Reducing Radioactive Wastes an Indian Perspective

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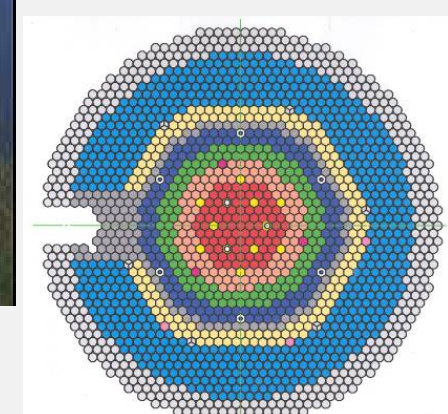
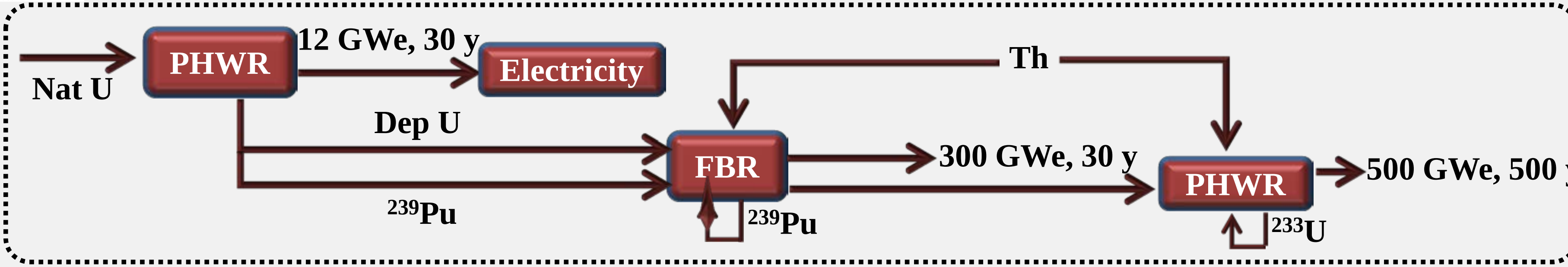
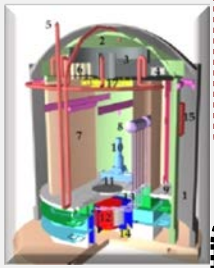


India’s Nuclear Power Programme



AHWR



STAGE 1
PHWRs

- ✓12 Operating
- ✓6 Under construction
- ✓Several others planned
- ✓Scaling to 700 Mwe
- ✓Gestation period being reduced
- ✓Power potential = 10,000 MWe

LWRs

- ✓2 BWRs Operating
- ✓2 VVERs Just commissioned

STAGE 2
FAST Breeder Reactor

- ✓40 MWth FBTR- Operating since 1985 Technology objective realized
- ✓500 MWe PFBR under construction
- ✓Power potential = 530,000 MWe

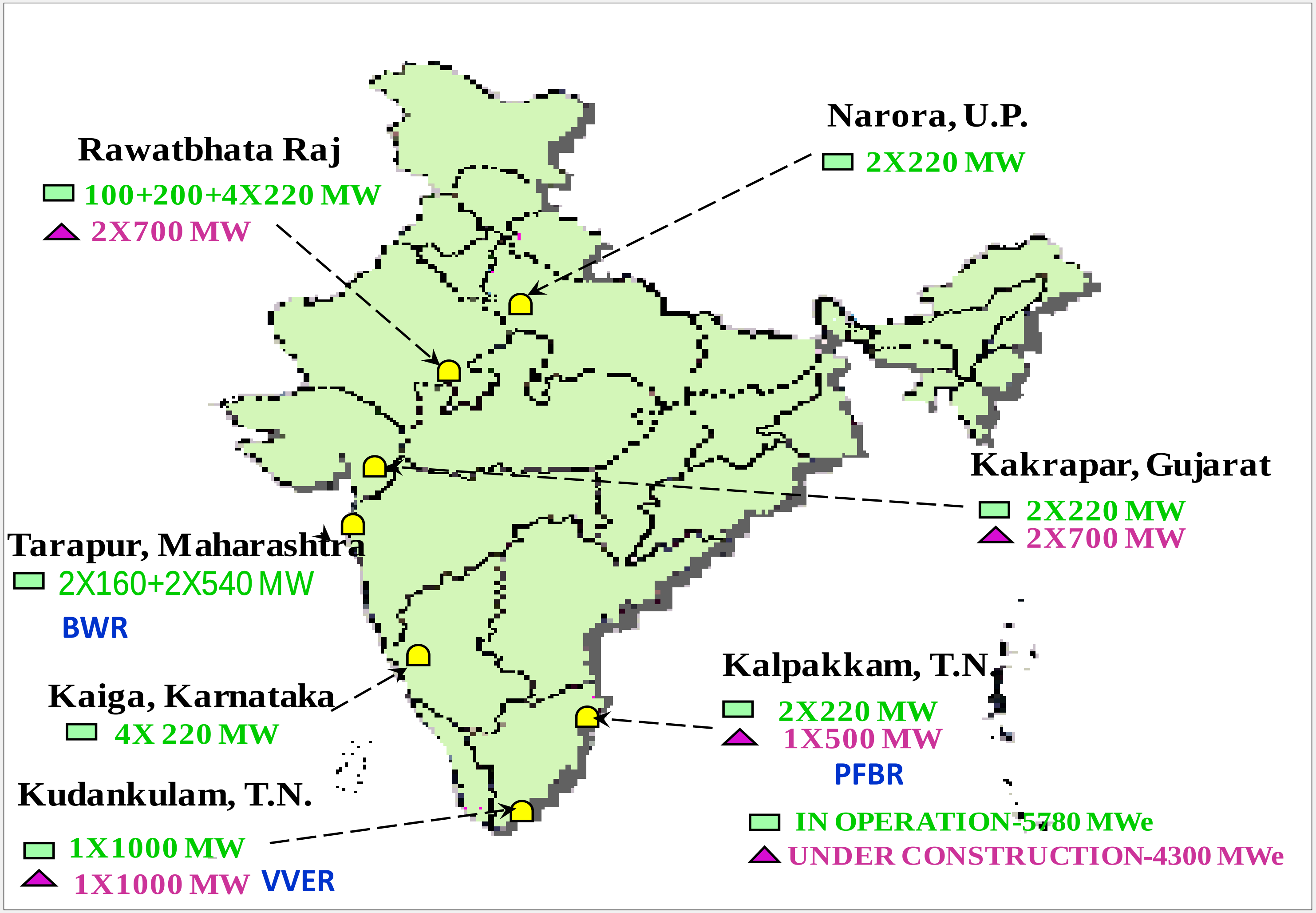
STAGE 3
Thorium Based Reactors

- ✓30 KWth KAMINI - Operating
- ✓300 MWe AHWR under development
- ✓Power potential is very large
- ✓Availability of ADS can enable early introduction of Th on a large scale

Baldevraj, A Perceptive of Fast Reactor Fuel Cycle in India.

India's Nuclear Power Programme

Currently Operating Reactors **PHWRs;** BWR; VVER
Total Powder Produced: 5780 MWe   4300 MWe (under construction)



Courtesy: NPCIL, INDIA

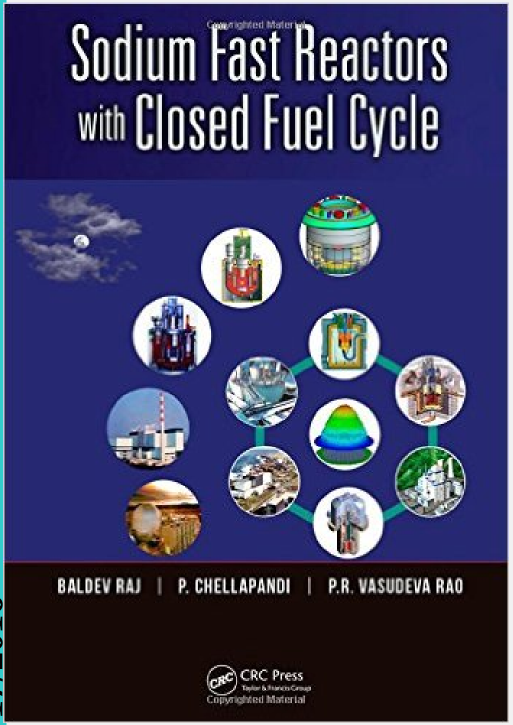
Factors driving the growth of the NPP in India

•Enhancement of installed capacity

•FBRs for Sustainability

•Safe and Proliferation Resistance Concepts-Metal Fuelled FBRs- Pyro

•Minimizing Radiotoxic Burden to the Environment



Closed Fuel Cycle

Efficient Waste Management

(Nuclear Recycle Board, BARC)

✓*Waste volume minimization*

✓*Recovery and recycle of valuables*

Wealth from Waste

✓Near zero release of radioactive wastes to the biosphere

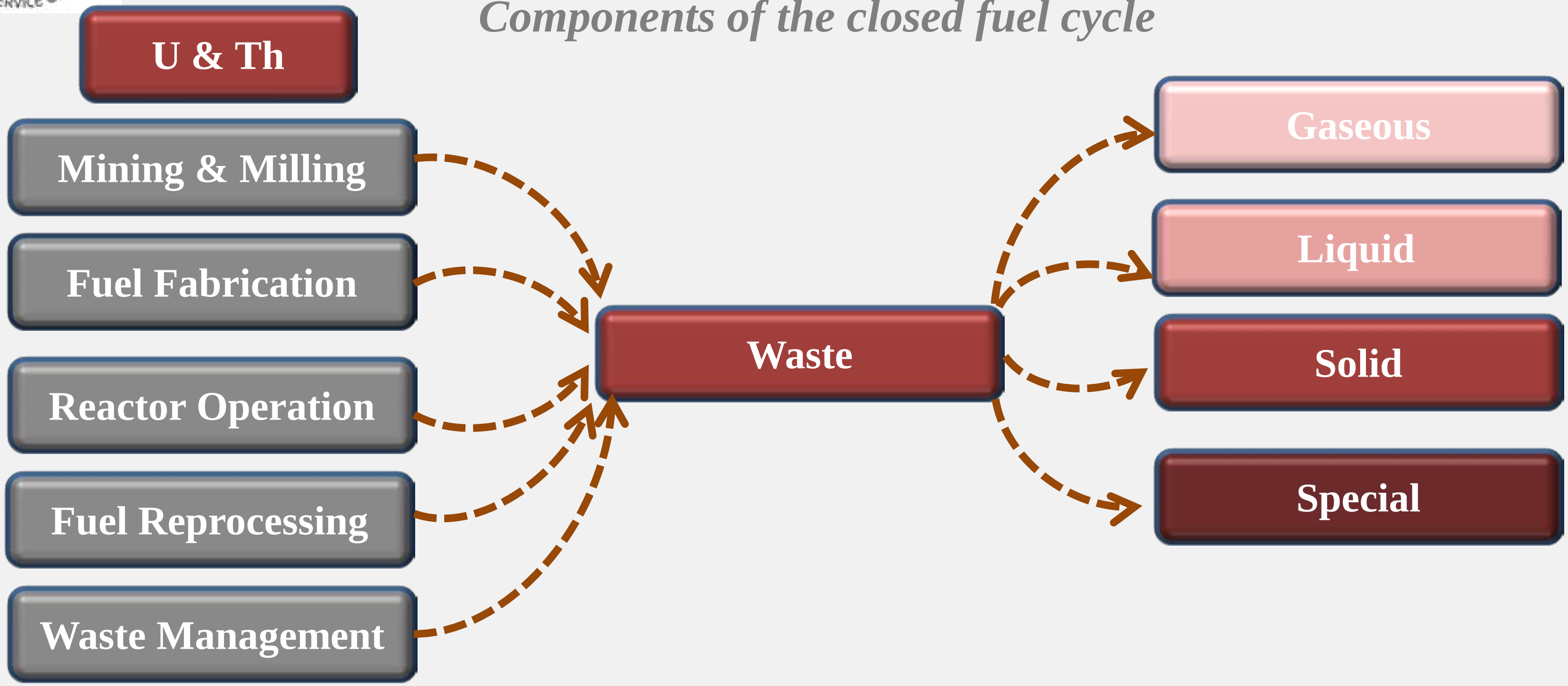
MA, P & T

✓Isolation of radioactive waste from environment for extended periods

✓**Advanced processes**

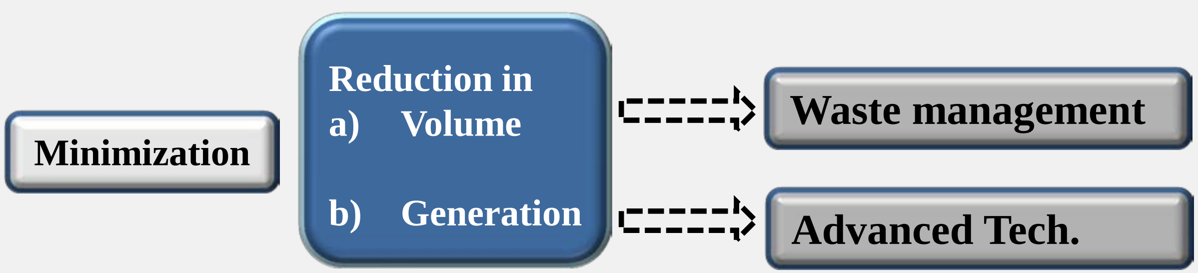
Waste Management in India – at a glance

Components of the closed fuel cycle



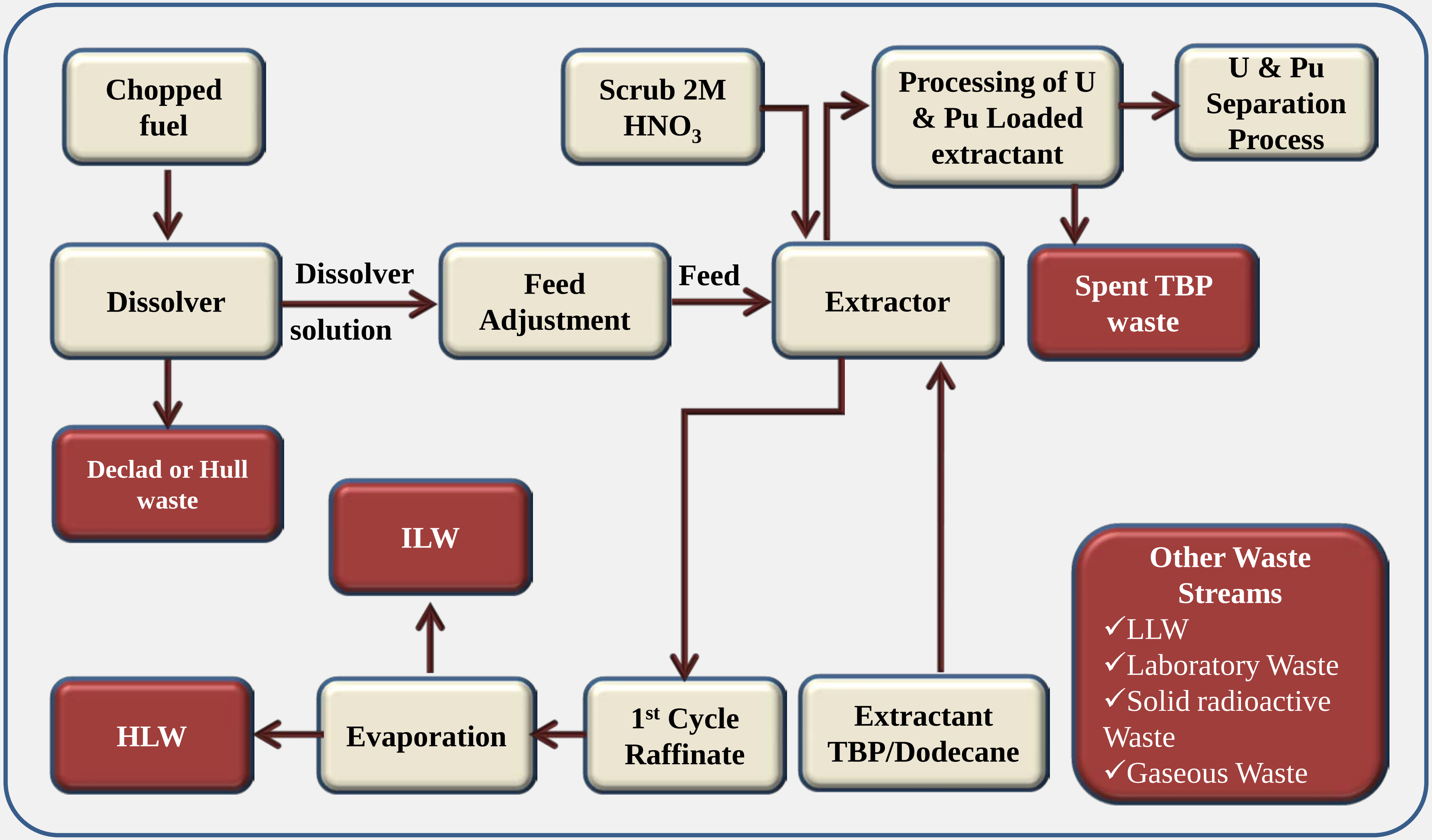
Reactors
- Research Reactors
- PHWR
- FBR
- AHWR

Reprocessing Flow-Sheets
- Aqueous Reprocessing (PUREX)
- Non-aqueous (Pyro-chemical)



R. G. Yeotikar, *IANCAS Bull*. 2007

Radioactive waste from the PUREX process



Adopted from Kanvar Raj et al. *Thoria-based Nuclear Fuels* **2013.**

Radioactive waste management - A schematic

CHARACTERIZATION		TREATMENT			CONDITIONING
LL	Gaseous	GASEOUS WASTE	LIQUID WASTE	SOLID WASTE	Cementation LLW / ILW
IL	Liquid	Scrubbing	Chemical Treatment	Compaction 5 times V Rdn.	Polymerization LLW / ILW
HL	Solid	Adsorption/Absorption	Ion Exchange	Incineration 50 times V Redn.	Bituminization
		Prefiltration	Reverse Osmosis 8 -10 times V Rdn	Size Fragmentation	Vitrification HLW
		High Efficiently Filteration	Evaporation Solar Rajasthan	Repacking	

LLW 1mCi - 10 mCi

ILW 10mCi – 10 Ci

HLW > 10 Ci

Adopted from Kanvar Raj et al. *Thoria-based Nuclear Fuels* **2013.**

Radioactive waste management - A schematic

INTERMIM STORAGE

- Alpha contaminated waste
- Waste requiring treatment /conditioning in future
- Vitrified waste for cooling pending disposal

DISPOSAL

- LIL Waste Short lived
- Earth/stone lined trenches
- Reinforced Concrete trenches
- Tile Holes

HLW & Short lived Waste

Deep Geological Disposal

ENVIRONMENTAL MONITERING/CONTROL

MONITORING water, soil, vegetation, near waste management facility.

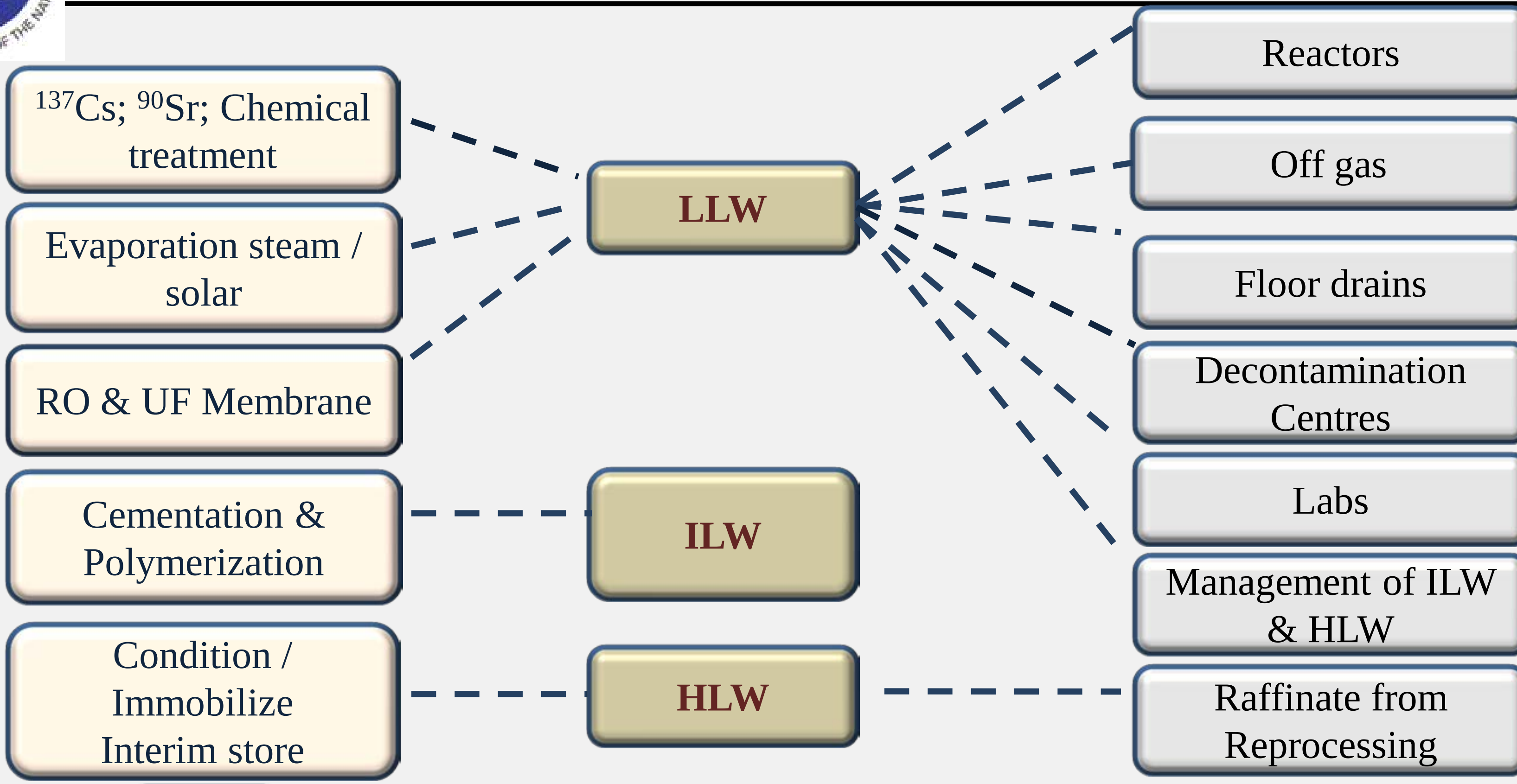
MONITORING of environment near nuclear facility.

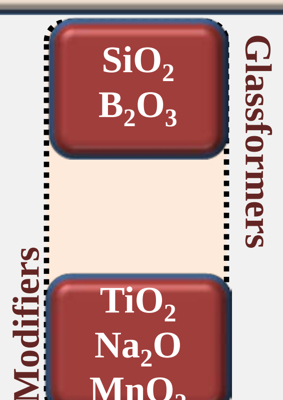
INSTITUTIONAL DISPOSAL of near surface disposal facility for 300 years

In India as a matter of National Policy Near Surface Disposal Facility is co-located with every nuclear facility. Currently 7 NSDFs are operational in the country

Adopted from Kanvar Raj et al. *Thoria-based Nuclear Fuels* **2013.**

Management of liquid waste





Fission Products:	AE, NM, TM, RE, Pd, Rh, Y, Mo, Ru.
Corrosion Products:	Fe, Cr, Ni, Mn.
Actinides:	U, Pu, MA.
Organics:	TBP degradation, diluents…
Process chemicals:	$NaNO_2$…
Alloy additives:	Al, Fe, Si, Mo..
Soluble Poisons:	Gd, Cd

Adopted from : Kanvar Raj et al. *IANCAS Bull.* 2007.

Management of HLW

Solid waste categories and disposal option

Category	Surface dose/activity	Disposal options	Nature of waste
I	< 2 mGy/h	Stoned Lined Earth Trenches	Paper trash, concrete chips, cotton mops, rubber items, etc.
II	2-20 mGy/h	RC Trenches	Contaminated equipment, hardware and filters
III	20-500 mGy/h > 500 mGy/h	RC Trenches Tiles Holes	Conditional/processed concentrates, sludges, spent resins. Hardware from reactors, highly contaminated equipment, conditional spent resins, etc.
IV	Waste bearing α activity (< 4000 Bq/g) (> 4000 Bq/g)	RC Trench and Tile Holes Tile Holes	Solidified α waste with β γ

Tile Holes

RC Trenches

Stone lined Trenches

(1) S. D. Mishra, *Energy Procedia*, 7 (2011) 474, **(2) K**anvar Raj and C. P . Kaushik, *IANCAS Bull.*. (2007).

Waste Matrices

Desirable Qualities

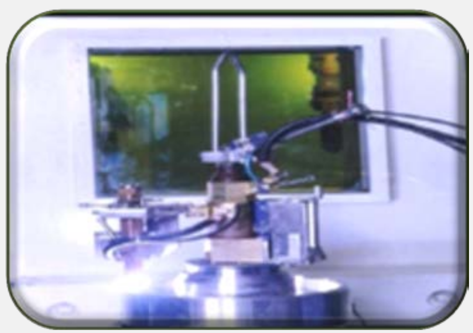
1. Chemical durability
2. Compatibility with canister
3. High λ
4. Minimum volatility
5. High loading
6. Mechanical strength (Impact)
7. Stability Thermal 10^5 y; & Radiation
8. Remote Manufacture
9. High ρ

Ceramic
- NZP
- SYNROC
- Supercalcine

Glasses
- Borosilicate — PHWR
- Phosphate — FR

Glasses →
- •Dev.
- •Production
- •Evaluation


Glass Pouring


Canister Welding


Shielded Canister Cask

R. G. Yeotikar, *IANCAS Bull*. 2007 & C. P . Kaushik, Indo-French Workshop, 2012

Vitrified waste processing

Typical NaBS Glass

T_f	: 850^0C
T_p	: 950^0C
T_s	: 560^0C
λ_{100^0C}	: $1\ Wm^{-1}K^{-1}$
α	: $1.02x10^{-5}\ K^{-1}$
ρ	: $2.992\ gcc^{-1}$
RIAJ	: 1.09

Mean Leach Rate : $1.5\ x10^{-4}\ gcm^{-2}$ /4 h

Formation

$T_{Formation}$; T_{Fusion} (process ppt);

$T_{pouring}$ (950^0-1150^0C)

Durability

Chemical (Repeated for 5 – 10 y)

- Accelerated Test
- Soxhlet
- Dynamic Leaching

Thermal

- Crystallization XRD – SEM f(t)
- T – T – T diagram

Radiation

- A In-situ/ (nα) ^{10}B ^{7}Li
- Irradiator/ Self Irradiation

Characterization

η

- **Liquid**
- **Solid-Beam Bending**

ρ, λ, α

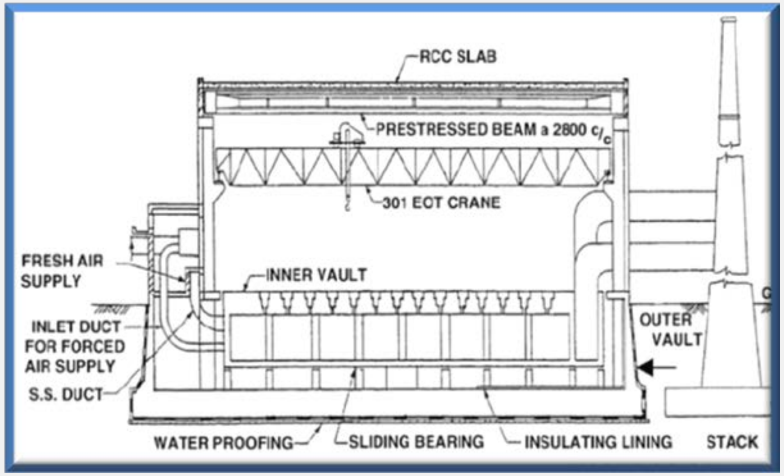
Impact strength RIAJ

Homogeneity

R. G. Yeotikar, *IANCAS Bull*. 2007

Interim storage and Georepositories

Schematic view of air-cooled solid storage and surveillance facility -Tarapur



Spent fuel storage facility at Tarapur

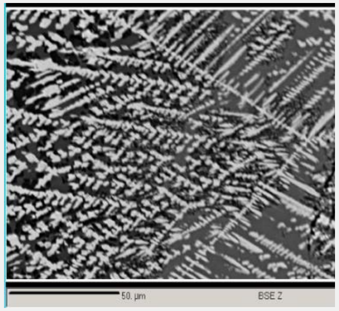
Thermo-Rockmechanical Experiment at 1 km dpeth in Kolar Mine

Thermo-Rockmechanical Experiment at 1 km dpeth in Kolar Mine

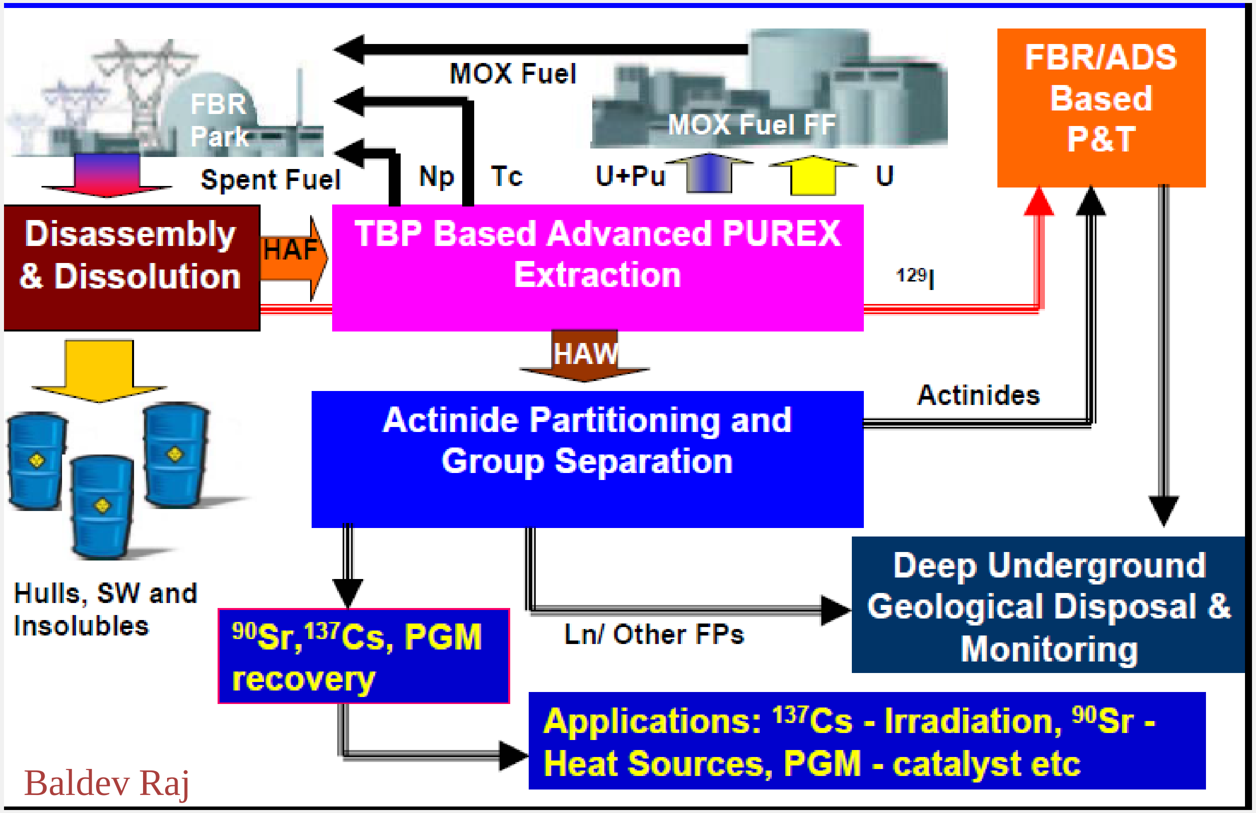
Courtesy: D. Mishra, *Energy Procedia*, 7 (2011) 474.

New endeavours in FR SNF - Reprocessing

Kothyal et al.



Li-Zn Silicate Glass-Ceramic



FAST Reactor Wastes

Higher Conc. *FP, MA and An*

Higher Waste volume (*3-4 times*)

Removal of MA & PGM- IPG glass 20-22% waste loading – H_3PO_4 condensate ???

Pyro-process waste

Higher Cl concentrations ??? – low solubility in BSG *Glass composites instead of Glass*

Transmutation of MA in FRs – IGCAR study

Minor Actinides

Np, Am, Cm, Bk, Cf, Es, & Fm are produced through neutron capture reaction in nuclear reactor

These are highly Radio-toxic & possess Long half lives

^{237}Np $t_{½}$ 2.15 x 10 6 y : ^{241}Am $t_{½}$ 432 y & ^{244}Cm t½ 18 y P & T

IAEA CRP on "Studies of Advaced Reactor T echnology Options for Effective Incineration of Radioacive Waste"

Overall Objective

Perform R&D contibuting towards the proof of practicality of Transmutation of MA s using ADS and reactors

***IGCARs participation:** Core simillar to PFBR to incinerate MAs*

***FBR Benchmark Characteristics**: **Power:** 1150 MWth*

3 rows of ThO_2 radial blanket and depleted UO_2 axial blanket

Two cores of U,Pu MOX with 19.5 and 27.1 % PuO_2

Uniform distribution of MAs (Homogeneous Core)

P&T MA in PFBR – Benchmark Results – IGCAR

Reductions in the MA for a cycle length of 195 days in core 1

For 25 GWd/t (single cycle) is 12%

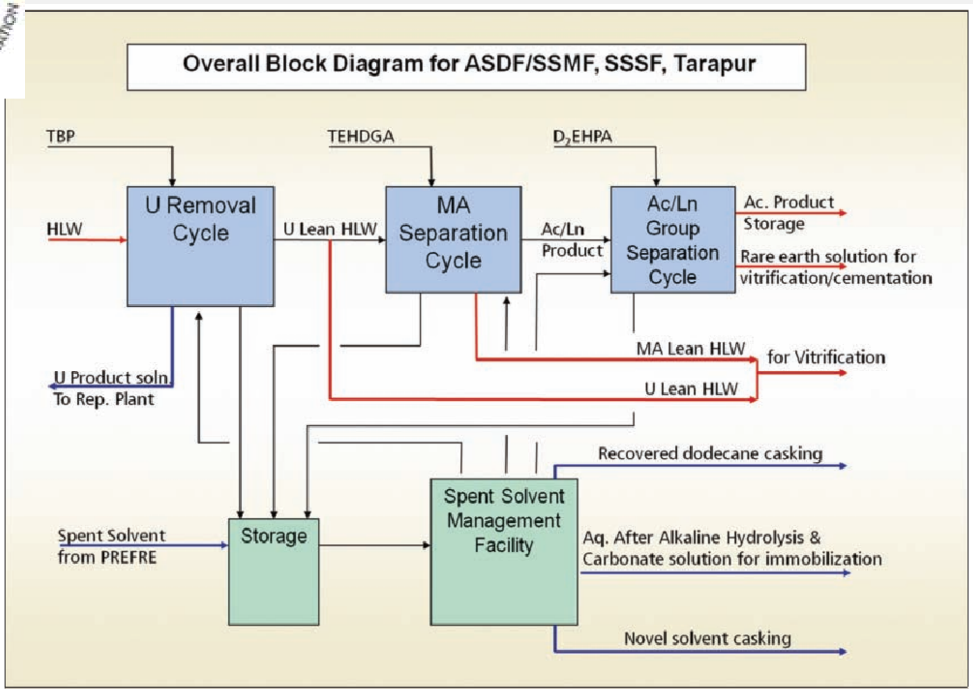
For 49 GWd/t (two cycles) is 22%

Thus the core is an effective incinerator

No significant MA is produced in the blanket

Overall safety is comparable to PFBR

Minor Actinide Partitioning at BARC



Step	Solvent System	Developmental status
Cycle I: Removal of residual U and Pu	PUREX (TBP) 30%TBP in n-dodecane	• Laboratory : using actual HLW • Engineering scale: using simulated waste
Cycle II: Bulk Separation of minor actinides with lanthanides	TRUEX (CMPO) 0.2 M CMPO + 1.2 M TBP in n-dodecane	• laboratory :using actual HLW • Engineering scale: using simulated waste
	Amide (TEHDGA) 0.2 M TEHDGA + 30% isodecyl alcohol in n-dodecane	• Laboratory: using actual HLW • Engineering scale: using simulated waste
Cycle III: Actinide Lanthanide Group Separation	TALSPEAK (D_2EHPA) 0.2 M D_2EHPA in n-dodecane	• Laboratory: using actual waste • Engineering scale: using simulated waste
	Polydendate(aza-amide)	Evaluation in progress

Smitha et al. BARC News letter 2013

Minor Actinide Partitioning – ADSS !

Basic scientific know-how for
Accelerator, target and subcritical core & advanced fuel forms

HRD for future R&D

Construction and validation of experimental facilities

NOW

Technology development - key areas

Design and Safety analysis of ADSS prototypes

Objective:

IN FUTURE

Short term: *5MW fission power ADS Subcirtical reactor: Near ambient T; 120 – 150 MeV few mA m proton beam; Verification and fine tuning of computational code U-Th fuel – to study burn-up reactivity kinetics without nuclear safety risks*

Long term: *Demonstration ADS 10-20 mA, 500-600MeV proton beam 100 MW fission power; coolant T 350°C.*

R & D On MA Fuels at IGCAR

Development of Processes for Preparing **Inert Matrix fuel** for P&T

Metal nitrate + **HMTA + UREA**

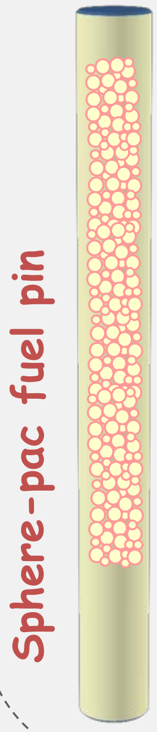
↓ **Sol droplet dispersion**

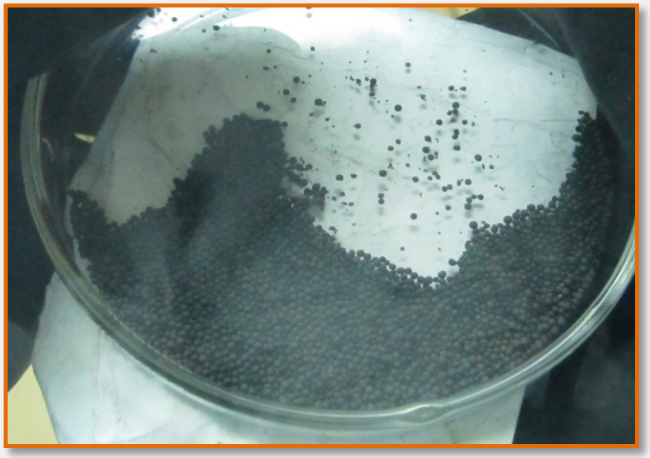
↓ **Internal gelation**

↓ **Collection & Washing**

↓ **Calcination**

↓ **Sintering**



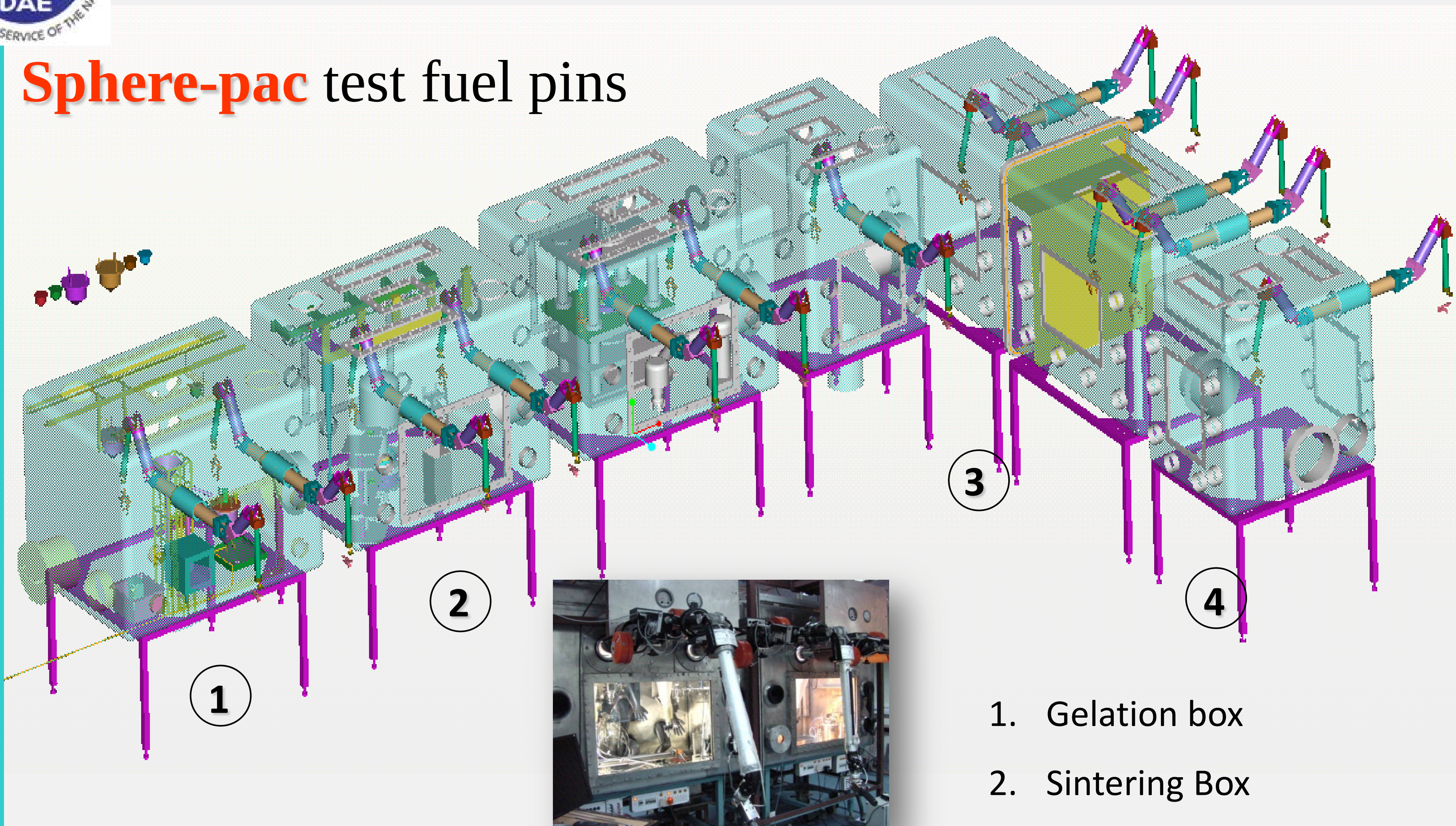


Calcined $(U_{0.79}Pu_{0.21})O_2$ microspheres

Green $(U_{0.95}Am_{0.05})O_2$ micrsopheres

R & D On MA at IGCAR

Sphere-pac test fuel pins



1. Gelation box
2. Sintering Box
3. Decontamination box
4. Vipac –welding box

- **Remotely operated facility** : Batch process with ease of remotization and automation inside the glove box.

Conclusions

India has a Rich Research Expertise on Waste Management

India has adopted the Closed Fuel Cycle concept from the very beginning

Adopting Th fuel cycle would help reduce the generation of minor actinides

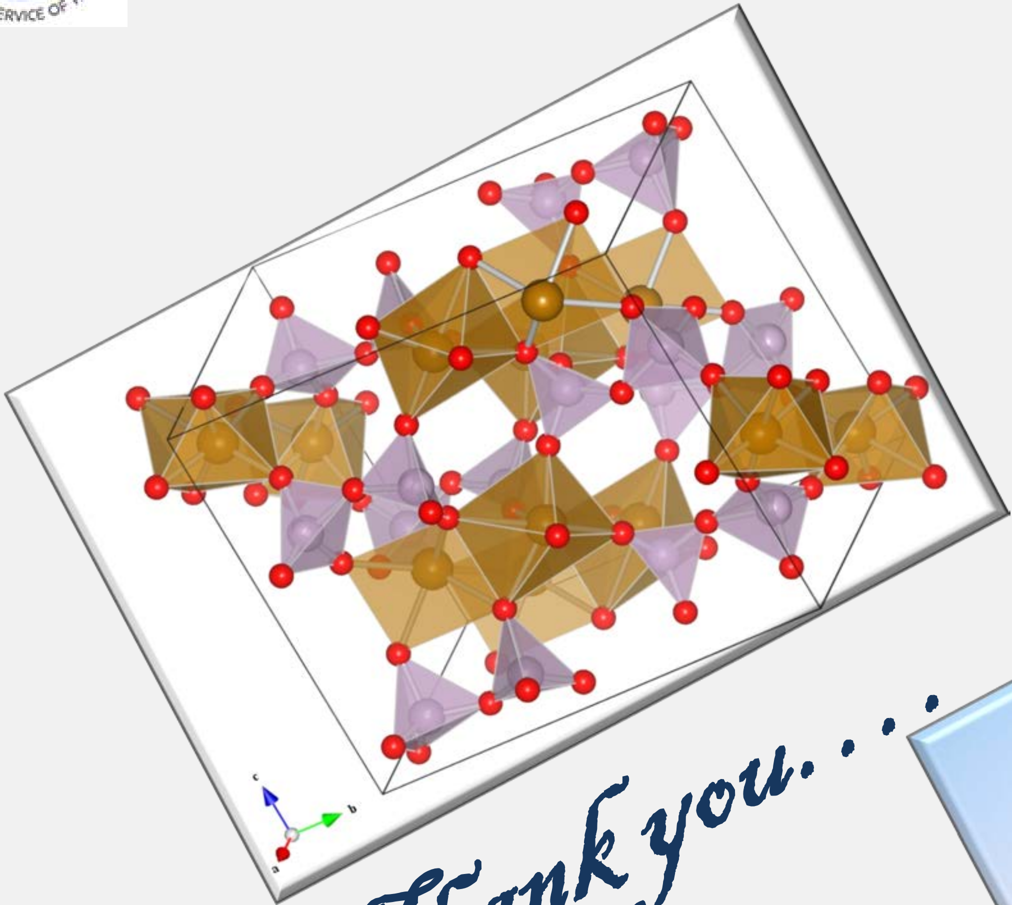
BARC has demonstrated the technology for partitioning the MA from the SNF

An intense FBR programme is being pursued at IGCAR

ADSS programme is expected to mature in the next three decades

INDIA IS KEEN ON PURSUING A CLEANER AND GREENER NUCLEAR POWER

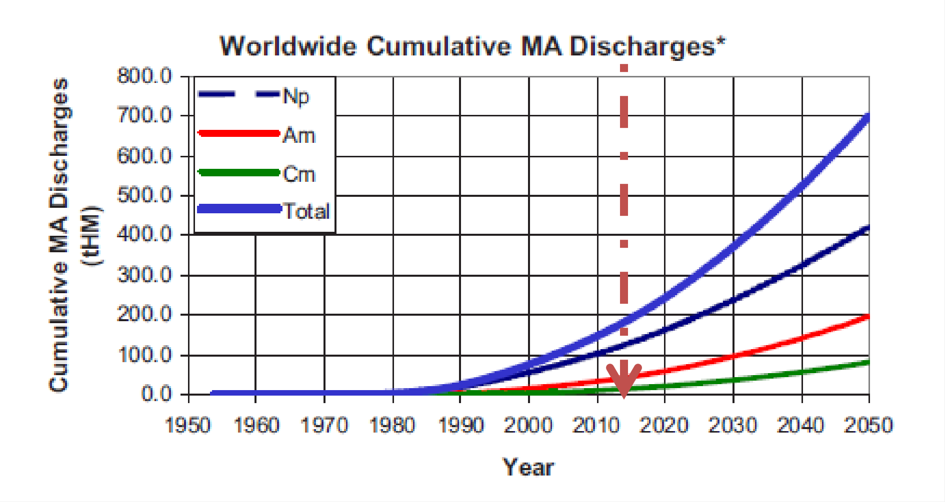
A fresh water lake at the IGCAR site



Thank you….

Radiotoxic burden from spent Fuel

After 100 years of cooling ^{241}Am contributes significantly to the decay heat compared to the others fission products



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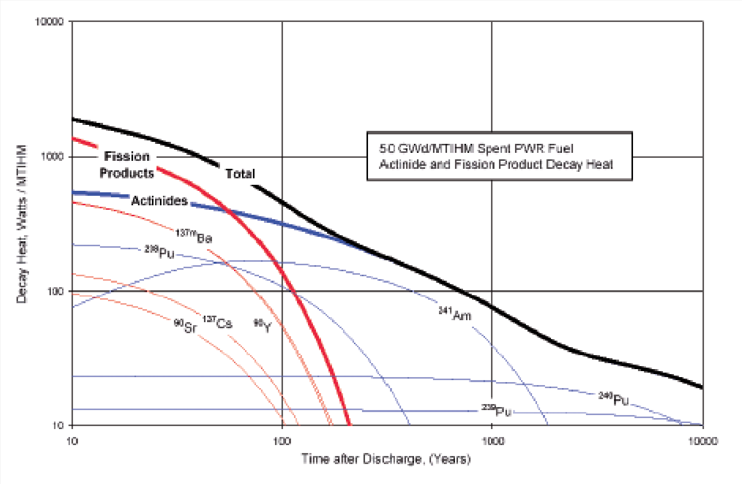

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Radiotoxic burden to the environment

Decay heat at the waste repository

1. WIGELAND, R. A., et al., Separations and transmutation criteria to improve utilization of a geologic repository, Nucl. Tech. **154 (2006) 95–106.**
2. OECD/NUCLEAR ENERGY AGENCY, Accelerator-driven System (ADS) and Fast Reactor (FR) in Advances Nuclear Fuel Cycle, A Comparative Study (2002).