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Preparing the future : new challenges for Nuclear Energy Systems

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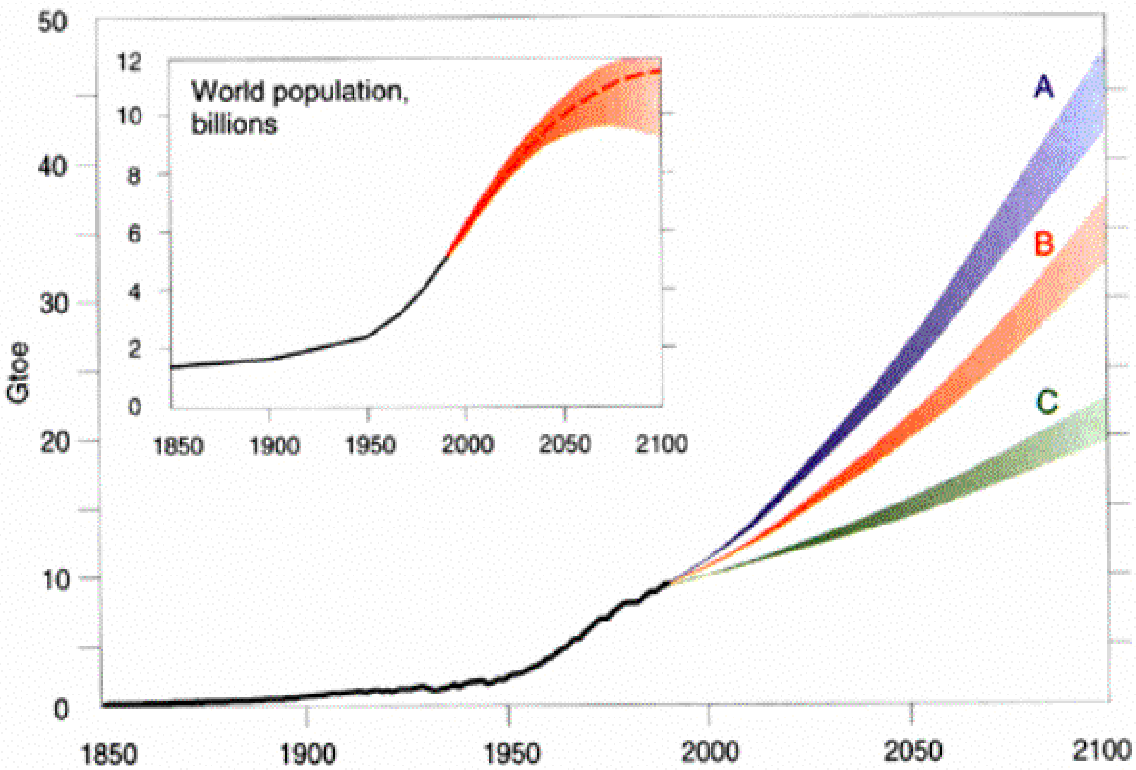
Needs for Energy during the 21st Century

- **Increasing energy demand in the world by 2050**



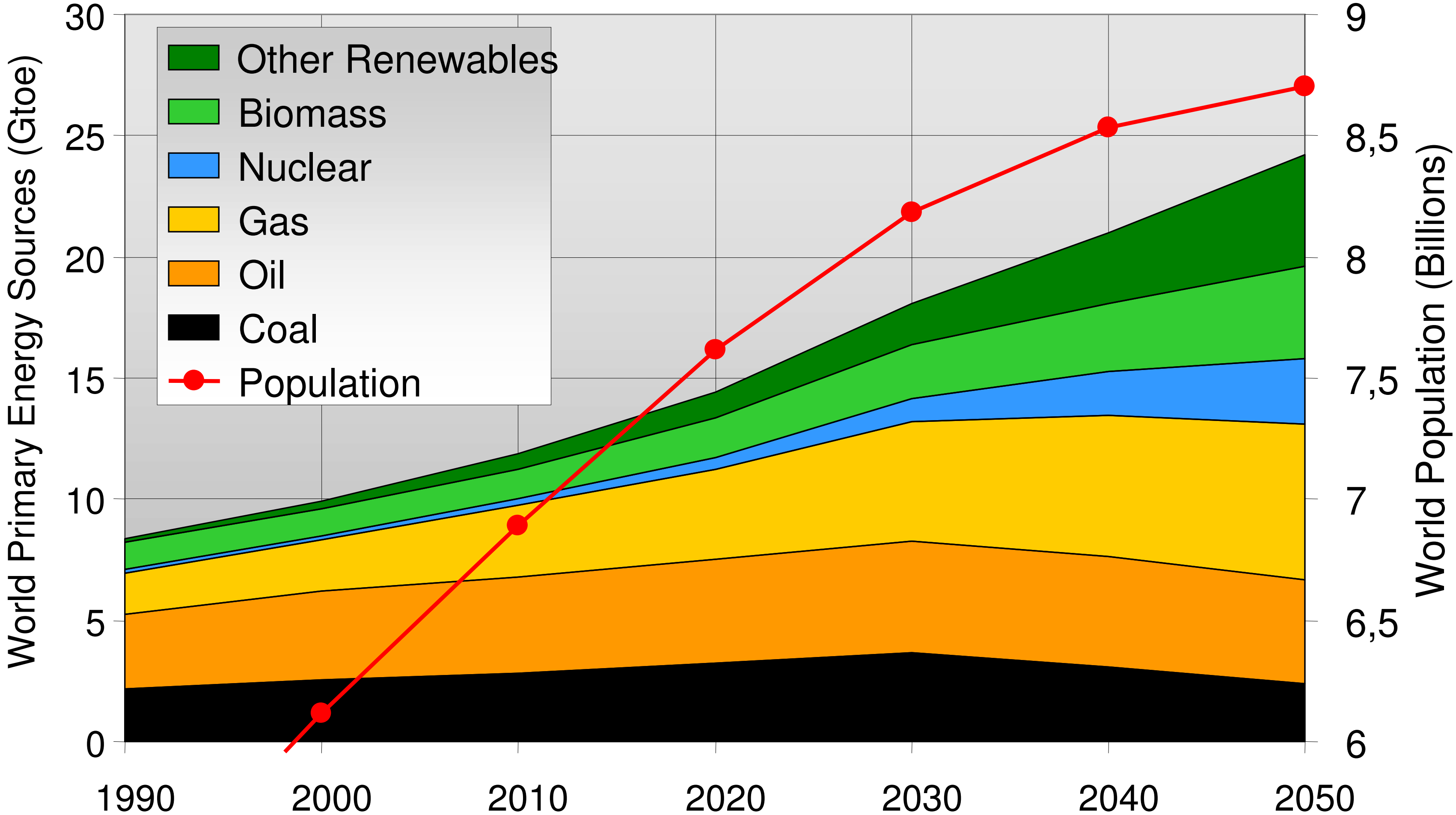
A : High growth (Income, energy, technology)

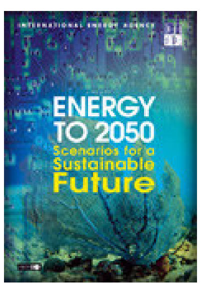
B : Modest growth

C : Ecologically driven growth

Source : IIASA/WEC, 1998

Sustainable Development Vision Scenario (*IEA 2003*)





Source IEA : Energy to 2050 -
Scenarios for a Sustainable Future

Why should Nuclear Energy play a major role ?

- No CO2 or GHG produced
  → no risks of Climate Change

- Nuclear Energy enhances the Energy Security Supply (versus fossile fuels) and reduces geopolitical / economical risks

- Promising assets to produce Hydrogen as a new energy vector for the transports sector

- An already competitive energy source with still expected improvements

- Safe and reliable with more than 10 000 year.reactors of experience

GEN IV : towards sustainable nuclear energy

➢ New requirements for sustainable nuclear energy

- Gradual improvements in :
  - ✓ Competitiveness
  - ✓ Safety and reliability
- Concepts with breakthroughs
  - ✓ Minimization of wastes
  - ✓ Preservation of resources
  - ✓ Non Proliferation

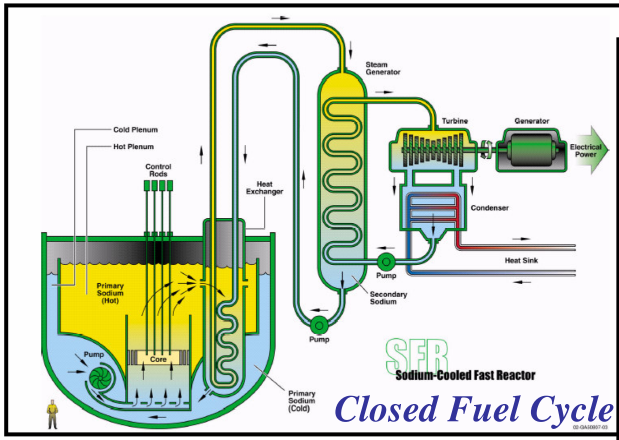
➢ Systems expected to reach technical maturity by 2030

➢ Assets for new markets

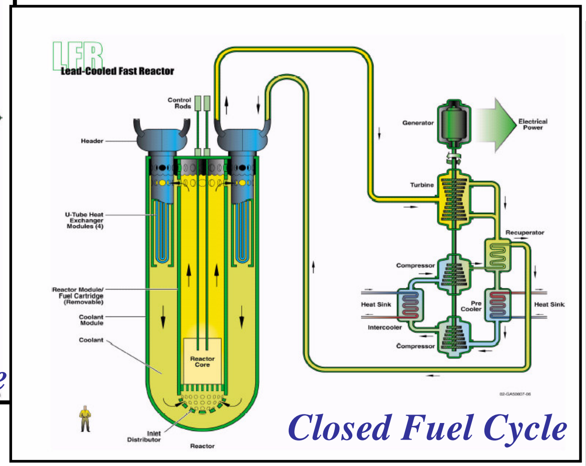
- hydrogen production
- direct use of heat
- sea water desalination

➢ An internationally shared R&D

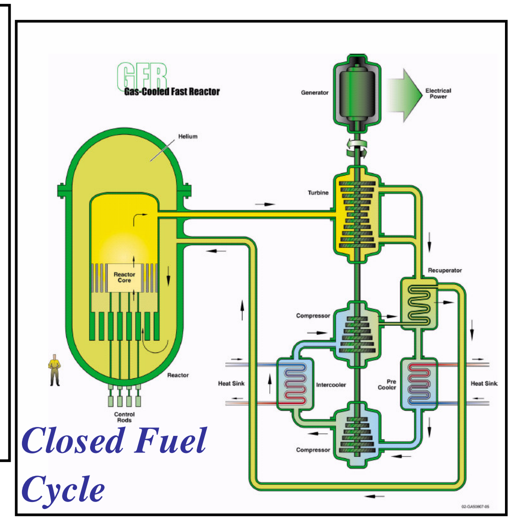
6 Innovative concepts with technological breakthroughs



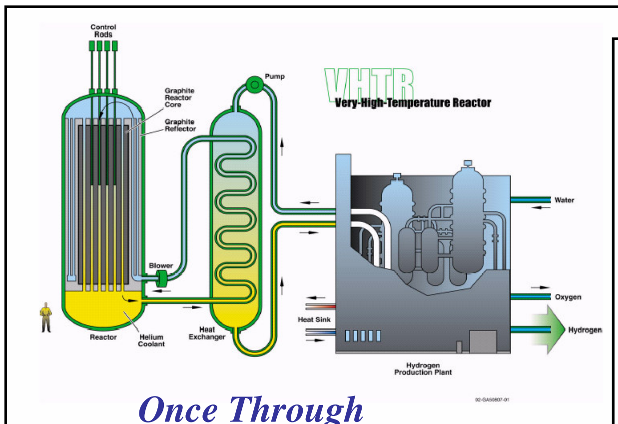
Sodium Fast reactor



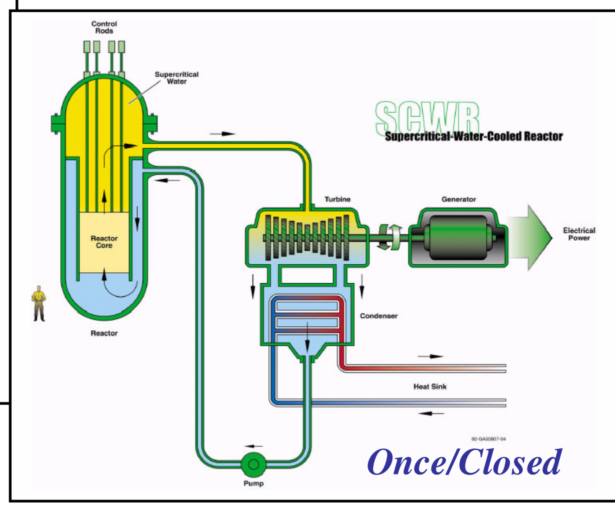
Lead Fast Reactor



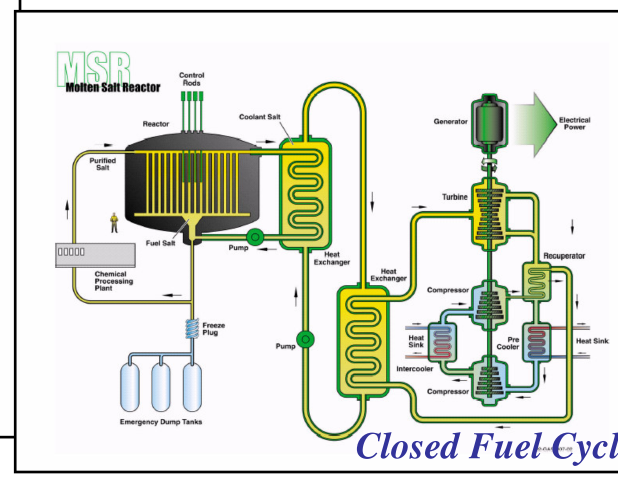
Gas Fast Reactor



Very High Temperature Reactor

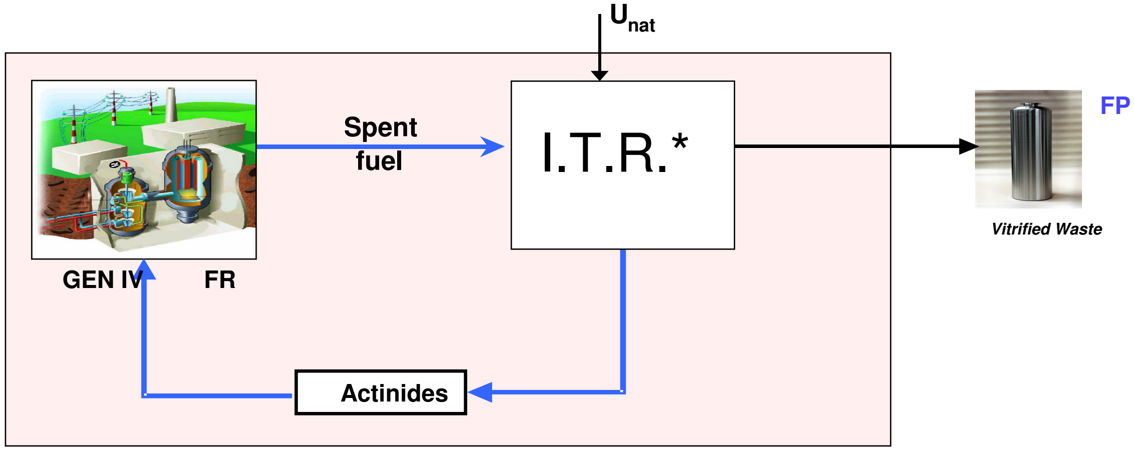


Supercritical Water Reactor

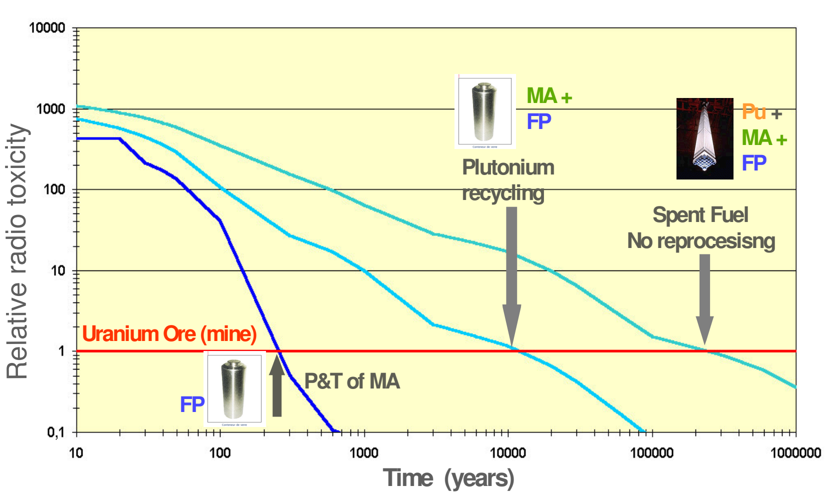


Molten Salt Reactor

Gen IV Systems : an integrated cycle with full actinide recycling



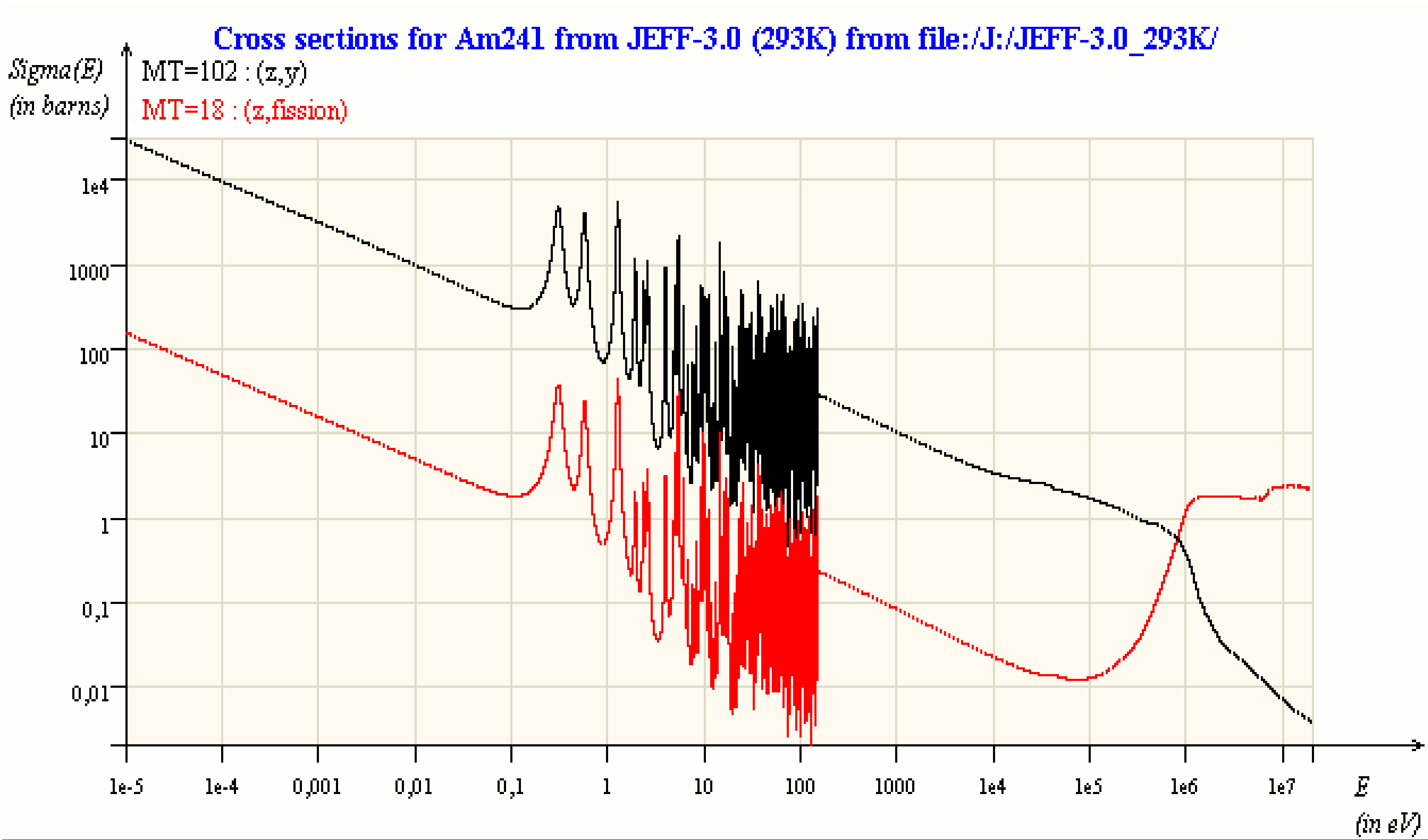
* : Integrated Treatment and Refabrication



- **A drastic minimization of ultimate waste :**
  - very small volumes,
  - decrease of heat loading,
  - hundreds of years versus hundreds of thousands
- **An optimal use of energetic materials**
- **Enhanced resistance to proliferation**

Influence of Neutron Spectrum on Minor Actinides Transmutation

^{241}Am Cross Sections



Influence of Neutron Spectrum on Minor Actinides Transmutation

- Neutrons capture and production of higher isotopes (x 50 for Am)
- Capture to Fission ratios not favorable to transmutation with thermal neutrons spectra

isotopes	LWR			FR		
	σ_f	σ_c	α	σ_f	σ_c	α
^{235}U	38,8	8,7	0,22	1,98	0,57	0,29
^{238}U	0,103	0,86	8,3	0,04	0,30	7,5
^{239}Pu	102	58,7	0,58	1,86	0,56	0,3
^{240}Pu	0,53	210,2	396,6	0,36	0,57	1,6
^{241}Pu	102,2	40,9	0,40	2,49	0,47	0,19
^{242}Pu	0,44	28,8	65,5	0,24	0,44	1,8
^{237}Np	0,52	33	63	0,32	1,7	5,3
^{241}Am	1,1	110	100	0,27	2,0	7,4
^{243}Am	0,44	49	111	0,21	1,8	8,6
^{244}Cm	1,0	16	16	0,42	0,6	1,4
^{245}Cm	116	17	0,15	5,1	0,9	0,18

What possible Physical Limits for Fast Reactors ?

- **Accumulation of Cm and undesirable isotopes in the cycle ?**

  Np 237 → Pu 238
  Am 241 → Cm 242 → Pu 238
  Am 243 → Cm 244 → Cm 245 → Bk → Cf
  - - > Pu 240

  → how fast do they accumulate ? do they stabilize ? At what level ? Is it acceptable or is a specific separation required ?

- **Maximum Minor Actinide contents in the core ?**
  - → Considering a global actinide recycling strategy in Gen IV Systems
  - → Considering also the M.A. production by earlier reactors (Gen II/III PWR) to be transmuted in Gen IV reactors
  - → Influence of coolant, of fuel concept, of power density, etc… ?

- **How to deal with the issue of blankets management versus non-proliferation requirements ?**
  - → Scenario of a large and dynamic worlwide nuclear development requiring the use of Fast Breeders

Innovative Technologies for Fast Reactors

- **Opening new strategies require fuel breakthroughs**

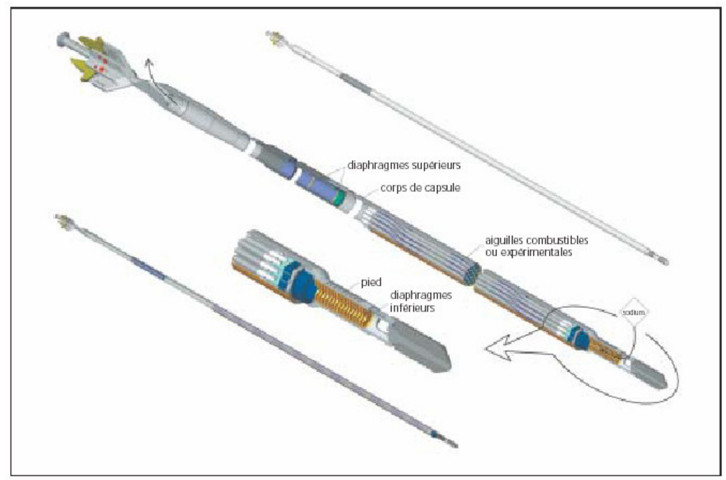
  - Good performance with hard neutron spectrum and Pu balancing requirements

  - Resistance to high temperatures : confinement of FP, high neutron fluence, high actinides density in the core and good thermal conductivity

  - Good performance for decay heat removal safety function

  - Compact spent fuel treatment for quantitative recovery and recycling of all actinides

- **Important R&D challenges for innovative fuel concepts**
  - in core fuel behavior
  - fuel fabrication

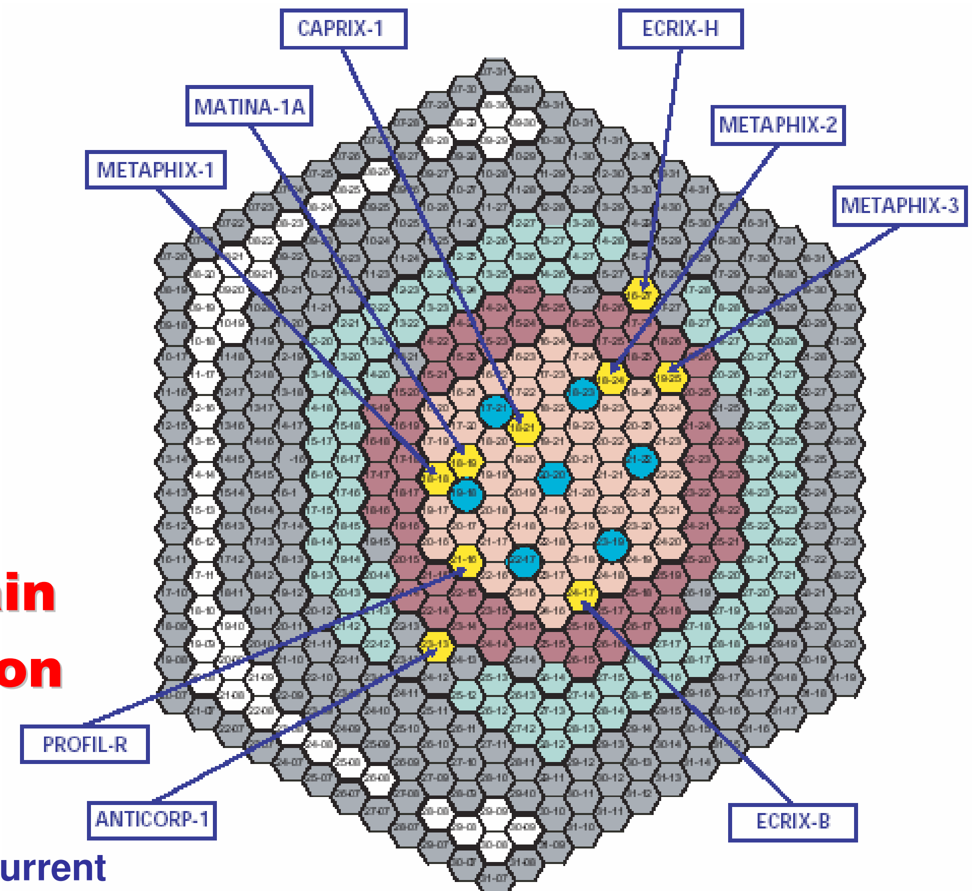


FUTURIX-FTA

Technology demonstrations for Fast Reactors

- **Necessary technology demonstrations related to Actinide transmutation and in pile behavior**
  - transmutation rates
  - He release
  - fast neutrons fluence
  - accidental behavior
  - …

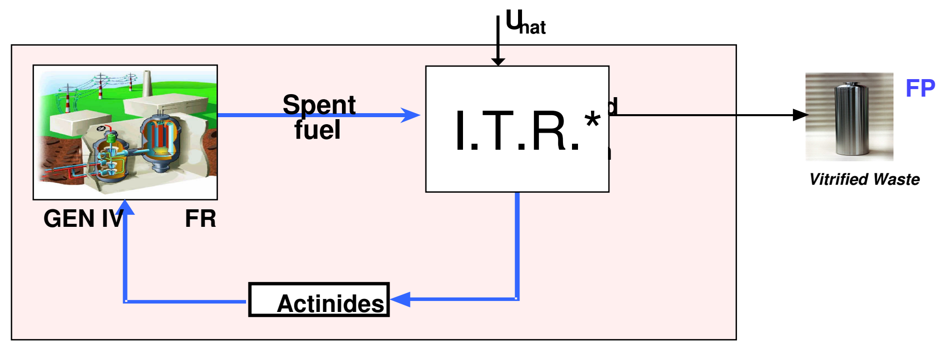
- **PHENIX reactor as a main technology demonstration facility**



Phénix current experimental irradiations

Technology demonstrations for the Cycle

- **A proliferation resistant Global Actinide Recycling**



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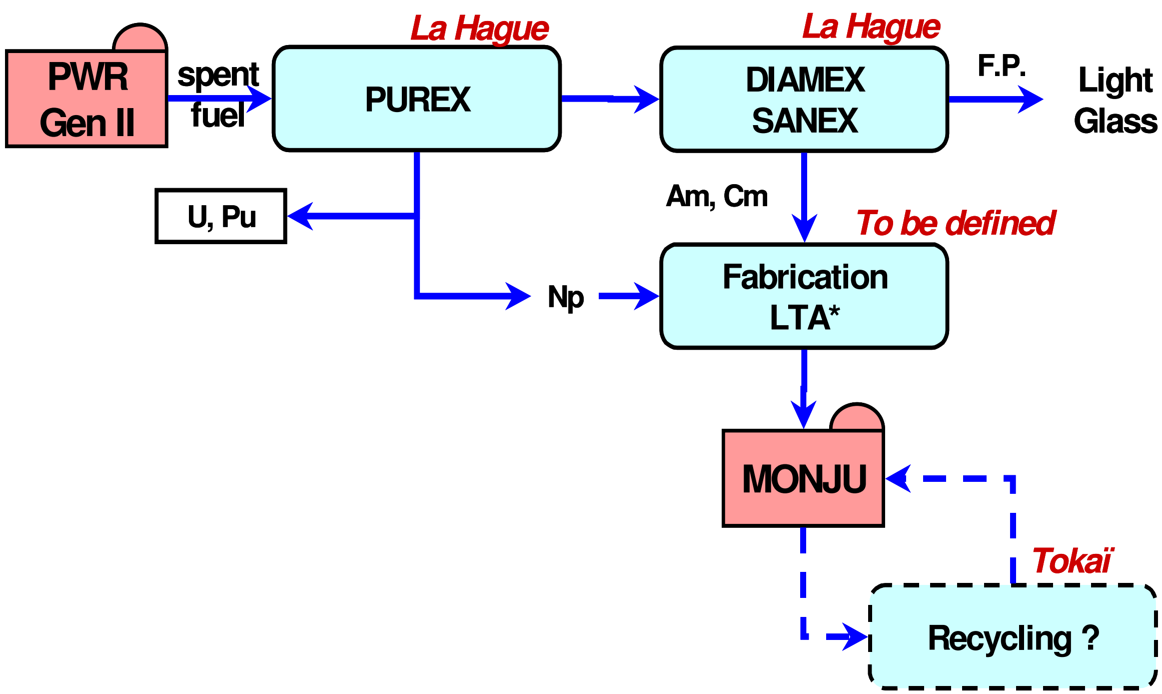
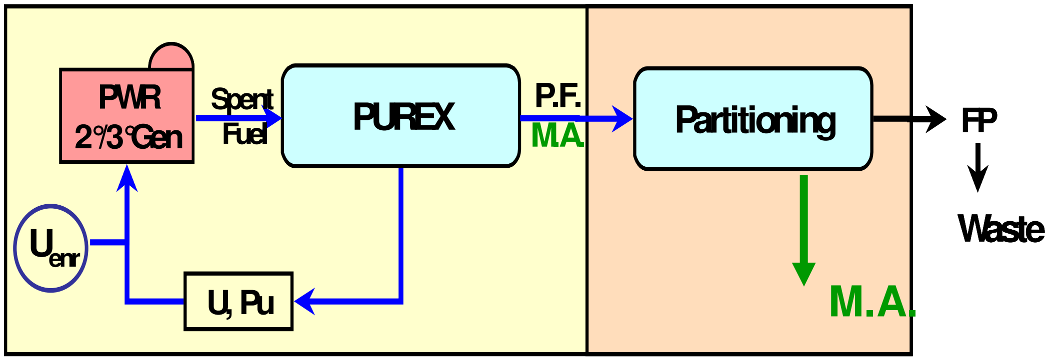


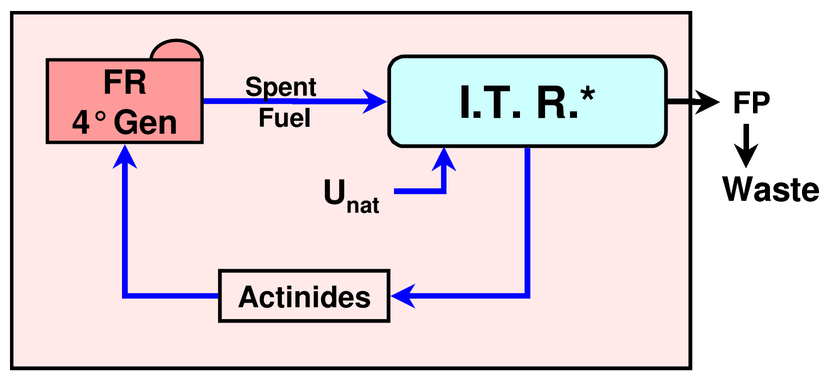
- **Demonstrate the Global Actinide Recycling in Gen IV Fast Reactors**

Base Scenario for Gen II/III to Gen IV transition



- Mono-recycling of Pu (20 PWRs 900 loaded with 30% MOX)
- Partitioning and interim storage of MA in order to minimize the amount of Actinides in the ultimate waste
- Maximum utilization of existing fuel cycle plants (La Hague, Melox)

- Management of Pu stockpile to deploy 4th generation fast neutron systems (> 2035)
- Recycling of MA from interim storage
- Integral recycling of Actinides in fast neutron 4th systems
- Non Proliferation



***I.T.R. : Integrated Treatment & Refabrication**

Actinides inventory in the base scenario considered

- **Pu Mono-recycling in PWR and then recycling in GenIV Systems as of 2035**

Inventories (t)	Pu Mono-recycling				Pu Mono-recycling → Gen IV FR			
	2035	2050	2070	2100	2035	2050	2070	2100
Pu (Total)	396	485	600	773	520	600	720	790
Np	20	31	48	75	18	16	15	15
Am	51	81	121	179	20	22	24	25
Cm	4.7	5.3	5.6	6.4	4	6	7	7
MA (Total)	76	118	174	260	42	44	46	47
Am+Cm (Total)	56	86	127	186	24	28	31	32
TRU (Total)	472	603	774	1033	562	644	766	837
Pu (outside reactor)	313	407	527	698	355	379	415	310
TRU (outside reactor)	383	519	696	952	13	14	15	16
% (Am+Cm) for 20% Pu	3.6	4.2	4.8	5.3	-	-	-	1.2
% MOX in the fleet	12	12	10	10	25	38	58	100

Global Actinides management : 1st conclusions

- The physics of transmutation incites to recycle Pu and M.A. in fast neutron reactors as soon as possible
- No major difficulty expected to manage the full actinides recycling in Gen IV systems
- Expected capability of Gen IV systems to absorb M.A. produced by previous generations
- Flexibility of Gen IV systems in case of a postponed recycling of Pu + M.A.

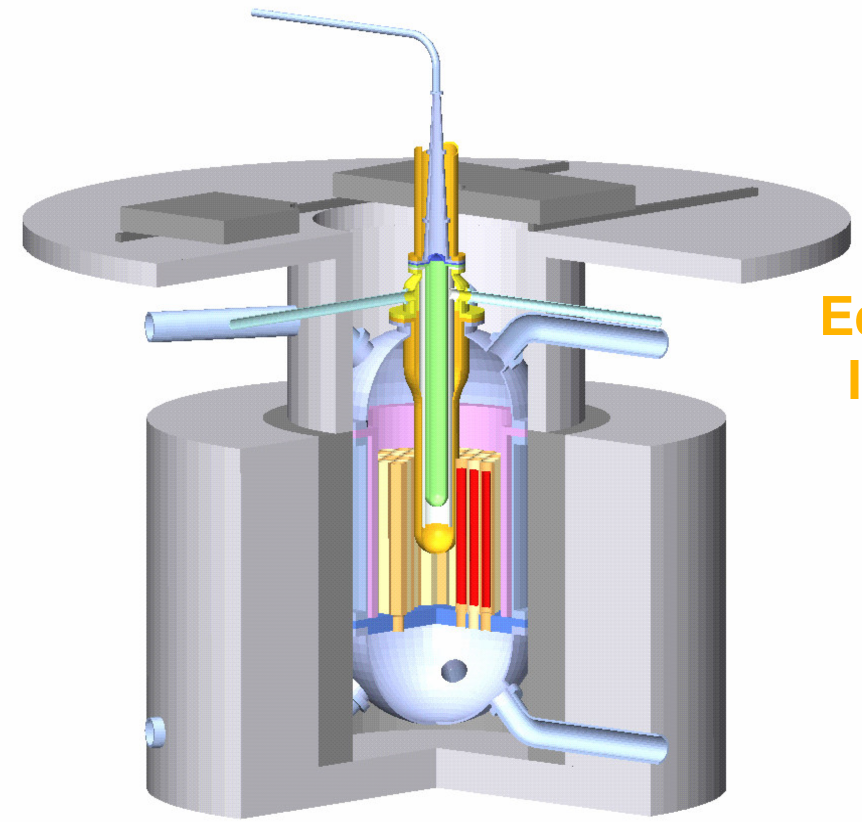
  … but with increasing difficulties with the date of deployment and with the type of previous fuel managements in PWR

An alternative route for MA transmutation

- **Subcritical Accelerator Driven Systems dedicated to transmute M.A.**

High content M.A. fuels

R&D for Sc. & Tech. feasability



Economical as part of a large fleet of reactors

Open technological issues

Fast spectrum cores, fast reactor technologies

Conclusion

- Increasing energy needs expected in the next 50 years
  → Nuclear Energy should play a key role

- Waste reduction and natural resources preservation, proliferation resistance are essential conditions for enhancing sustainable nuclear energy systems development

- Fast neutron 4th Generation systems afford :
  → a realistic option to transmute all actinides they generate and also those produced by earlier Generations (PWRs)
  → a good flexibility for actinide management regarding uncertainties on the date of their deployment

- R&D need to study the physical limits of fast reactors. Necessary Technology Demonstrations for reactors and cycle to support the scenarios developped for M.A. management