Muriel Rocher, François Marsal, Didier Gay, Marc Philippe, Delphine Pellegrini

International overview of investigated alternatives to deep geological disposal of high-level waste and long-lived intermediate-level waste

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

MEMBER OF ETSON | EUROPEAN TECHNICAL SAFETY ORGANISATIONS NETWORK

EUROSAFE | 2019

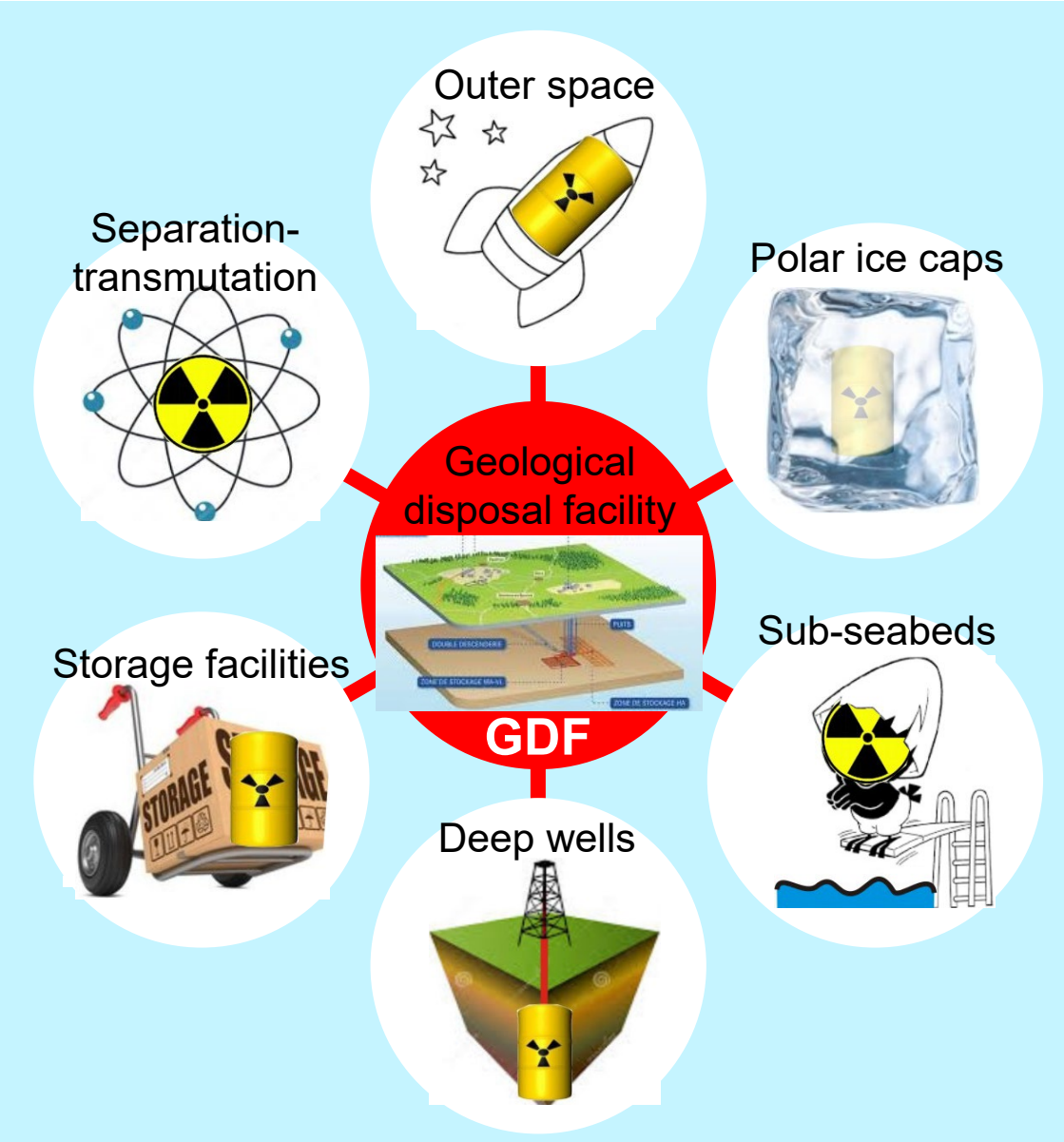
Introduction

- Request of *National Commission for Public Debate* to prepare the public debate on the *national plan for radioactive materials and waste* (PNGMDR, 2019-2021)
  pngmdr.debatpublic.fr
- Literature review conducted by IRSN, based on public documents from
  - international agencies (IAEA, OECD/NEA in particular)
  - national institutional organizations
  - scientific journals,
  - non-governmental organisations…
- Not intended to be exhaustive and to provide IRSN's point of view, but
  - historical and scientific keys to understand in which context the different considered options for managing HLW appeared and were explored
  - technical and societal questionings associated to these options

➢ Complete IRSN report (French or English) on *www.irsn.fr*

6 families of alternatives identified

(for HLW and IL-LLW)



Launching into outer space

Principles

- Permanently rid the Earth of the most harmful radioactive waste
  - Launching beyond the atmosphere, using spacecraft
  - Several ultimate destinations were considered, including the sun

Options explored around the world

- In the 1970s: studied by NASA (United States)
  - Only for most harmful waste that would result from the envisioned reprocessing of SF
  - waste package must withstand any situation of atmospheric transfer or falling (thermal and mechanical resistance), while remaining extremely light
  - launching into a low Earth orbit on board of a space shuttle, then transport using a space tug (or a heavy launcher) to the Moon, in orbit around the sun, etc.
- Also USSR & Kazakhstan in the 1980s; US researchers in space technology…

Obstacles faced/ perspectives

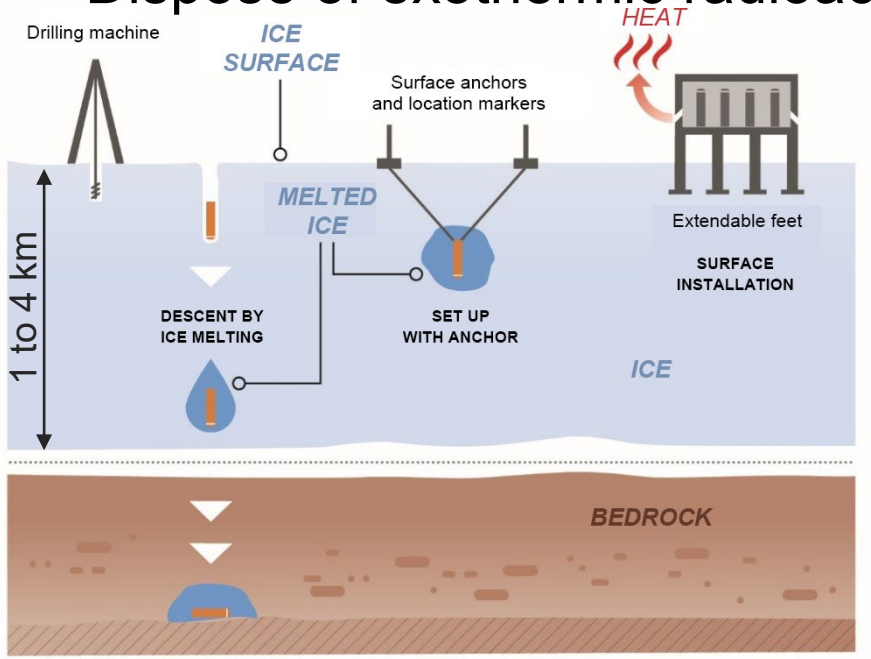
⊖ Abandoned because:

- Excessively high cost
- Requirements on waste packages
- Political and legal aspect
- Accidents of the space shuttles Challenger in 1986 and Columbia in 2003…

Option not specifically studied in **France**

Immobilize waste in polar ice caps

- Dispose of exothermic radioactive waste in ice sheets



- On the ice: its melting would lead to the gradual descent of the waste
- At shallow depth, restraining waste packages with cables to allow their retrievability
- In a surface repository that allows the heat to dissipate until the snow finally buries the facility

Studied by the United States until the 1980s

Not envisioned in France

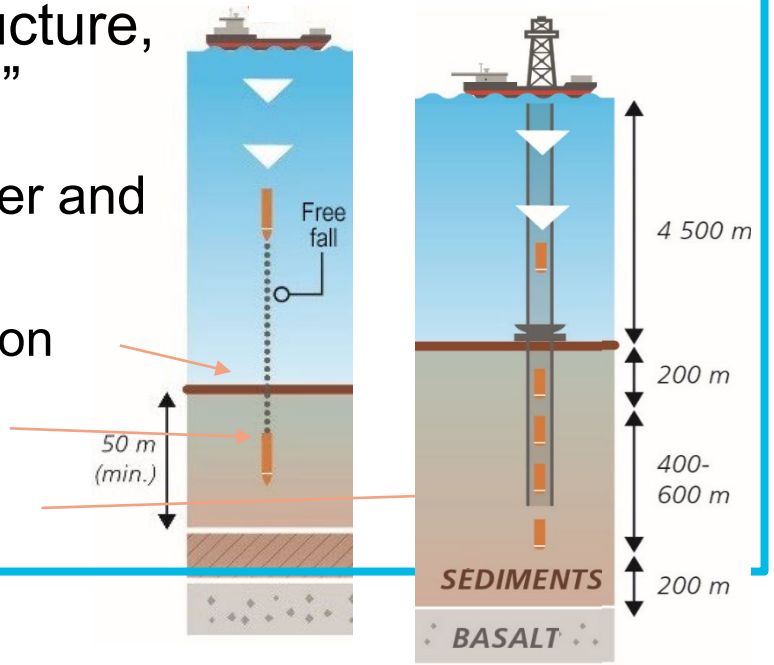
⊖ dropped out because:

- presence of salted pockets trapped in the ice → risk of extremely rapid corrosion of steels
- Stability problems associated with the movement of ice on the bedrock
- Impossibility to rest assured that the ice caps will remain for 100 000s years
- 1959 Antarctic Treaty; the Greenland icecap belongs to Denmark…

Sub-seabed disposal (1)

- Operated from a boat or an offshore structure, by means of **boreholes** or "**penetrators**"

1) Disposal in « **deep seabeds** » (>5000m water and fast sedimentation)
   - On the seabed → to be covered by sedimentation
   - Buried in the unconsolidated (soft) sediments
   - Placed into boreholes drilled in basement rock



🌍 From 1976, *Subseabed Disposal Program* (United States, France, United Kingdom, Japan…)

- Penetration tests of mock containers in sediments
- Various studies on heat transfer, diffusive transport, radiological impact…

→ Participation of **France**

No technical work nor reflection followed after 1986

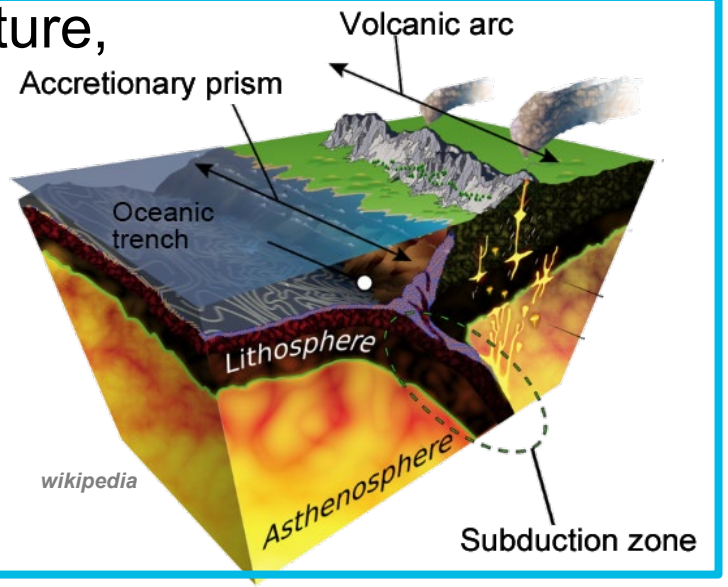
⊖ After USA withdrawal in 1986 + becoming inconsistent with changes in Maritime Laws (1972 London Convention, 1996 Protocol…) → progressively given up

Sub-seabed disposal (2)

- Operated from a boat or an offshore structure, by means of **boreholes** or "**penetrators**"

1) Dispose in « **deep seabeds** »

2) Dispose to the right of **subduction zones**



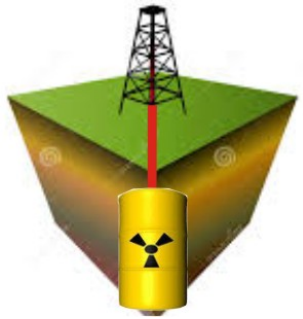
🌍 Phenomenon just known in 1960s → better understood in 1970s (USA, United Kingdom, Canada…)

→ Not envisioned by **France**

⊖ Discounted because:

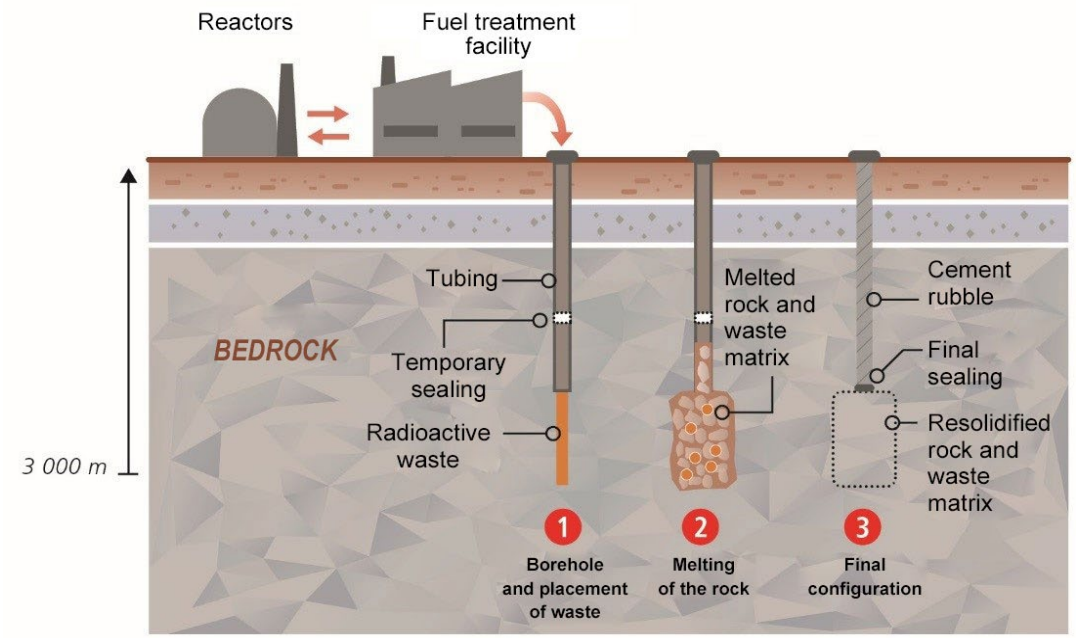
- Soft sediments on the crust tend to stay at surface (accretionary prism)
- Very slow process: 1 to 10 centimetres by year
- Earthquakes, explosive volcanisme

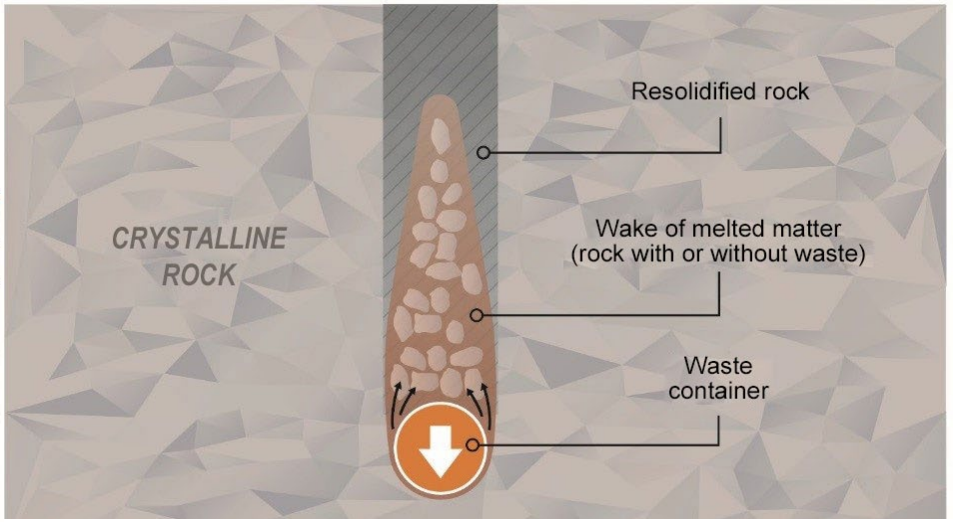
Borehole disposal (1)



- Waste placed in the bottom of deep rock excavations
  - As for an underground disposal facility, aims at isolating waste from the natural phenomena at surface, from humans and at preventing the dispersion of their contents into the environment …
  - …but operated from the surface and depth may be much higher

1) Immobilisation of exothermic waste by **melting of the rock**



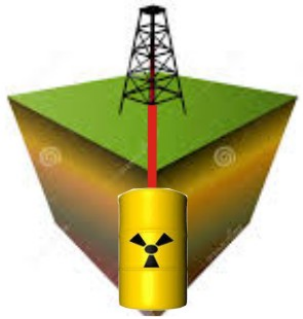


France : nuclear tests in Polynesia brought feedback.

Studies not pursued

⊖ Concepts aiming at melting the host rock were rejected

Borehole disposal (2)



- Waste placed in the bottom of deep rock excavations
  - As for an underground disposal facility, aims at isolating waste from the natural phenomena at surface, from humans and at preventing the dispersion of their contents into the environment …
  - …but operated from the surface and depth may be much higher

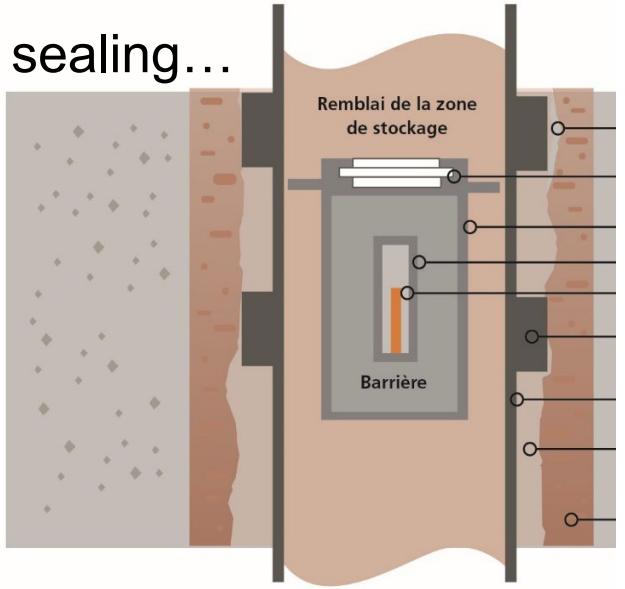
1) Immobilisation of exothermic waste by **melting of the rock**
2) Stacking of packaged **solid waste** in boreholes

- 1st concept in United States (NAS), 1957: Waste packages at bottom of boreholes of 5 000m
- Important technical progresses since 1980 → new impetus

Need for additional knowledge: digging at great depth, handling, sealing…

- ✓ Project of scientific borehole 5 000 m (DBFT) in USA
- ✓ Feedback /shallower boreholes for small volumes of waste /DSS (IAEA Guide, 2009)
- ✓ Scientific watch by UK, Sweden, Belgium, Germany, S Korea, China, Australia…

Not studied in **France**



Waste storage

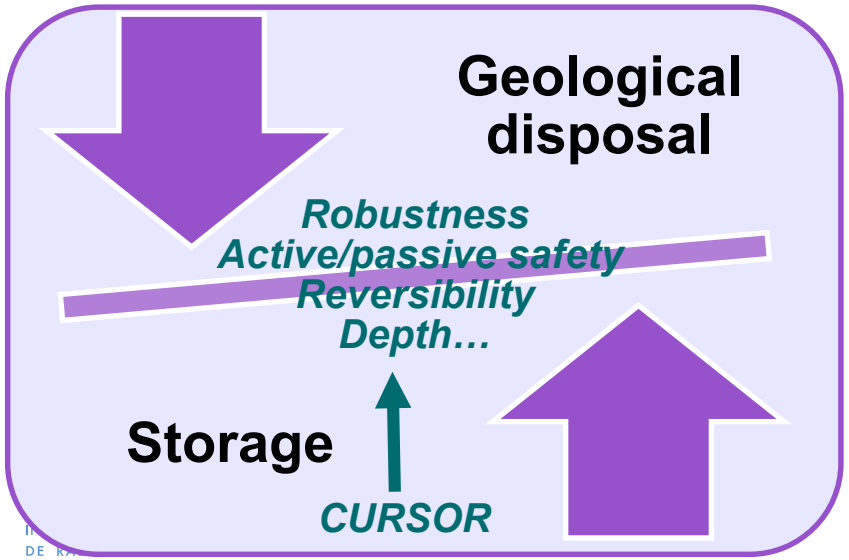
- Emplace waste in a safe location for a fixed duration
  - Remove it **≠ disposal** is definitive
  - **Active safety** : need human action ≠ disposal post-closure safety is passive

1) « **Long-term storage** » : a few hundred years

2) « **Permanent storage** » : likely to remain intact over up to 100 000s y

⇒ **giving the choice** *versus* **transfer the responsibility to future generations**

- Examined until 2004-2006 by United Kingdom, Canada, Switzerland, France…
- IAEA conference in 2003



In **France** :

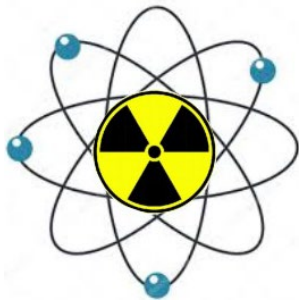
CEA studies 1991-2005 /« Bataille » Law:
- Concepts at surface and shallow depth, 300 y

Underground store /NGO, indep. experts…
- Convertible into GDF
- Interim solution (shallow surface in side of granite hill)+ further researches…

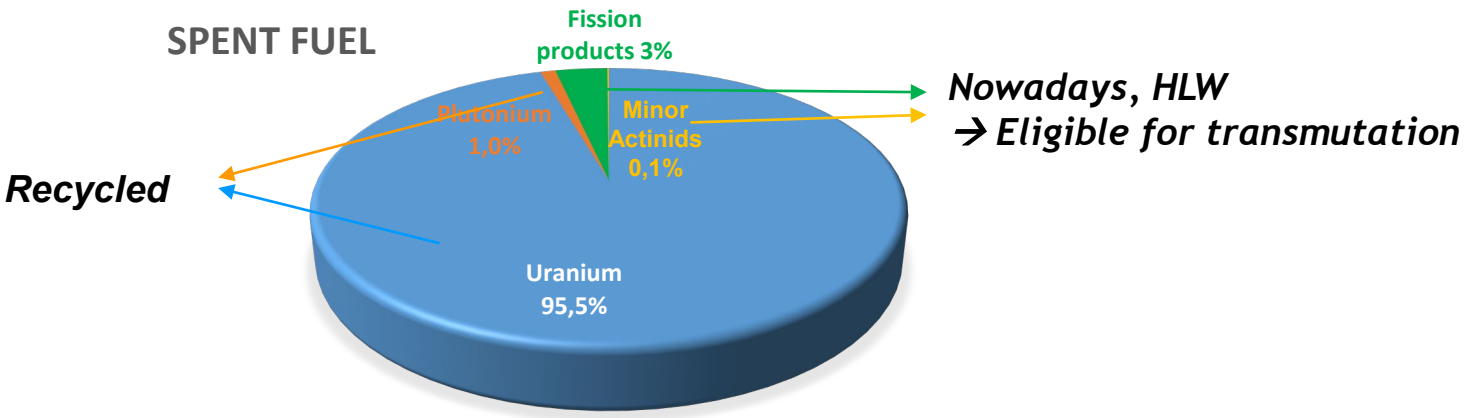
❙ Risk of abandon during thermal phase (exothermic waste)

✓Interim solution in Italy, The Netherlands…

Partitioning-transmutation (1)



- Make the HW-LL atoms less nocive/for shorter time



- **Partition** these elements (hydrometallurgical or pyrochemical processes)
- **Manufacture** the fuels or "transmutation targets" for irradiation
- Transmutation = **transfo an atom into another** by modification of its nucleus

⇒ Need for specific new nuclear facilities

Transmutation of **Fission Products**

🌍 simple **capture of a "slow" neutron** (those produced in almost all NPPs operated worldwide) → **Tests** carried out

In **France** :
CEA studies 1991-2005
(« Bataille » Law)

⊖ Complex partitioning (caesium 133), low transmutation rates (technetium 99), safety of reactors (iodine-129)… → studies not pursued

Partitioning-transmutation (2)

Transmutation of **Minor actinids**

= capture of a « **fast** » **neutron** then fission

⇒ **Several ways to generate fast neutrons :**

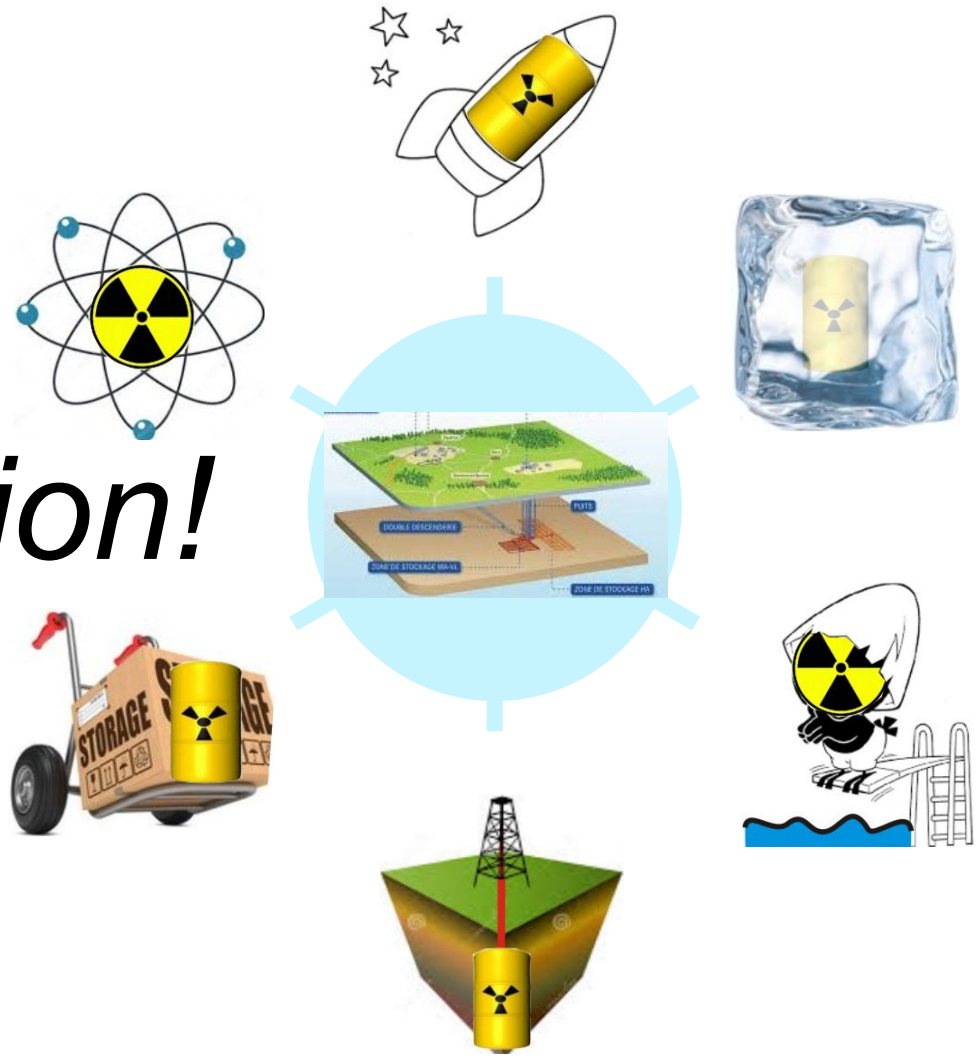
- **Fast Neutron Reactors** = FNR
  - Numerous FNR were operated by the past
  - ✓4 presently operated (Russia, India, China) + several projects…
  - ❙ For transmuting accumulated MA: need for a new fleet of reactors, operated for a long duration
- Dedicated system « **accelerator + reactor** » = ADS
  - Researches from various teams in the world (’80s-’90s)
  - ✓Projects in China, South Korea, India, Belgium (Myrrha)…
  - ❙ Multi-recycling needed (repeated passes in reactor)
- Dedicated system « **laser + reactor** »
  - ✓Team Pr. G. Mourou (France) : D ion accelerator driven by a laser → fusion D-D → fast neutrons → Molten salt reactor
  - ❙ Technological locks to undo at each step as well as for their combination

In **France** → CEA:

- Feedback Phénix & Superphénix
- ASTRID project (FNR-Na)
- Participation to the Myrrha project

⇒ **Transmutation in « new » reactors = Basic research**

Thanks for your attention!



IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

MEMBER OF
ETSON
EUROPEAN
TECHNICAL SAFETY
ORGANISATIONS
NETWORK

EUROSAFE | 2019