CHALLENGES & DIRECTIONS IN FUEL CYCLE RESEARCH AND DEVELOPMENT

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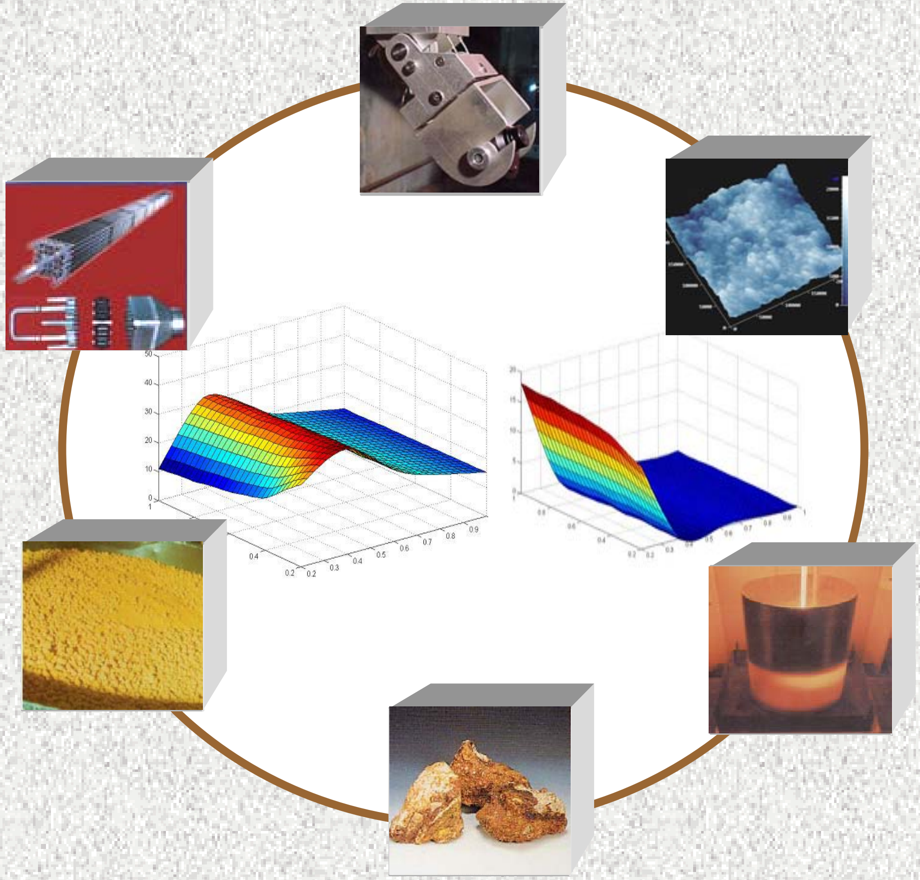


INTRODUCTION

- New Technologies & Approaches needed for the Growth of Nuclear Power
- Innovative nuclear energy systems

i) INPRO project

(***15 nations, including India***)
methodology for assessing innovations in reactor systems as well as fuel cycles being established)

ii) GIF - Generation IV International Forum

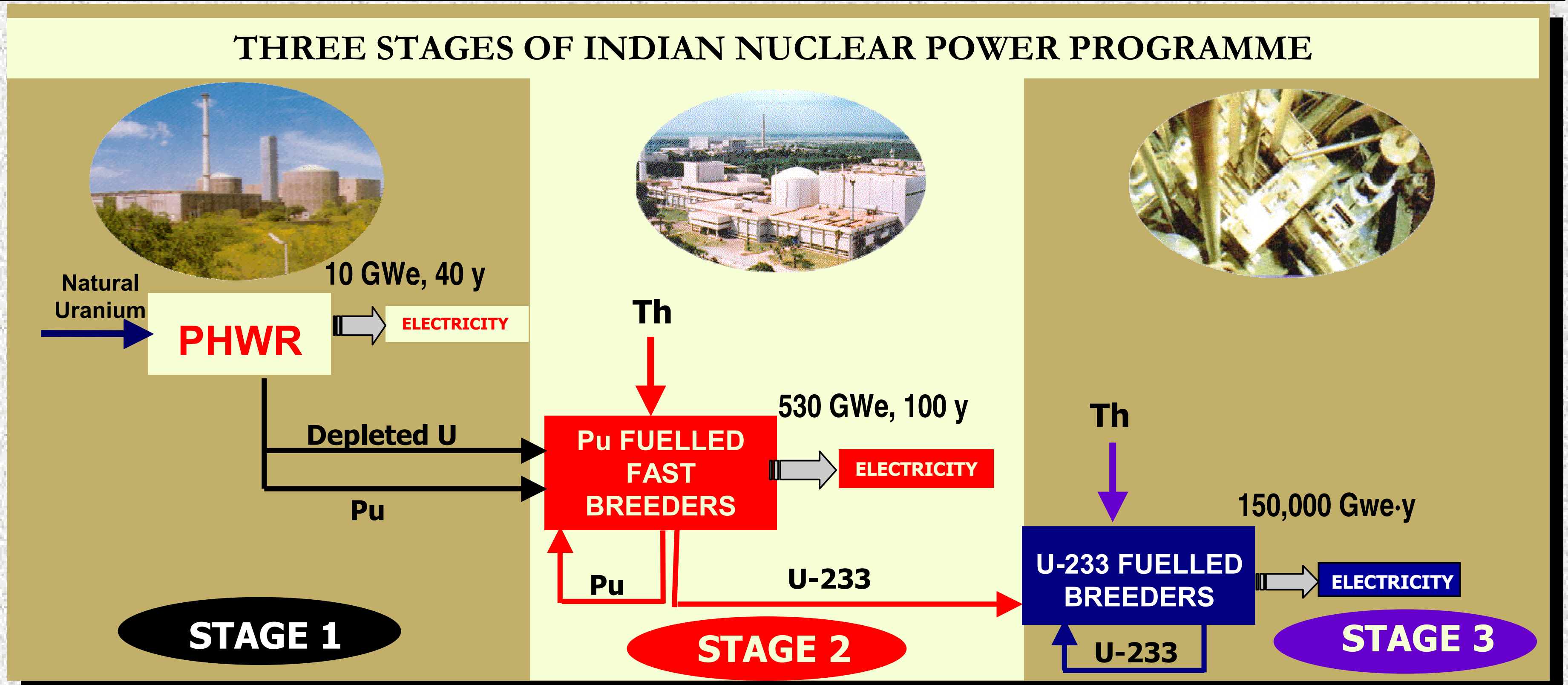
10 Nations, 6 Reactor concepts

(4 of these are *fast reactors*)

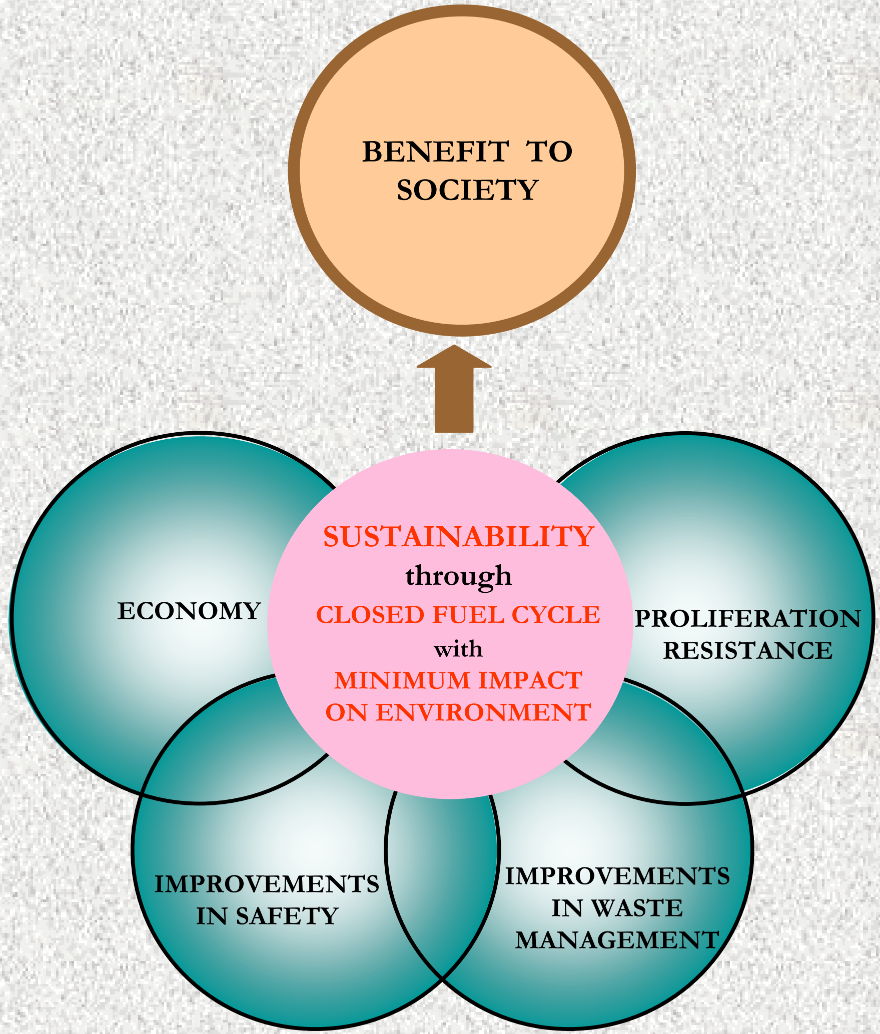
INTRODUCTION

Fuel Cycle: A vital & integral
component of nuclear technologies
It is intimately linked to a) choice of the reactor systems &
b) national policies

CLOSED FUEL CYCLE ALONE CAN PROVIDE SUSTAINABLE NUCLEAR ENERGY OVER LONG TERM WITH REDUCED IMPACT ON ENVIRONMENT



Key Performance Indices for Nuclear Fuel Cycle

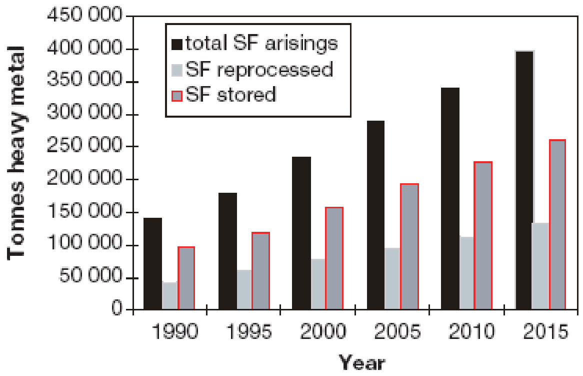


- Safety
- Economy
- Environmental impact
- Sustainability &
- Proliferation resistance

R&D TARGETS FOR IMPROVING FUEL CYCLE

- Increase in burn-up to reduce mining milling and other processing requirements – *better economy and sustainability* and less impact on environment
- Increased remotisation of fuel cycle operations to permit processing of short cooled / recycled fuel
- Partitioning and transmutation of minor actinides & long lived fission products and recovery of fission products of commercial value (eg. ^{137}Cs, ^{90}Sr and noble metals) to reduce long term radiation hazards and create wealth from waste

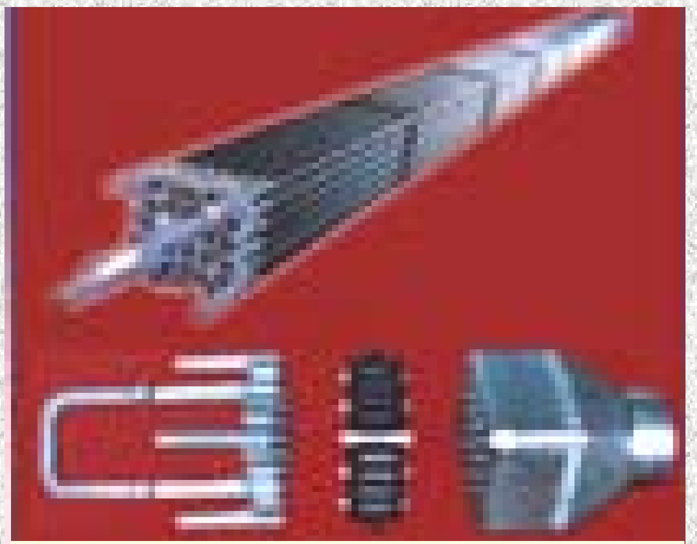
R&D TARGETS FOR IMPROVING FUEL CYCLE



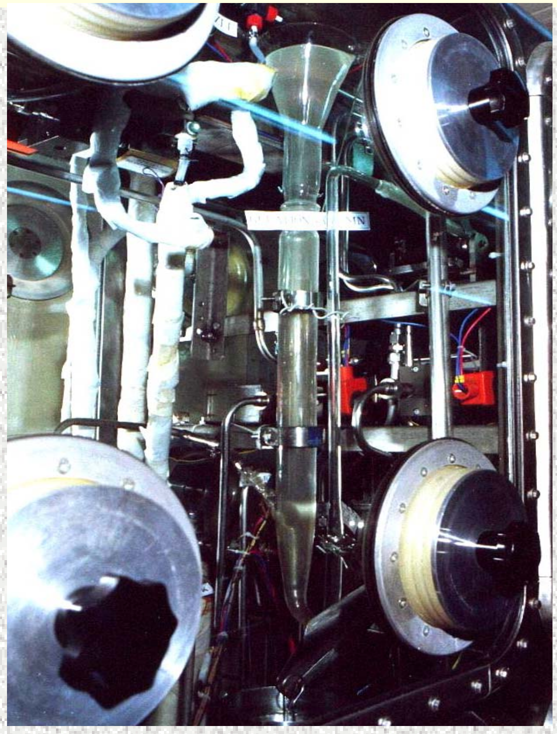
Cumulative worldwide spent fuel arisings, reprocessing and storage 1990-2015 (**IAEA**)

- Compact plants, simplified processes, higher emphasis on automation and co-location of facilities to improve economy of fuel cycle
- New processes and approaches to minimise waste and reduce secondary waste generation
- R & D to augment strategies to enhance public acceptance of waste management philosophies: *Robust process and matrix for immobilization of waste, technologies for surveillance of waste, comprehensive modeling to ensure long term stability*

Pu in LIGHT WATER REACTORS



BWR fuel subassembly, TARAPUR



Sol-gel facility for MOX fuel

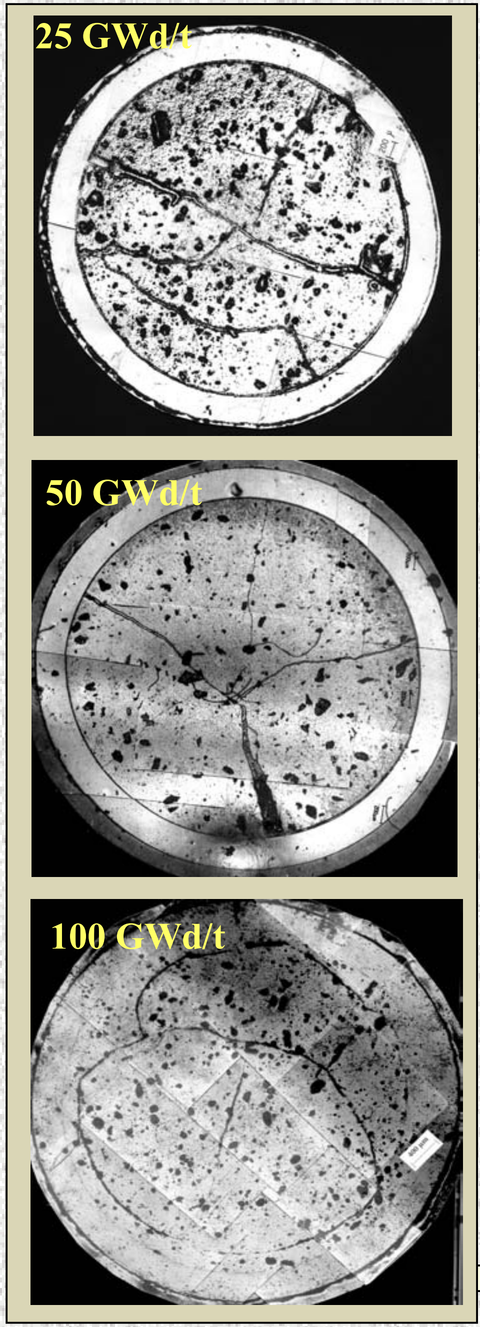
- Large scale deployment of uranium, plutonium mixed oxide fuel is one of the directions in utilization of Pu stockpile in water reactors

- This demands R&D for critical evaluation of novel recycle technologies (co-precipitation, sol-gel microsphere pelletisation, coating / impregnation, remote fabrication, etc) to reduce waste generation and reduce man-rem exposure

FAST REACTORS

IMPORTANT CANDIDATES FOR NEXT GENERATION REACTORS

- Development of clad and structural components for increasing the burn-up to a value of 200,000 MWd/t
- Integrated fuel cycle facilities to reduce cost and enhance proliferation resistance
- Development and Demonstration of matrices for deep burning of Pu
- Improved aqueous reprocessing schemes for processing high burn-up short-cooled fuel
- Development of pyrochemical processing route on industrial scale for oxide, metallic & other fuels
- Development and performance evaluation of Vibro-pac fuels: towards reduction in waste and man-rem exposure



MICROGRAPHS OF IRRADIATED (U, Pu) MIXED CARBIDE (70 % Pu) FUEL AT DIFFERENT BURN-UPS

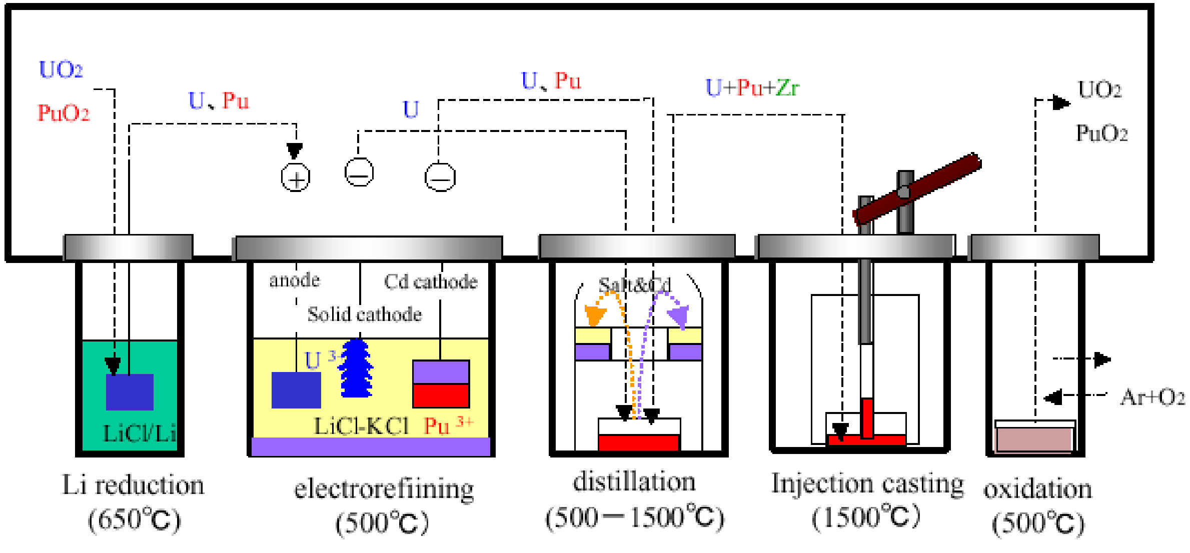
FBTR Fuel subassembly

R & D TARGETS for FBRs

METALLIC FUELS WITH PYROCHEMICAL PROCESSING

- Higher burn-ups (up to 20 at % achieved)
- Greater degree of Passive safety
- Potential for high breeding
- High resistance to proliferation

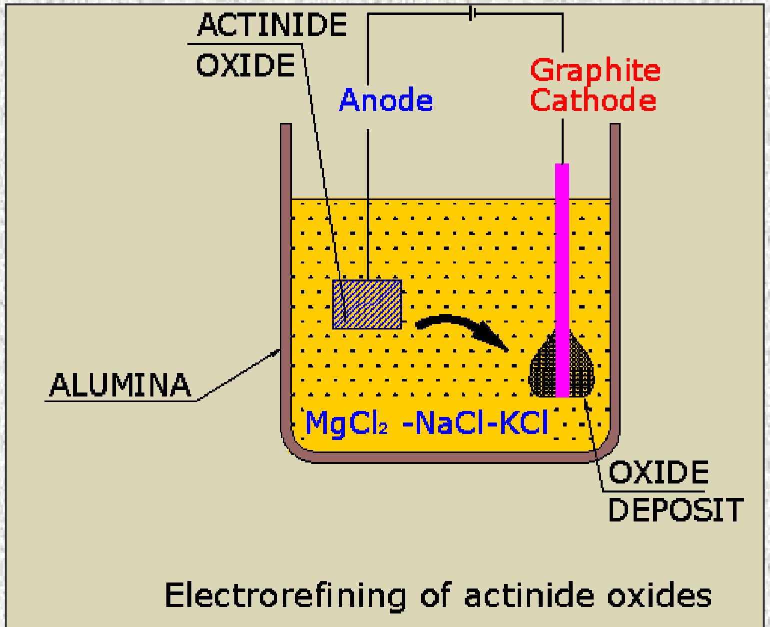
PYROPROCESSING – PROCESS AT JPC, TOKAI, JAPAN



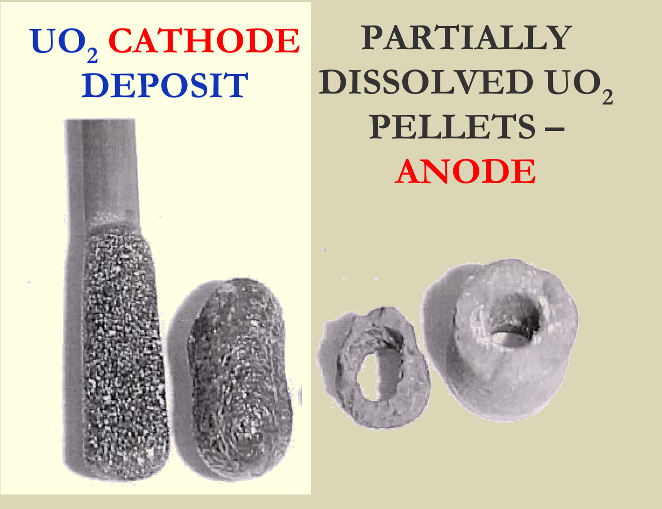
R & D Targets related to Metallic fuels for Fast Reactors

Injection casting in Glove Box

- Development of comprehensive data base on physicochemical properties of metallic fuel
- Modeling
    - Safety studies on reactor size optimization
- Transmutation of minor actinides – characterisation and chemistry of recycled fuel to be studied



Lower Melting & Less Expensive Electrolytes



PYRO-ELECTRO-METALLURICAL
PROCESS FOR UO_2

Pyrochemical Processing

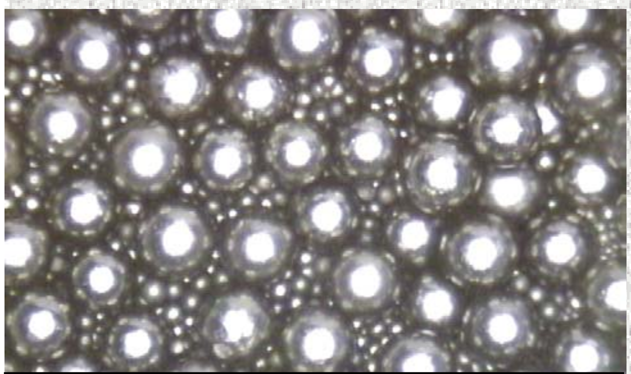
- **Developmental needs:**
  - **Corrosion-resistant materials**
  - **Remote handling techniques**
  - **Characterization techniques &**
  - **Waste management**

THORIUM BASED FUELS

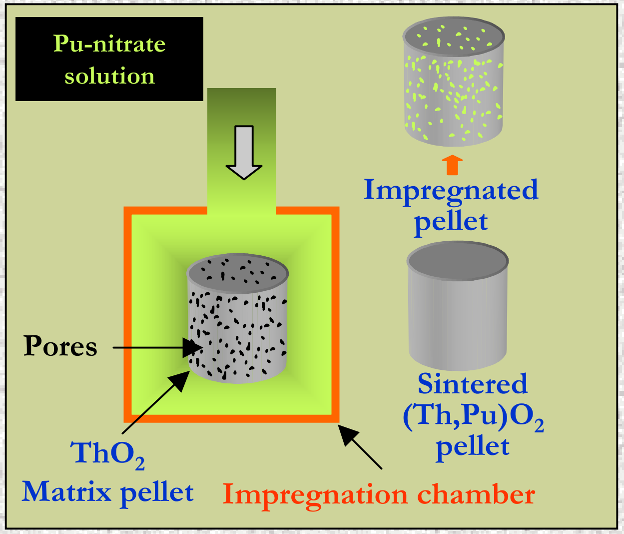
Salient features of thorium based fuels

- Thorium is an excellent host for Pu
- Makes the fuel cycle more sustainable and proliferation resistant
- Enables much deeper plutonium burning with manageable reactor characteristics even when the entire core is loaded with Pu bearing fuel assemblies
- Th-U fuel cycle has the advantage of absence of production of minor (heavy) actinides

THORIUM BASED FUELS
R& D issues



Sol-gel derived microspheres



Fuel Fabrication:

- New technologies for the production of U-Th and Th-Pu oxide fuels (sol-gel, Impregnation,etc.)
  Reduction in sintering temperature,
  Improvement of homogeneity

Fuel Reprocessing:

- Dissolution without use of HF?
- Three component separations U,Th,Pu
- ^{233}U clean-up (removal of ^{232}U) by laser separation

ACTINIDE PARTITIONING AND TRANSMUTATION

- **Partitioning flow sheets**

  Comprehensive techno-economic evaluation to consider:

  i) Secondary waste production,

  ii) Need for An/Ln separation,

  iii) Utility value of actinides

  iv) Simplification in alpha waste management

- **Transmutation**

  Fast reactors or Accelerator driven sub-critical systems?

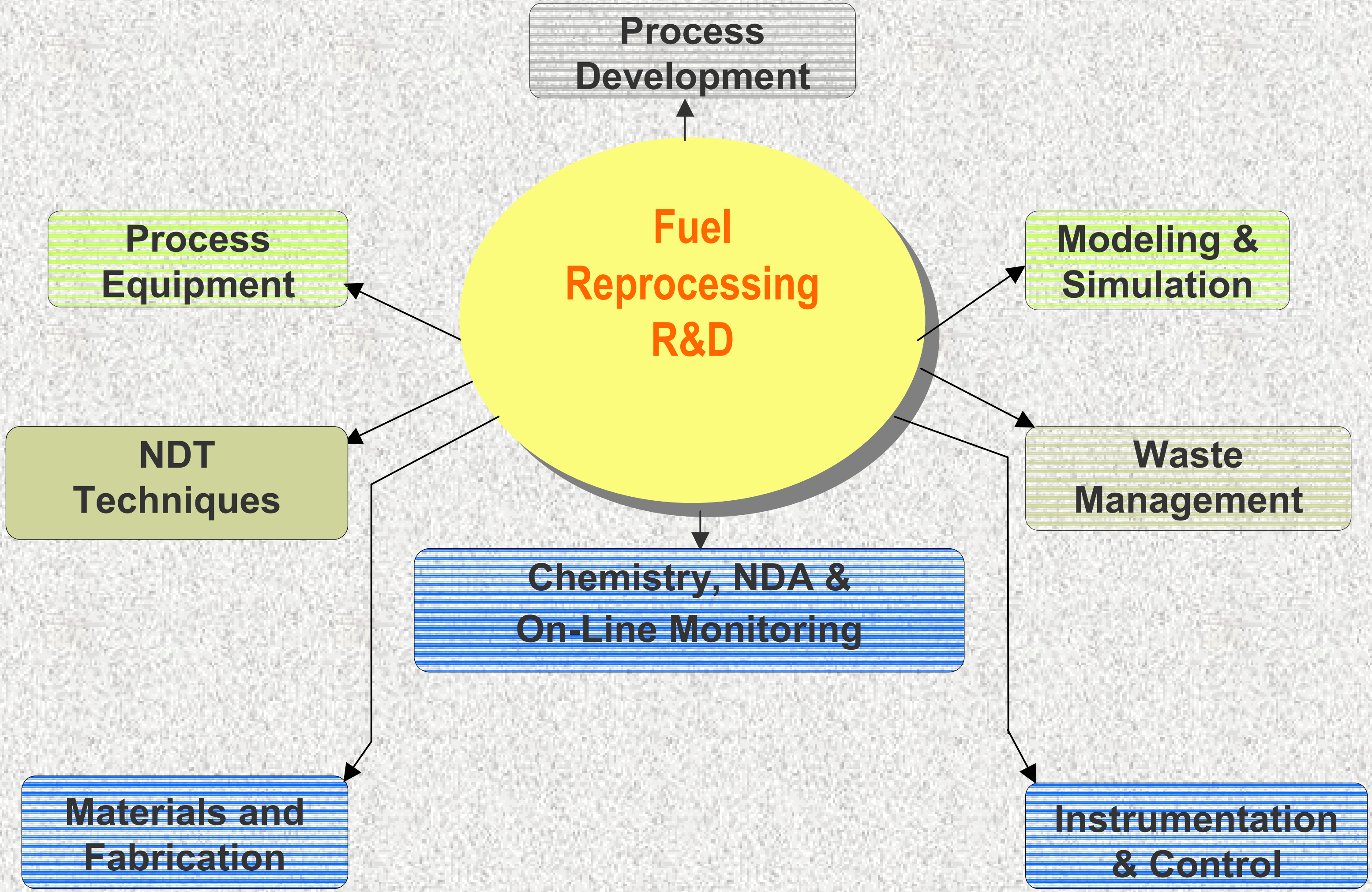
- **Choice of ADS fuel cycle**

  would be influenced by its goal:
  Actinide Breeding / Actinide burning/
  Power production

- **Burning in fast reactors**

  choice of fuel cycle would depend on matrix :
  metal / oxide / nitride

AQUEOUS FUEL REPROCESSING



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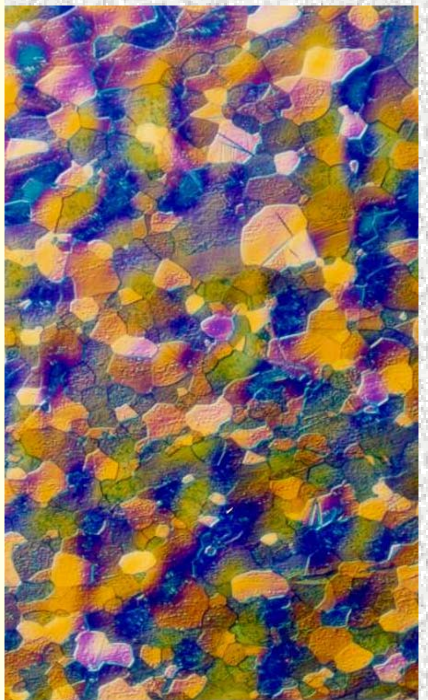
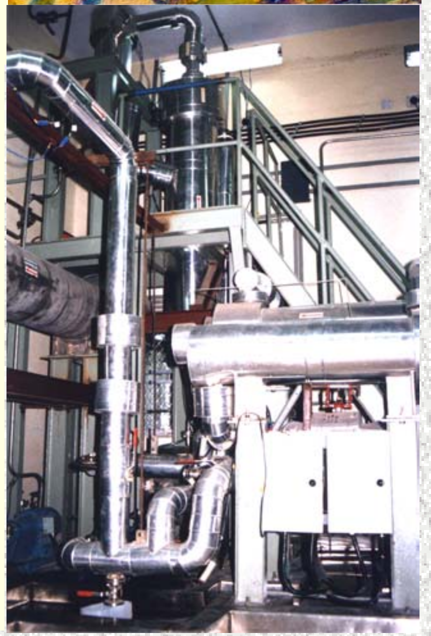


Mircrograph of Corrosion resistant Ti-5Ta-1.8 Nb

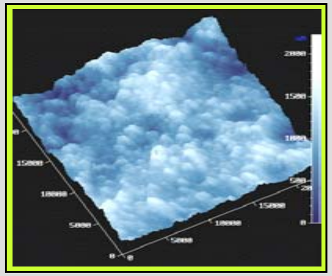


Nitric acid loop for corrosion studies

Increase in plant life

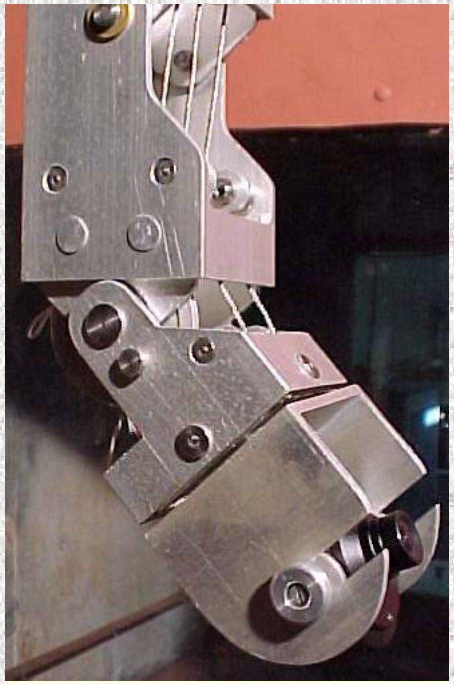
Use of corrosion resistant materials to withstand high concentrations of nitric acid and high temperatures in high radiation environment

- Systematic studies on corrosion behaviour of materials
- Development of special coatings on materials
- On-line monitoring of health of the equipment

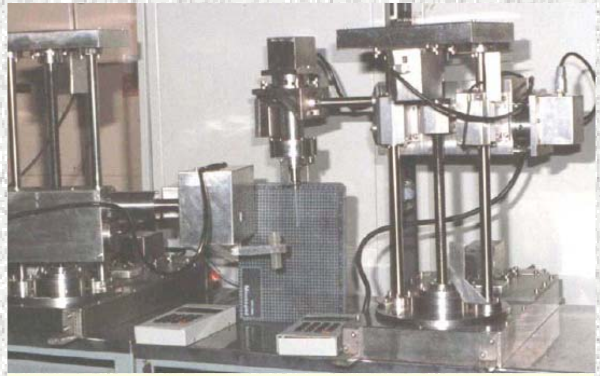


AFM IMAGE OF CORROSION RESISTANT NANO-COATING

AUTOMATION AND REMOTISATION OF OPERATIONS



Multi-link manipulator

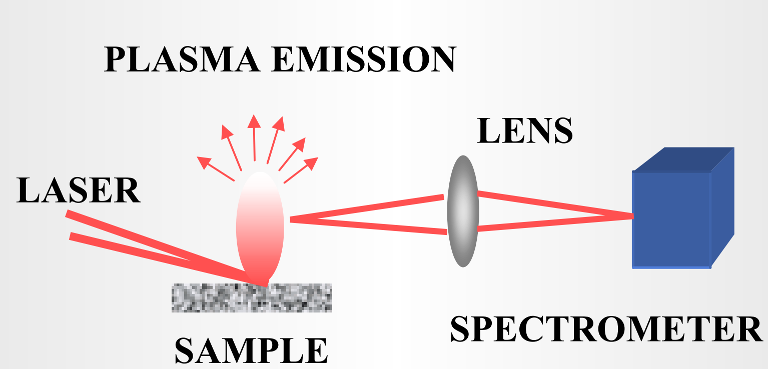


Pipetting Robot & Sample handling robot

- **Simplified plant maintenance** through development of remote handling tools
- **Reduction in man-rem exposure** through increased remotisation of equipment and operations

AQUEOUS FUEL REPROCESSING

Neutron collar for on-line monitoring



LASER INDUCED BREAKDOWN SPECTROSCOPY **(LIBS)**

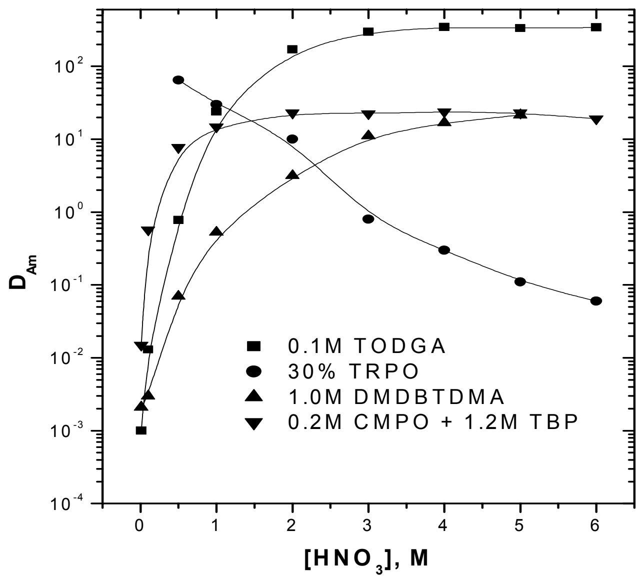
FOR THE ESTIMATION OF U, Pu IN RAFFINATES, FUEL PELLETS

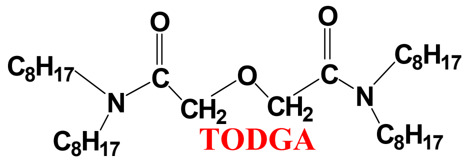
- Reduction of waste generation: Adoption of salt-free processes for reducing secondary wastes
  (new organic soluble reductants for Pu; electrochemical and photochemical steps)
- Minimising loss of actinides to waste streams & discharges to environment
- Development of new extractants and resins
- Comprehensive on-line monitoring of Pu (at low as well as high concentrations) to improve process control and safety

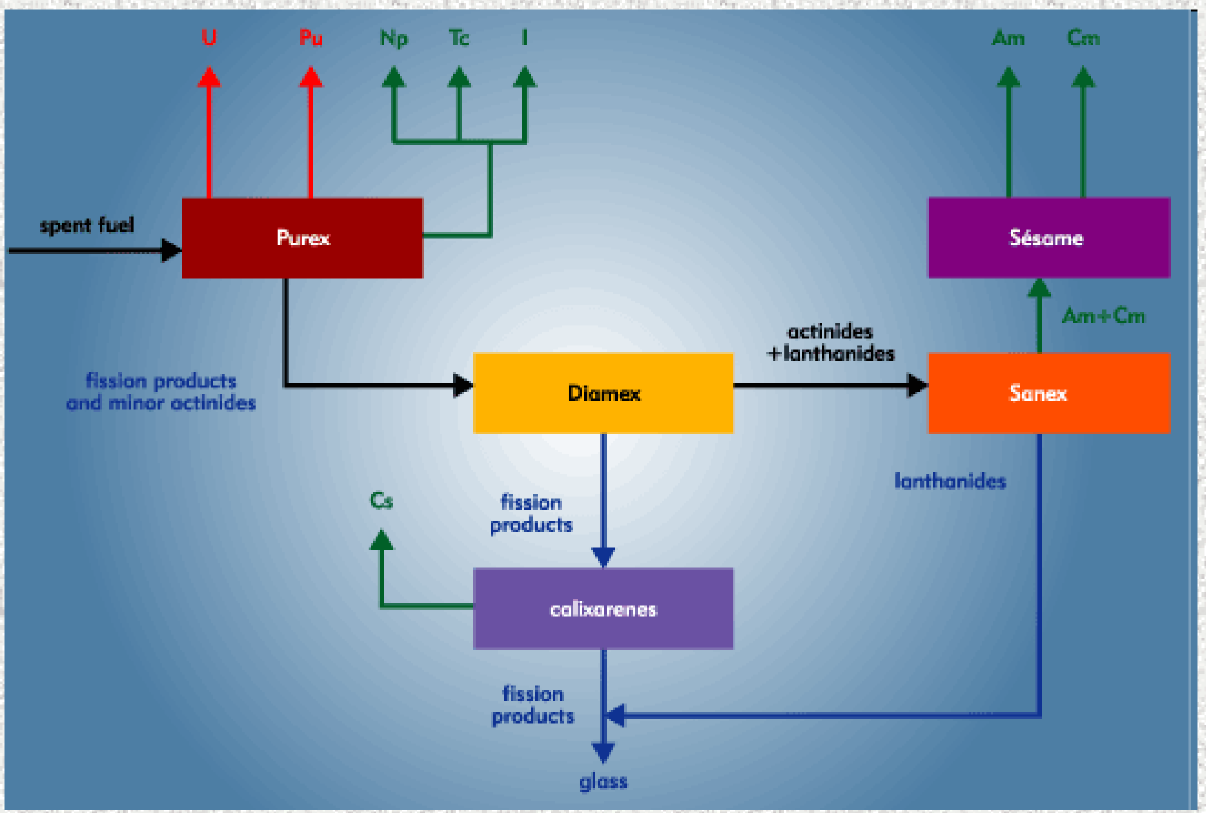
- New extractants: higher loadings, higher decontamination, lesser degradation & economical manufacturing.

- Comprehensive fuel reprocessing flow sheet: Near-Quantitative Extraction of actinides, and recovery of minor actinides &valuable fission products

Variation of D_{Am} with nitric acid concentration; Diluent: *n*-dodecane; Temperature: 25°C

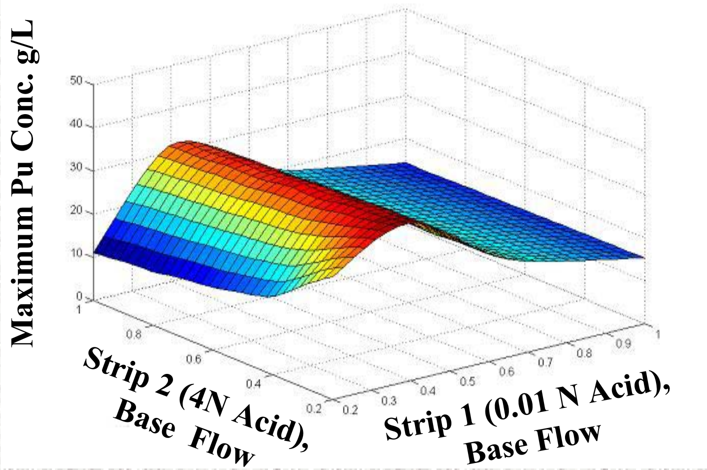




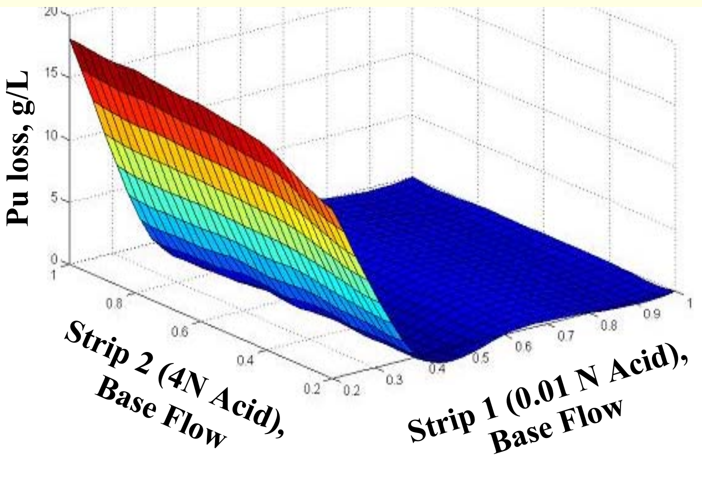


AQUEOUS FUEL REPROCESSING

Variation of maximum aqueous Pu concentration inside the HC contactor: SIMPSEX results for 70%U+30%Pu flowsheet with feed concentration of 72 g.L^{-1} (U+Pu).



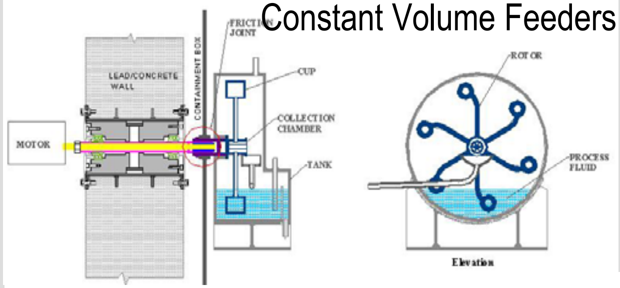
Pu loss in organic phase in HC Contactor: SIMPSEX results for 70%U+30%Pu flowsheet with feed concentration of 72 g.L^{-1} (U+Pu).



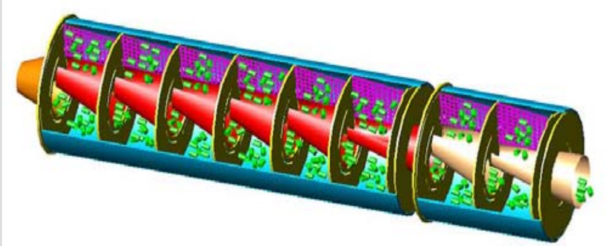
- **Development of comprehensive modeling capability to design improved processes and equipment.**

- **Development of equipment with reduced maintenance**

Constant Volume Feeders



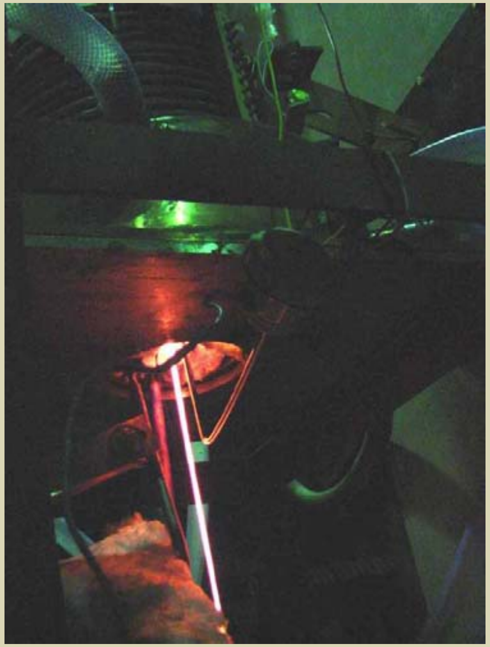
Accurate metering of crucial streams.

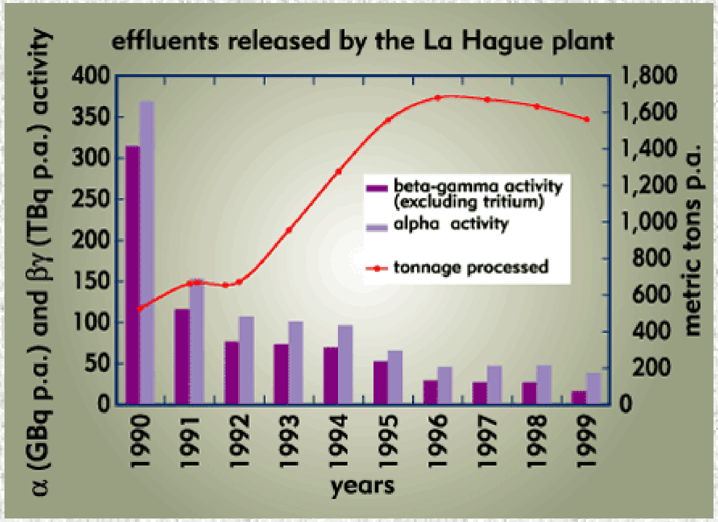


Rotary Semi-Continuous Dissolver

WASTE MANAGEMENT

Molten glass flowing from a "COLD CRUCIBLE"





- R & D on glass and ceramic matrices to adapt to fast reactor fuel reprocessing waste
- Processes benign to environment: *Supercritical extraction*
- Processes which generate minimum or no secondary wastes
- Electrochemical and photochemical steps
- Ultrafiltration, Supported liquid membranes, Microwave techniques

INTEGRATED FUEL CYCLE FACILITIES

Objectives

Reduction in number of process steps
Minimization of waste generation
Economy of operation
Reduction in man-rem exposure

R& D Targets

- Oxide fuels:
  - i) Integration of Fuel Fabrication & Reprocessing
    (by adopting sol-gel vibro pac or SGMP process)
  - ii) Sol-gel process to be demonstrated on commercial scale
- Metallic fuels:
  - i) Integrated fuel fabrication plant
  - ii) Very little liquid waste,
  - iii) Compact size,
  - iv) Economy

CONCLUSIONS

- Closed Fuel Cycle and Th utilisation
  – sustainable long term strategy for nuclear energy

- Cost Reduction of Nuclear Fuel Cycle – R & D is vital;
  Key issues – plant life, safety & reduced burden
  on environment

- R & D emphasis should be on innovative approaches
  for reactor systems as well as fuel cycle

Thanks