The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

Workshop on

ROLE OF PARTITIONING AND TRANSMUTATION IN THE MITIGATION OF THE POTENTIAL ENVIRONMENTAL IMPACTS OF NUCLEAR FUEL CYCLE

20 - 24 November 2006

ICTP - Trieste, Italy

1774/4

Proliferation Resistance Aspects in Nuclear Fuel Cycle

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Proliferation Resistance Aspects in Nuclear Fuel Cycle

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The proliferation resistance of a spent fuel treatment option "is defined as that characteristic that impedes the diversion or undeclared production of fissile material or misuse of its technology"[1]. Under diversion we understand also theft by sub-national groups and define fissile material as weapon useable Pu, Np and Am-241[2].[3]

[1] IAEA-TECDOC-1434, p.133 (2004)
[2] IAEA restricted distribution Doc.GOV/1998/61,1998 and IAEA Doc. Safeguards Criteria, section 7, TS no.3, 1994
[3] The term spent nuclear fuel standard from thermal or fast reactors is here extended to the separated actinide-mix (with a 50% U content and a Cm abundance of 1% or more) and containing about 2% of fission products. Like spent fuel is this mixture not weapon useable unless the fissile material is separated.

The concern about nuclear weapon proliferation is threefold:

- Spread of knowledge to design a nuclear device
- Transfer of sensitive technologies for U-235 isotope enrichment or for the chemical separation of pure weapon grade fissile material
- Diversion or theft of weapon useable materials

The misuse of the "peaceful" technologies for producing highly enriched uranium and weapon useable plutonium reduced public acceptance of nuclear energy generation.

States with an established closed fuel cycle technology.

Emerging from its military application the **PUREX** *technology has been adapted to process spent fuel from civil nuclear energy generation. Some states (e.g. U.K., France) offer this service to other states*

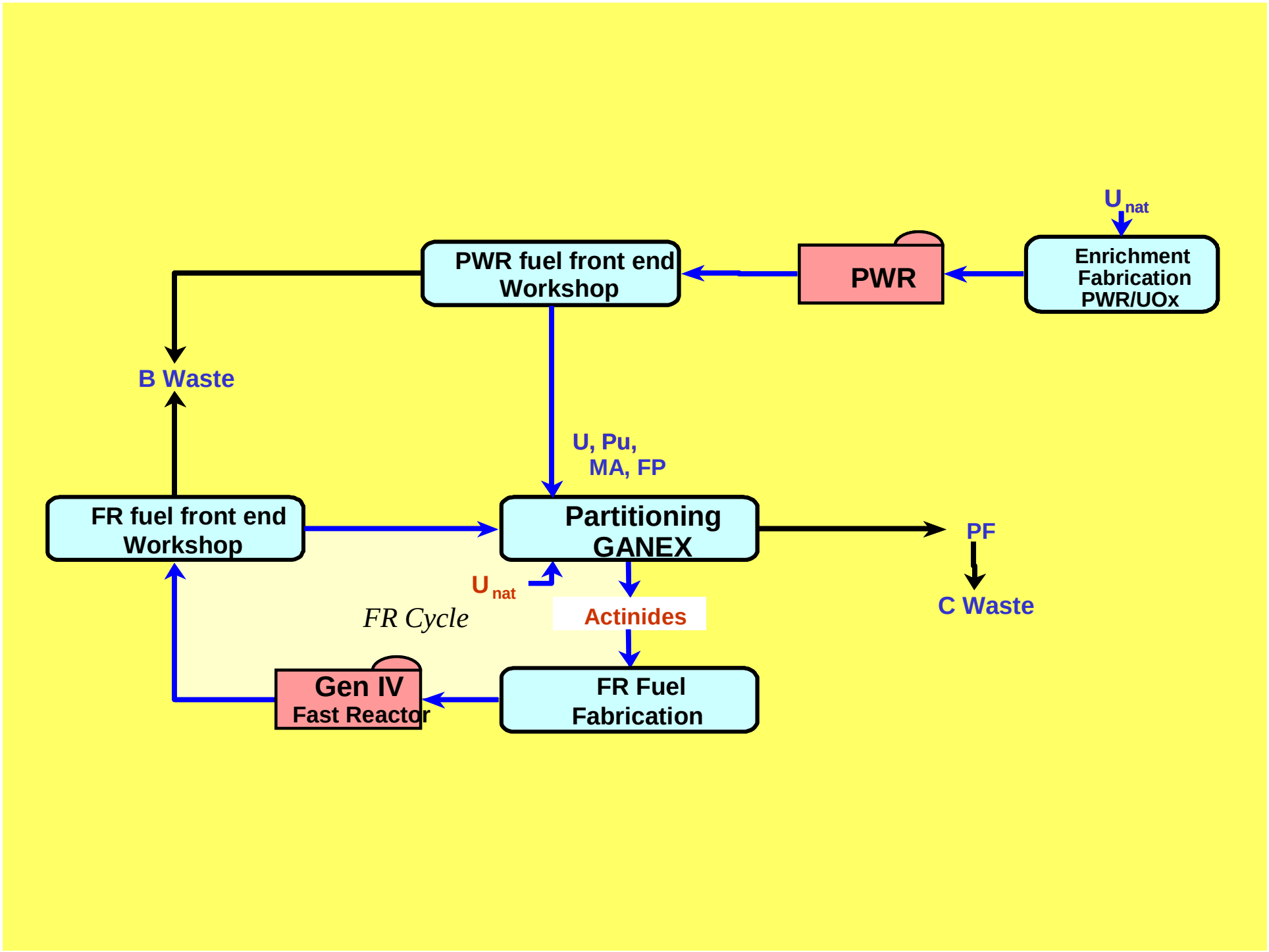
Development of advanced spent fuel reprocessing aims at technologies with intrinsic barriers that - under normal operation - exclude the production of weapon useable fissile material at all stages of the process. Complementary institutional measures would have to verify the declared operation and detect any alteration of the licensed process for a clandestine production of weapon useable fissile material. Technical barriers must hamper a change of the licensed process.

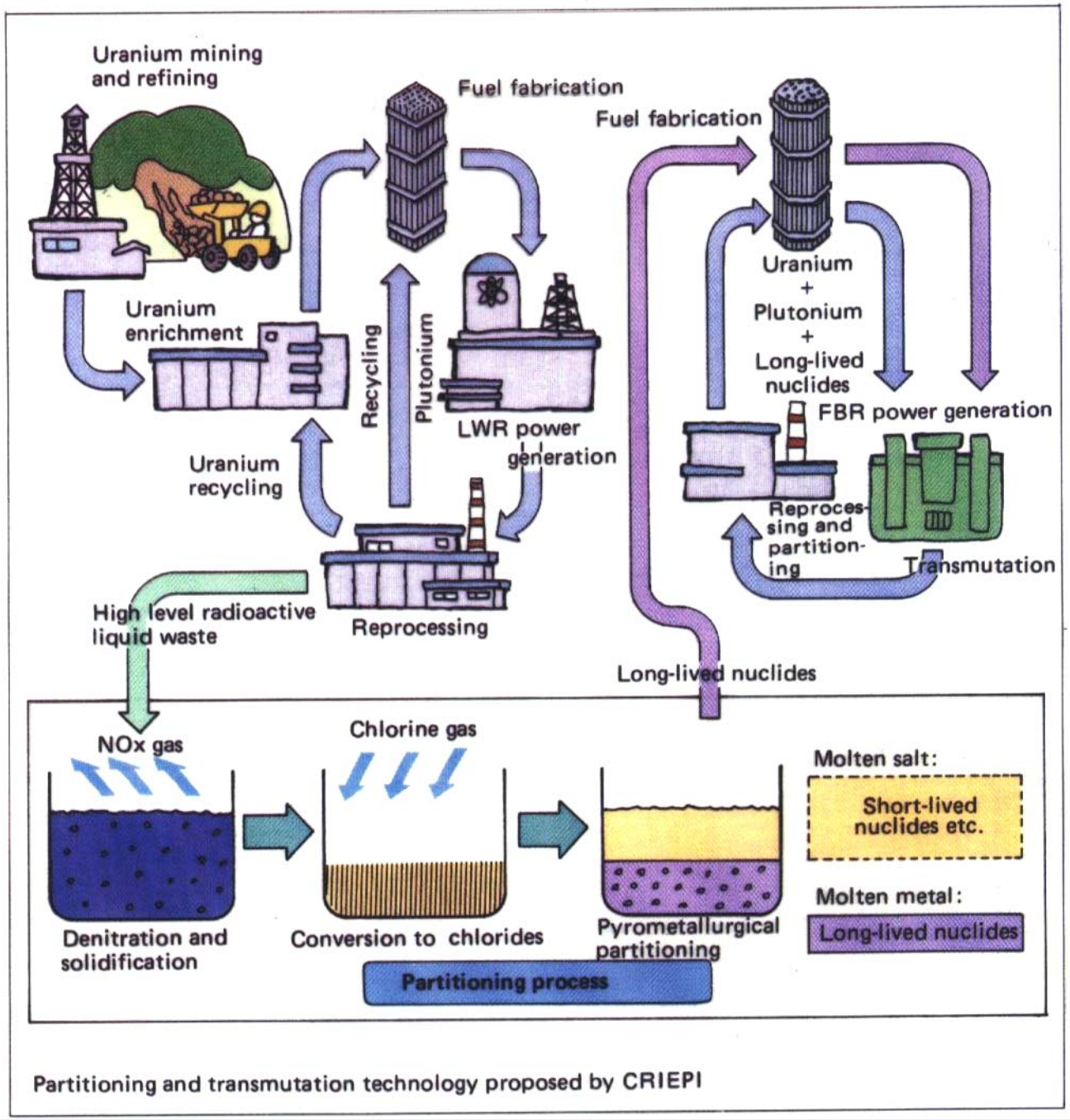
The detection of clandestine operations is subject to **IAEA** *safeguards under the "additional protocol". Hence for such a scenario the role of international safeguards by the* **IAEA** *would rather be to verify the absence of weapon useable fissile material than of verifying the existence of a declared mass of weapon useable fissile material*.

Advanced reprocessing will separate TU elements together.

French GANEX *process*

CRIEPI *electrorefining*


U nat
Enrichment Fabrication PWR/UOx
PWR
PWR fuel front end Workshop
B Waste
U, Pu, MA, FP
FR fuel front end Workshop
Partitioning GANEX
PF
C Waste
U nat
FR Cycle
Actinides
Gen IV Fast Reactor
FR Fuel Fabrication



Partitioning and transmutation technology proposed by CRIEPI

According to **IAEA TEC-DOC-***1434, 136 proliferation resistance criteria should meet two basic principles: "proliferation features and measures shall be implemented throughout the full life for innovative nuclear energy systems … and both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself."*

However we should note that intrinsic features are superior to extrinsic features. The latter are subject to malevolent human interventions. Therefore processes with a large intrinsic proliferation potential must be preferred.

Intrinsic proliferation resistance features of advanced reprocessing:

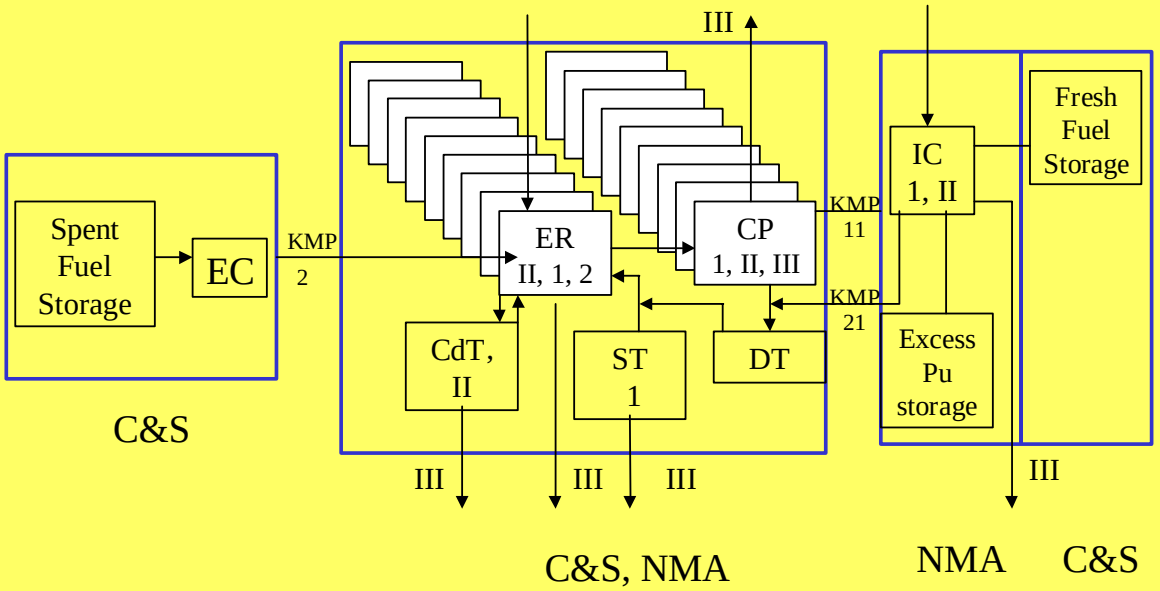
- degree of difficulty to separate out fissile material from final or intermediate products.
- Ease to change or to adapt a technology from normal to abnormal operation to separate out weapon useable fissile material.
- Group separation of actinides.

- The process has only intermediate or final products emitting a fatal radiation dose for significant quantities.
- Integrated concepts are favouring C&S measures.

Applicable institutional measures

- C&S comprising the reactor with integrated pyro-processing plant
- NRT accountancy
- Verification of process layout
- Surveillance of FR blanket processing

Measures of internationl safeguards applied to a pyro-proceesing and fuel fabrication plant



Intrinsic Proliferation Barriers of the Mixed An-Product

- Lethal dose by external radiation of KG size masses
- Fatal dose by incorporation of radiotoxic material
- Requires biological shielding
- Heat production to degrade detonators and to distort sphere shape (more than 200 W per device)
- High neutron background to initiate preignition (more than 100 neutrons in a microsecond per device)

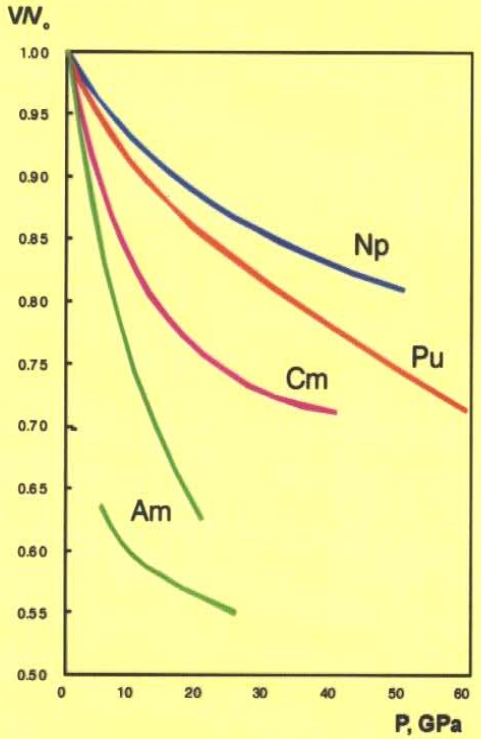
Radiation Type per	g TU mix	g LWR Pu
• alpha-activity (Ci)	2	0.1
• n-activity (n/sec)	7 E04	3 E2
• photons/sec	5 E10	5E8
• MeV/sec	2 E10	5 E6

If the present spent LWR fuel is processed in due time, then we can expect a decay heat of at least of 300 W in a 5 Kg nuclear device made of the obtained **TU-mix**, *enough to have the detonator melting and phase transitions changing the shape of the fissile material sphere*

Weapon grade plutonium will generate 0.1 neutrons by spontaneous fission during a spherical shock wave period of about 5 micro sec. Depending to what extend Cm-244 has reached equilibrium concentration in repeated recycling, we will observe much more neutrons than for a nuclear device made of a one year old TU mix with 100 to 5,000 neutrons.

	half-lives [a]		critical mass [kg]
	α- decay	spontaneous fission	metal sphere, steel reflector
^{237}Np	2.14 E6	> E 18	55
^{241}Am	43 2		34
^{242m}Am	14 1	9 .5E11	38
^{243}Am	7.38 E3	20 E14	36
^{244}Cm	18.1	1 .35 E7	54
^{239}Pu	2.41 E4	5 .5E15	7
^{240}Pu	6.56 E3	1. 34E11	35

Phase	Transformation temperature at STP, °C
Neptunium	
α	280
β	576
γ	
Americium	
α	ca. 658
β	
Curium	
α	ca. 1277



In summary one has to consider ^{237}Np as a potential weapon grade material. Am in the expected isotopic mixtures would require a highly sophisticated design to turn it into an explosive device. Nevertheless, one should not underestimate the danger of nuclear explosions even with "fizzy yields" to which this material renders itself.

Nuclides	Weight (g)	N neutrons (n/s)
Np-237	248	
Pu-238	91	2 E5
Pu-239	2540	
Pu-240	1130	1 E6
Pu-242	280	5 E5
Am-241	46	
Cm-242	1.5	3 E7
Cm-244	18	2 E8
Cm-246	0.8	7 E6
Total	5000	2.5E8

Predicted preignition yields of TU-*mix*

With a neutron background of E8 to E9 n/sec in a 5 Kg mass device (with reflector), preignition will occur instantly (with detonation after ca.10 nsec) when criticality is reached. At this point the implosion shockwave has not yet compacted the mass strongly.

According to a simplified approach (J.C. Mark, Science & Global Security, Vol.4 p.111ff , 1993) the released energy yield is to nth power of the nominal yield of a trinity device (nominal yield being .94 of 20.000 t TNT, n equal 250 times higher neutron background). With a fast compaction the yield is 4 Kg TNT

According to (W.Seyfritz Nukleare Sprengkörper, K.Thiemig Verlag p.54, 1983)the released energy is 7.5 (NT) exp.-1.5. With T=5 E-6 sec again and N= 1 E9 neutrons/sec, a 5 Kg device would release an energy equivalent of about 3 Kg TNT

States with nuclear energy generation - but having not yet established a closed fuel cycle technology are planning to substitute **PUREX** *technology by developing alternative processes (e.g.* **DUPIC** *or advanced reprocessing with a co-separation of actinide elements).*

The objective is threefold: reduction of the long living radio-toxicity, by enlarging the storage capacity of repositories at the same time and increase of proliferation resistance