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

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Description of Nuclear Fuel Cycle Options

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Description of Nuclear Fuel Cycle Options

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The direct thermal fission of U-235,

the fissile nuclide occurs in nature

in abundant supply;

- Fission of plutonium

which is produced from the fertile nuclide U-238 as a by-product of fissioning U-235

- Fission of U-233,

is obtained by irradiating the fertile nuclide thorium,

which occurs in abundant amounts.

Nuclear Fuel Cycle Options

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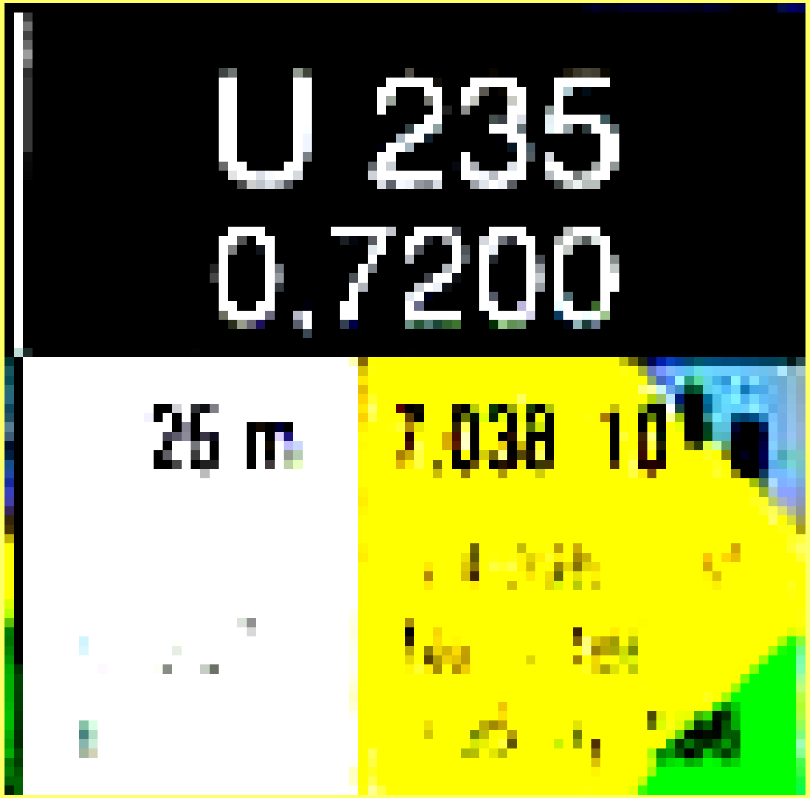
- *All nuclear fuel cycle options base on **thermal** fission of U-235*

Nuclear Fuel Cycle Options

- *U-235 with an isotopic abundance of 0.72% in natural uranium.*
- *All nuclear fuel cycle options base on **thermal** fission of U-235*
- *(Except Th,U-233 - fission initiated by spallation neutrons – energy amplifier)*

Nuclear Fuel Cycle Options

- *Fission by normal (light) water moderation needs U-235 enrichment above 2.1%*
- *About 2000 million years ago U-235 enrichment was more than 3%. Natural reactors were found at OKLO, Gabun*
- *Today fission reactors with natural uranium are only possible by graphite or heavy water moderation*



The open U fuel cycle strategy with LWR and HWR is fully developed. Power stations using this strategy are operating presently at the lowest costs of any nuclear option. Speculative uranium resources (recoverable at costs up to $130 per kg) of 4,440,000 tones are expected to be adequate through 2050.

There are mainly three types of Light Water moderated Reactors, LWR in operation:

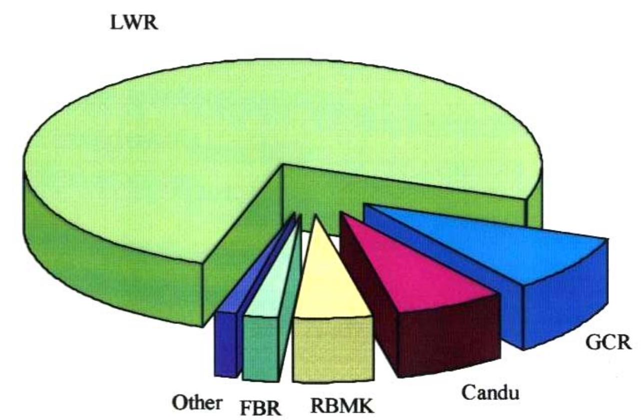
BWR, PWR, VVR

Improved designs are being deployed

Ca.440 nuclear reactors with an electricity generation capacity of about 350 (GWe)

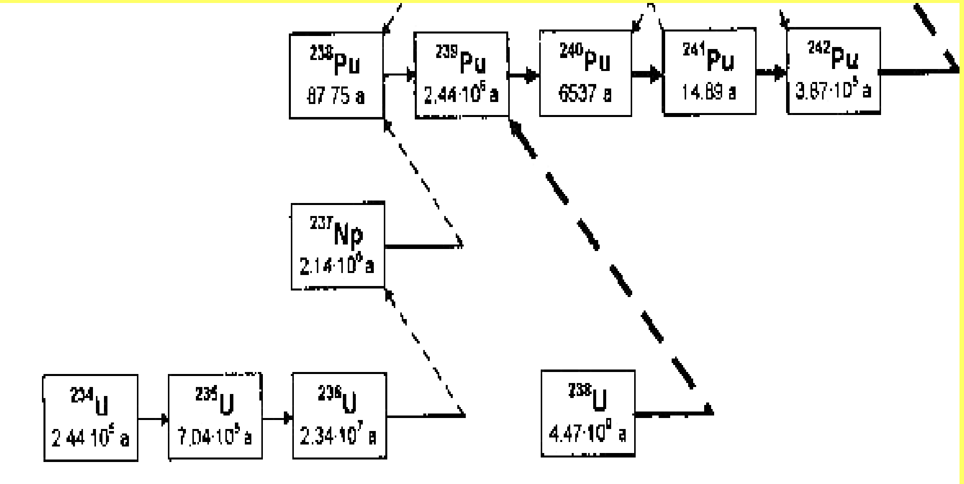
- The share of LWR and HWR is increasing
- Whereas RBMK and GCR are getting shut down
- Presently there are only 3 FR operating

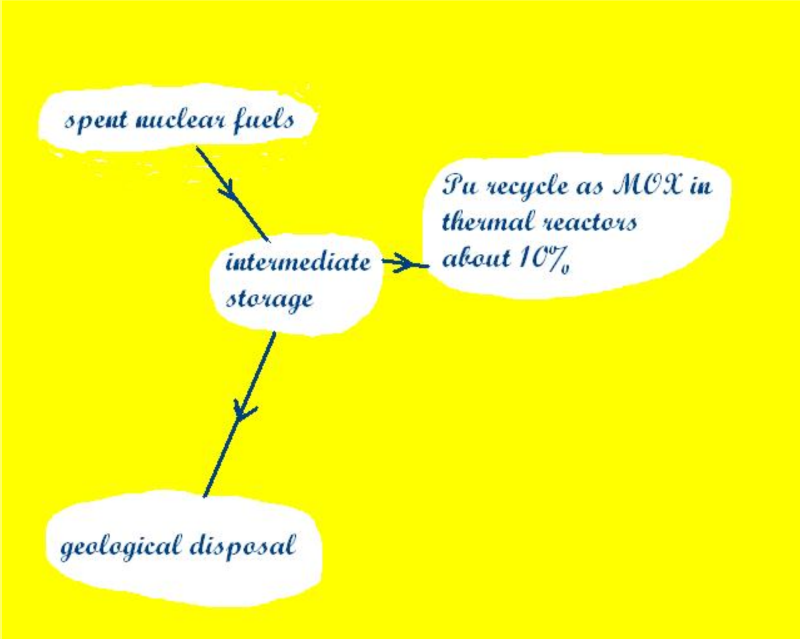
  (Jap. RF. F)



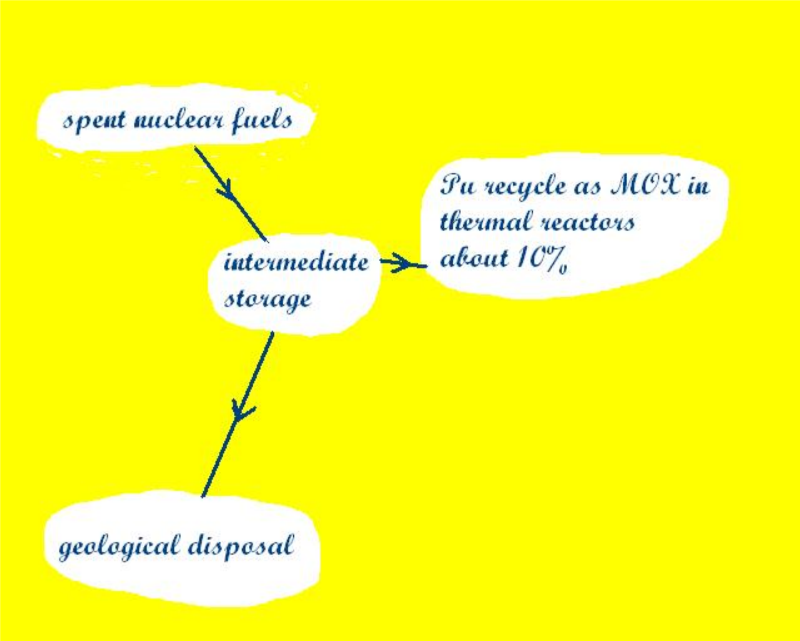
Share of reactor types in worldwide fission energy generation

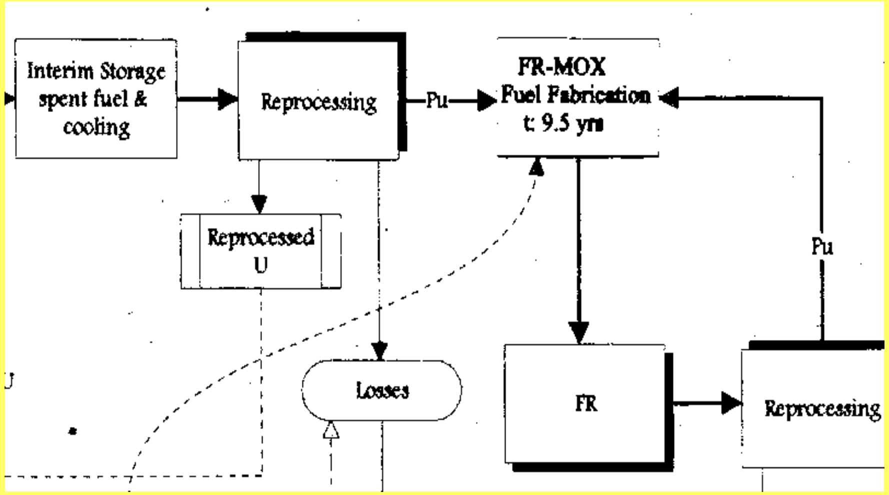
About 300.000 t HE of spent nuclear fuel have accumulated.
Present annual arising about 10.000 t HE.
Is built-up Pu a fuel or is it waste ?



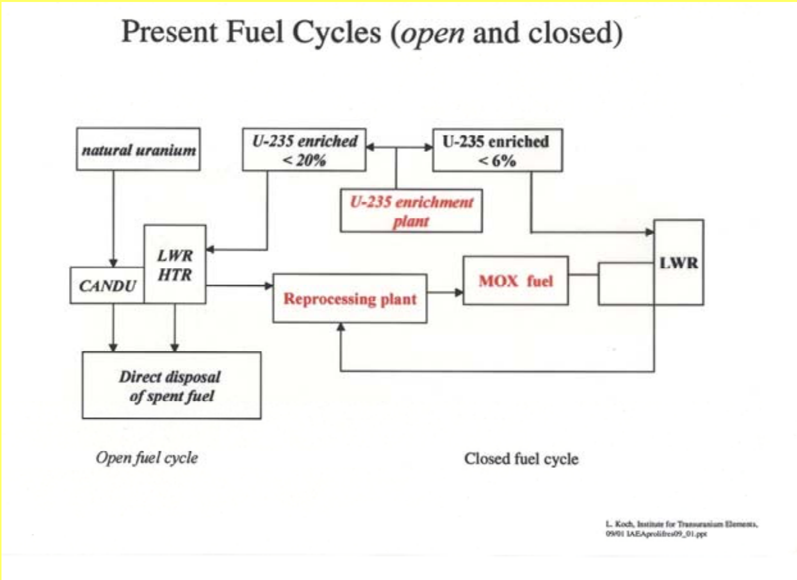


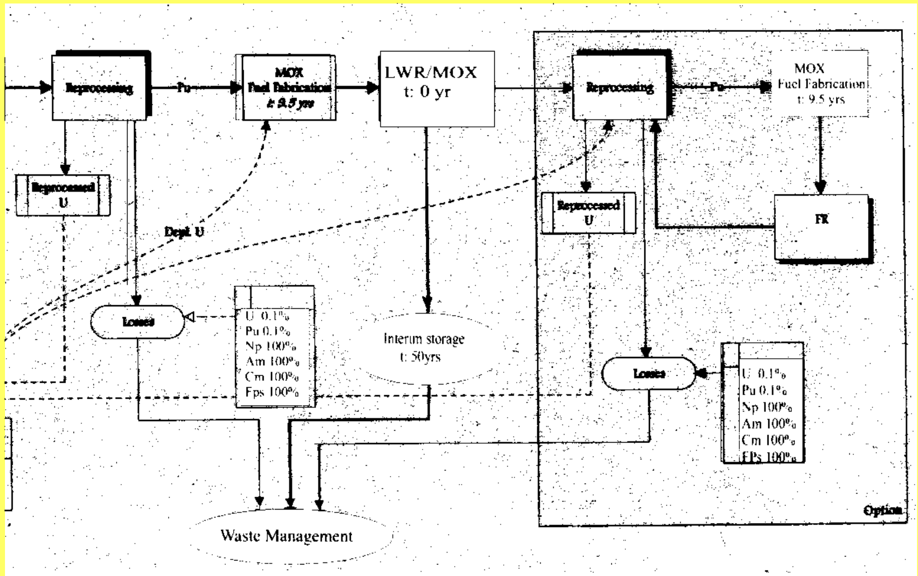
Pu recovered presently from spent LWR (HWR) fuel was foreseen to initiate future U-238 - Pu breeding in FR



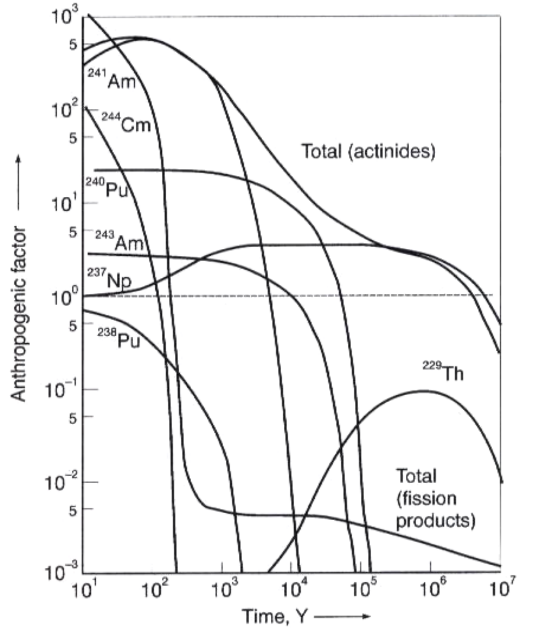


Surplus Pu (from PUREX *and dismantled weapons)* *will be recycled as MOX in LWR instead of FR*





Spent LWR fuel, when stored in a geological repository will decay slowly and constitute a hazard to future generations

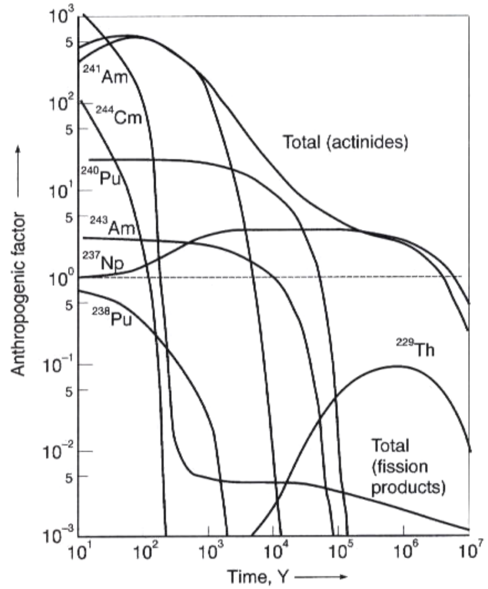


Time-dependence of radiotoxicity in a spent LWR fuel 33 GWd/t normalized to the radiotoxicity of the uranium ore (dashed line) mined to produce the fuel

<u>The radiological hazard can be expressed</u>

- *Volume of water to dilute to* **MPC**
- *Cancer doses*
- *Number of* **ALI** *dosis (anthropogenic factor)*

Actinides in spent LWR fuel, when stored in a geological repository will decay slowly and constitute a hazard to future generations

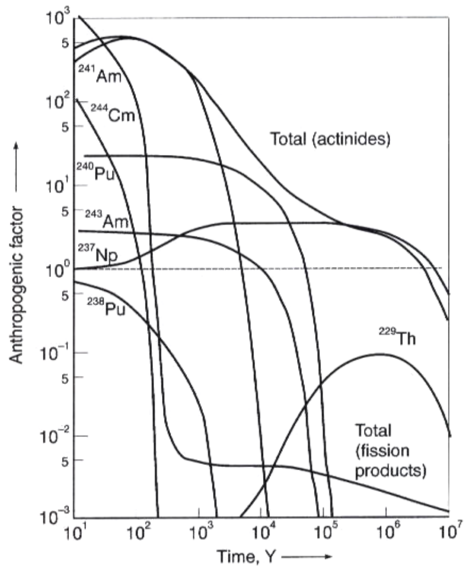


Time-dependence of radiotoxicity in a spent LWR fuel 33 GWd/t normalized to the radiotoxicity of the uranium ore (dashed line) mined to produce the fuel

Table Radioactivity [Bq] of built up actinides in 1 t of HM of a typical PWR fuel and HWR fuel at discharge and 10000 a

Radionuclide	Discharge PWR	Discharge HWR	10000 a PWR	10000 a HWR
^{236}U	$1 \cdot 10^{10}$	$2 \cdot 10^{9}$	$1 \cdot 10^{10}$	$3 \cdot 10^{9}$
^{237}Np	$1 \cdot 10^{10}$	$2 \cdot 10^{8}$	$5 \cdot 10^{10}$	$4 \cdot 10^{9}$
^{238}Pu	$8 \cdot 10^{13}$	$5 \cdot 10^{11}$	–	–
^{239}Pu	$1 \cdot 10^{13}$	$6 \cdot 10^{12}$	$1 \cdot 10^{13}$	$4 \cdot 10^{12}$
^{240}Pu	$2 \cdot 10^{13}$	$7 \cdot 10^{12}$	$7 \cdot 10^{12}$	$2 \cdot 10^{12}$
^{241}Pu	$5 \cdot 10^{15}$	$5 \cdot 10^{14}$	$3 \cdot 10^{9}$	$1 \cdot 10^{6}$
^{242}Pu	$7 \cdot 10^{10}$	$4 \cdot 10^{9}$	$8 \cdot 10^{10}$	$4 \cdot 10^{9}$
^{241}Am	$5 \cdot 10^{12}$	$3 \cdot 10^{11}$	$3 \cdot 10^{9}$	$3 \cdot 10^{6}$
^{242m}Am	$1 \cdot 10^{11}$	$6 \cdot 10^{9}$	–	–
^{243}Am	$6 \cdot 10^{11}$	$5 \cdot 10^{9}$	$3 \cdot 10^{11}$	$2 \cdot 10^{9}$
^{242}Cm	$2 \cdot 10^{15}$	$2 \cdot 10^{13}$	–	–
^{243}Cm	$6 \cdot 10^{11}$	$4 \cdot 10^{9}$	–	–
^{244}Cm	$7 \cdot 10^{13}$	$1 \cdot 10^{11}$	–	–
Total	$6 \cdot 10^{15}$	$6 \cdot 10^{14}$	$2 \cdot 10^{13}$	$7 \cdot 10^{12}$

Fission product radiotoxicity in spent LWR fuel, when stored in a geological repository, will decay in about 200a below that of U-ore, but still could constitute a hazard to future generations



Time-dependence of radiotoxicity in a spent LWR fuel 33 GWd/t normalized to the radiotoxicity of the uranium ore (dashed line) mined to produce the fuel

List of long-lived radionuclides considered as candates for nuclear transmutation

Nuclide	$T_{1/2}$ [a]
^{14}C	$5.7 \cdot 10^{3}$
^{36}Cl	$3.0 \cdot 10^{5}$
^{129}I	$1.6 \cdot 10^{7}$
^{135}Cs	$2.0 \cdot 10^{7}$
^{79}Se	$6.5 \cdot 10^{4}$
^{93}Zr	$1.5 \cdot 10^{6}$
^{90}Sr	$2.9 \cdot 10^{1}$
^{121}Sn	$5.0 \cdot 10^{1}$
^{126}Sn	$1.0 \cdot 10^{5}$
^{137}Cs	$3.0 \cdot 10^{1}$
^{99}Tc	$2.1 \cdot 10^{5}$

The presently operating nuclear reactors are mainly uranium-fuelled thermal reactors operating on an "open" fuel cycle. Less than 10% recycle plutonium.

In order to be able to continue the use of the open fuel cycle strategy for several centuries, it will be necessary to exploit unconventional uranium supply resources. If uranium can be extracted from sea water at competitive prices, uranium fuels would have a practically unlimited, "eternal" supply.

An alternative is U-238-Pu breeding in Fast neutron Breeder Reactors, FBR, which is presently more expensive.

The Th-U-233 breeding is regarded as an option in the future.

Options of nuclear waste disposal

- stable geological formations
  crystalline rock, salt or clay
- transmutation of long living radiotoxic
  nuclides into short lived or stable ones
- evacuation into outer space or sun