2011 December

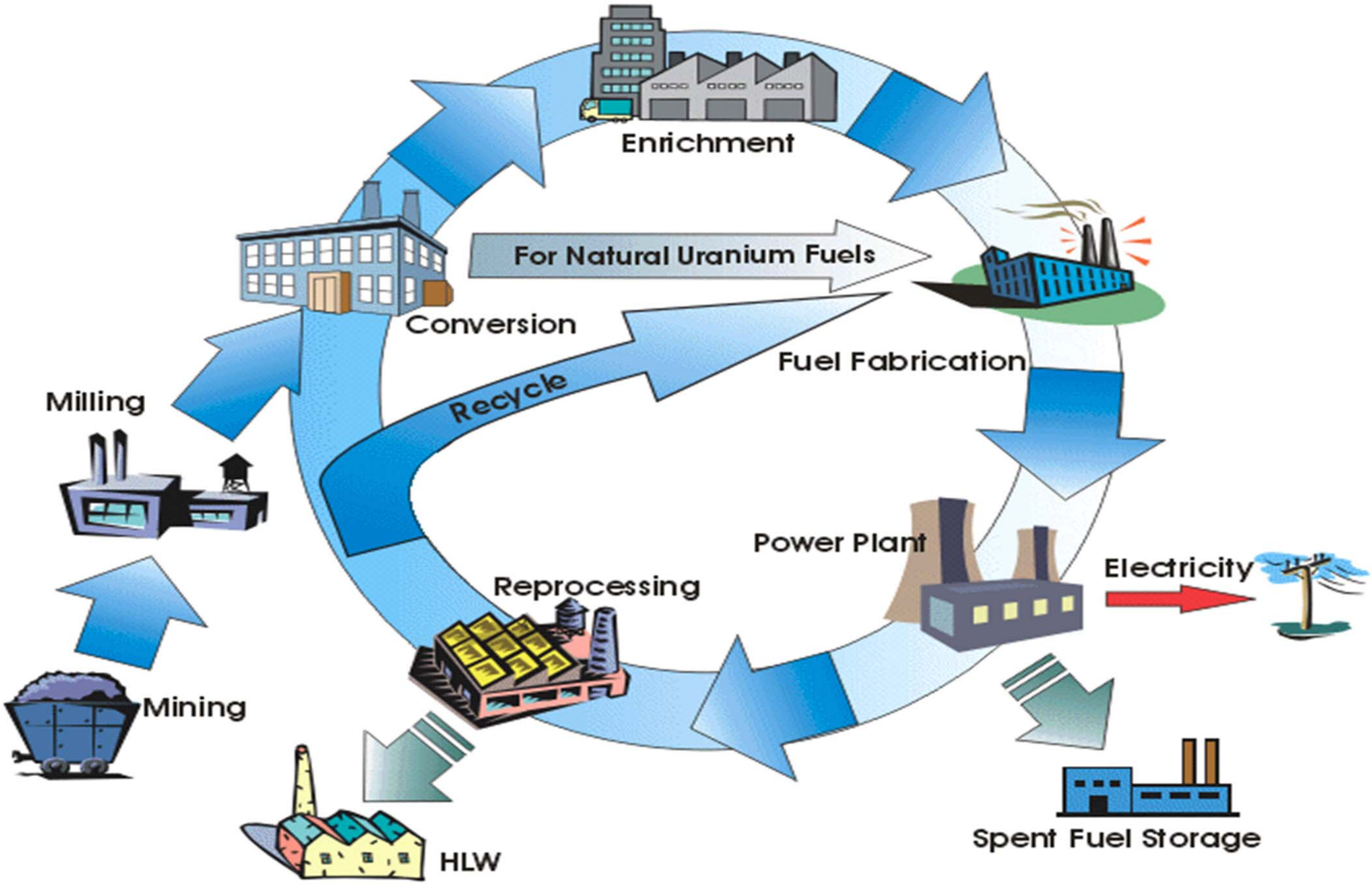
Current Reprocessing and Pu Utilization

Gary Dyck
Nuclear Fuel Cycle and Materials

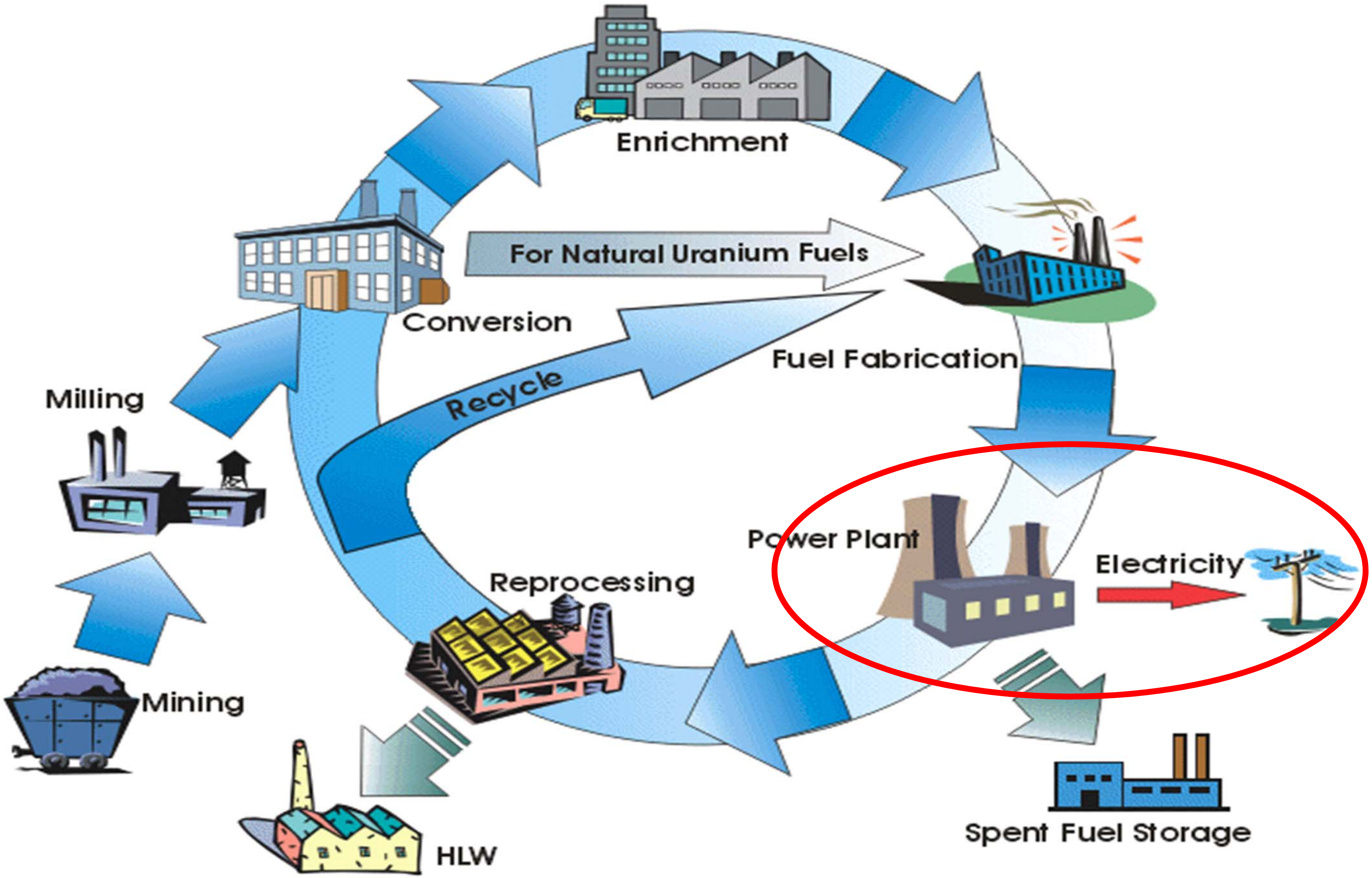
Nuclear Fuel Cycle

- Uranium Production
- Conversion
- Enrichment
- Reactor Fuel Fabrication
- In-Reactor Fuel Performance
- Spent Fuel Management
- Spent Fuel Recycle
- Advanced Fuel Cycles and Materials
- Disposal

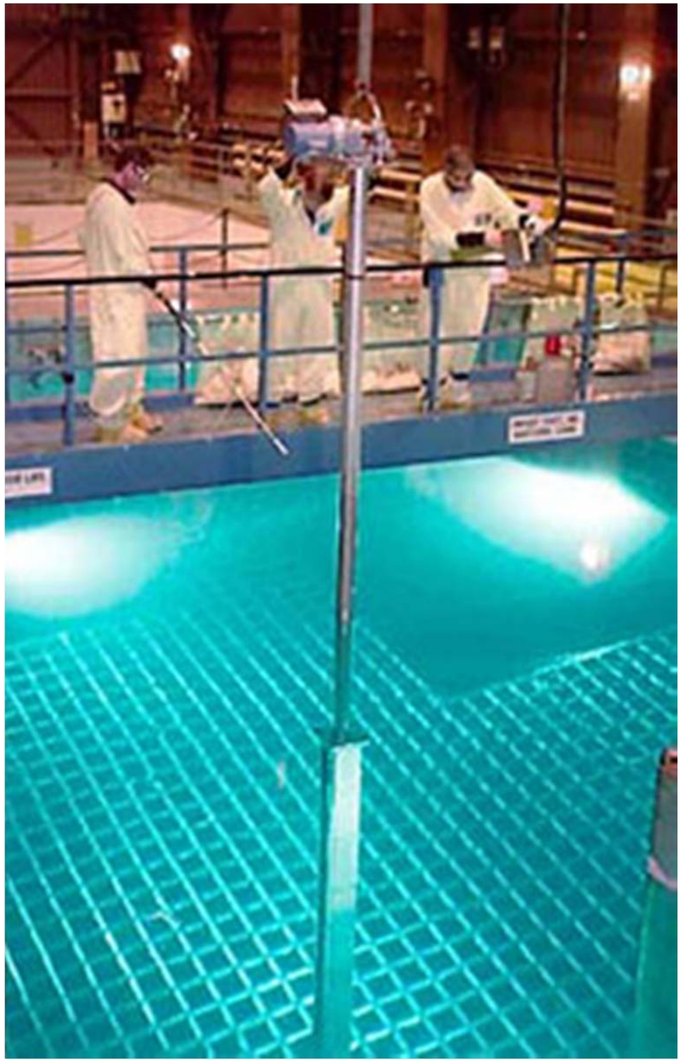
Nuclear Fuel Cycle



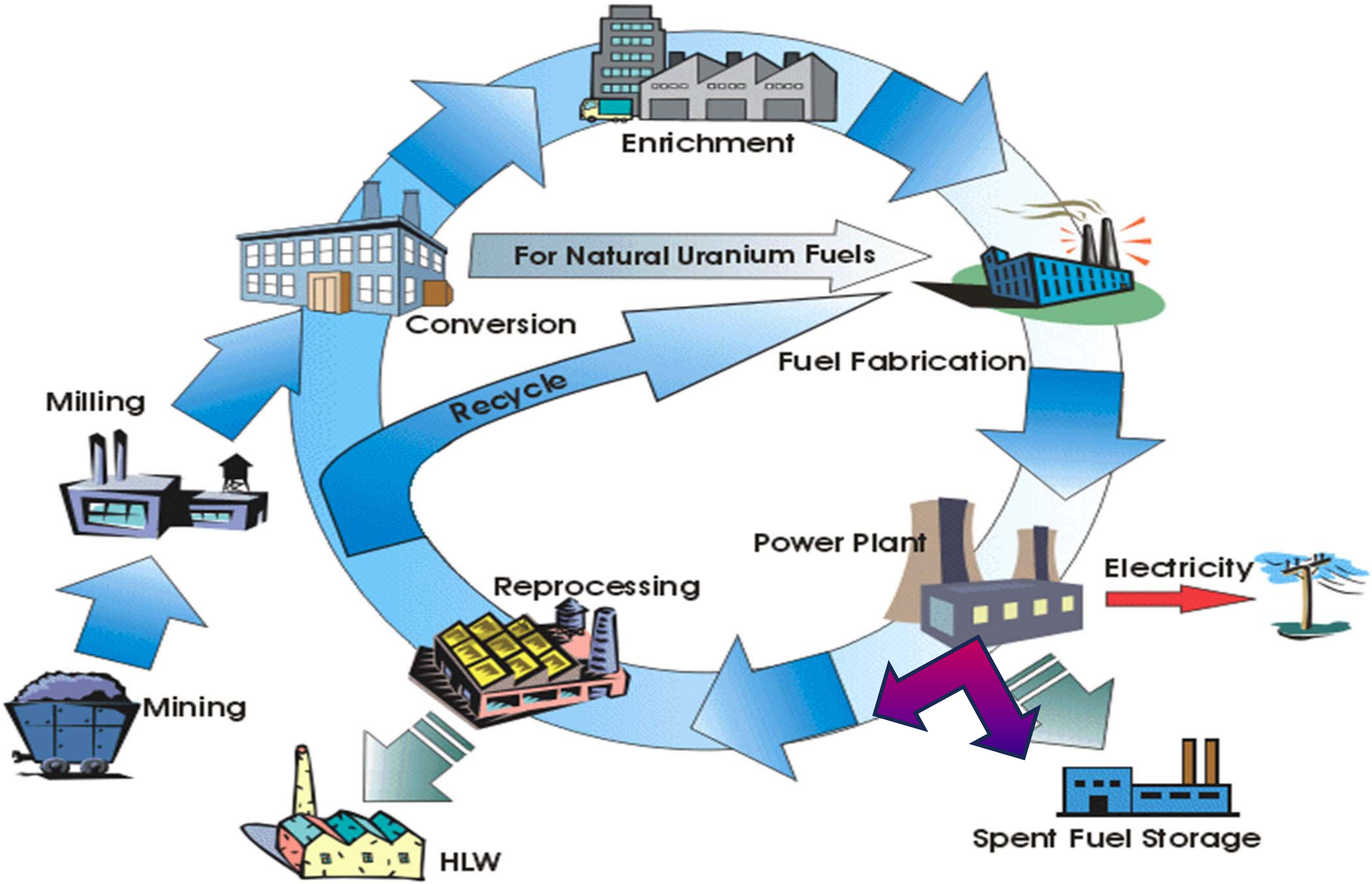
Nuclear Fuel Cycle



Spent Fuel



Nuclear Fuel Cycle

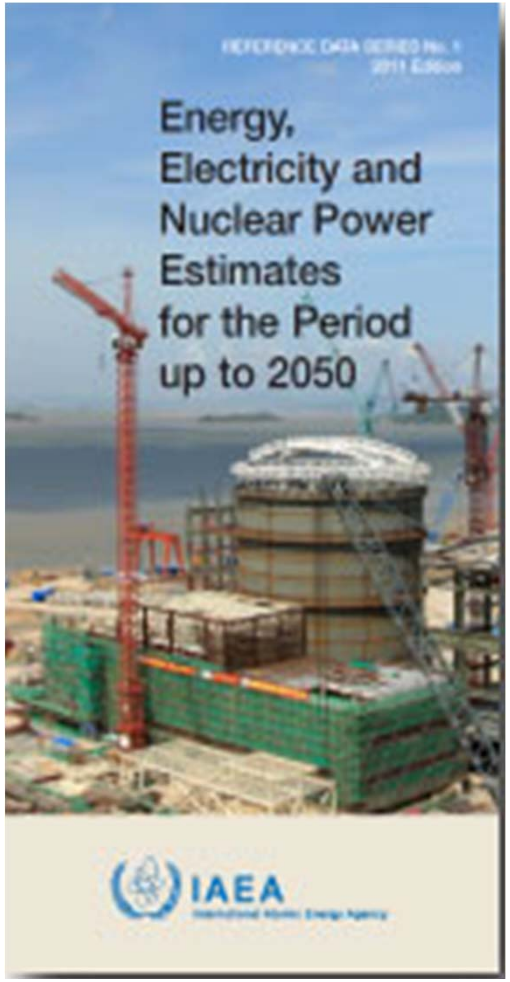


Nuclear Demand Projections

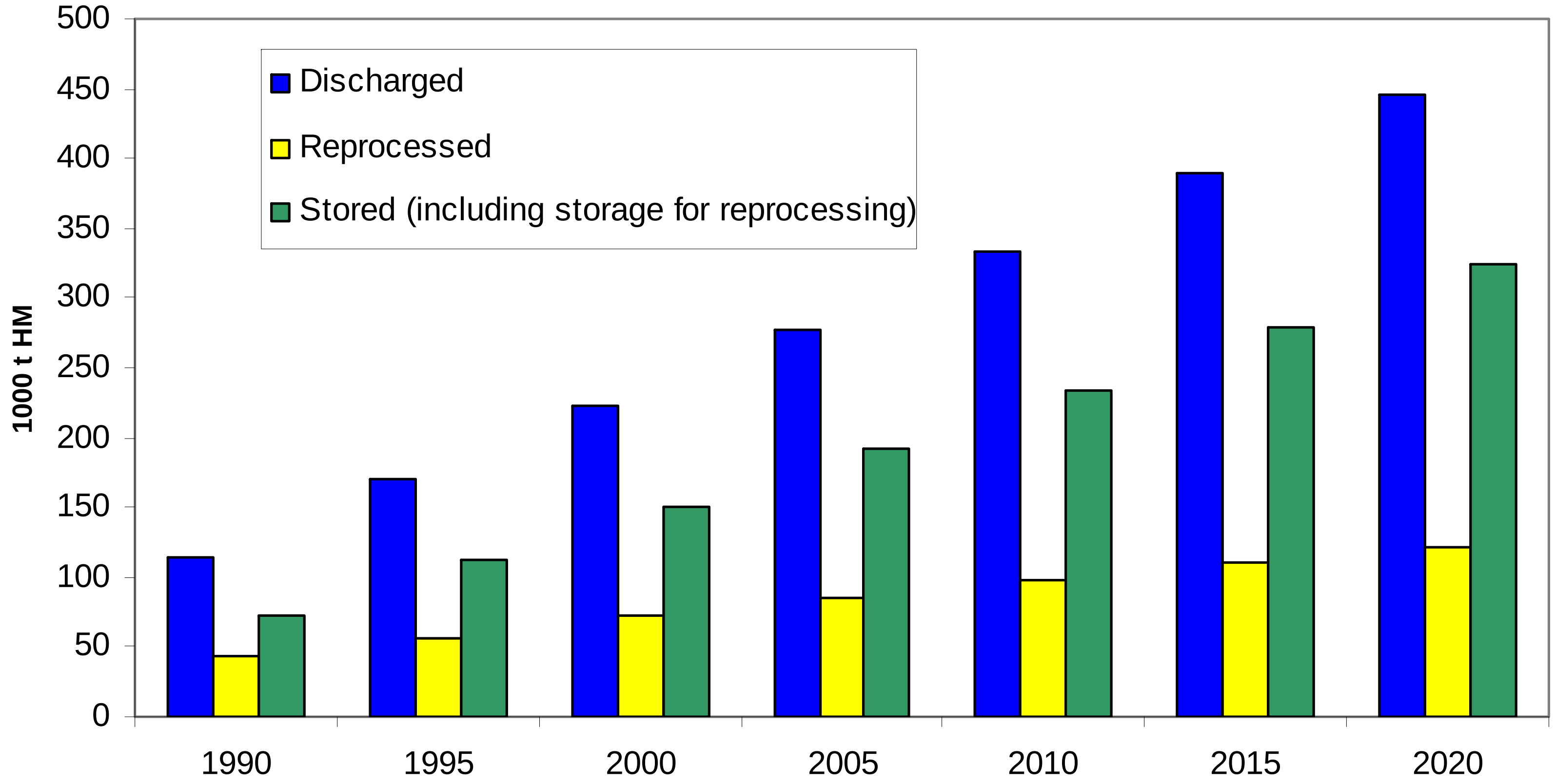
Reference Data Series #1

- Now includes "effect" of Fukushima

http://www.iaea.org/OurWork/ST/NE/Pess/RDS1.html

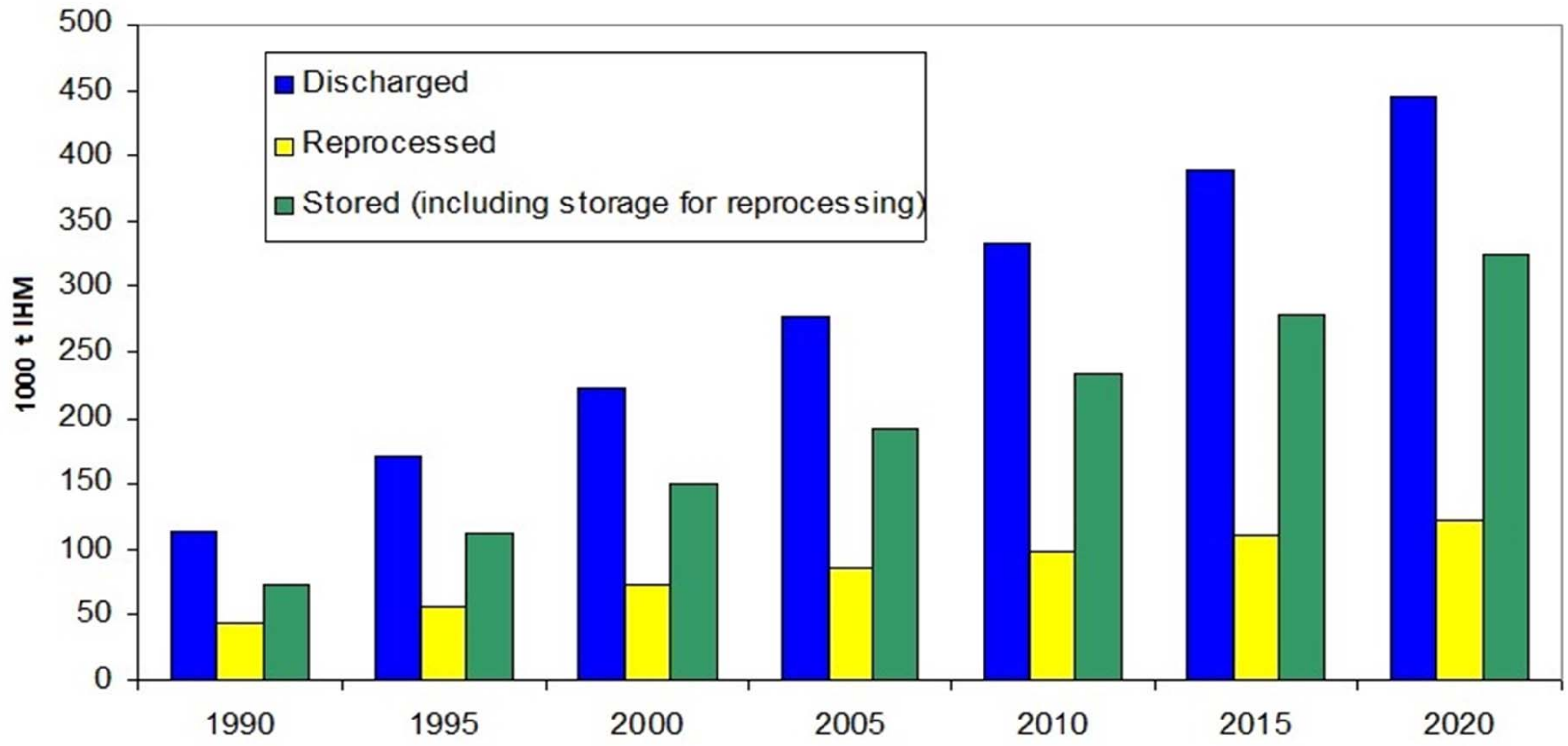


Status of Spent Nuclear Fuel



- The total amount of spent fuel that has been discharged globally is approximately 334 500 tonnes of heavy metal (t HM).
- The annual discharges of spent fuel from the world's power reactors total about 10 500 tHM per year.

Status of Spent Nuclear Fuel



- The total amount of spent fuel that has been discharged globally is approximately 341 000 tonnes of heavy metal (t IHM) in 2011.
- The annual discharges of spent fuel from the world's power reactors total about 11 300 t IHM per year.

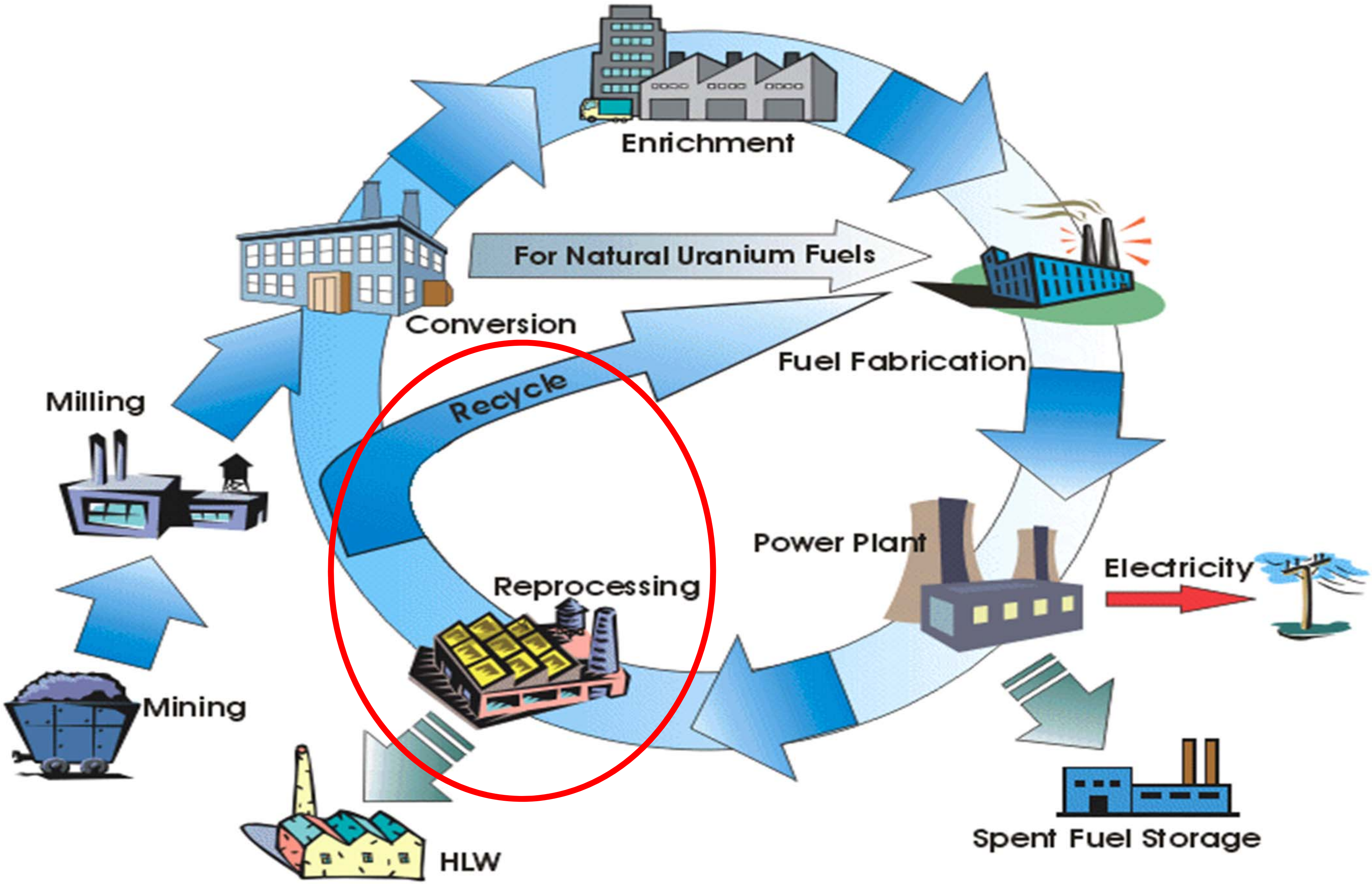
Spent Fuel Storage

- Wet and dry storage have provided flexibility for spent fuel management

Wet Storage (CLAB-Sweden)

Dry Storage (Surry – USA)

Nuclear Fuel Cycle



Spent Fuel Recycle

When is waste
not waste?

When it is
valuable.

PUREX Spent Fuel Recycle

- Recycled uranium can be re-enriched and re-used as reactor fuel, or re-used “directly” in HWRs
- Plutonium can be used as fissile material in MOX fuel for thermal reactors or saved for use as fuel in fast reactors
  - Between 30-50% of the cost of fuel is enrichment

Spent Fuel Recycle

- Who Recycles?

China
Lanzou 50
(Future 800)

UK
Magnox 1500
Thorp 900

India
Trombay 60
Tarapur 100, 150
Kalpakkam 100, 150

Russia
Chelyabinsk 400
(Krasnoyarsk 1500)

France
La Hague 2x800

30%

Japan
Tokai-mura 90
(Rokkasho-mura 800)

MOX Fuel Management

MOX RELOADS IN COMMERCIAL PWRs AND BWRs FROM 1981 TO THE END OF 2000

Country reactor type (FA type)	Number of reactors licensed for MOX	Number of assemblies reloaded	Maximum FA average Pu_{tot} (Pu_{fiss}) (%)/ carrier material	Maximum FA burnup (GW·d/(t HM))*
Belgium				
PWR (17x17 – 24)	2	96	7.5 (4.9)/U_{tails}	47.7
France				
PWR (17x17 – 24)	20	1400	6.7 (4.5)/U_{tails}	40.0
Germany				
PWR (18x18 – 24)	2	72	6.9 (4.6)/ U_{tails}	43.4
PWR (16x16 – 20)	5	504	6.3 (4.2)/ U_{tails}	49.0
PWR (15x15 – 20)	1	32	4.3 (3.0)/U_{nat}	42.0
PWR (14x14 – 16)	1	45	5.6 (3.8)/U_{nat}	37.0
BWR (9x9 – 1, 10x10 – 9Q)	2	212	5.4 (3.6)/ U_{tails}	50.5
India				
BWR (6x6 – 1)	2	10		16.0
Switzerland				
PWR (15x15 – 20)	1	68	7.3 (4.8)/ U_{tails}	51.0
PWR (14x14 – 17)	2	152	6.2 (4.1)/ U_{tails}	40.0

* Maximum MOX assembly burnup of regular reloads (not lead test assemblies).

MOX Fuel Management

STATUS OF COMMERCIAL MOX LICENSING IN THERMAL REACTORS AT 2000

Country	Reactors licensed for MOX (reactor type)	Maximum fresh MOX fuel assemblies per reload	MOX fuel assembly content (%)	Maximum[a] Pu_{tot}/Pu_{fiss} in the core (wt%)	Maximum[a] discharge burnup
Belgium	2 (PWR)	[b]	24	[b]	50
France	20 (PWR)	16	31	Equivalent to 3.25 wt% 235U	[c]
Germany[d]	9 (PWR)	24	50	[b]/4.65	[e]
	2 (BWR)	68	38	[b]/4.04	
Japan	2 (PWR)	[b]	25	Equivalent to 4.1 wt% 235U	45
	2 (BWR)	[b]	44	d Equivalent to 3.0 wt% 235U	40
Switzerland[d]	3 (PWR)	16	40	[b]/4.8	[b]

[a] Fuel assembly average. [b] No individual restriction. [c] Limited by maximum of three in-core cycles; no explicit burnup restriction.

[d] Individual licensing situation for each plant type; maximum values provided if applicable.

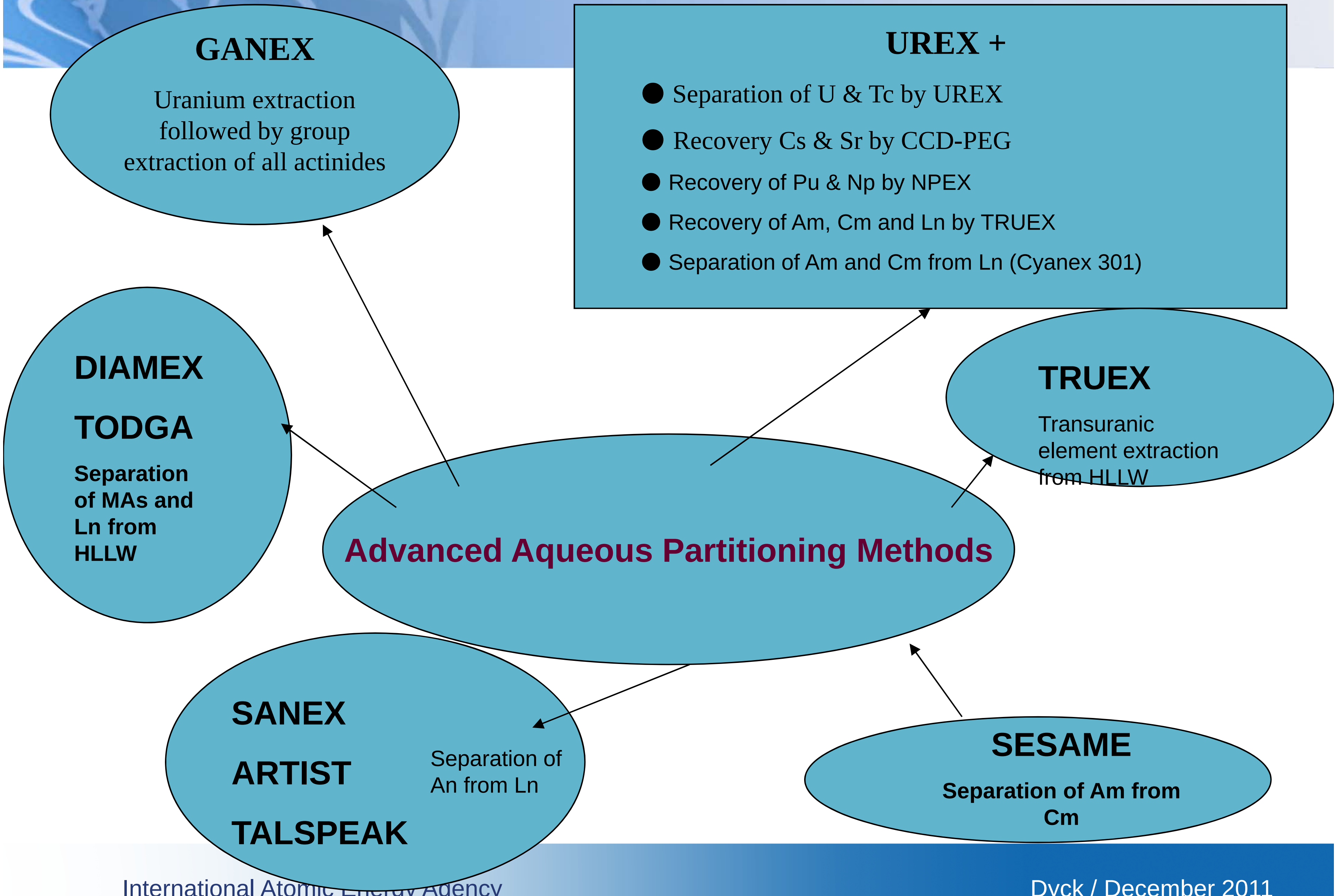
[e] No general restriction; temporary restriction to fuel rod burnup of 55 MW·d/kg for some plants.

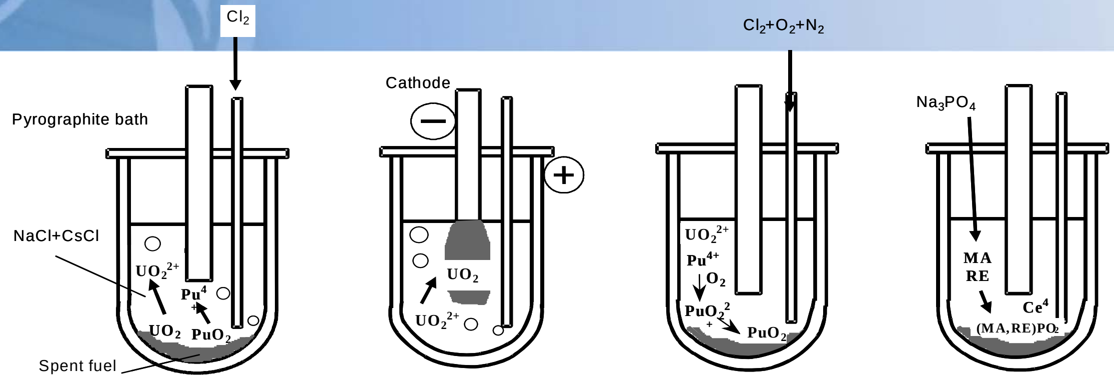
MOX Use

Country	Commercial LWRs licensed For MOX (end of 2000)
Belgium	2 PWR
France	20 PRW
Germany	9 PRW 2 BWR
Japan	2 PWR 2 BWR
Switzerland	3 PWR

MOX Use

Country	**MOX Reloads (LWR) from 1981 to 2000**
Belgium	96
France	1400
Germany	850
India	10
Switzerland	220


GANEX
Uranium extraction followed by group extraction of all actinides
UREX +
Separation of U & Tc by UREX
Recovery Cs & Sr by CCD-PEG
Recovery of Pu & Np by NPEX
Recovery of Am, Cm and Ln by TRUEX
Separation of Am and Cm from Ln (Cyanex 301)
DIAMEX
TODGA
Separation of MAs and Ln from HLLW
TRUEX
Transuranic element extraction from HLLW
Advanced Aqueous Partitioning Methods
SANEX
ARTIST
TALSPEAK
Separation of An from Ln
SESAME
Separation of Am from Cm



Chlorination (dissolution) (650°C)

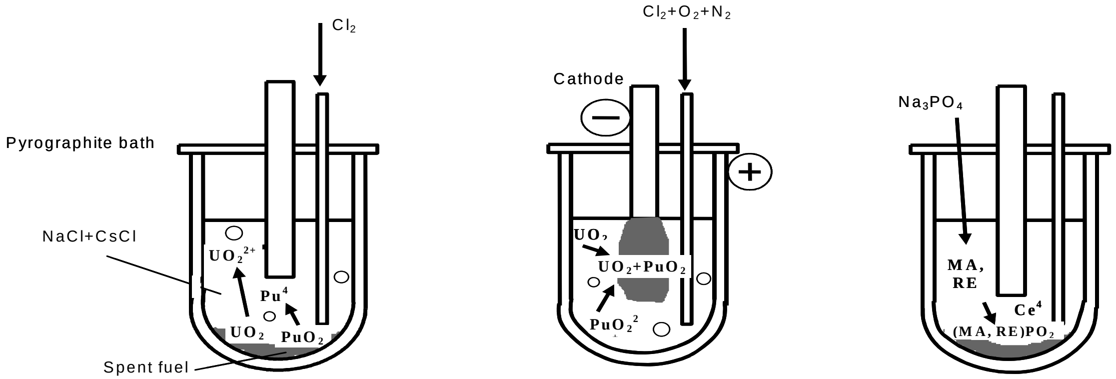
UO_2 electrolysis (630°C)

PuO_2 precipitation (630°C)

Purification of melt (650°C)

Cathode: $UO_2^{2+} + 2e^- \rightarrow UO_2$ $Pu^{4+} + O_2 + 2Cl_2 \rightarrow PuO_2^{2+} + Cl_2$

Anode : $2Cl^- \rightarrow Cl_2 + 2e^-$ $PuO_2^{2+} + 2Cl_2 \rightarrow PuO_2 + Cl_2$



Chlorination (dissolution) (650°C)

Additional electrolysis (630°C)

Purification of melt (650°C)

Cathode: $UO_2^{2+} + 2e^- \rightarrow UO_2$ $PuO_2^{2+} + 2e^- \rightarrow PuO_2$

Anode : $2Cl^- \rightarrow Cl_2 + 2e^-$

Some IAEA findings on reprocessing

- The design of advanced reprocessing methods must deal with (1) safety, (2) the control and minimization of plant effluents, (3) minimization of the waste generation, (4) the production of stable and durable waste forms, and (5) economic competitiveness.
- International collaboration on the development of advanced reprocessing methods is essential to facilitate the future deployment of these technologies.

In Conclusion

- SNF (341 000 tonnes) can be considered a waste or a resource
- About 30% of SNF is recycled (PUREX/MOX)
- All of the rest is currently in storage
- For the future, PUREX may not be the most appropriate technology
- Many new advances in both hydro- and pyro-metallurgical methodologies

Thank you for your attention