



Ordine degli Ingegneri
della Provincia
di Roma



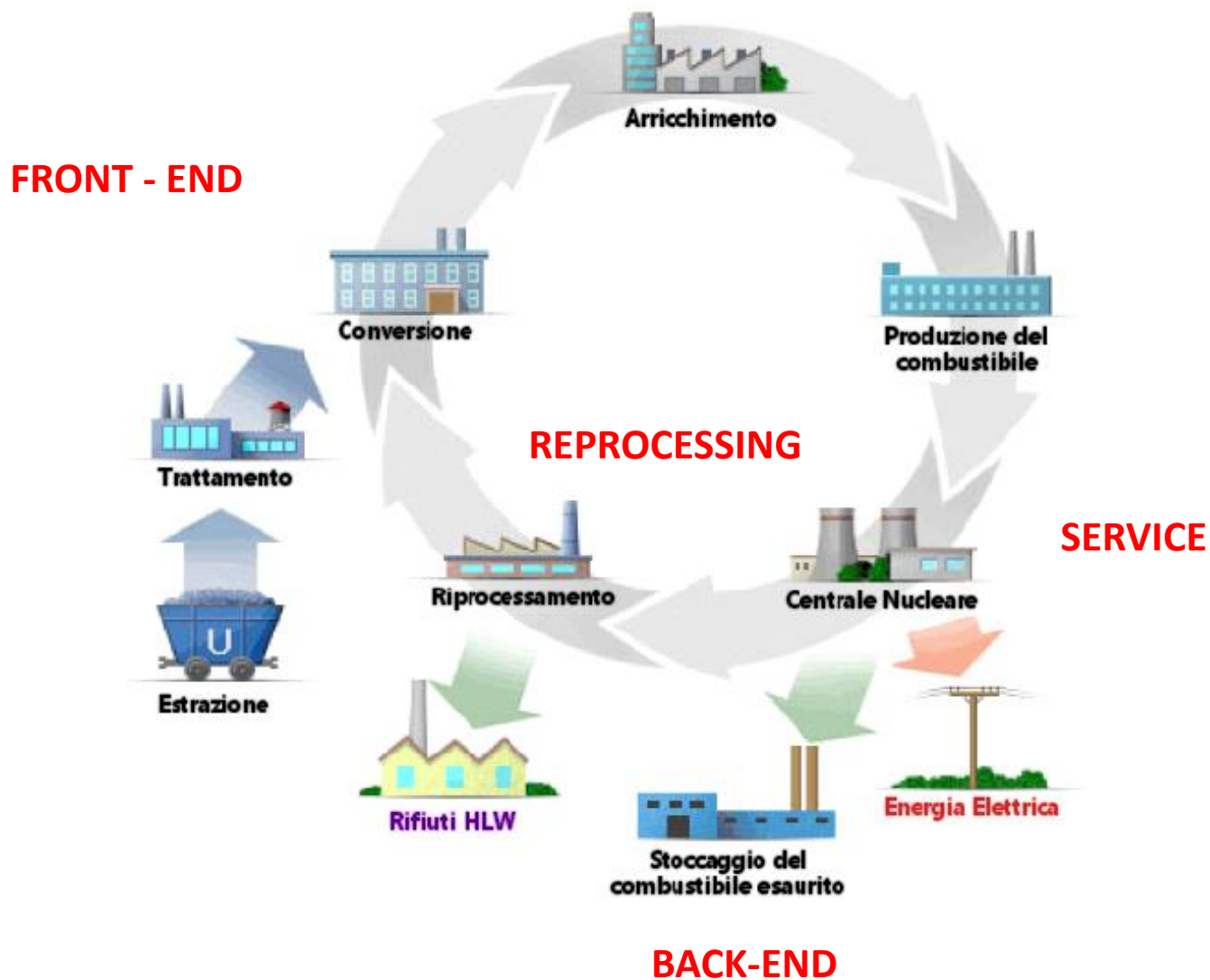
IL CICLO DEL COMBUSTIBILE NUCLEARE

Ing. Massimo Sepielli
Presidente
Commissione Ricerca e Reattori Innovativi

Seminario - Giovedì 13 febbraio 2025

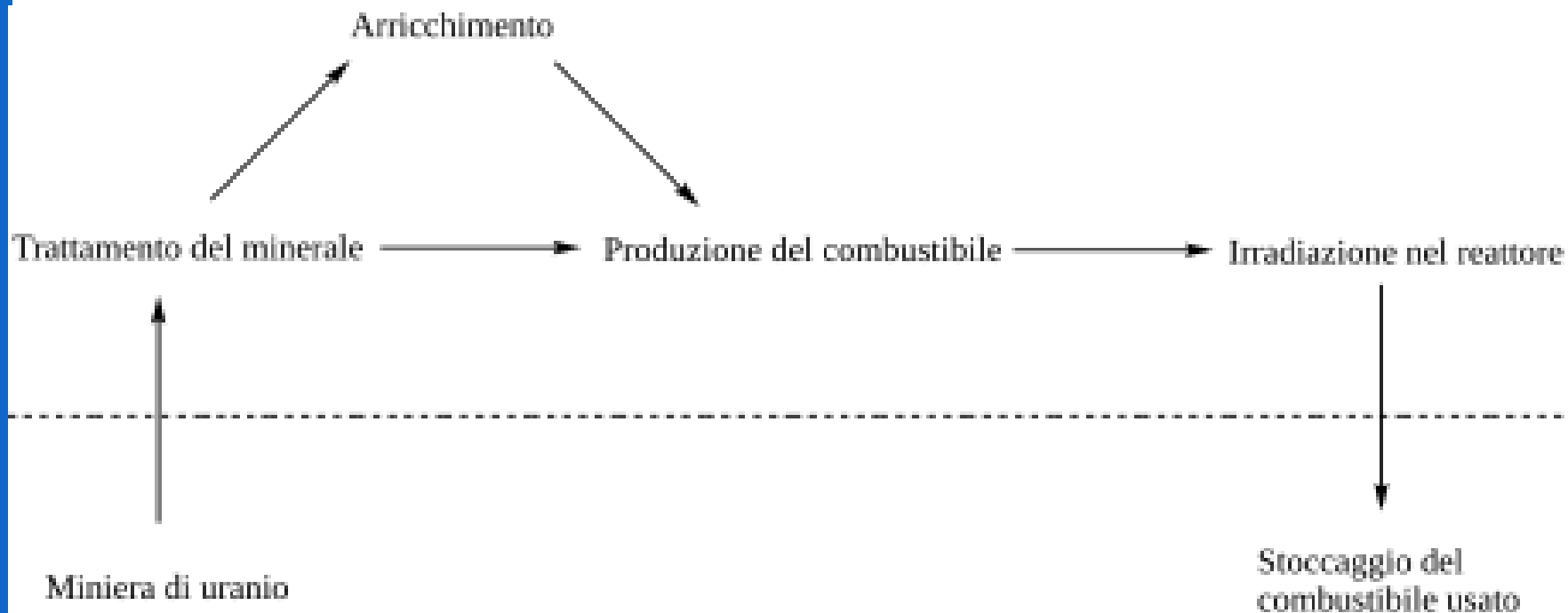


CICLO DEL COMBUSTIBILE NUCLEARE





Ciclo aperto





Arricchimento principali filiere

Type	Nuclear Reactor	Neutron	Fuel	Coolant	Moderator
Thermal Reactor	Pressurized Water Reactor (PWR)	Thermal	3 - 5% Enriched UO_2	H_2O	H_2O
	Boiling Water Reactor (BWR)	Thermal	3 - 5% Enriched UO_2	H_2O	H_2O
	Pressurized Heavy Water Reactor (PHWR)	Thermal	Natural UO_2	D_2O	D_2O
	Advanced Gas Cooled Reactor (AGCR)	Thermal	3 - 5% Enriched UO_2	CO_2	Graphite
	Light Water Graphite Reactor (LWGR)	Thermal	3 - 5% Enriched UO_2	H_2O	Graphite
Fast Reactor	Fast Breeder Reactor (FBR)	Fast	15 - 20% Enriched UO_2	Liquid Na or Pb	Not Required

www.difference.minaprem.com



FRONT END

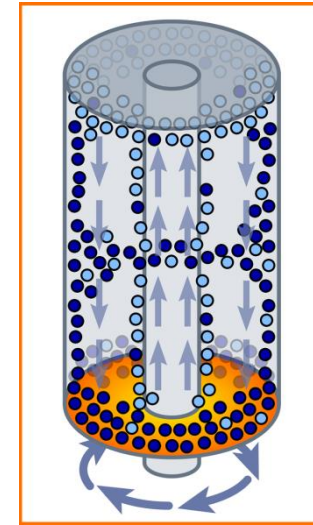
Trattamento, arricchimento e fabbricazione



Uraninite



Yellow cake U3O8



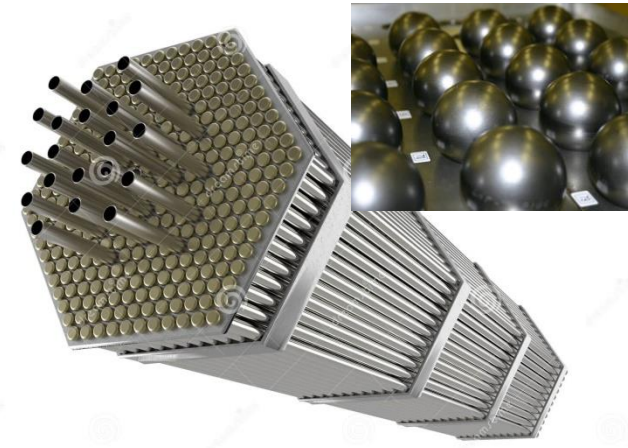
Gas UF6



Centrifughe x arricchimento in U235

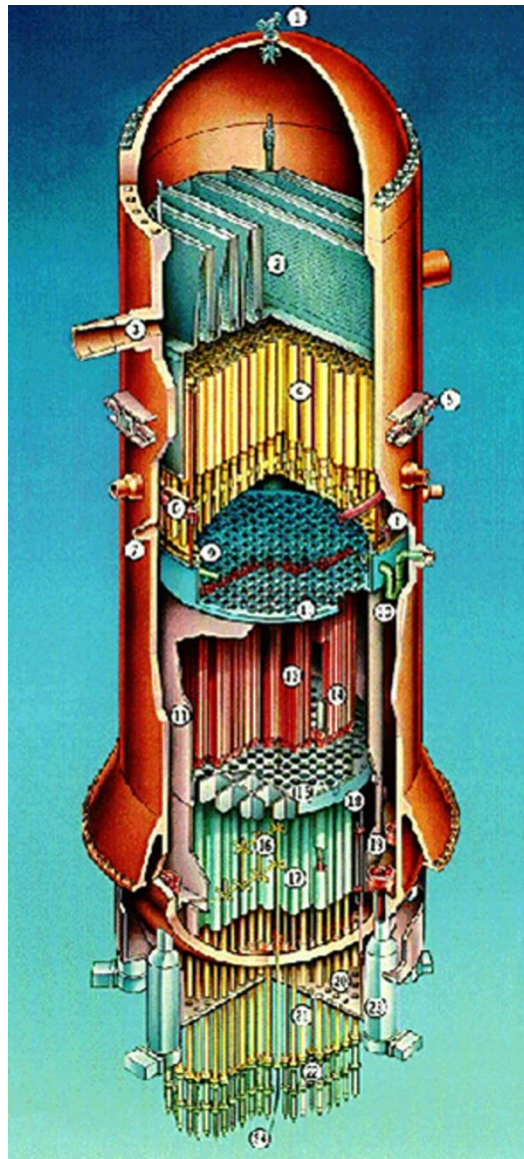


Pellet (UO2) e barretta



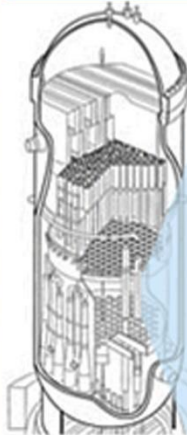
Elemento di combustibile

Assemblaggio elemento di combustibile



72 fuel rods are bundled with tie plates and spacers.

Boiling Water Reactor (BWR)

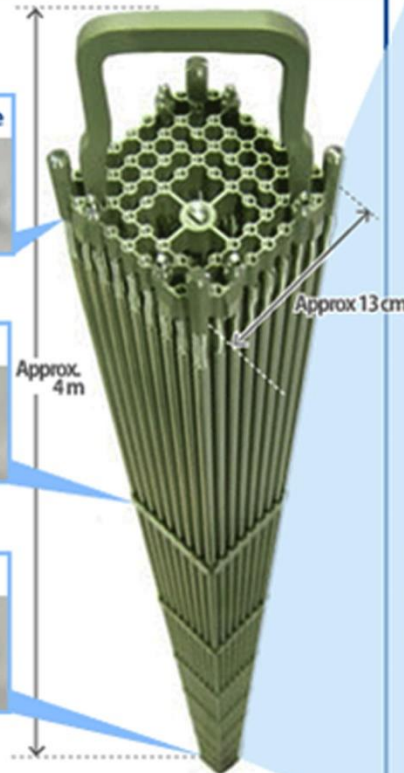


Fuel Assembly (9 x 9 type)

Top tie plate

Spacer

Bottom tie plate

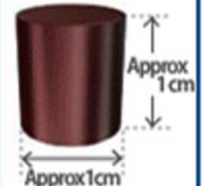


Weight: Approx. 300 kg

Fuel Rod

◀ A metal pipe contains 350 pellets with both ends plugged. Those pellets are fixed with springs.

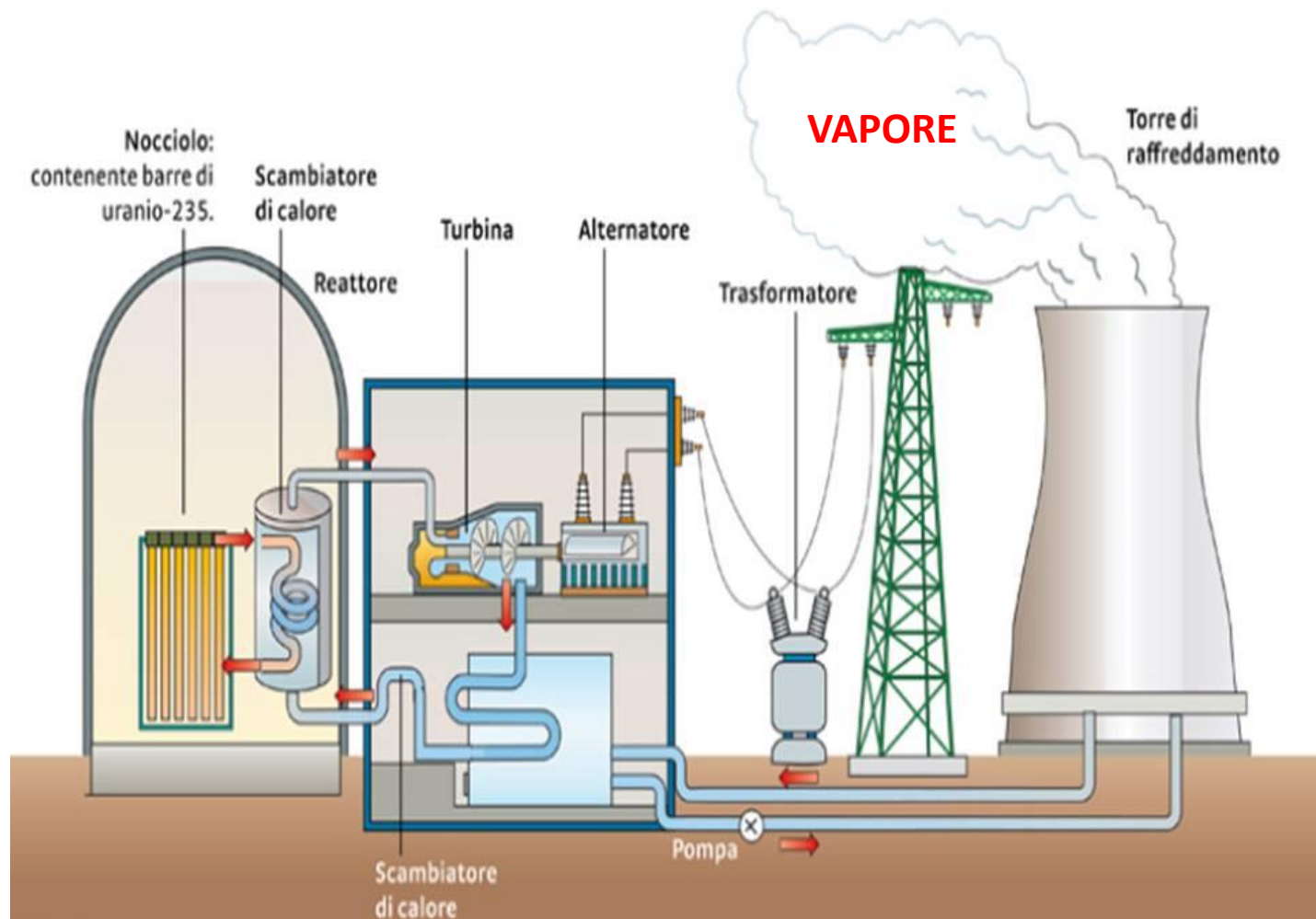
Pellet



▲ Uranium powder is baked into the pellet form in a cylindrical shape. About eight grams of the pellet can produce electricity by that could support a normal household life for eight months.



Periodo di servizio (Service) Bruciamento in reattore e produzione



Raffreddamento e decadimento del combustibile nucleare in piscina /presso l'impianto



Ing. Massimo Sepielli – Presidente Commissione Ricerca e Reattori Innovativi

- Webinar Commissione RRI - Non Chiamatele scorie



BACK - END

Cask per stoccaggio a secco del combustibile



Cask per trasporto del combustibile esausto



Ing. Massimo Sepielli – Presidente Commissione Ricerca e Reattori Innovativi

- Webinar Commissione RRI - Non Chiamatele scorie

Smaltimento geologico

Lo smaltimento in profondità dei rifiuti radioattivi a lunga vita ed alta attività e del combustibile irraggiato è attivamente avviato in Finlandia, Svezia, Stati Uniti, mentre altri Paesi (Francia, Giappone, Belgio, etc) sono in una fase di studio e di progetto molto avanzata (**Laboratori Sotteranei**).

Le formazioni geologiche scelte sono principalmente i depositi salini, le sedimentazioni argillose e le rocce granitiche.

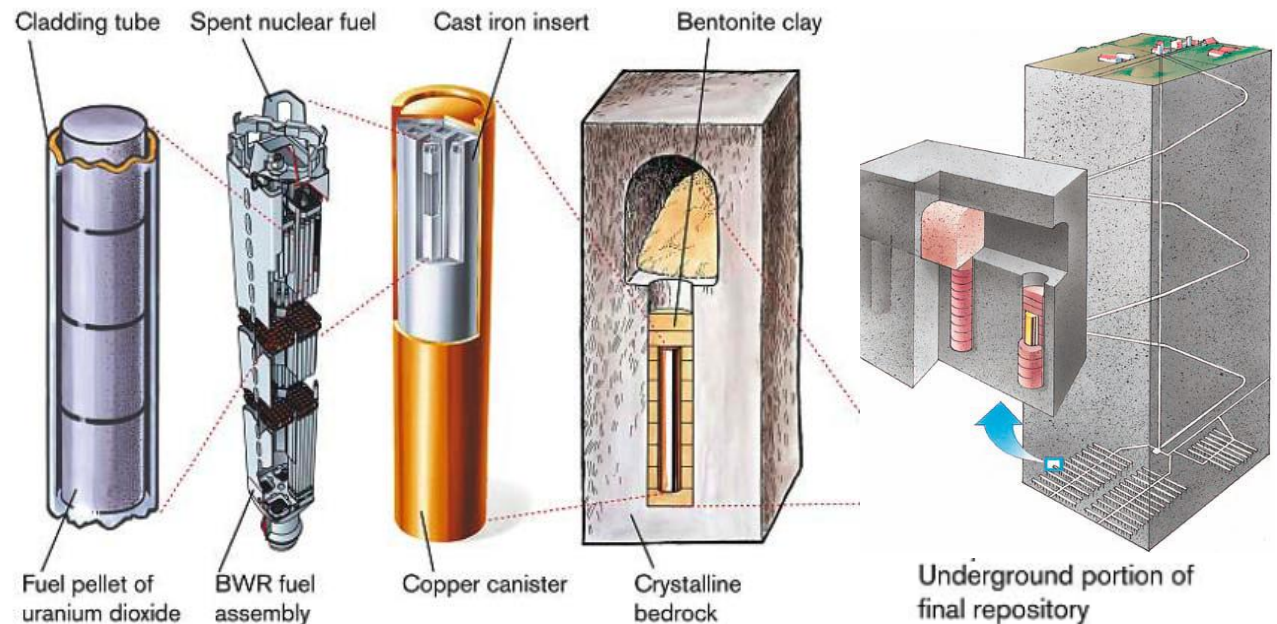


Forsmark, Svezia

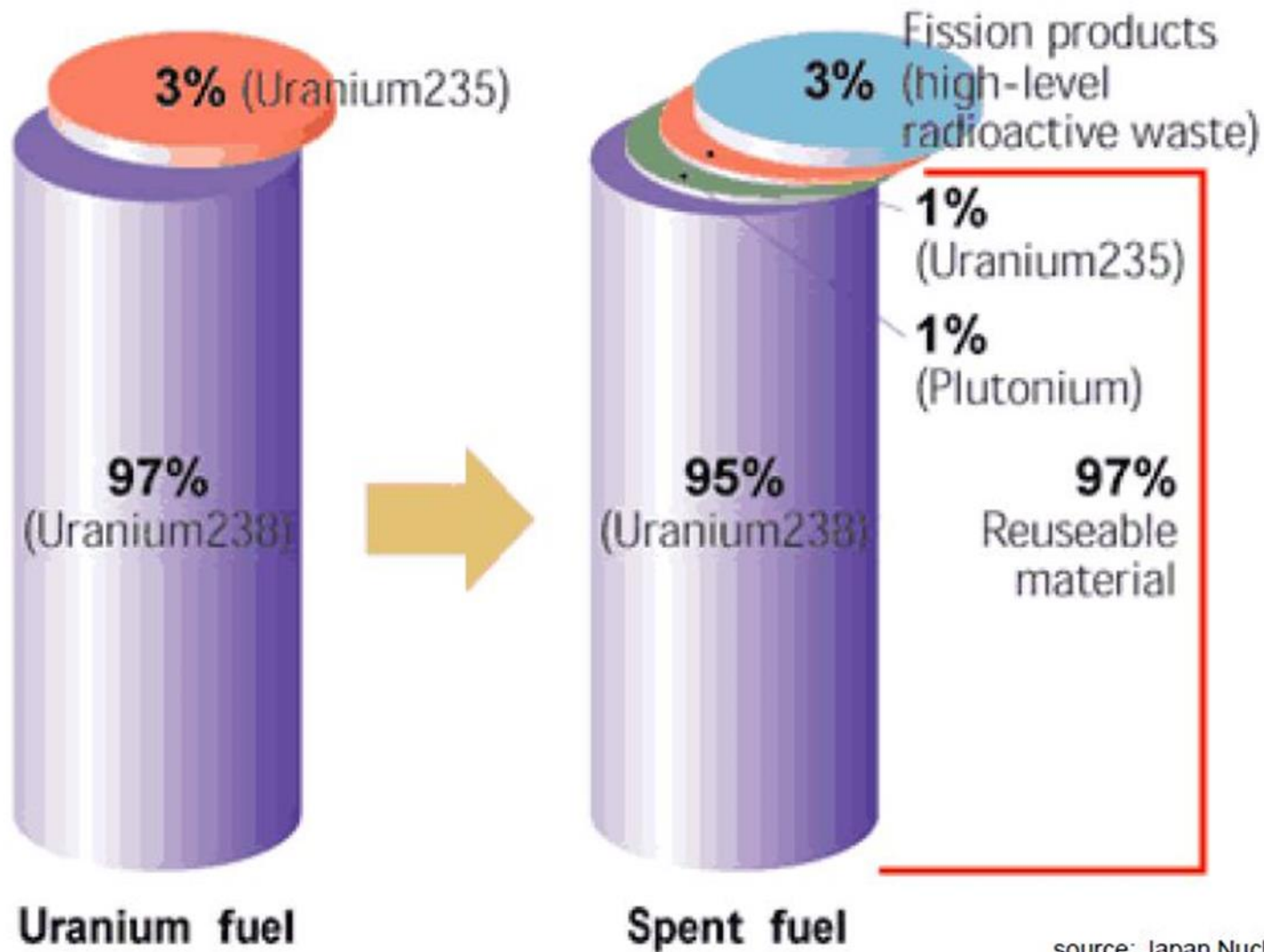
Costruzione: 2015-2022

Esercizio: 2023-2070

Formazione di granito
500 m di profondità



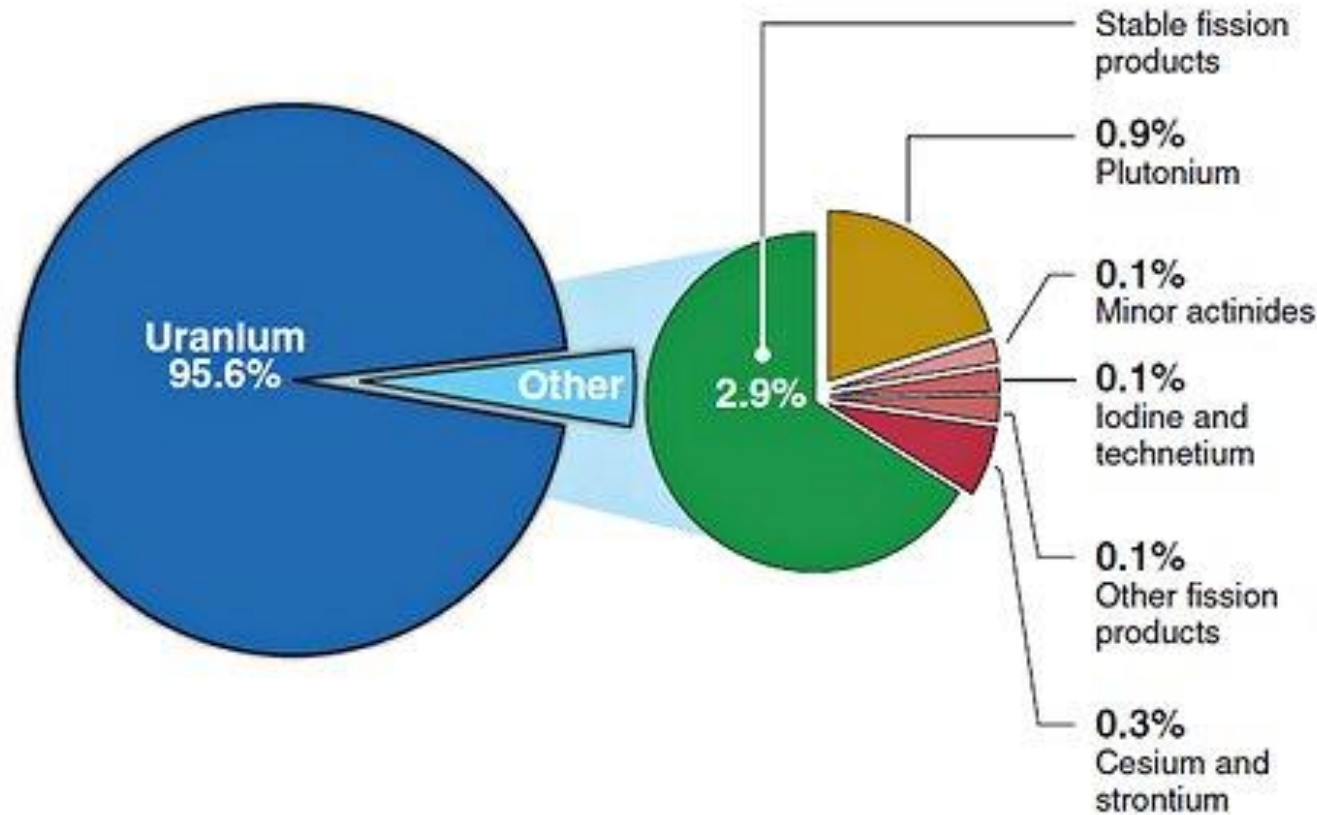
COMBUSTIBILE FRESCO E SPENTO



source: Japan Nuclear

Inventario del combustibile irraggiato

Figure 1: Composition of Spent Nuclear Fuel

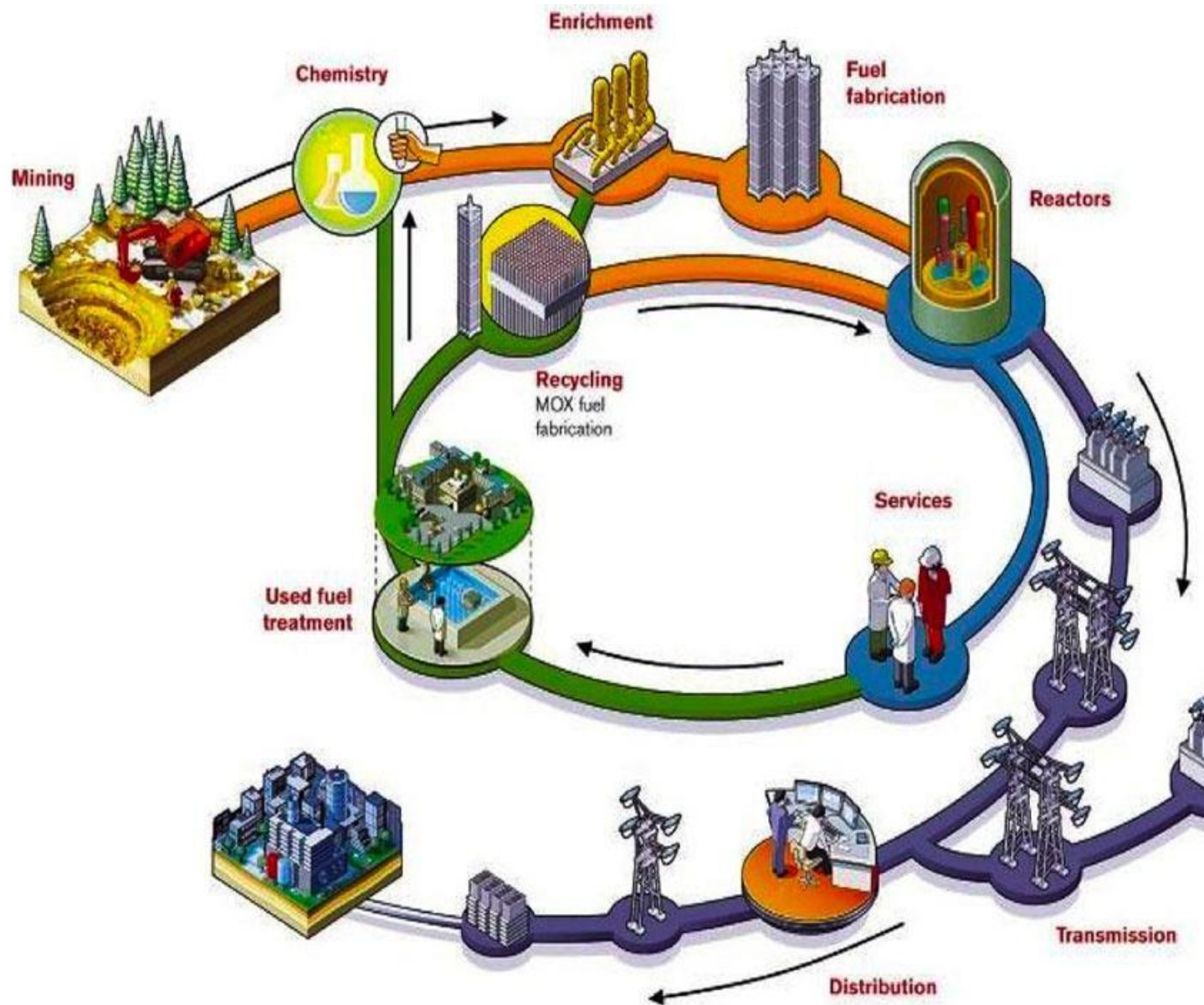


Isotopes	Mass (kg/year) per unit PWR ^a
²³⁷ Np	15.1
²³⁸ Pu	16.1
²³⁹ Pu	205
²⁴⁰ Pu	120
²⁴¹ Pu	72.7
²⁴² Pu	41.6
²⁴¹ Am	6
^{242m} Am	0.00793
²⁴³ Am	21.8
²⁴⁴ Cm	15.6
²⁴⁵ Cm	1.74

^a Pressurised-water reactor, fuel with plutonium recycle, 1000-Mwe reactor, 80% capacity factor, 33 MWd/kg, 32.5% thermal efficiency, 150 days after discharge. Nuclear Chemical Engineering, p. 370, Table 8.5 [4].

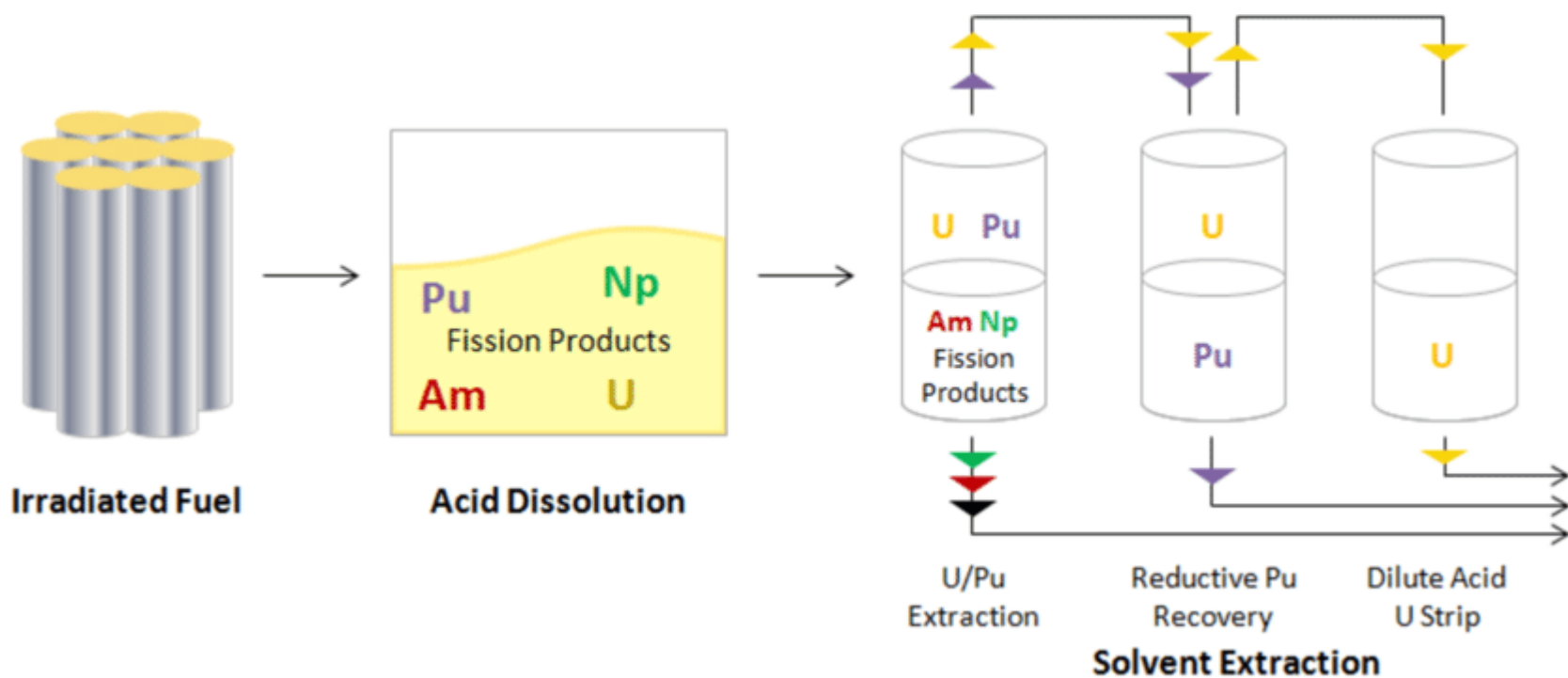
Riprocessamento del combustibile nucleare

Riciclo U e Pu per MOX

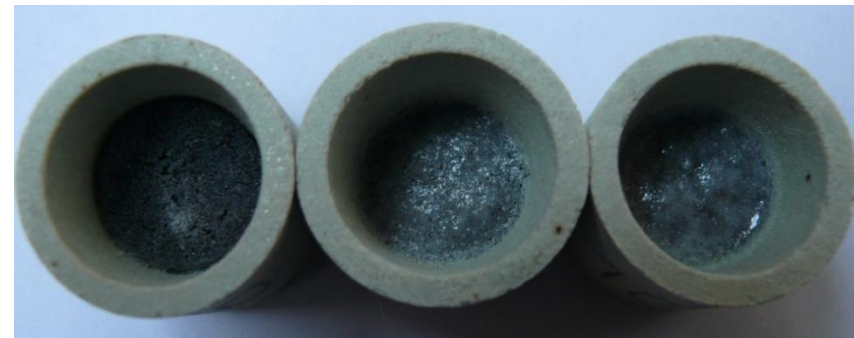
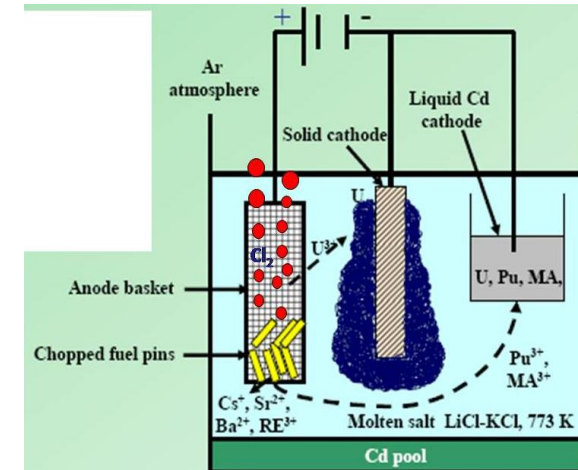
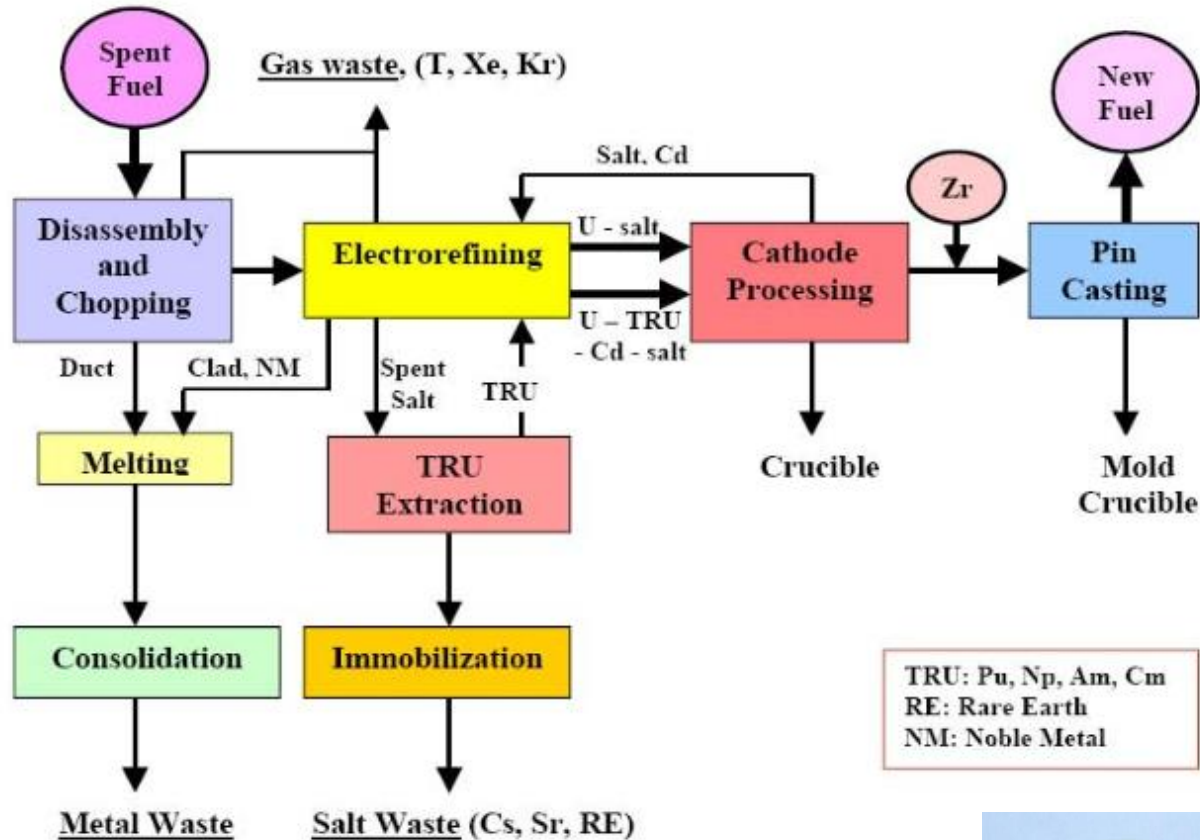


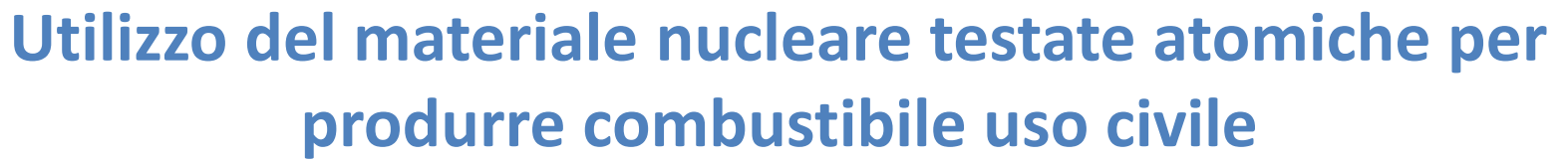


Separazione di U e Pu con solvente in soluzione acquosa (PUREX)



PYRO TREATMENT OF METAL FUEL





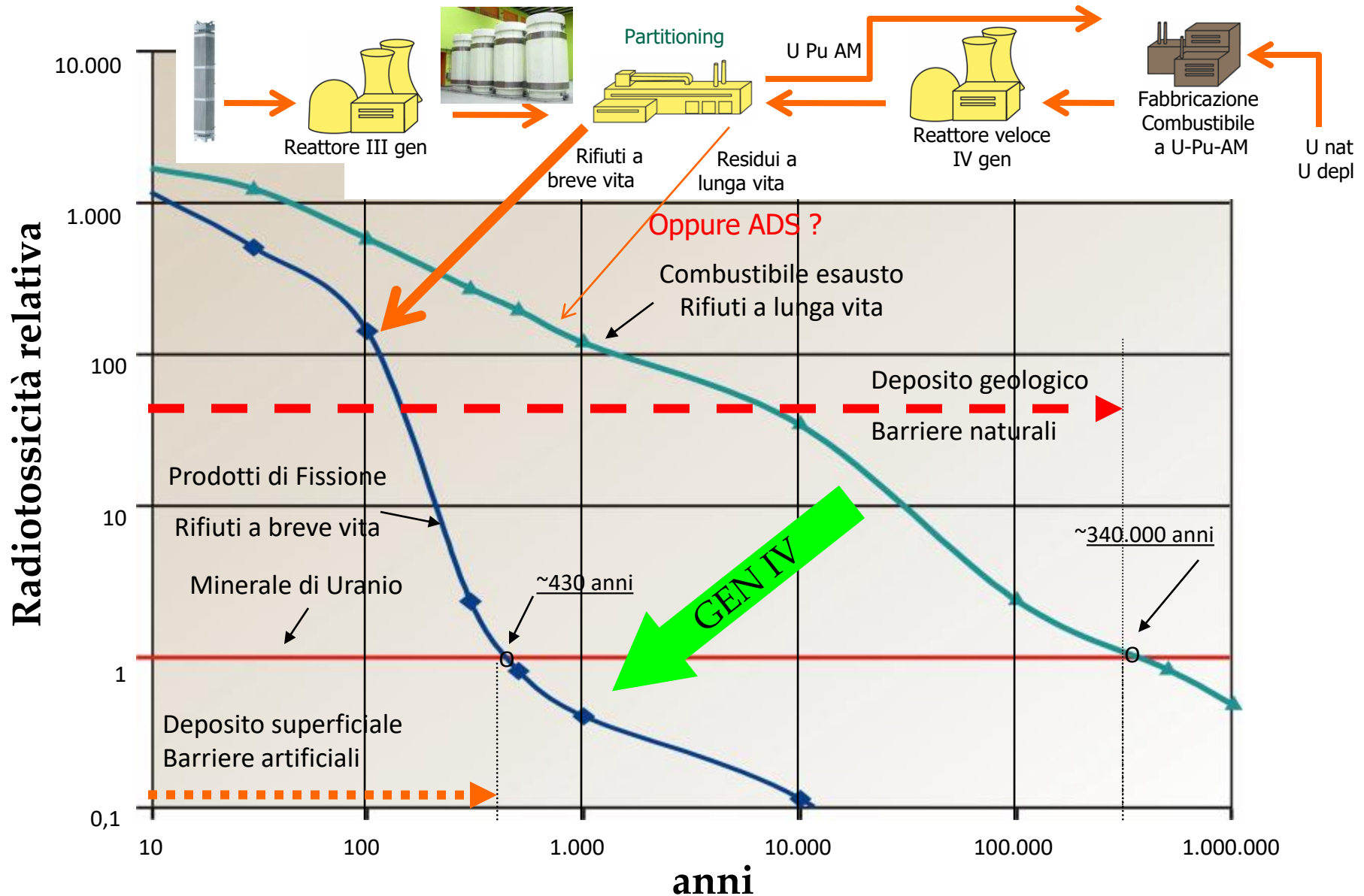
The diagram illustrates the nuclear fuel cycle with the following components and flows:

- HEU - PU DOWN BLENDING** (Yellow box): The starting point for fuel blending, receiving input from LEU and PU.
- LEU DOWN BLENDED MOX** (Blue box): The result of blending LEU and PU, which is then sent to fuel fabrication.
- Fuel Fabrication** (Dark blue box): Processes **Fresh UO_2** and **Fresh MOX** into fuel for the reactor.
- Reactor** (Dark blue box): The core of the cycle where fuel is used to generate power.
- Storage** (Dark blue box): Contains **Pool** and **Dry Cask** storage for spent fuel.
- Reprocessing Facility*** (Dark blue box): Processes **Spent MOX** and **Spent UO_2** into **Reprocessed Uranium**.
- Disposal** (Dark blue box): The final destination for **Depleted Uranium** and **Deconversion of Depleted Uranium**.
- Uranium Recovery** (Dark blue box): Includes **In Situ**, **Mining**, and **Heap Leach** methods to extract **Natural Uranium**.
- Conversion** (Dark blue box): Converts **Natural Uranium** into **Enrichment**.
- Enrichment** (Dark blue box): Produces **Enriched Uranium** from **Depleted Uranium**.
- Depleted Uranium** (Dark blue box): The byproduct of enrichment, which can be sent to disposal or reprocessed.
- Uranium-Plutonium Mixture** (Dark blue box): The result of reprocessing, which is then sent to fuel fabrication.



Downblending di HEU/Pu weapon-grade a LEU grade

Ciclo chiuso con reattori a neutroni veloci (Gen IV)



RIFIUTI A BREVE-MEDIA VITA / LLW-ILW

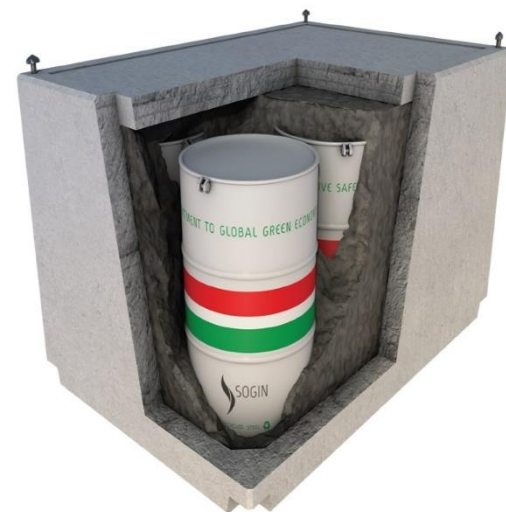
PRIMA BARRIERA: MANUFATTO

I rifiuti radioattivi, condizionati con matrice cementizia in contenitori metallici (**manufatti**), vengono trasferiti al Deposito Nazionale



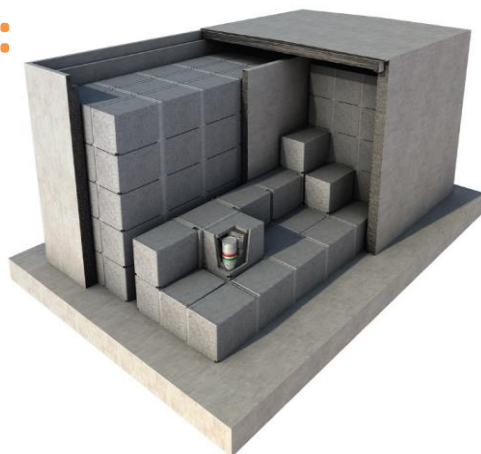
SECONDA BARRIERA: MODULO

I manufatti vengono inseriti e cementati in **moduli** di calcestruzzo speciale (3m x 2m x 1,7m), progettati per resistere 350 anni



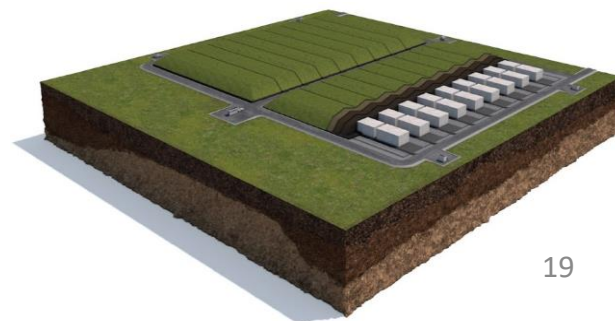
TERZA BARRIERA: CELLA

In ogni **cella** di cemento armato (27 m x 15,5 m x 10 m), progettata per resistere almeno 350 anni, vengono inseriti 240 moduli



QUARTA BARRIERA: COPERTURA MULTISTRATO

Una volta riempite, le celle (circa 90) vengono sigillate e ricoperte con più strati di materiale per prevenire le infiltrazioni d'acqua



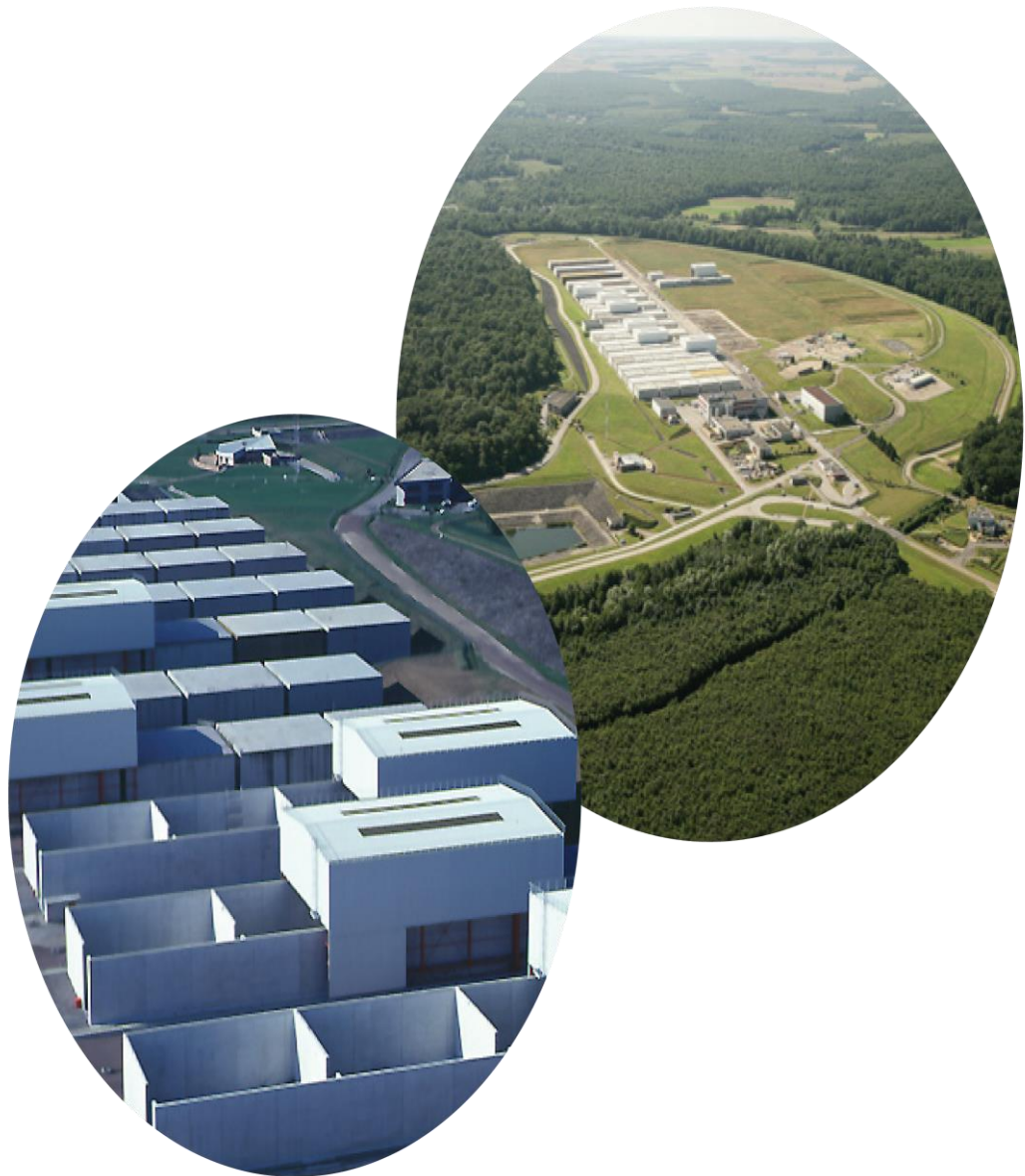
ESEMPI DI DEPOSITO DEFINITIVO FRANCESE (L'AUBE)

RIFIUTI A BASSA E MEDIA ATTIVITÀ

 Capacità : 1.000.000 mc
Esercizio: dal 1992



ESPERIENZE INTERNAZIONALI





Conclusioni

Basta cambiare paradigma e considerare i rifiuti radioattivi
risorse pregiate

- Risorse energetiche (materiale nucleare combustibile di altissimo valore energetico)
- Radioisotopi (prodotti di fissione) per usi medici, industriali e per la ricerca scientifica e tecnologica che bisognerebbe comunque produrre

Questo consente, inoltre:

- Aumento della produttività specifica (MWh/Ton U estratto)
- Riduzione drastica dello scarto finale (ultimate waste)
- Sostenibilità ambientale in estrazione e smaltimento

Non chiamatele scorie !!!



Source: Philip Finck and Massimo Salvatores, INL, FUNI-2, Frascati, October 2016