ROLE OF MINOR ACTINIDES MINIMIZATION TECHNOLOGIES AND APPROACHES IN ADDRESSING ECO-FRIENDLY ADVANCED NUCLEAR FUEL CYCLES

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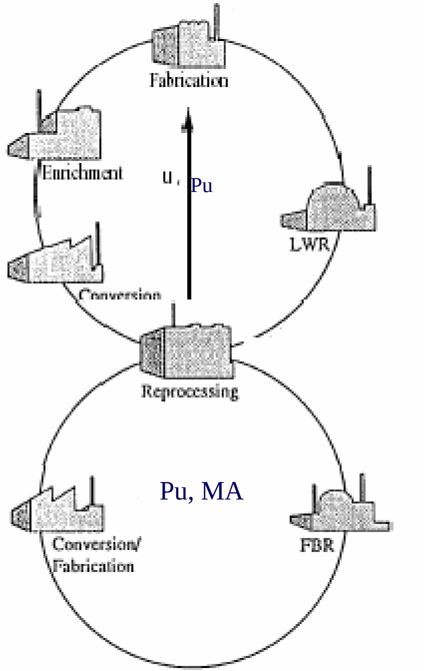
Outline of the presentation

- IAEA Programme of Work
- Partitioning & Transmutation potentials
- Advanced fuel cycles – MA technologies
- Fuel cycle approaches, LMFRFC
- Thorium fuel cycle, Inert Matrix Fuel includes coated particle
- MA-Fuel / databank
- Link between process losses and environmental impact
- Role of Pyro-chemical processes in AFC
- Concluding Remarks



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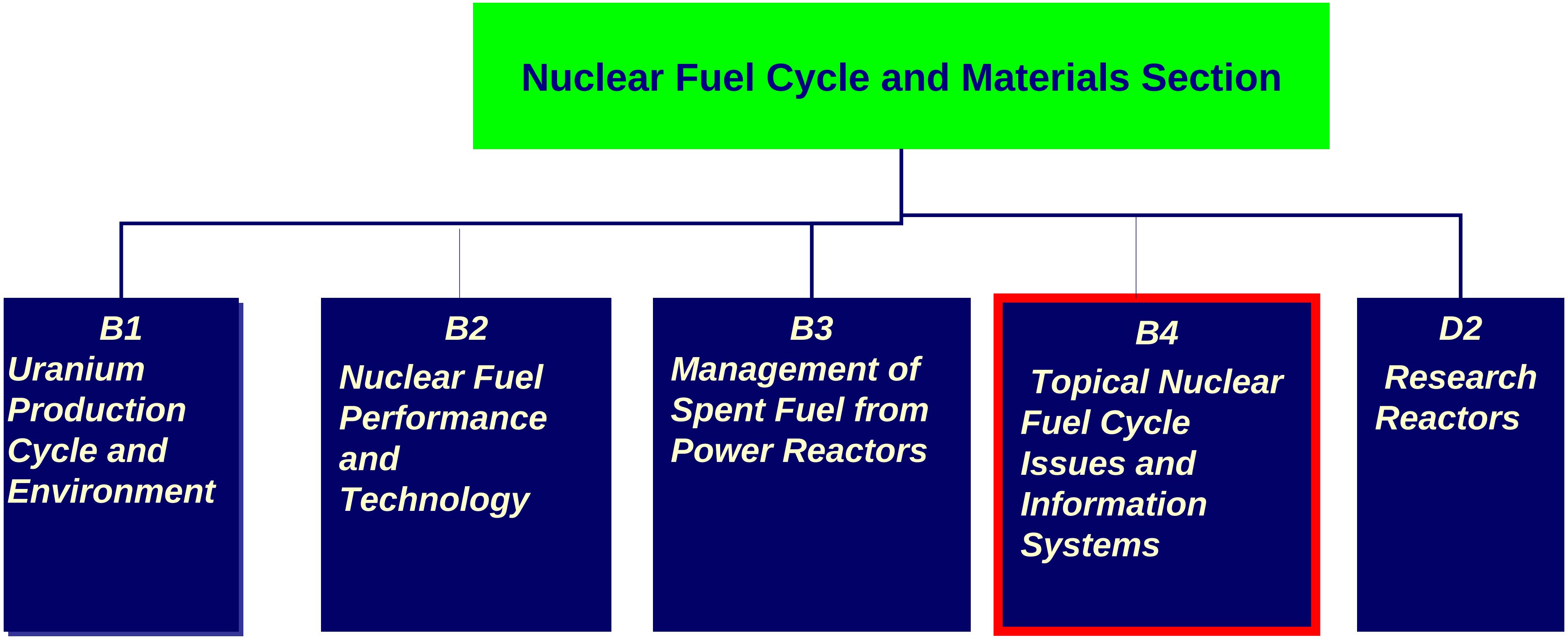


Nuclear Fuel Cycle and Materials Section

B1
Uranium Production Cycle and Environment

B2
Nuclear Fuel Performance and Technology

B3
Management of Spent Fuel from Power Reactors

B4
Topical Nuclear Fuel Cycle Issues and Information Systems

D2
Research Reactors

B4: Topical Nuclear Fuel Cycle Issues and Information Systems

Facilitating innovative nuclear fuel cycle technologies for sustainability

- **Partitioning and transmutation**
- **HTGR & MA fuel**
- **IMF & Th Fuel Cycle**
- **HEU, Pu & RepU management**

Promoting solutions of nuclear fuel cycle issues

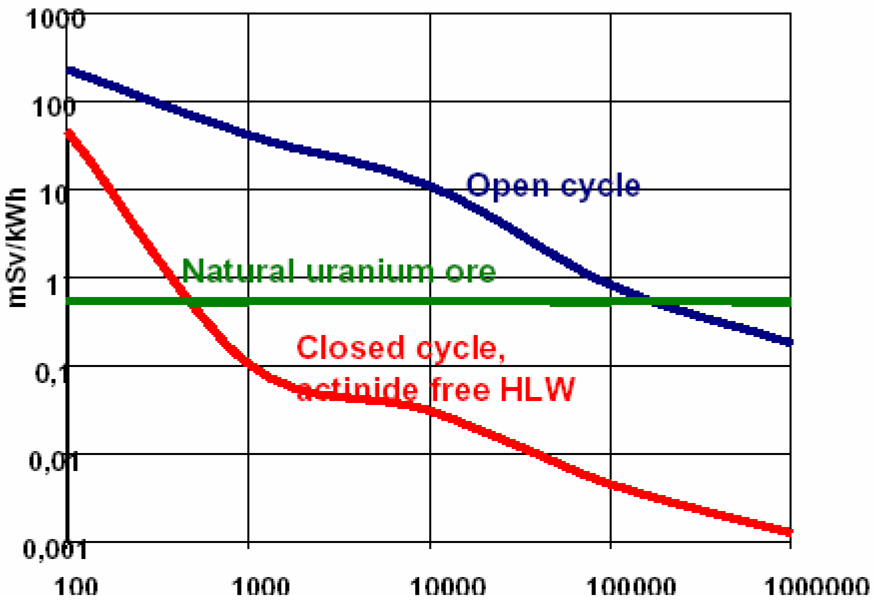
Maintaining and updating nuclear fuel cycle information systems

Fissile Material Management Strategy in NFC for Sustainable Nuclear Development

Genesis of the problem

Partitioning and Transmutation to deal with nuclear waste

- Reduction of long-term radio-toxicity
- Determination of a period to terminate the disposal site (From over million years to less than ≈700 years)
- Reduction of repository space requirements
- Increased resource utilization



CEA Program on Partitioning & Transmutation, D. Warin and H. Safa, *International Meeting on Accelerator Driven Transmutation System Technologies, University of Nevada, Las Vegas, April 29, 2003*

- Scientific, technical and economical feasibilities
- Reduce Proliferation concern

IAEA cooperations in P&T Activities

- Evaluation of actinide Partitioning and Transmutation (1982)
- Use of fast reactors for actinide transmutation (1993)
- Feasibility of separation of noble metals from HLLW (1989)
- Transmutation of separated Pu
- Review of nuclear data for ADS related R&D (1998)
- Overview of development of accelerator-driven sub-critical reactors (ADS) for transmutation of waste (1998)
- Utilization of thorium based fuel-cycle for ADS (1998)
- Feasibility of hybrid reactor concepts (1999)
- Non-proliferation and environmental aspects of P&T (2001)
- Emerging nuclear energy and transmutation systems: Core physics and engineering aspects (2003)

Advanced Fuel cycle

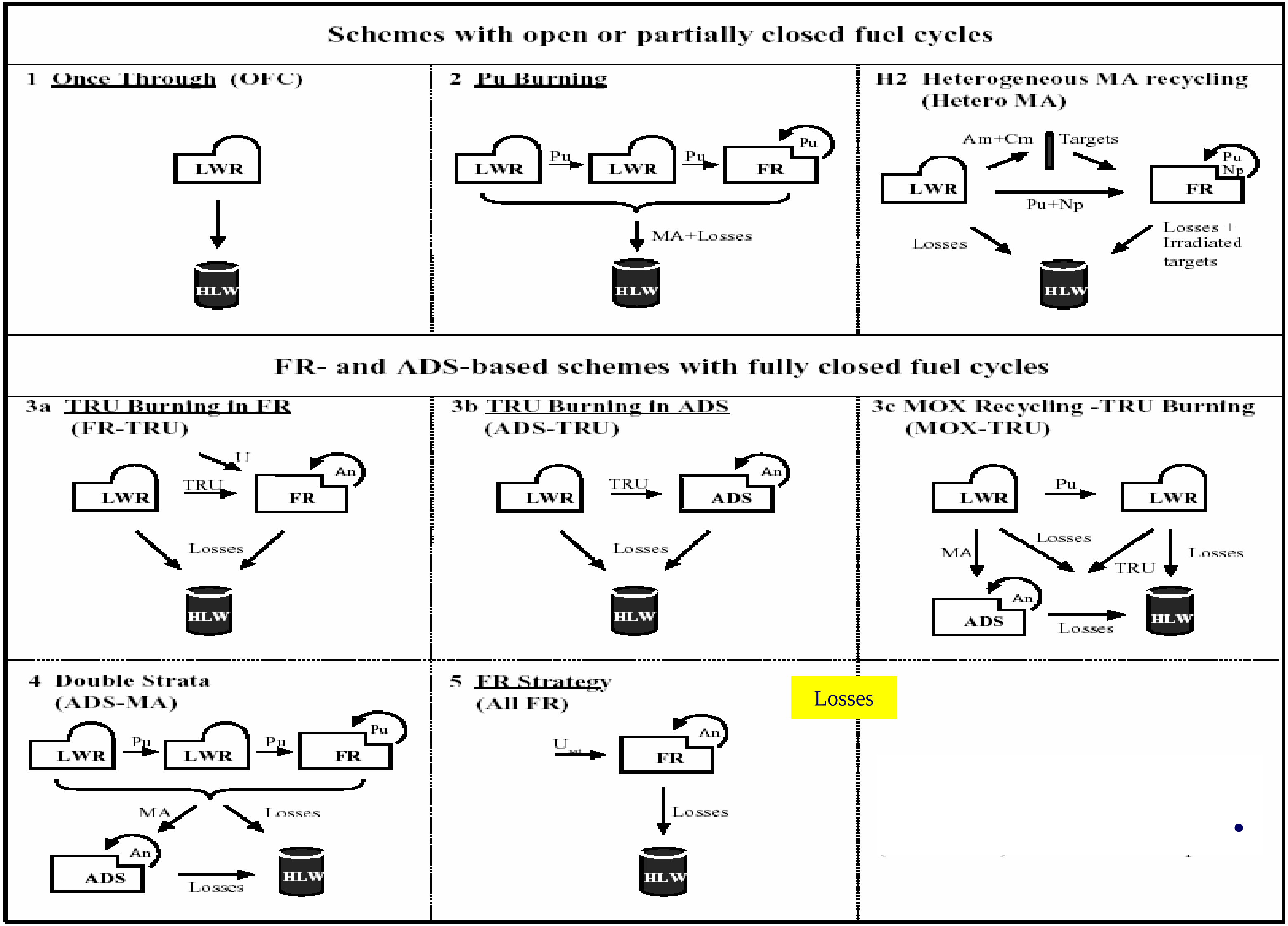
Fuel Cycle that incorporate P&T to burn TRU elements is called Advanced Fuel Cycle

1. Separation of TRUs and LLFPs
2. Fabrication of TRU-rich fuel and targets
3. Transmutation in Thermal &/or Fast reactors or ADS

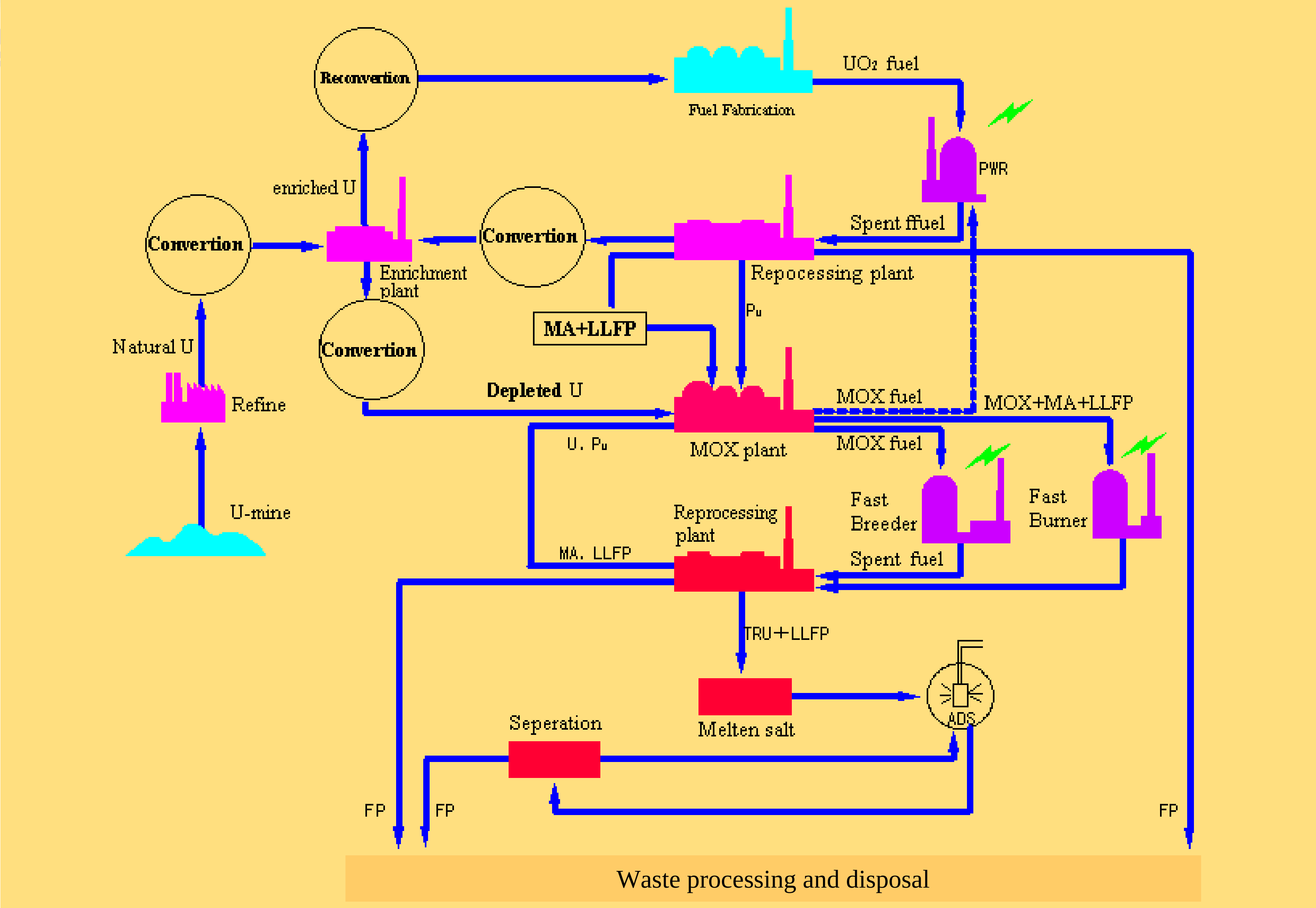
Advanced Fuel Cycle consists

a) Reprocessing of LWR-UO_2 fuel
b) Separation of minor actinides from HLLW resulting from LWR-UO_2 reprocessing
c) Fabrication of MA targets for heterogeneous irradiation in LWRs
d) Quantitative recycling of U and Pu into LWR-Mixed Oxide (MOX) fuel
e) Reprocessing of spent LWR-MOX fuel in adequate facilities (higher Pu inventory)
f) Separation of MAs from HLLW & conditioning of individual elements MAs
g) Fabrication of FR -fuel (MOX, -metal or -nitride) with limited MA content
h) Irradiation in FRs or dedicated hybrid facilities to very high burnup
i) Reprocessing of spent FR-fuel in specially (aqueous and non-aqueous)
j) Quantitative separation of all TRUs from the spent FR (and /or ADS) fuel processing during multiple recycling
k) Multiple recycling of FR-MOX fuel with major TRU content until significant depletion
l) Separation of certain fission products with long half-lives if required for the disposal step

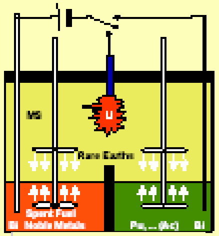
Source: P&T as a Waste Management Option in a Future Nuclear Era, L.H. Baestslé, in Proc. Workshop on Hybrid Nuclear Systems for Energy Production, Utilisation of Actinides & Transmutation of Long-lived Radioactive Waste, IAEA, Sep 3-7, 2001, ICTP, Trieste, Italy, and IAEA, Vienna, Austria, 2001, IAEA/SMR/1326-3



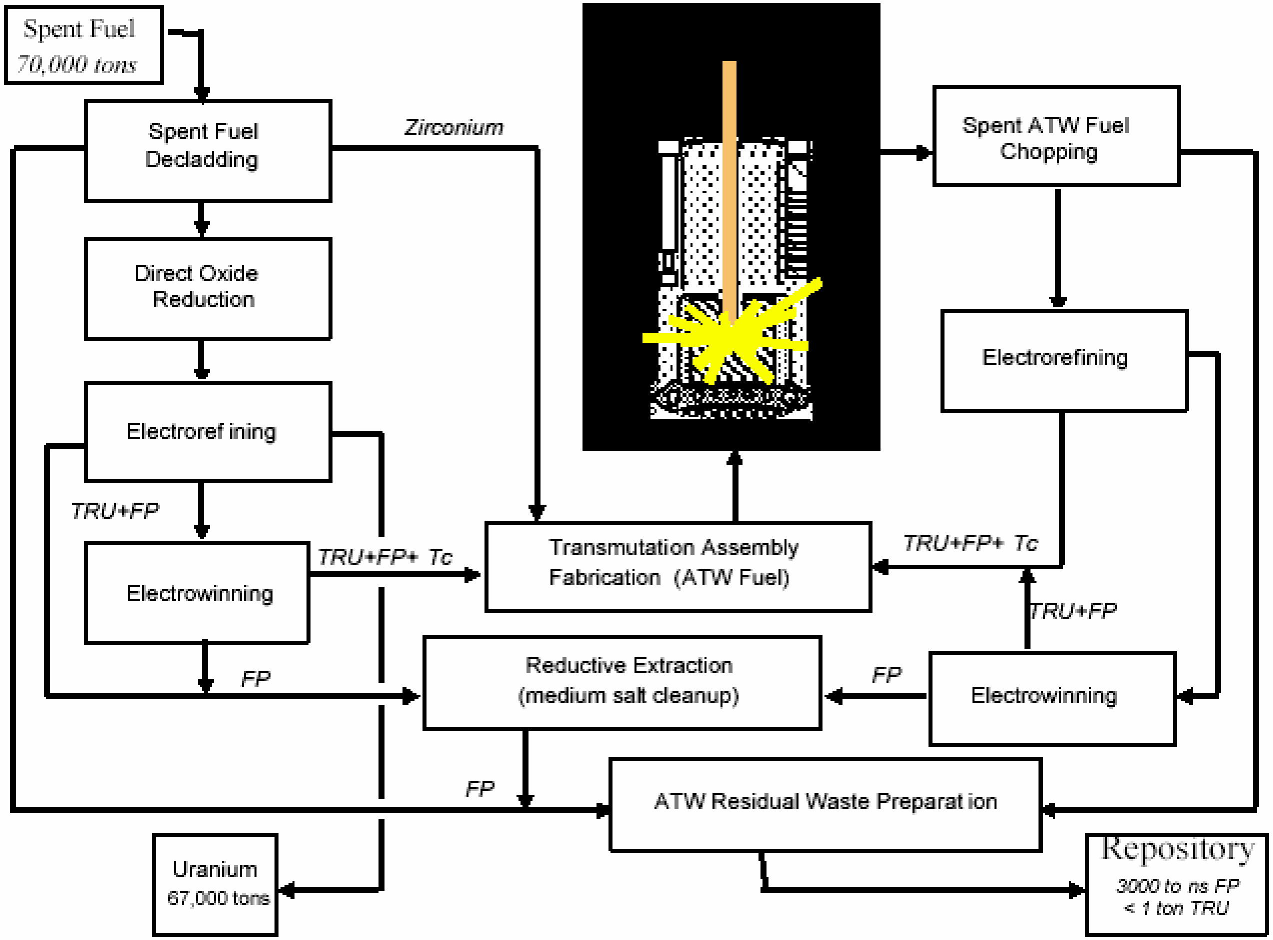
Source: Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles, A Comparative Study, **(2002)** *NUCLEAR ENERGY AGENCY ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT*


Reconvertion
Fuel Fabrication
UO₂ fuel
PWR
enriched U
Convertion
Enrichment plant
Convertion
Spent ffuel
Repocessing plant
Natural U
Convertion
MA+LLFP
Pu
Refine
Depleted U
MOX fuel
MOX+MA+LLFP
U. Pu
MOX plant
MOX fuel
U-mine
Fast Breeder
Fast Burner
Reprocessing plant
MA. LLFP
Spent fuel
TRU+LLFP
ADS
Seperation
Melten salt
FP
FP
FP
Waste processing and disposal

Pyrochemical Processes



Proliferation resistant, low environmental impact



Spent Fuel
70,000 tons

Spent Fuel Decladding

Zirconium

Direct Oxide Reduction

Electrorefining

TRU+FP

Electrowinning

TRU+FP+ Tc

FP

Transmutation Assembly Fabrication (ATW Fuel)

Spent ATW Fuel Chopping

Electrorefining

TRU+FP+ Tc

TRU+FP

Electrowinning

FP

Reductive Extraction (medium salt cleanup)

FP

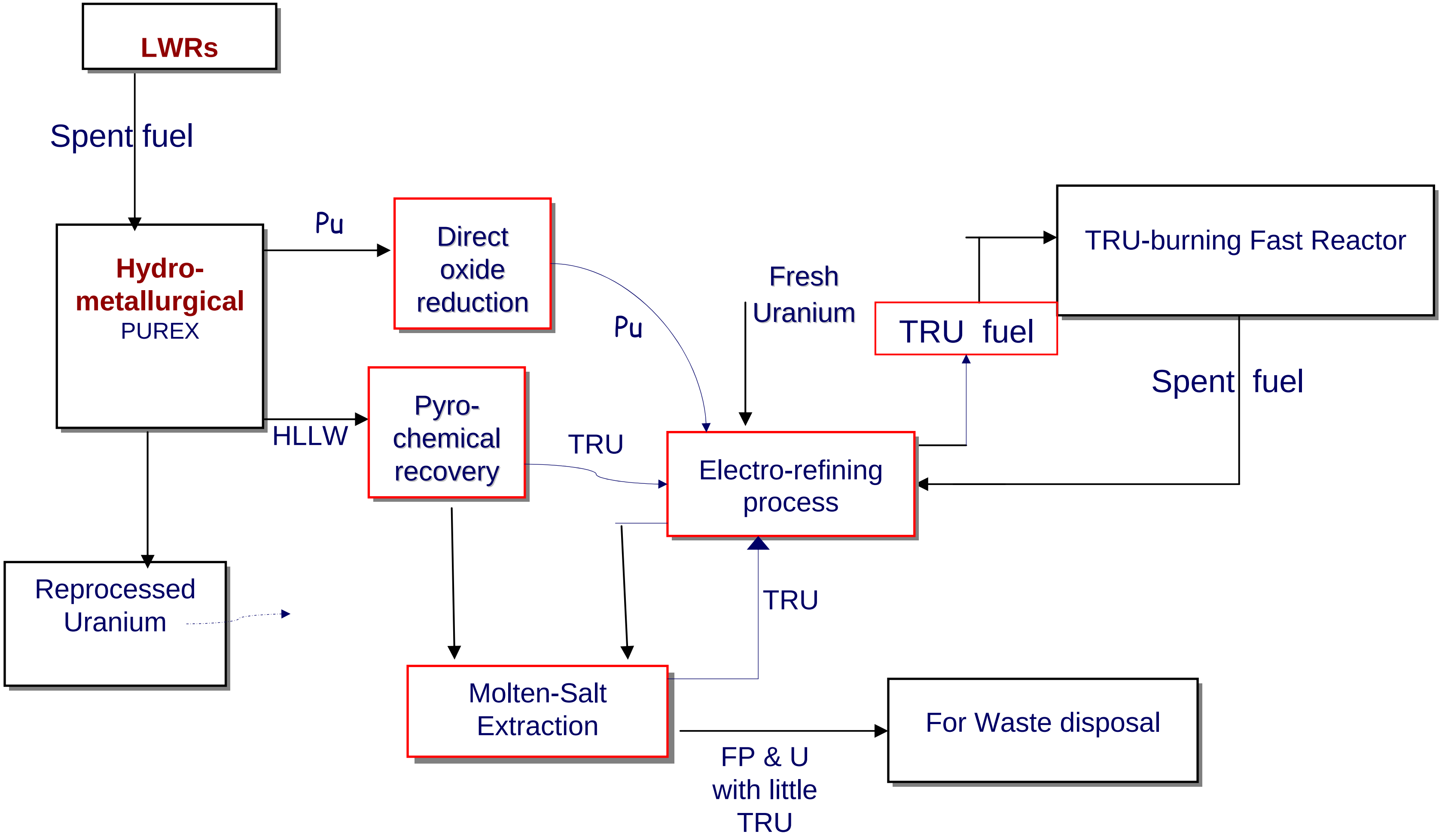
ATW Residual Waste Preparation

Uranium
67,000 tons

Repository
3000 to ns FP
< 1 ton TRU

Schematic ATW waste treatment flowsheet.

TRU- FR burner, multiple recycling fuel cycle scenario



Fabrication experience of LMFR fuels in Laboratory(L), Pilot(P) & Commercial(C) scales

Sl. No.	Country	Oxide UO_2,$(U,Pu)O_2$	Carbide UC, (U,Pu)C	Nitride UN, (U,Pu)N	U-Fs &U-Pu-Zr
1.	**USA**	**P**	L	L	**P**
2.	**Russia**	C	L	L	
3.	**France**	C	L	L	
4.	**India**	L	P	L	
5.	**Japan**	P	L	L	
6.	**UK**	C	L		
7.	**Germany**	C	L		

Fabrication R&D on LMFR fuels for Minor actinide based fuels

Sl. No.	Country	Oxide	Advanced fuel forms	Nitride	Metallic
1.	USA	Yes	Yes		Yes
2.	Russia	Yes	Yes	Yes	
3.	France	Yes	Yes		
4.	Japan	Yes		Yes	Yes
5.	EU	Yes	Yes		Yes

LMFR-System Rests on Environmentally Benign Nuclear Fuel Cycle

- Reduced radio-toxic waste inventories as well as longevity (long-term radio-toxicity)
- Reduced containment duration
- Less stringent repository requirements
- Increased resource utilization

Some Potential Challenges in Addressing Environmentally Benign LMR-FR Fuel Cycles

- Development of transuranic-based fuel and fuel cycles
- Reprocessing of such fuels, in combination with the immobilization of separated non-reusable radiotoxic nuclides and noble metals for ultimate disposal
- Suitable matrixes for ^{14}C and ^{15}N should be developed for the realization of advanced fuels such as coated particle or nitride fuel etc.,
- Methods to recycle and reuse fission products should be addressed
- To increase the capacity of repository by separating the heat producing radio-nuclides and prepare these for cooling storage
- Operational exposure: minimize workers' exposure-limits for such fuel fabrication and spent fuel treatment.

Technical Meeting on

"Current Status and Future Prospects of Liquid Metal Cooled Reactor Fuel Cycle and fuels"

(TM-LMFR-2005)

3-7 Oct 2005*

at

Central Institute of Improvement of Qualification (TSIPK), Obninsk, Russian Federation

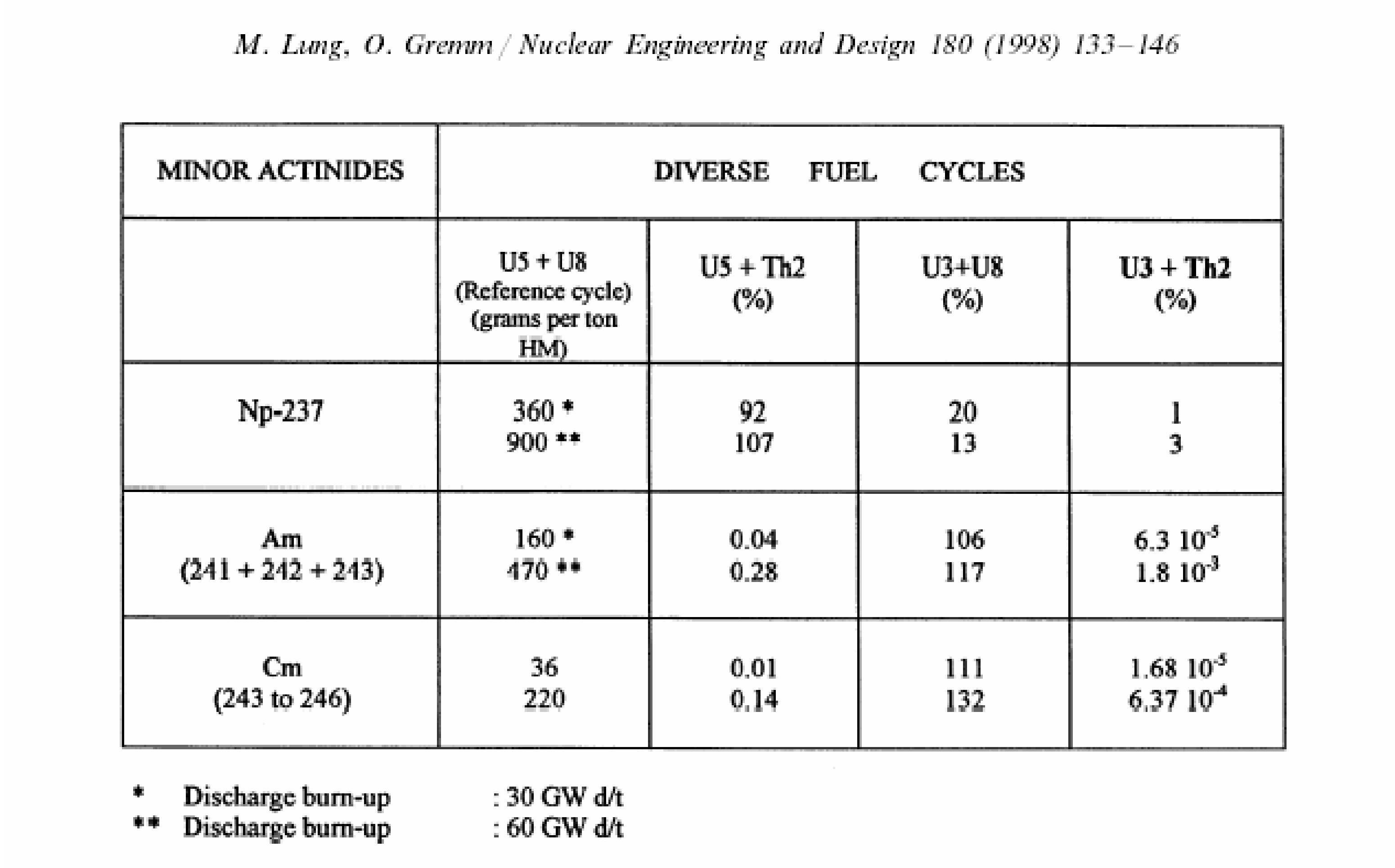
with cooperation from
Institute of Physics and Power Engineering (IPPE)
Obninsk, Russian Federation

* Subject to clearances and approvals

Provisional programme

- Role of LMFRs in sustainable nuclear energy development
- General LMFRs developments / new concepts
- Current status of LMFR fuel cycles
- Economics of LMFBR fuel cycles and its comparison with the other fast reactor fuel cycles
- Current status of liquid metal-cooled reactors fuels
- Advanced fuel fabrication, design including conventional one/new concepts
- Development of fuel fabrication technology including QA and QC
- Irradiation testing, fuel performance in normal and transient conditions and fuel modelling
- Existing and planned facilities and experimental programs
- Advances in materials development for fuel cycle application
- Trends in innovative fuel cycle concepts including partitioning and transmutation pertinent to LMFR fuel cycle development specially encompassing the subject areas:
  - Theory, Design, Development, irradiation testing and performance
  - Status and innovations in partitioning as well as transmutation methods Waste reduction, proliferation-resistance and environmental improvement through LMFR fuel cycles
  - Challenges and R&D needs in LMFR fuel cycle
  - Cross-cutting and infrastructure issues
- Knowledge conservation on LMR fuel cycle
- Prospects for international collaboration and co-ordination of R&D activities
- IAEA’s role in meeting the needs for information exchange and collaborative R&D.

Thorium fuel cycle



M. Lung, O. Gremm / Nuclear Engineering and Design 180 (1998) 133–146

MINOR ACTINIDES	DIVERSE FUEL CYCLES			
	U5 + U8 (Reference cycle) (grams per ton HM)	U5 + Th2 (%)	U3+U8 (%)	U3 + Th2 (%)
Np-237	360 * 900 **	92 107	20 13	1 3
Am (241 + 242 + 243)	160 * 470 **	0.04 0.28	106 117	$6.3\ 10^{-5}$ $1.8\ 10^{-3}$
Cm (243 to 246)	36 220	0.01 0.14	111 132	$1.68\ 10^{-5}$ $6.37\ 10^{-4}$

*	Discharge burn-up	: 30 GW d/t
**	Discharge burn-up	: 60 GW d/t

Relative production of minor actinides in diverse cycles

Thorium fuel cycle

- **Very large thorium resources could be utilized for nuclear energy generation apart from increasing efficiency of U-resource utilization**

- **Neutron yields of ^{233}U in the thermal and epithermal regions are higher than those of ^{239}Pu and also , ^{232}Th is a better 'fertile' material than ^{238}U in thermal reactors**

- **Improved operating margins due to better thermo-physical properties of ThO_2 fuel even at high burnup, compared to those of UO_2 fuel**

- **Potential for fuel cycle cost reduction, the reduction in ^{235}U enrichment requirements**

- **Reducing long-lived radioactive waste inventories by diminishing the production of plutonium and minor actinides**
- **Th-based fuels and fuel cycles have intrinsic proliferation-resistance due to the formation of ^{232}U via (n,2n) reactions with ^{232}Th, ^{233}Pa and ^{233}U. The half-life of ^{232}U is only 73.6 years and the daughter products have very short half-life and some like ^{212}Bi and ^{208}Tl emit strong gamma radiations**

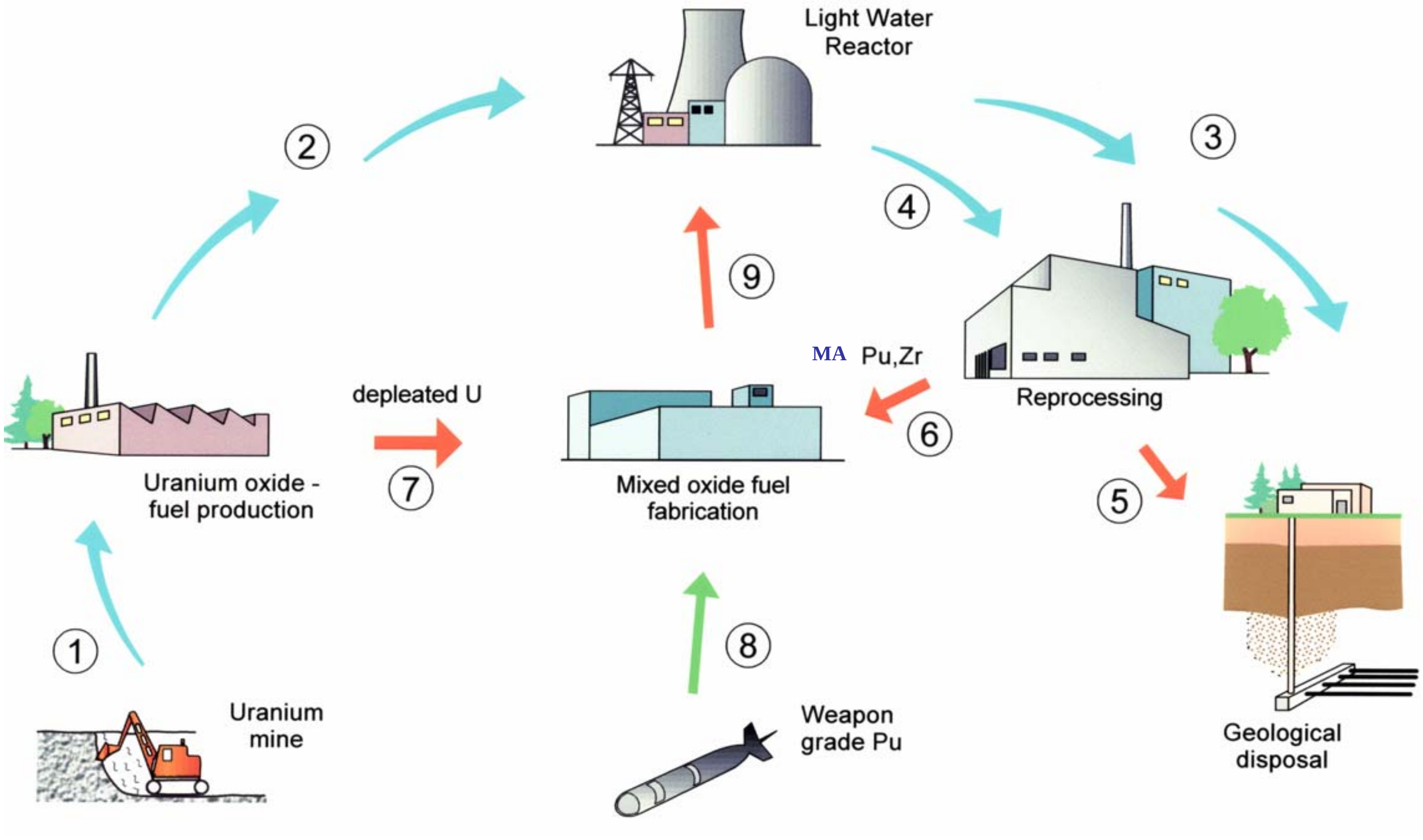
Name and Country	Type	Power	Fuel	Operation period
AVR, Germany	HTGR Experimental (Pebble bed reactor)	15 MWe	Th+^{235}U Driver Fuel, Coated fuel particles Oxide & dicarbides	1967 – 1988
THTR, Germany	HTGR Power (Pebble Type)	300 MWe	Th+^{235}U, Driver Fuel, Coated fuel particles Oxide & dicarbides	1985 - 1989
Lingen, Germany	BWR Irradiation-testing	60 MWe	Test Fuel $(Th,Pu)O_2$ pellets	Terminated in 1973
Dragon, UK OECD-Euratom also Sweden, Norway & Switzerland	HTGR Experimental (Pin-in-Block Design)	20 MWth	Th+^{235}U Driver Fuel, Coated fuel particles Dicarbides	1966 - 1973
Peach Bottom, USA	HTGR Experimental (Prismatic Block)	40 MWe	Th+^{235}U Driver Fuel, Coated fuel particles Oxide & Dicarbides	1966 – 1972
Fort St Vrain, USA	HTGR Power (Prismatic Block)	330 MWe	Th+^{235}U Driver Fuel, Coated fuel particles Dicarbide	1976 - 1989
MSRE ORNL, USA	MSBR	7.5 MWth	^{233}U Molten Fluorides	1964 - 1969
Borax IV & Elk River Reactors, USA	BWRs (Pin Assemblies)	2.4 MWe 24 MWe	Th+^{235}U Driver Fuel Oxide Pellets	1963 - 1968
Shippingport & Indian Point, USA	LWBR PWR (Pin Assemblies)	100 Mwe 285 MWe	Th+^{233}U Driver Fuel, Oxide Pellets	1977 – 1982 1962 - 1980
SUSPOP/KSTR KEMA, Netherlands	Aqueous Homogenous Suspension (Pin Assemblies)	1 MWth	Th+ HEU Oxide Pellets	1974 - 1977
NRU & NRX, Canada	MTR (Pin Assemblies)		Th+^{235}U Test Fuel	Irradiation–testing of few fuel elements
KAMINI, CIRUS, & DHRUVA, India	MTR Thermal	30 kWth 40 MWt 100 MWt	Al-^{233}U Driver Fuel ‘J’ rod of Th & ThO_2 ‘J’ rod of ThO_2	All three research reactors in operation
KAPS 1&2, KGS 1&2, RAPS 2,3&4, India	PHWR (Pin Assemblies)	220 MWe	ThO_2 Pellets For neutron flux flattening of initial core after start-up	Continuing in all new PHWRs
FBTR, India	LMFBR (Pin Assemblies)	40 MWt	ThO_2 blanket	In operation

Technical document on Thorium fuel cycle options: Potential benefits and challenges

- RATIONALE FOR THORIUM-BASED FUEL CYCLES
- IMPLEMENTATION SCENARIOS AND OPTIONS
- CURRENT INFORMATION BASE
- FRONT-END ISSUES AND CHALLENGES
- BACK-END ISSUES AND CHALLENGES
- PROLIFERATION RESISTANCE
- ECONOMIC ISSUES

IMF Goal and Objective

- **Desired goal: eliminate plutonium excesses and minor actinides**
- **Desired objective: use them to produce energy in reactors**



Examples of Inert Matrix

Inert Matrix type	Inert Matrix formula
Element	C, Mg, Al, Si, Cr,V, Zr, Mo, W
Inter-metallics	AlSi, AlZr, ZrSi
Alloy	Stainless steel, zirconium alloys
Carbide	SiC, TiC, ZrC
Nitrides	AlN, TiN, ZrN, CeN,
Binary oxide	MgO, Y_2O_3, ZrO_2, CeO_2
Ternary oxide	$MgAl_2O_4$, $Y_3Al_5O_{12}$, $ZrSiO_4$
Oxide solid solution	$Y_yZr_{1-y}O_{2-y/2}$, $Mg_{(1-x)}Al_{(2+x)}O_{(4-x)}$

Examples of Inert Matrix design and additives

Design	Composition
Solid solution	**$An_zY_yPu_xZr_{1-y}O_{2-\psi}{}^*$**
Cercer	$MgAl_2O_4$ - $Y_yPu_xZr_{1-y}O_{2-y/2}{}^*$
Cermet	Zr - $Y_yPu_xZr_{1-y-x}O_{2-y/2}{}^*$
Metmet	$PuAl_4{}^*$-Al

Technical Document on

Viability of Using Inert Matrix Fuel in Reducing Plutonium in Reactors

1. Overview:
2. Potential IMF application; environmental, fuel cycle aspects, economic, non-proliferation aspects, historical before 80’s, current programs
3. R&D activities for IMF qualification
4. Country Specific programs
5. International programs: Irradiations
6. Overview of IMF workshops
7. Outlook and Results

Technical meeting on
Current status and future prospects of Gas-Cooled Reactor fuels
(Jun 2004)

There were 27 technical presentations from 37 Participants from 17 Member States, EC and 3 IAEA Experts

Technical programme: 1.) Countries Overview 2.) Coated Particle Fuel modelling 3.) Coated Particle Fuel Performance and technology and 4.) Novel ideas and application related to Coated Particle Fuel

Panel Discussion: 1.) Requirements regarding Coated Particle Fuel characteristics for Hydrogen Generation 2.) Desirability of creating a central data-book for coated particle fuel data by the Agency and 3.) Measures for improving international cooperation in Coated Particle Fuel development

Adaptability of MA-fuel fabrication to remote handling in shielded cells

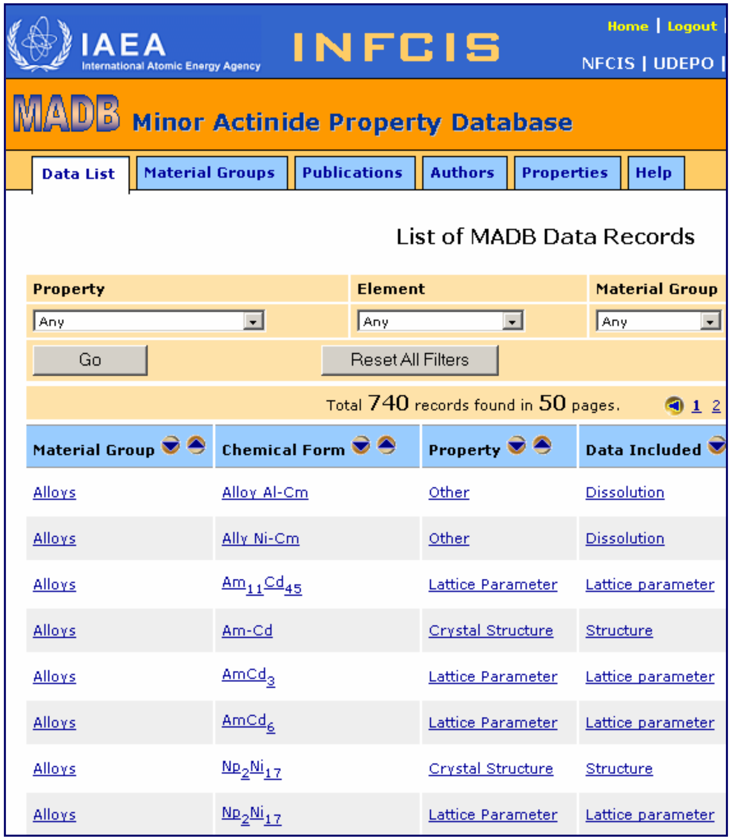
Oxide	Powder metallurgy of pellet fuel	Not easily adaptable to remote handling	SOL-GEL coprecipitation of TRUs from nitrate solution Alternative fuel forms such as Vibro-pac or sphere-pac
Nitride	Powder metallurgy by nitration + carbothermic reduction	Need for very high temperature and very high affinity of Zr for oxygen	Use of SOL-GEL with direct compact could reduce number of steps
Metal-alloy	Injection-casting of alloy fuels	Americium vaporization	Americium trapping system for recover and reuse. Alternatively powder metallurgical method viz., mixing, pellet making & sintering

MA-Fuel development research

- ★ MA-fuel fabrication processes: Powder-metallurgy, Injection casting, SOLGEL, Carbothermic reduction, Vibro-pac, Coated particle development, direct coagulation casting, etc.,
- ★ MA-fuels (targets) and fuel types & forms- catalogue (CERMET, CERCER, IMF, & METMET, as well as MA-MOX, Coated particle, Metal-alloys & Nitride)
- ★ Potential innovative methods for remote fuel fabrication with reduced losses; Waste-generation at the fuel fabrication stages
- ★ Disposition / flexibility to reprocessing /multi-recycle
- ★ Advanced core materials
- ★ Pertinent thermo-physical properties for fuel design, fabrication process and performance Irradiation screening tests, modeling, fuel design and post-irradiation examination

• Minor Actinide Property Database (MADB) Under Preparation

- **Bibliographic database on thermodynamic and thermophysical properties of minor actinide (Np, Am, Cm) metals, alloys and compounds**
- **Access on the internet with some search and filter capabilities (www-nfcis.iaea.org)**



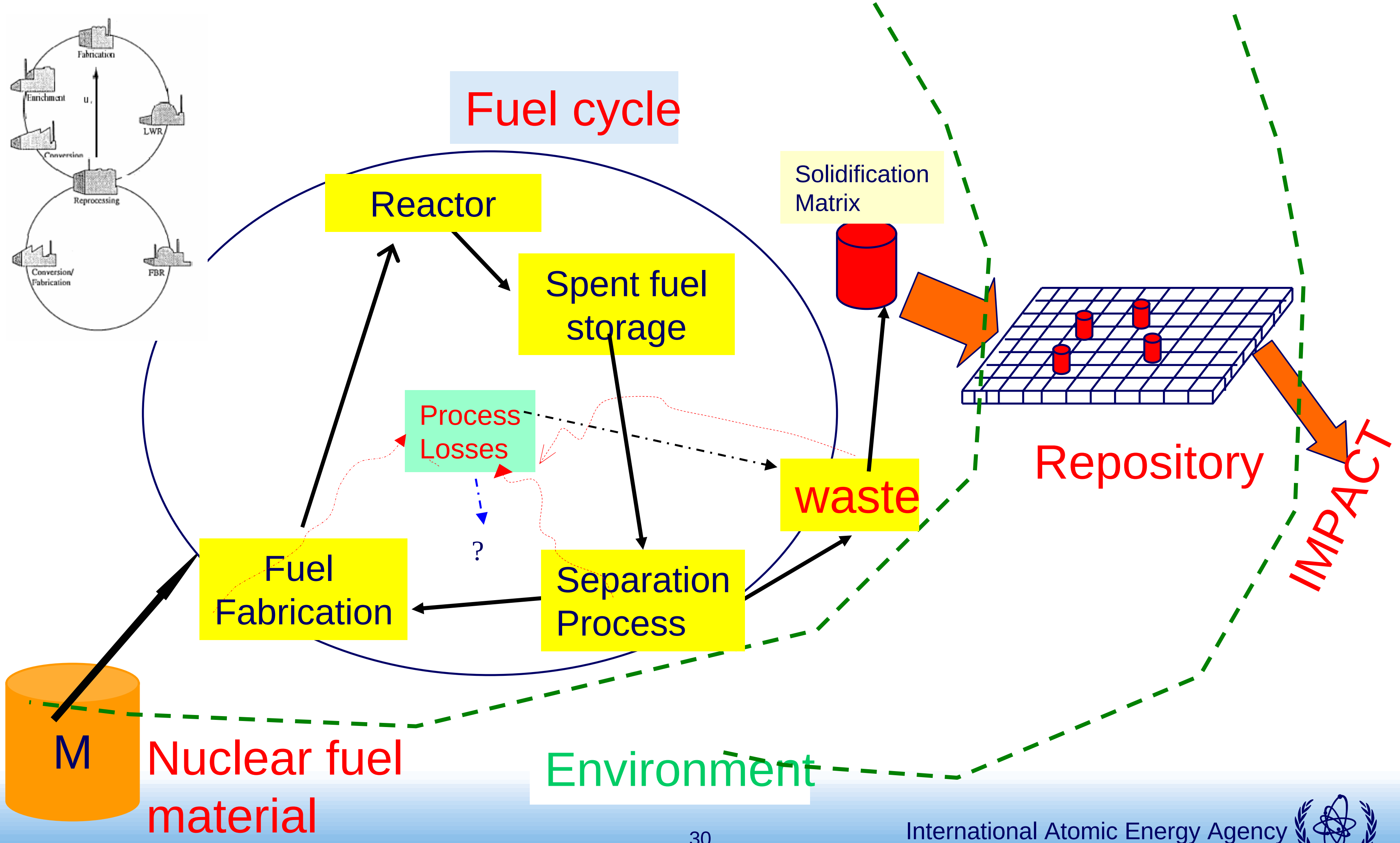
List of MADB Data Records

Property	Element	Material Group
Any	Any	Any

Total 740 records found in 50 pages. 1 2

Material Group	Chemical Form	Property	Data Included
Alloys	Alloy Al-Cm	Other	Dissolution
Alloys	Ally Ni-Cm	Other	Dissolution
Alloys	$Am_{11}Cd_{45}$	Lattice Parameter	Lattice parameter
Alloys	Am-Cd	Crystal Structure	Structure
Alloys	$AmCd_3$	Lattice Parameter	Lattice parameter
Alloys	$AmCd_6$	Lattice Parameter	Lattice parameter
Alloys	Np_2Ni_{17}	Crystal Structure	Structure
Alloys	Np_2Ni_{17}	Lattice Parameter	Lattice parameter

Relation between Process Losses in Nuclear Fuel cycle and Environmental Impact



Fuel cycle

Reactor

Spent fuel storage

Solidification Matrix

Process Losses

?

waste

Repository

IMPACT

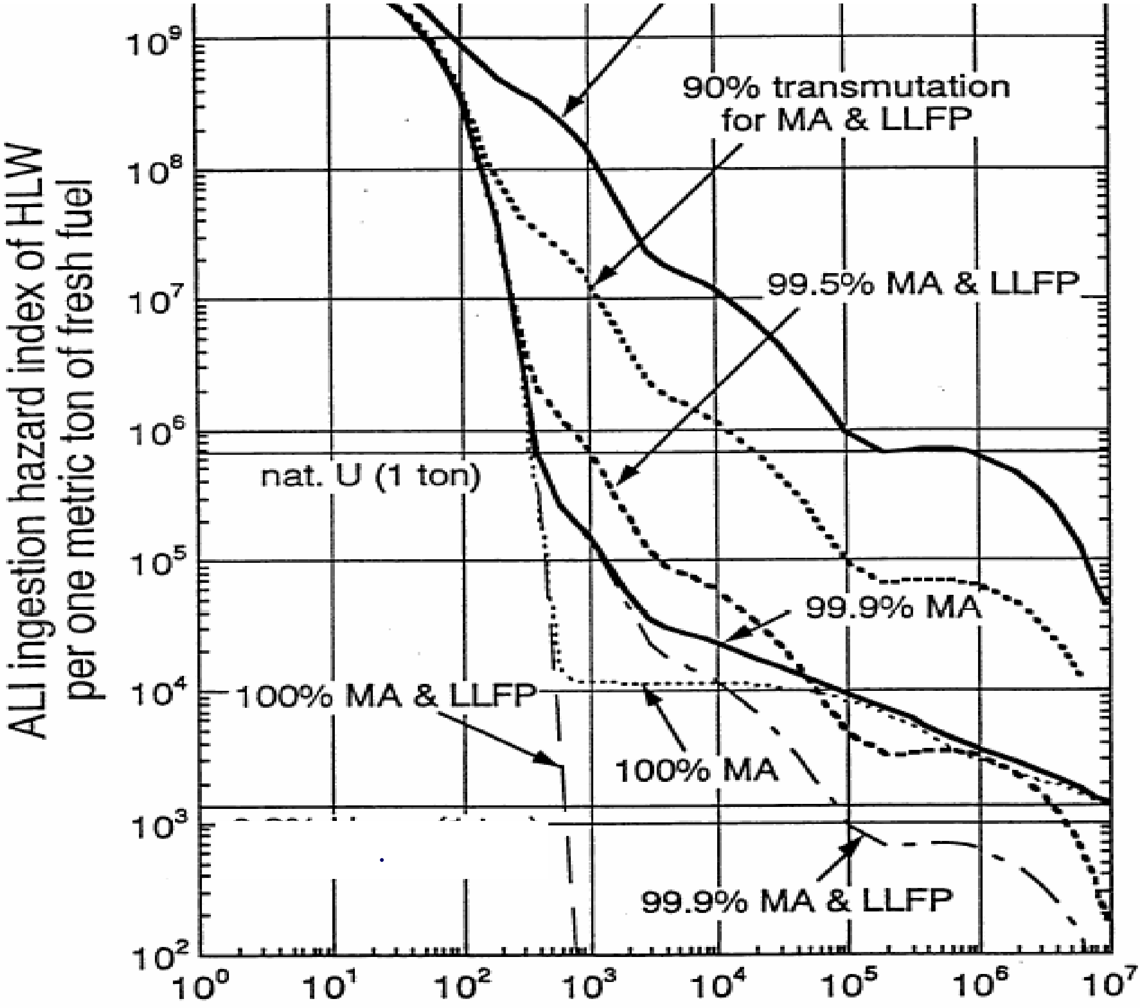
Fuel Fabrication

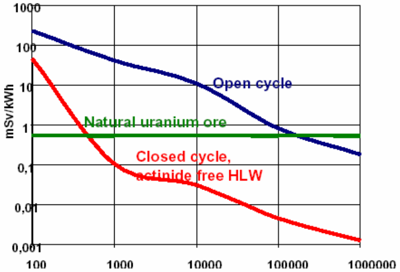
Separation Process

M

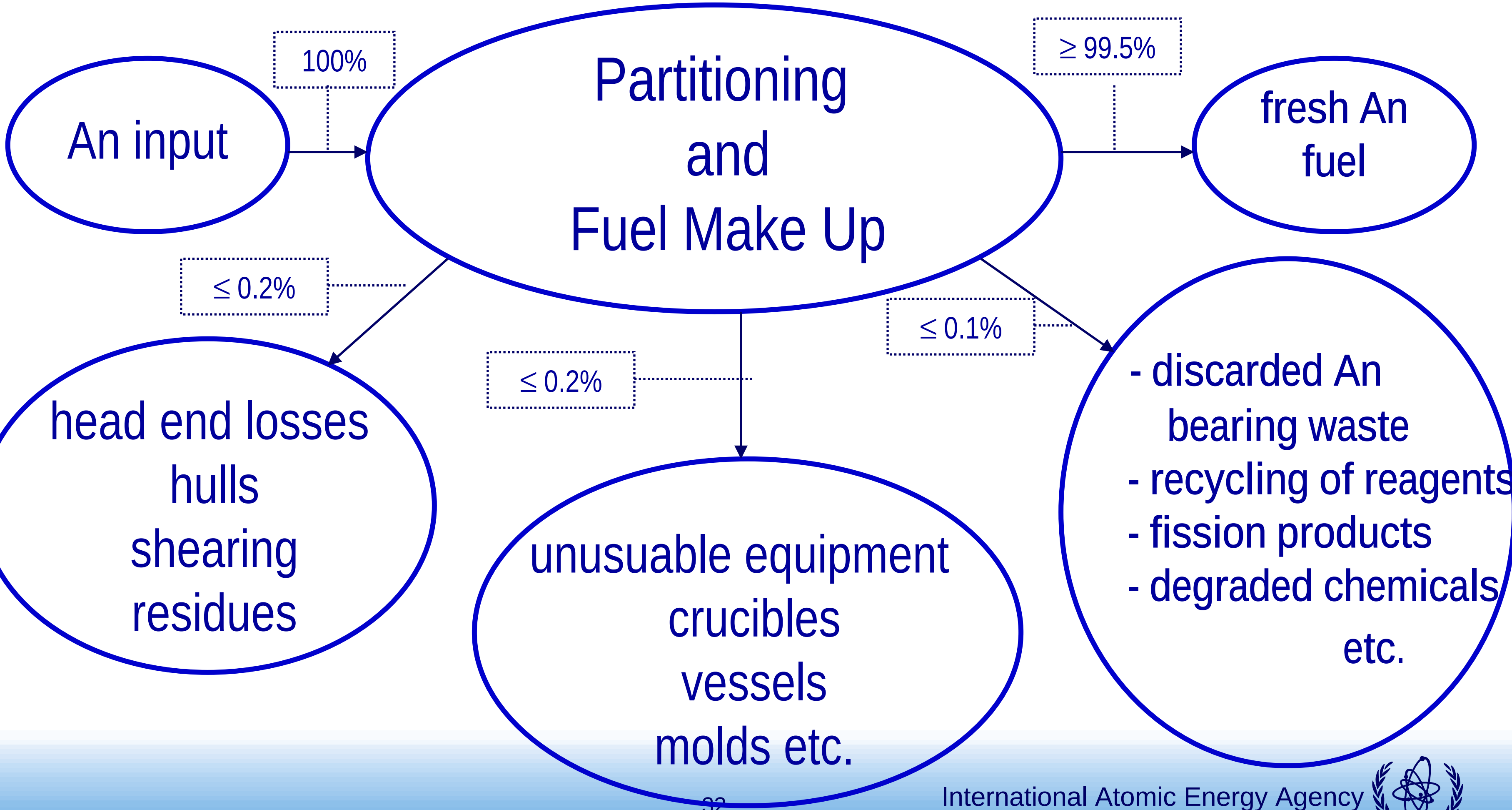
Nuclear fuel material

Environment


ALI ingestion hazard index of HLW per one metric ton of fresh fuel
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
90% transmutation for MA & LLFP
99.5% MA & LLFP
nat. U (1 ton)
99.9% MA
100% MA & LLFP
100% MA
99.9% MA & LLFP


mSv/kWh
1000
100
10
1
0,1
0,01
0,001
100
1000
10000
100000
1000000
Open cycle
Natural uranium ore
Closed cycle, actinide free HLW

Target Values for
An-Losses to Achieve a Transmutation Rate of about 100



An input

100%

Partitioning
and
Fuel Make Up

≥ 99.5%

fresh An
fuel

≤ 0.2%

head end losses
hulls
shearing
residues

≤ 0.2%

unusuable equipment
crucibles
vessels
molds etc.

≤ 0.1%

- discarded An
  bearing waste
- recycling of reagents
- fission products
- degraded chemicals
  etc.

Review of pyro-chemical methods

	Metal Electro-refining	Oxide Electro-winning	Chloride / fluoride volatility	Nitride electro-refining	Pyro for HLLW	Novel and auxiliary methods
1. Fuel form	Zr-based actinide alloys	Mixed actinide oxides	ADS targets & TRISO fuel	Actinide nitride	Link from aqueous methods	Plasma process Li reduction
2. MA loading	Fuel fabrication	Different steps	Ideal for MAs processing	High MA loading		
3. Scale	Semi-plant	Semi plant	Laboratory	Laboratory	Laboratory	Laboratory
4. Some of the interested Member States	USA, Japan, EU, Korea, India	Russia, Japan,EU	USA, EU	Japan	USA, Russia, Japan, EU	USA, Russia, Japan, EU

Review of other aqueous partitioning methods

- DIAMEX process to extract Am+Cm
- SESAME process for Am/Cm separation
- NEXT process includes uranium crystallization step
-
- GANEX Process (Actinide Group Separation method)
- UREX process

Combination of Pyro-chemical and Wet process

	Pyro-chemical process	Wet process
Product Purity	**Mixture of TRU** **- Low**	**High** **Single elements (U,Pu,Np,Am,Cm)**
Process	**Batch**	**Continuous**
Throughput	**Low**	**High**
Process losses	**To be established**	**Established**

Steps to achieve synergetic combination of both processes

Coordinated Research Project (CRP)

“Study of Process Losses in Separation Processes in Partitioning and Transmutation (P&T) Systems in view of Minimizing Long Term Environmental Impacts”

- 1st Scope Definition Meeting - Oct. 2002, Vienna
- China, Czech Republic, Germany, India, Japan, Republic of Korea, Russian Federation and USA
- 1st Research Coordination Research Meeting -Dec 2003, Vienna
- 2nd Research Coordination Research Meeting - Dec 2004, Czech Republic

CRP Objectives

- Minimization of losses
- Advanced characterization methods for actinides
- Separation criteria to minimize environmental impact
- List of critical radio-nuclides
- Defining environmental impact associated with partitioning and transmutation processes
- Defining proliferation resistance attributes

Minimization of losses

Studies on minimization of process losses in separation processes define the scope in reducing actinides losses in the waste fraction and in-turn minimizes the ultimate environmental impact. For any Partitioning process the acceptable losses to the waste determine the separation criteria.To achieve public acceptance for nuclear energy generation with transmutation, the reduction of long living radiotoxicity must be impressive.

a) **Identify Sources of losses of long living radiotoxic waste**

b) **Understand chemical forms of actinides and others in process**

c) **Assess the behavior of actinides and FP in the process, such as volatilization, precipitation, etc.,**

Advanced characterization methods for actinides

Advanced characterization methods should be developed for transuranic elements to support the minimization of environmental impact. Procedures for measuring the possible material hold-up and reduction of radio-toxicity with accuracy should be inventorized and improved and analytical techniques should be developed

With the following objectives

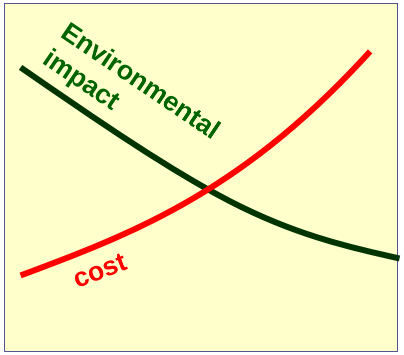
1. **Environmental release (discard of long living radiotoxic nuclides)**
2. **fissile material safeguards (flow of fissile material across the plant)**
3. **criticality control (tracking of fissile material masses in the different criticality zones)**

Characterization methods for

- ❖ **Hold up of nuclide masses in process units**

- ❖ **Characterisation of discards in its different forms namely i) remains in hulls** ii) **fines from shearing iii) dross in crucibles**

Separation criteria to minimize environmental impact



Reduction of Radiotoxicity

Establishment of criteria for the separations processes in order to realize the target environmental benefits. Conflict between ecological and economic impact by P&T. Cost increases exponentially with the reduction of losses to the waste.

Criteria for Separation

- Establishment of quantitative relationship between environmental impact and separation criteria
- How high separation efficiency should be required
- Possible method for separation and technological feasibility
- How should be treated or utilized the separated species

Additional Considerations

- Handling facilities for treatment and treated material processing

  - Dose considerations
- Reactor fuel qualification
- Reduction of depth of disposal

List of critical radio-nuclides

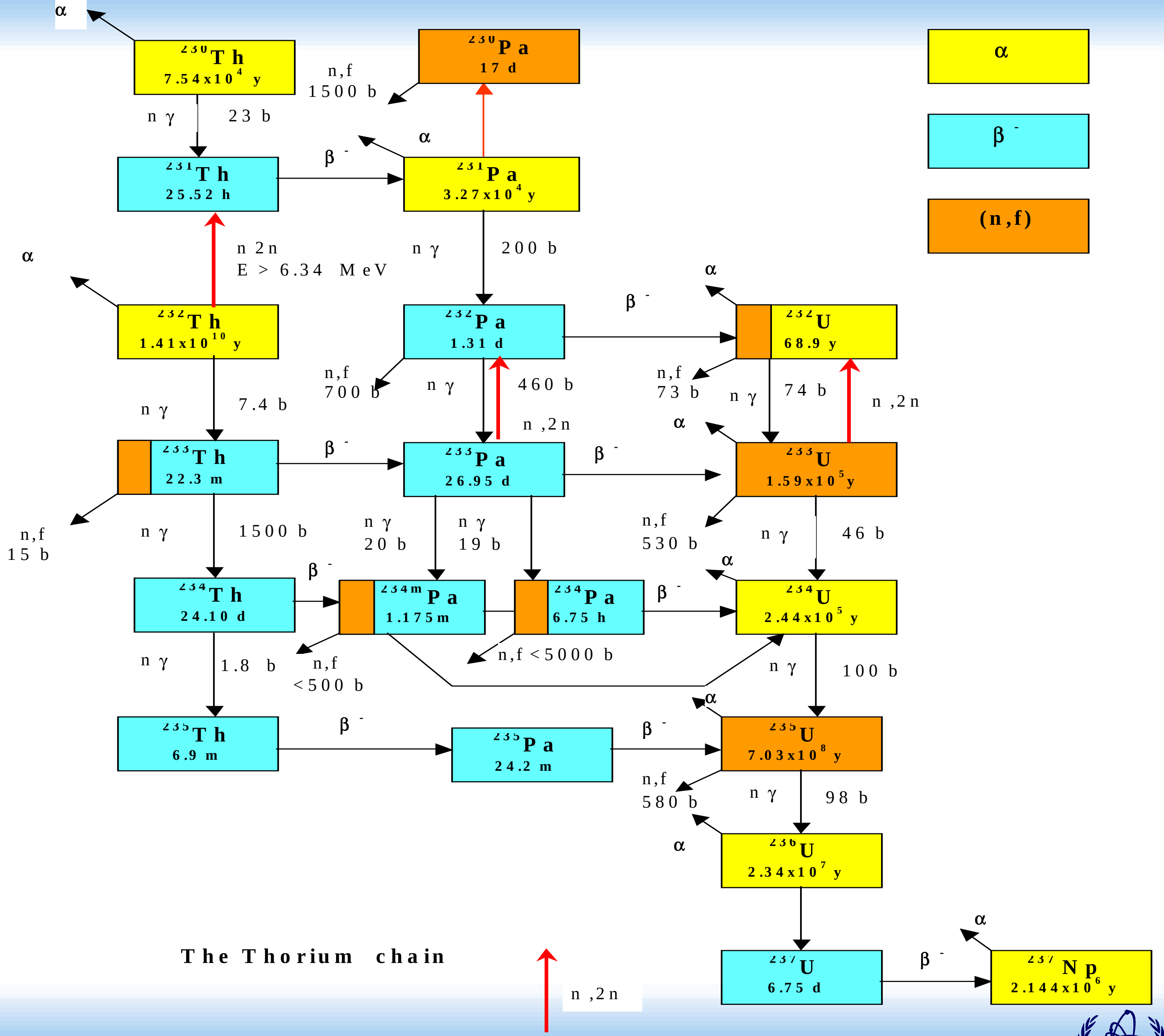
Identify and List the Species

- **Species to contribute the intrinsic reduction of toxicity**
- **Species to affect on the safety assessment with dose rate**
- **Species to contribute the volume reduction of waste to be disposed at deep geologic formation**
- **Species for possible utilization**

Conclusions

- Identification of sources of loss (e.g. of long living radiotoxic waste)
  - Understanding of chemical processes (e.g. of actinides)
  - Understanding of the physical processes (e.g. actinides and FP taking part in volatilization, precipitation, etc.,)
  - Adaptation of the processes to suppress losses
- Development of advanced characterization methods for P&T;
- Group separation of all Actinides
- Integration of treatment and re-fabrication processes and technologies
- Innovative fuel cycles such as thorium fuel cycle
- Establishing a knowledge database for development of partitioning and transmutation technology matured towards environment friendly fuel cycles.
- Development of Regional and International approach

Thank you for your kind attention



The Thorium chain

Agency Coordination in Fuel Cycle Studies

Completing

- **Thorium Fuel Cycle: Potential Benefits and Challenge**
- **Viability of Using IMF in Reducing the Plutonium in Reactors**
- **Current Status and Future Trends of HEU**

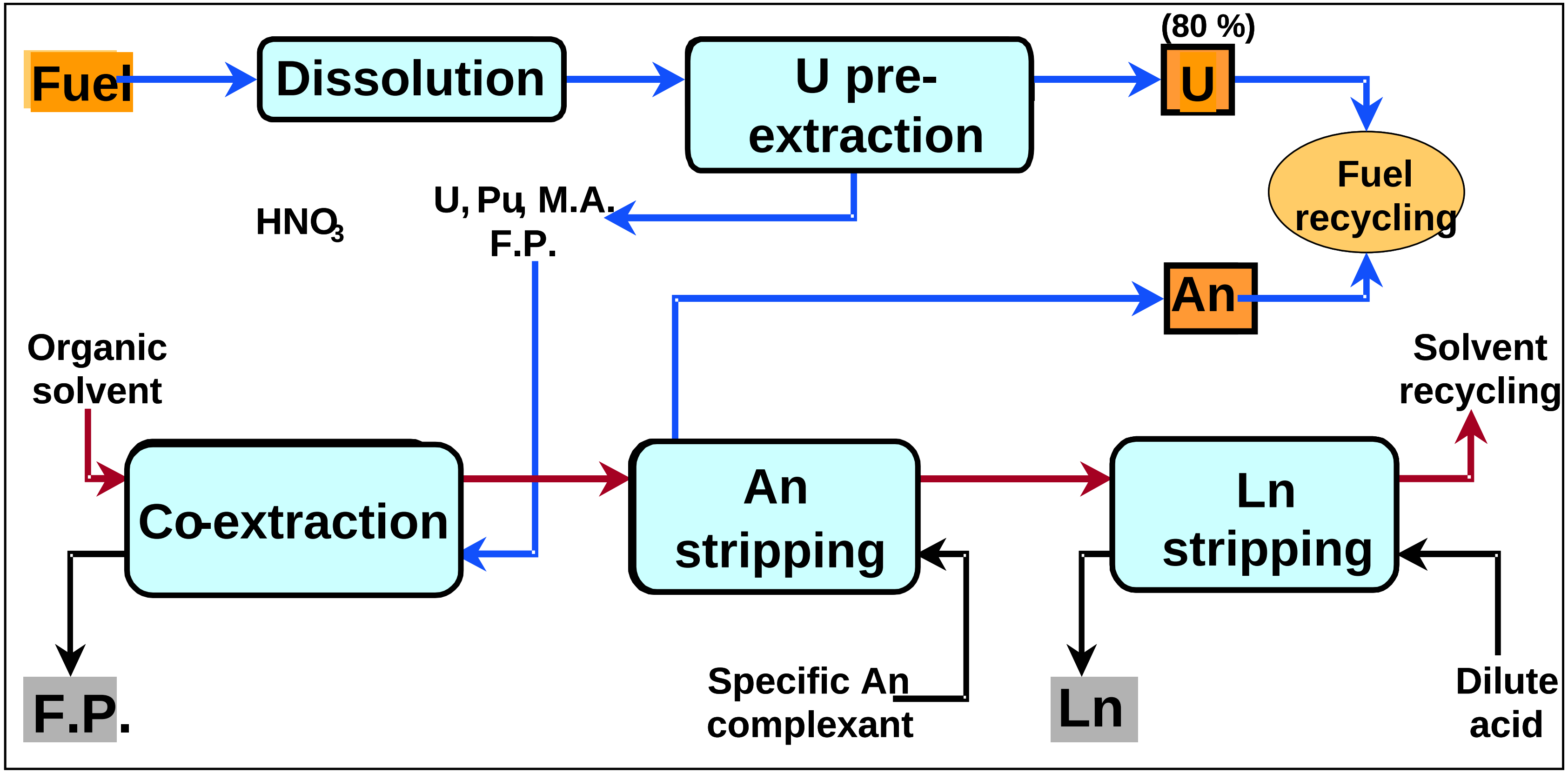
Ongoing

- **Management of RepU**
- **Process and property of minor actinide compounds and alloys for nuclear fuel and target for incineration in thermal and fast neutron spectra**
- **Current status and future prospects of gas cooled reactor fuels**
- **Minor actinide database for advanced fuel cycles**
- **Study of process-losses in separation processes in P&T systems in view of minimizing long term environmental impacts**

Commencing

- **Current status and future perspective of liquid metal-cooled reactor fuel cycle**

The GANEX concept : Group ActiNides EXtraction



Fuel

Dissolution

U pre-extraction

(80 %)

U

Fuel recycling

HNO$_3$

U, Pu, M.A. F.P.

An

Organic solvent

Solvent recycling

Co-extraction

An stripping

Ln stripping

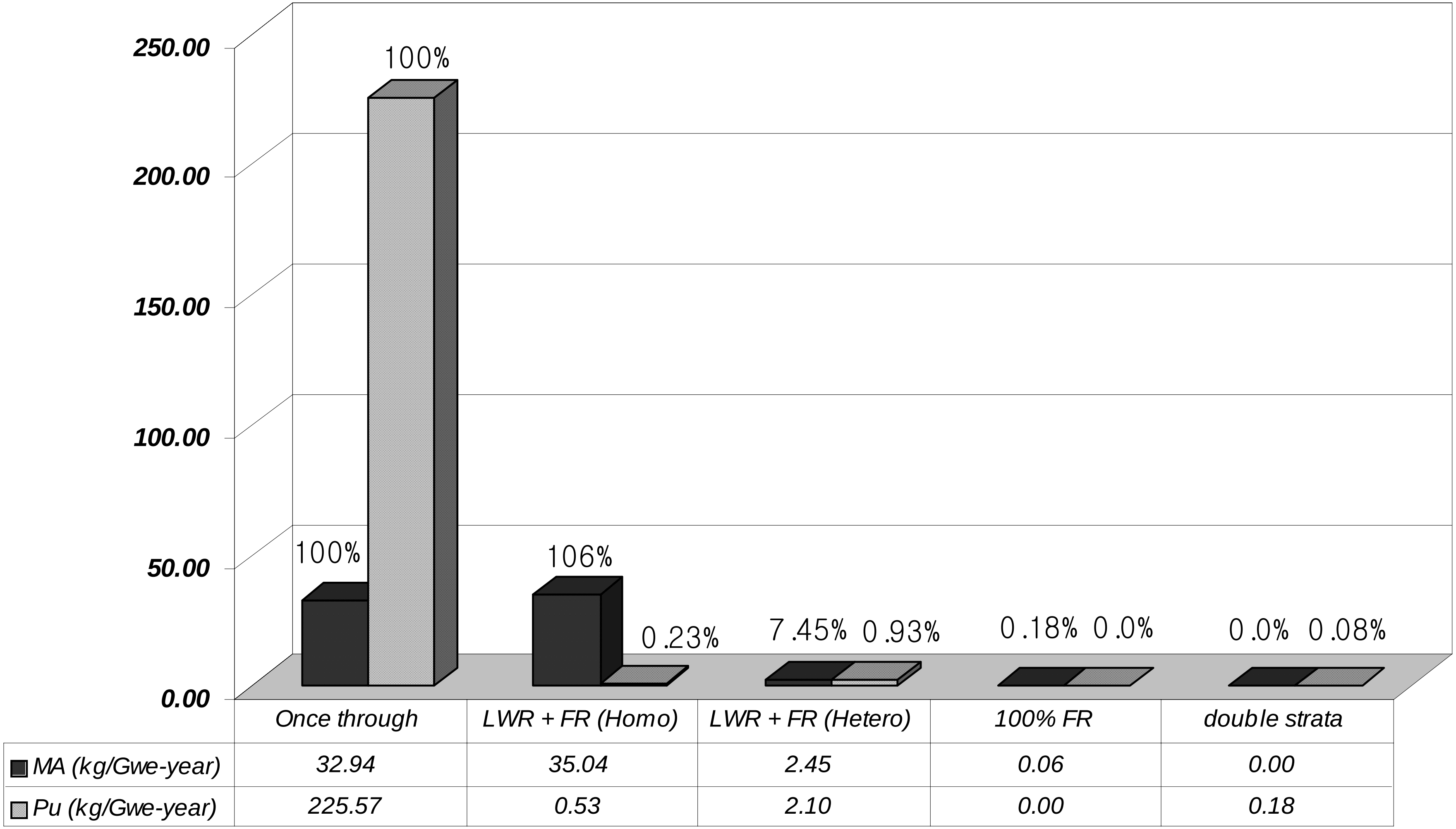
F.P.

Specific An complexant

Ln

Dilute acid

Reduced Pu and Minor Actinide Inventory with LMFR Fuel Cycle



	Once through	LWR + FR (Homo)	LWR + FR (Hetero)	100% FR	double strata
■ *MA (kg/Gwe-year)*	*32.94*	*35.04*	*2.45*	*0.06*	*0.00*
▨ *Pu (kg/Gwe-year)*	*225.57*	*0.53*	*2.10*	*0.00*	*0.18*