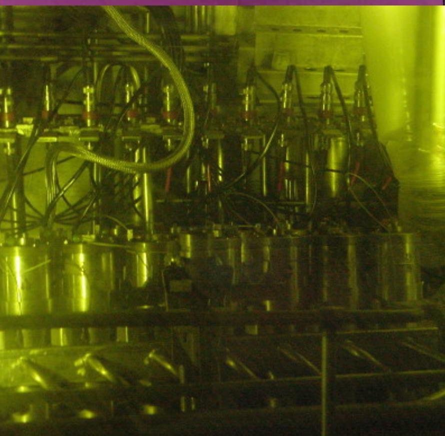



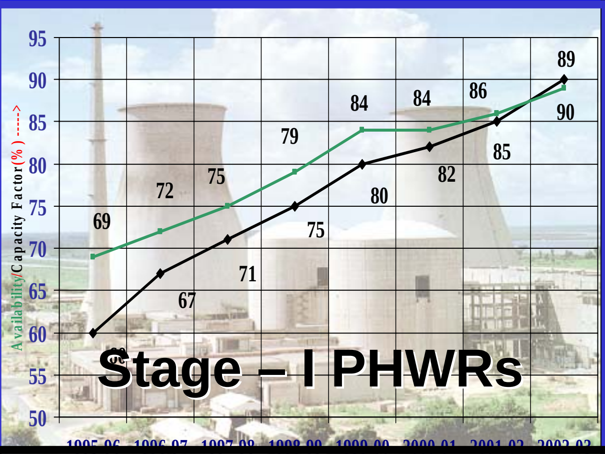


Carbide Fuel Reprocessing and Fast Reactor Fuel Cycle Development

Baldev Raj

Distinguished Scientist and Director,
Indira Gandhi Centre for Atomic Research
Kalpakkam 603 102

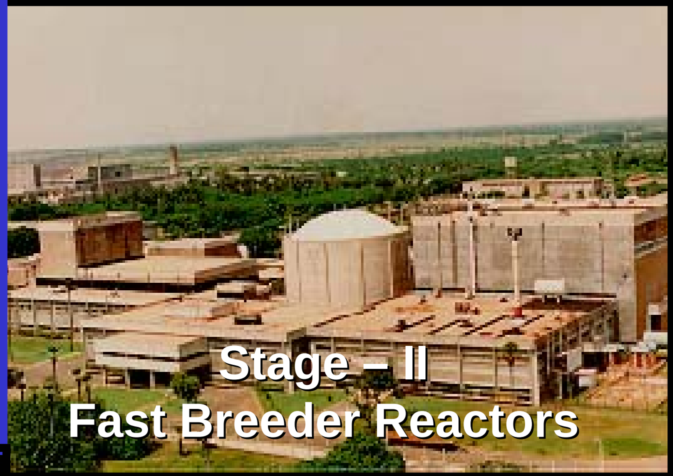
THREE STAGE NUCLEAR POWER PROGRAM



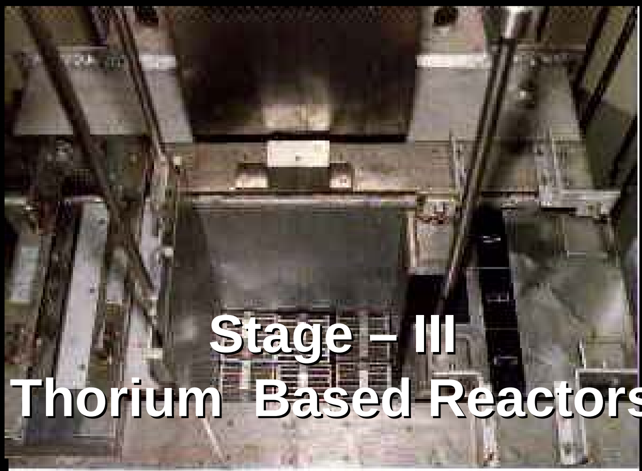
- 15- Operating
- 5 - Under construction
- Several others planned
- Scaling to 700 MWe
- Gestation period being reduced
- POWER POTENTIAL ≅ 10,000 MWe

LWRs

- 2 BWRs Operating
- 2 VVERs under construction



- 40 MWth FBTR - Operating Technology Objectives realised
- 500 MWe PFBR- construction commenced
- POWER POTENTIAL ≅ 540,000 MWe

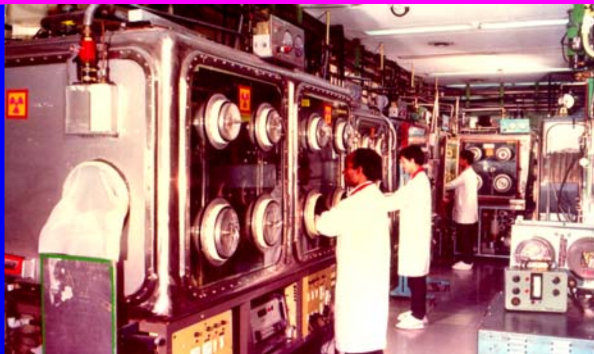


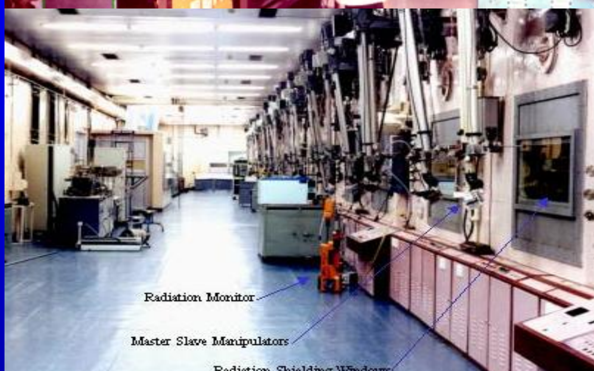
- 30 kWth KAMINI- Operating
- 300 MWe AHWR- Under Regulatory Examination
- POWER POTENTIAL ≅ Very Large. Availability of ADS can enable early introduction of Thorium on a large scale

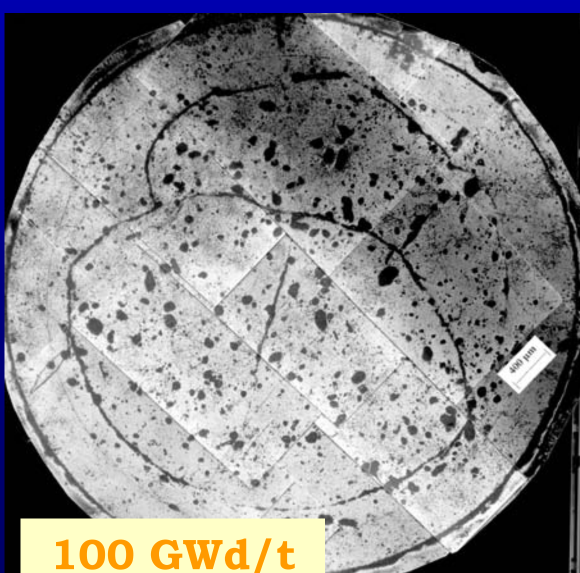
Five Phase Programme of the Indian FBR Fuel reprocessing

- **Phase I: Development phase consisting of Process formulation, validation, design and development of equipment**
- **Phase II: Construction and operation of a pilot plant called CORAL (COmpact Reprocessing of Advanced fuels in Lead shielded cells, formerly known as the Lead Mini Cell, LMC).**
- **Phase III: Construction and operation of DFRP (Demonstration fast reactor Fuel Reprocessing Plant) to gain experience in FBR reprocessing with high availability factors and throughput**
- **Phase IV: Construction and operation of PFRP (PFBR Fuel Reprocessing Plant) for commercial reprocessing.**
- **Phase V: Construction and operation of a Pyrochemical Reprocessing Plant**

Carbide Fuel Cycle of FBTR







- Fuel fabricated at BARC
- Comprehensive PIE of FBTR fuel at 25, 50 and 100 GWd/t in hot cells under inert atmosphere: destructive as well as non-destructive techniques employed
- FBTR Mark I Fuel has now reached 154 GWd/t without fuel pin failure in the core
- Fuel discharged at 25, 50 and 100 GWd/t reprocessed in CORAL facility

FBR Fuel Reprocessing in CORAL facility

Reprocessing Group

IGCAR

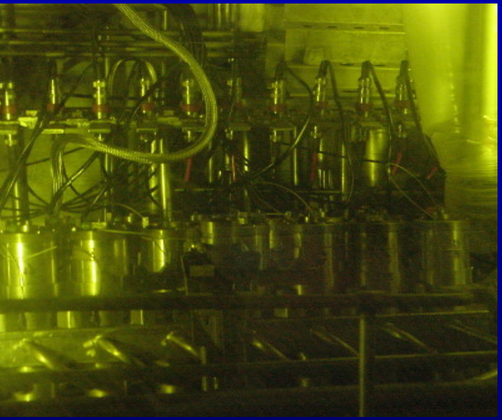
CORAL@RpGIGCAR

(Earlier known as LMC)

- CORAL is a compact lead shielded facility with α-tight containment, designed on a no-direct maintenance concept.
- Houses all the equipments like single-pin chopper, dissolver, centrifuge, Centrifugal Extractors (CEs), sampling units etc.
- Gadgets like Radiation Shielding Windows(RSW) in-cell crane and articulated arm type MSM (Master – Slave manipulators) enable remote operation and maintenance.
- Annular or slab type process vessels for avoiding criticality.
- CORAL took up progressive reprocessing exercise of low burn-up fuel pins, 25 GWd/T, 50 GWd/T and 100 GWd/T fuel pins with stage-wise safety clearances.

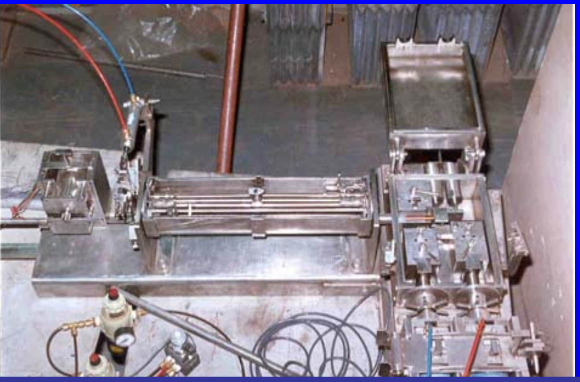
16-stage CE bank during assembling

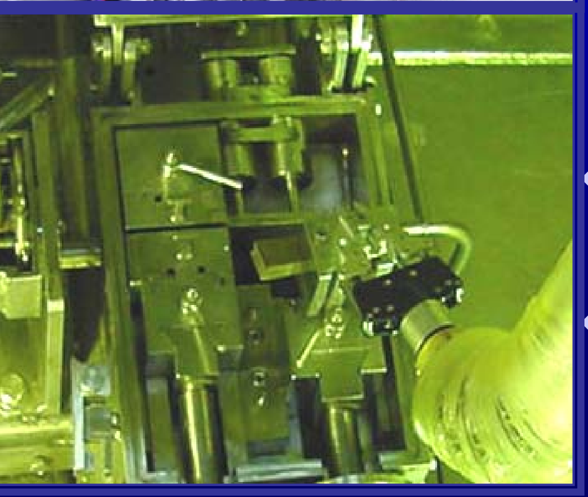
16 Stage CE Bank



CEs inside CORAL Facility

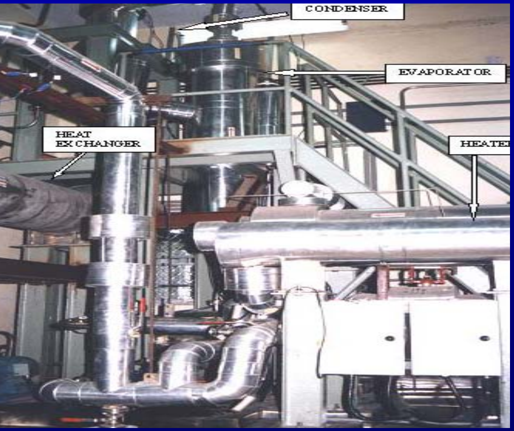
- The initial batch runs of the extraction and stripping for the first two batches of the conditioned dissolver solution were carried out in active laboratory thereby establishing the extraction parameters in the plant.
- On the basis in-house studies, the strategy for the destruction of dissolved carbon was finalized. The Pu losses in the raffinate stream during the various CORAL campaigns were low.
- In the successive CORAL campaigns with higher burn-up spent fuels, Pu retention in the lean organic was further minimized by the multiple point introduction of uranous nitrate stream in the strip section.
- All the models of CE (fixed weir, adjustable weir and belt driven) used in CORAL performed well.
- Based on the remote operation and maintenance, suitable choice could be made for future plants.





- The Single Pin Chopper (SPC), developed at RDL is modular in nature with remotely maintainable parts using the Master Slave Manipulators (MSM).
- A prototype SPC was installed in CORAL after rigorous testing under non-radioactive conditions.
- CORAL experience imparted confidence to take up similar campaigns with still higher burn-up fuels discharged from FBTR.
- The decontamination and recovery factors achieved during these campaigns have formed the inputs for finalising the process flowsheet for the forthcoming plants DFRP and PFRP.
- DFRP intended to meet the total requirement of FBTR irradiated fuel reprocessing.
- Provision exists for reprocessing PFBR fuels subassemblies.

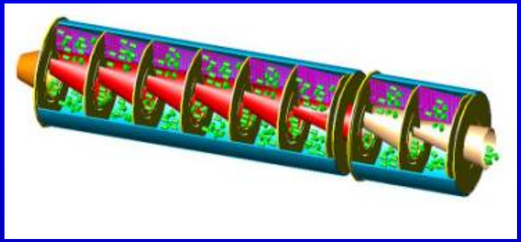
Ti Dissolver



Acid Loop for Corrosion Studies

- Facilities for solvent treatment and raffinate evaporation (not part of CORAL) provided
- DFRP scheduled for commissioning in 2009.
- The long felt need for online or quick process control analysis of Pu in raffinate and loaded organic stream will be addressed in DFRP to gain operating experience with this system. The determination of Pu in the hulls is difficult because of high Co^{60} background. An indirect method using Ce^{144} has been successfully deployed to measure the Pu in the hull in CORAL facility.
- Heavy duty manipulators with extended arm type and three piece type are used with special containment to avoid α contamination during maintenance.
- The DFRP, under erection, will aid in estimating the various performance factors of plant operation. Its operation will further enable improvement in recovery and reduction in number of cycles.

Perspex Model of Dissolver

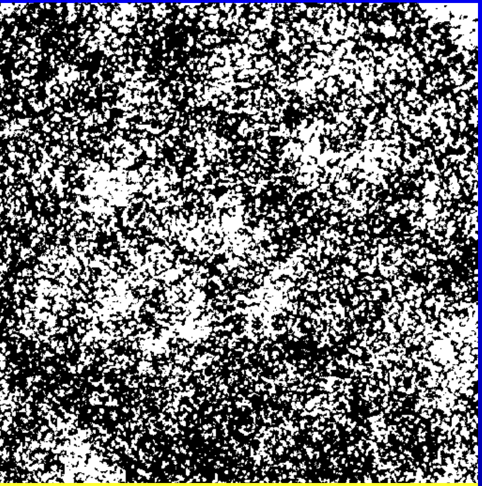


Conceptual Rotary Dissolver

Prototype Rotary Dissolver

- Advanced process equipments like the multi-pin chopper, rotary dissolver, screw calciner, microware oven for direct denitration and a compact layout design with poison tube cylindrical vessels etc. are being developed.
- A small scale dissolver in Zircaloy fabricated and undergoing testing.
- Alloys like Ti-5%Ta-1.8%Nb are being developed for corrosion resistant dissolver and evaporator.
- A compact LINAC based neutron generator is being developed at IGCAR for use in the active neutron interrogation system

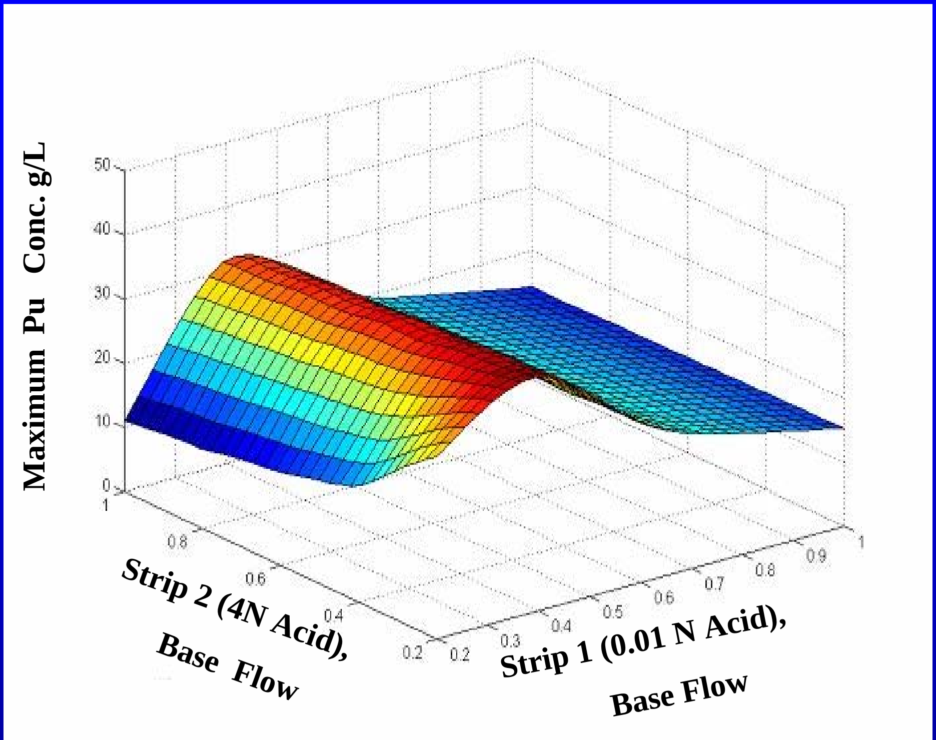
Studies on Ionic Liquids

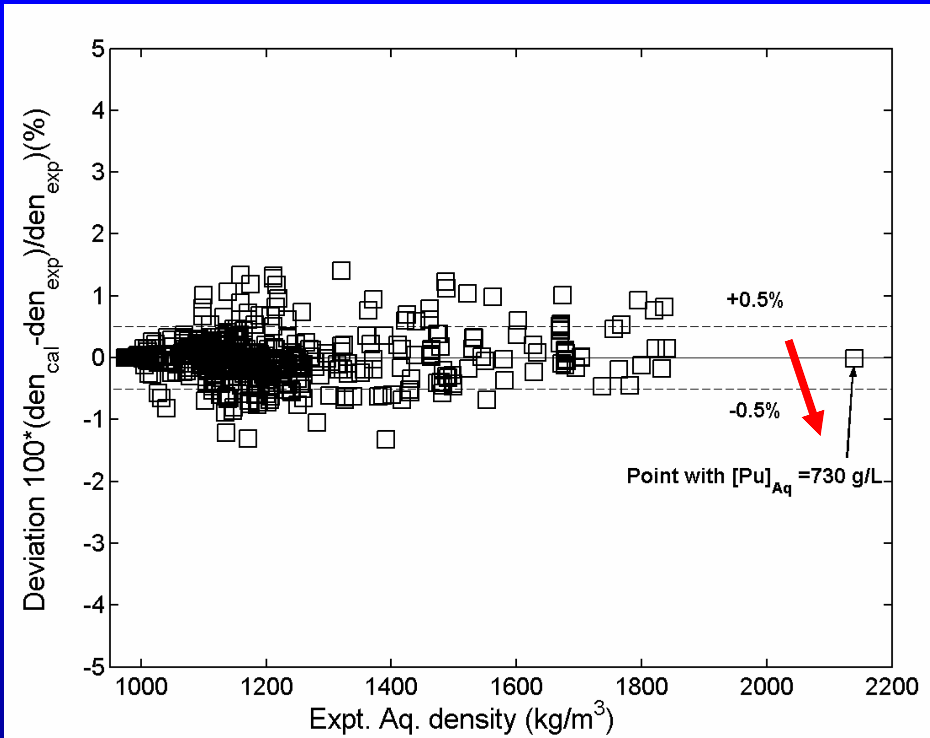


Palladium deposit obtained from ionic liquid as electrolyte

- **Extraction of uranium by TBP in ionic liquid**
- **Effect of chain length of alkyl groups in IL**
- **Use of RTIL for replacing conventional diluent**
- **Non-aqueous reprocessing**
  - **Palladium electrodeposition from ionic liquid**
  - **Uranium oxide electrodeposition**
- **Extraction-cum-electrodeposition**
  - **Palladium extraction followed by Electro deposition**

Modeling for Reprocessing





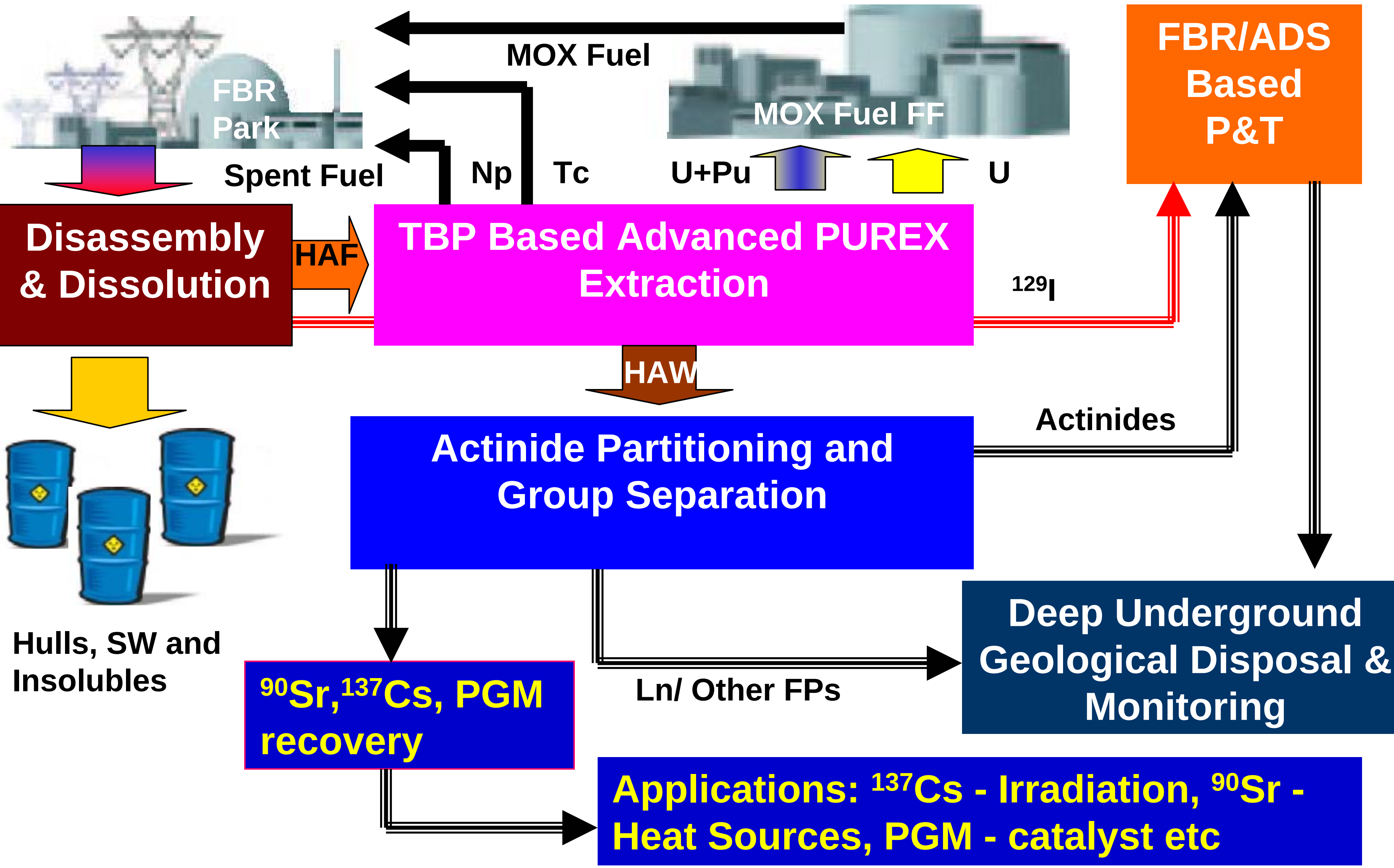
Variation of Max. Pu Concentration in the HC contactor: Results from SIMPSEX code developed at IGCAR

Plot of deviations for Model developed for density of multi-solute solutions. Point with arrow mark indicates deviation for the extreme Pu concentration of 730 g/L at 59° C: Researchers at JNC, Tokai, found it as the best equation among the ones listed in the literature.

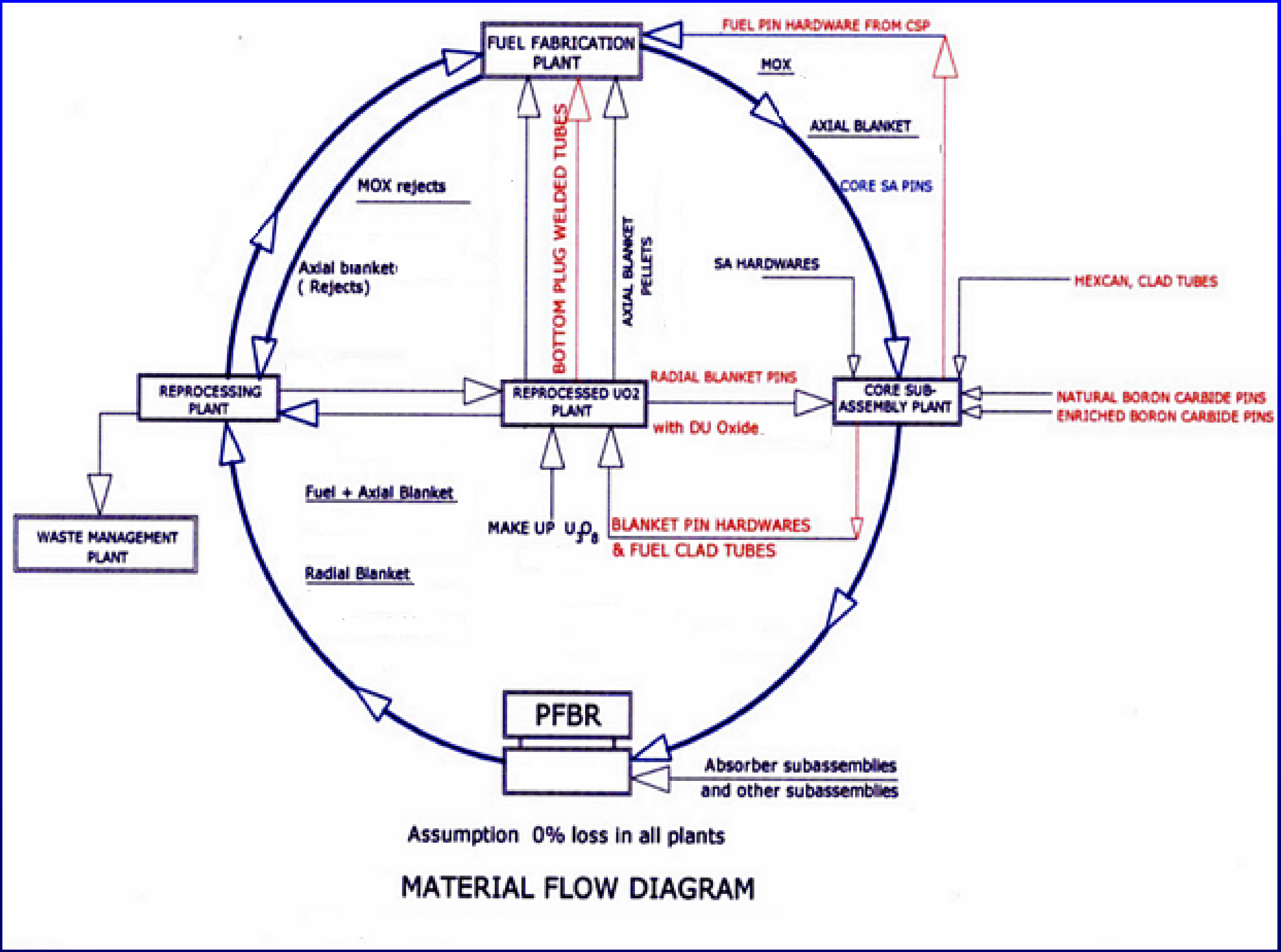
FBR Fuel Reprocessing – New Directions

- Improvements in process to handle fuel of high burn-up with better solvents as well as better extractors
- Studies on the behaviour of important fission products e,g., Zr, Ru, Tc and Np for achieving high DF
- Reduction in number of equipment by simple plant design and simpler technology implementations
- Use of Borated/poisoned Steels to realise compact plant size
- Reduction of plant construction time
- Increased availability of the plant
- Newer technologies like supercritical extraction, ionic liquids and advanced pyroprocessing

Redefining Reprocessing: Recovery of ALL valuable elements from irradiated fuel



Integrated Fast Reactor Fuel Cycle Facility (FRFCF)



Thorium Fuel Cycle Related Studies

KAMINI Reactor@IGCAR

- Some of the equipments developed were also deployed in the reprocessing campaigns of irradiated thorium fuel rods to recover U-233.
- A part of the recovered U-233 was used in the fabrication of FBR MOX fuel for the irradiation experiments in FBTR.
- Recovered U-233 was also used for making driver fuel for KAMINI reactor.
- At present, 30 kWt KAMINI reactor in Kalpakkam is the only reactor in the world operating with U-233 as its driver fuel.

Computational Benchmarking of Transmutation in FBR

IAEA has initiated a CRP on "Studies of Advanced Reactor Technology Options for Effective Incineration of Radioactive Waste"

Overall objectives

- Perform R&D contributing towards the proof of practicality of transmutation of MAs using ADS and reactors
- IGCAR is participating with an option of fast reactor core similar to PFBR for MAs separated from PHWRs

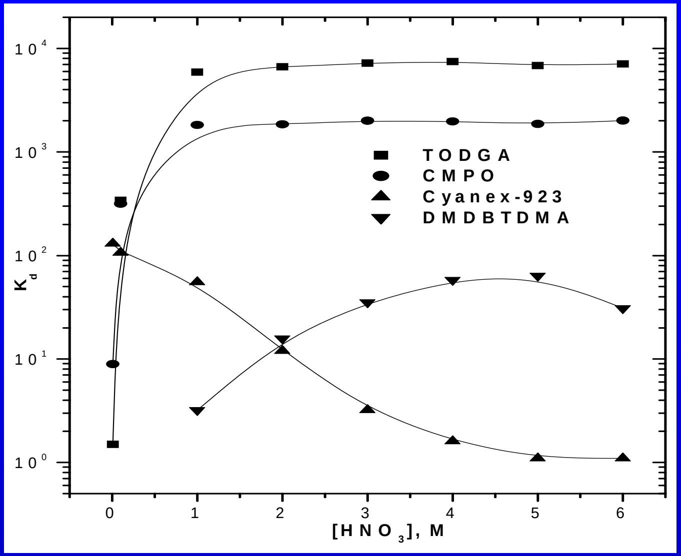
FBR Benchmark characteristics

- Power : 1150 MWth
- 3 rows of ThO_2 radial blanket and depleted UO_2 axial blanket
- Two cores of $(U,Pu)O_2$ MOX with 19.5 and 27.1% PuO_2 enrichment
- MAs uniformly distributed throughout the core

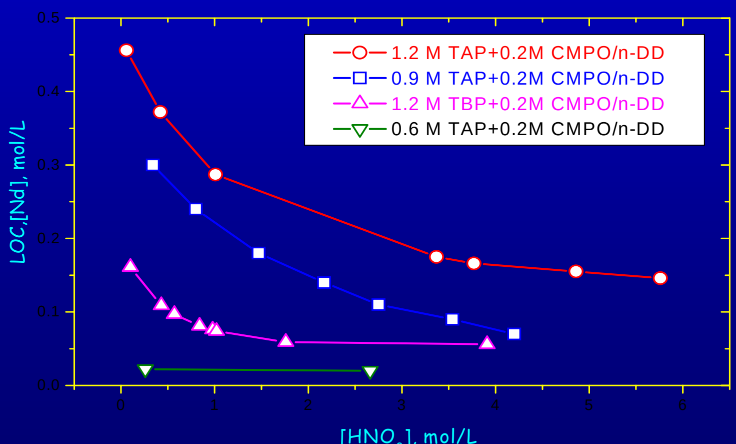
Benchmark Results

- Reductions in the MA for a cycle length 195 days in core 1,
- for 25 GWd/t (single cycle) is 12%
- for 49 GWd/t (two cycles) is 22%
- Thus the core is an effective incinerator
- No significant MA is produced in ThO_2 blanket
- Overall reactor safety due to incineration of MA is comparable to PFBR

Studies on Partitioning



Am(III) uptake



Third phase formation in TAP-CMPO /n-DD-Nd$(NO_3)_3$ system

- **Extensive batch and counter current liquid-liquid extraction runs with actual and simulated HLWs typically generated by different reprocessing operations with OΦCMPO, malonamide, and diglycolic amides (TODGA and TEHDGA)**

-Extraction chromatographic studies

-Studies on third phase formation

-Studies on Actinide/Lanthanide separation

PARTITIONING OF HLW - STATUS

- ***Removal of residual U & Pu from HLW***
  - **PUREX (Industrially Established)**
    - **TBP (Industrially available)**

- ***Partitioning of Minor Actinides (Bulk Separation)***
  - **TRUEX (Inactive engineering scale trials)**
    - **CMPO (Indigenously synthesized)**
  - **TODGA Process (Inactive engineering scale trials)**
  - **TEHDGA (Indigenously synthesized)**

- ***Actinide-lanthanide Group Separation***
  - **TALSPEAK**
    - **HDEHP (Industrially available)**
  - **N, S Based Solvents**
    - **N,S solvents (Diaza diamide based; triazines) (under development)**

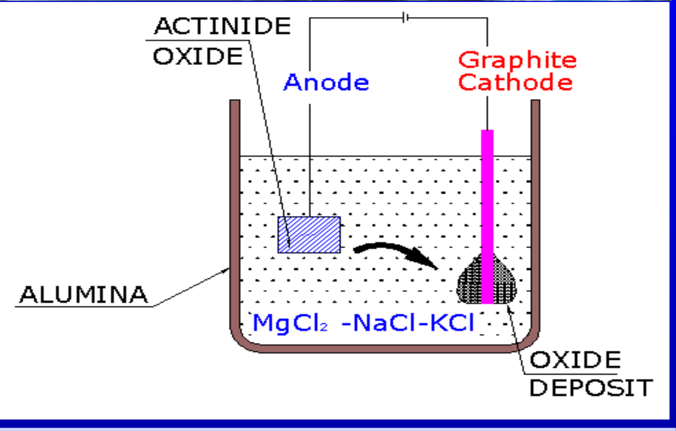
Indigenously Synthesized Actinide Partitioning Solvents – *Performance on Plant Scale Trials (Inactive)*

	CMPO (0.25 M CMPO + 1.2 M TBP in n-dodecane)		TEHDGA (0.2 M TEHDGA in n-dodecane with iso-decyl alcohol)	
	% Extracted	**% Stripped**	**% Extracted**	**% Stripped**
Ln	**97.58**	**99.60**	**97.27**	**99.71**
Ce	**98.45**	**~100**	**99.72**	**~100**
Mo	**88.31**	**95.68**	**16**	**94.56**
Ru	**20.0**	**~100**	**15**	**~100**
Sr	**NA**	**NA**	**3.0**	**94.85**

Contactors: Ejector Mixer Settler & Combined Air Lift mixer settlers

Run Duration : 6-8 Hours

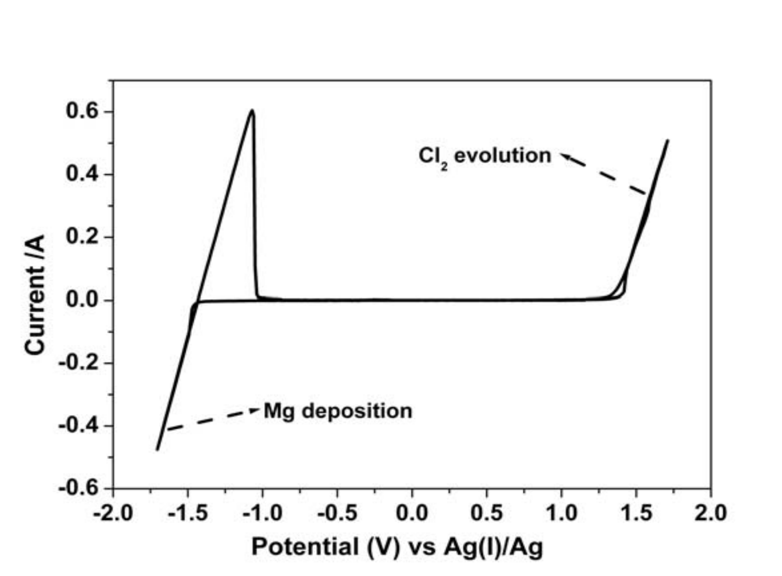
Pyrochemical Reprocessing

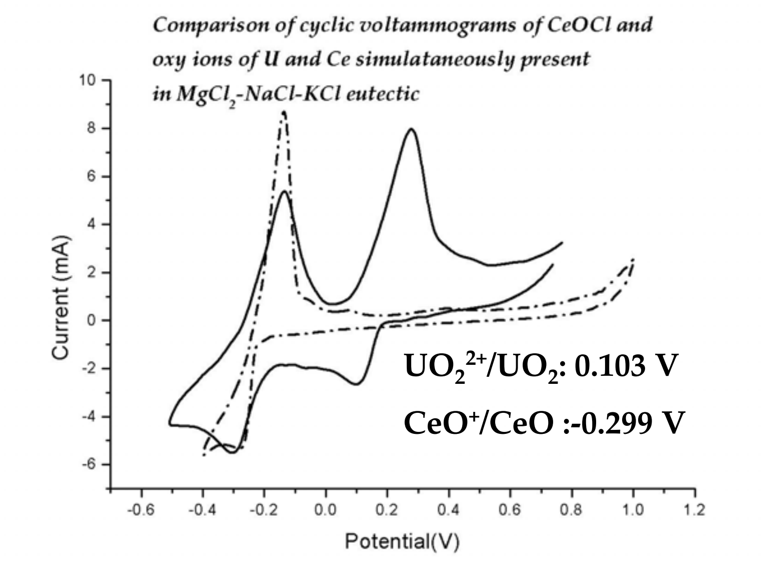


- ❖Suitable for for High burn-up, short-cooled fuels
- ❖Molten Salt Electrorefining Process - Ideally suited for Metallic fuels
- ❖Lab scale studies
- ❖Engineering scale facility in glove box with provision for manipulators
- ❖Feasibility of electrorefining of UO_2 established
- ❖No bulk chlorination, saving energy
- ❖Development of $MgCl_2$ salts as alternate electrolyte to CsCl-NaCl
- ❖Electrorefining of UO_2 in $MgCl_2$ based electrolyte established
- ❖Separation factor for Ce in this electrolyte determined to be in the range 60-100 (IAEA – CRP- Project)

Oxide Electrowinning Process

- **Development of 50% $MgCl_2$-30%NaCl-20%KCl salt as alternate electrolyte to 2 CsCl-NaCl**
  - Lower melting temperature, Less expensive than 2 CsCl-NaCl
  - Anhydrous $MgCl_2$ available as by-product from Zr sponge plant of Nuclear Fuel Complex, Hyderabad

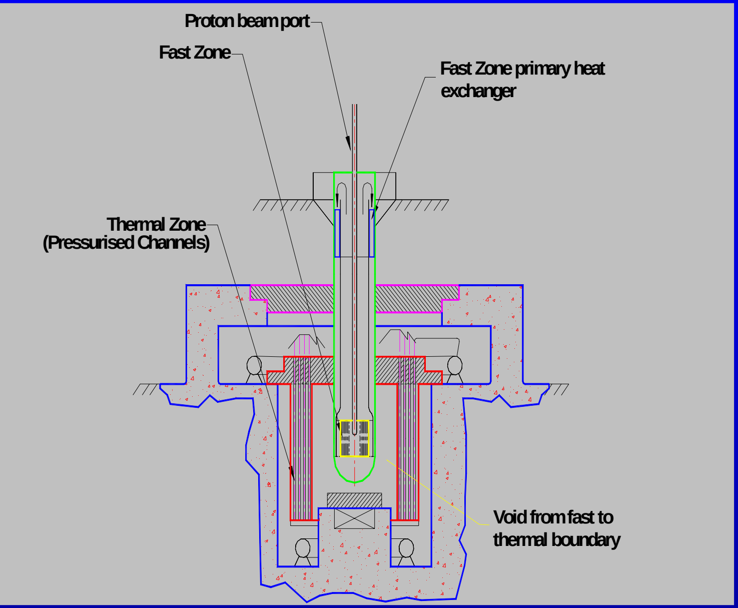




Sufficient electrochemical window for oxide fuel processing

Separation of U and Ce oxides feasible

Schematic of Indian concept of Fast-Thermal ADS



Fast zone loaded with higher actinides-rich fuel.

Thermal zone with Th-U fuel & D_2O moderator-coolant.

Ongoing Indian activities on ADS development

- Reactor physics codes and data.
- Studies and computations for target nuclear reactions.
- Experimental LBE loop for thermal hydraulics and materials development.
- Experimental sub-critical reactor physics with 14-MeV neutron generator.
- High intensity proton sources and low-energy linear accelerator project.
- Superconducting RF cavity development for high-energy section of proton LINAC.

Roadmap for ADS development

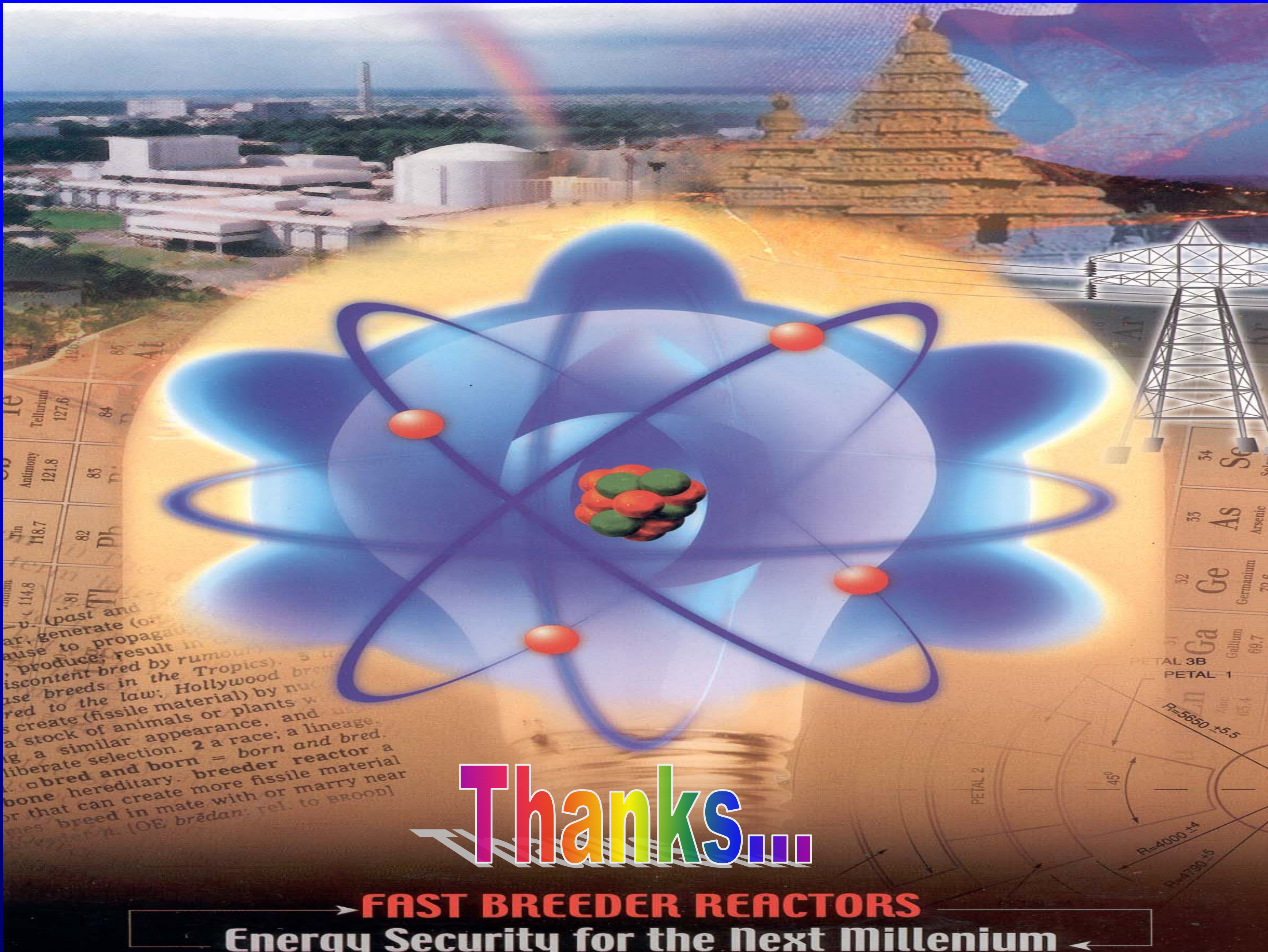
- Developing basic scientific know-how for accelerator, target and sub-critical core with new fuel species.
- Developing human resources to conduct R & D programmes.
- Construction and utilization of Experimental validation facilities.
- Technology development in priority areas.
- Design and safety analysis of ADS prototypes.
- Spin-off applications of developmental projects.

Future plans on ADS

- ❖Initially a 5 MW fission power ADS is planned
- ❖This will be a sub-critical reactor operating at near ambient temperature & driven with a few mA proton beam of 120-150MeV
- ❖ ADS would be used to verify and fine tune calculation code with U-Th fuels to study burn-up reactivity kinetics without "nuclear safety" risks
- ❖In the long range a demonstration ADS with 10-20mA, 500-600MeV proton beam driving a sub-critical reactor of 100 MW fission power is planned with a coolant temperature of ~350^{o}C

Conclusions

- All phases of fast reactor fuel reprocessing have been demonstrated.
- Emphasis is on processing of irradiated fuels with high Pu content, High burnup and short-cooling.
- Indian R&D on fast reactor fuel cycle is mature.
- India is redefining reprocessing as a process with emphasis on recovery of all the valuable materials for societal use. Wealth from waste is also a piller of strength in the Indian strategy.
- Work on the processes for MA separation and partitioning is under progress.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