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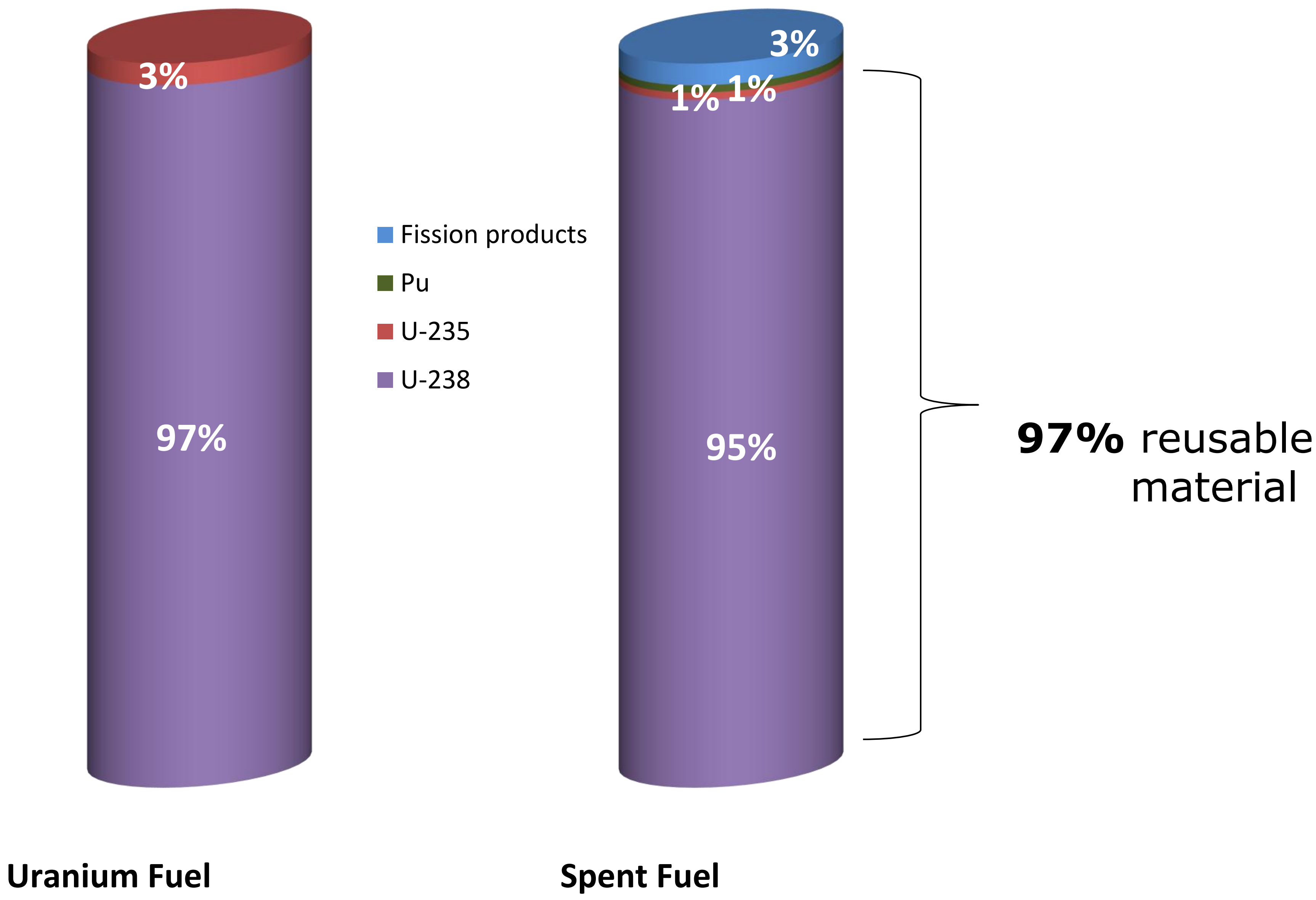
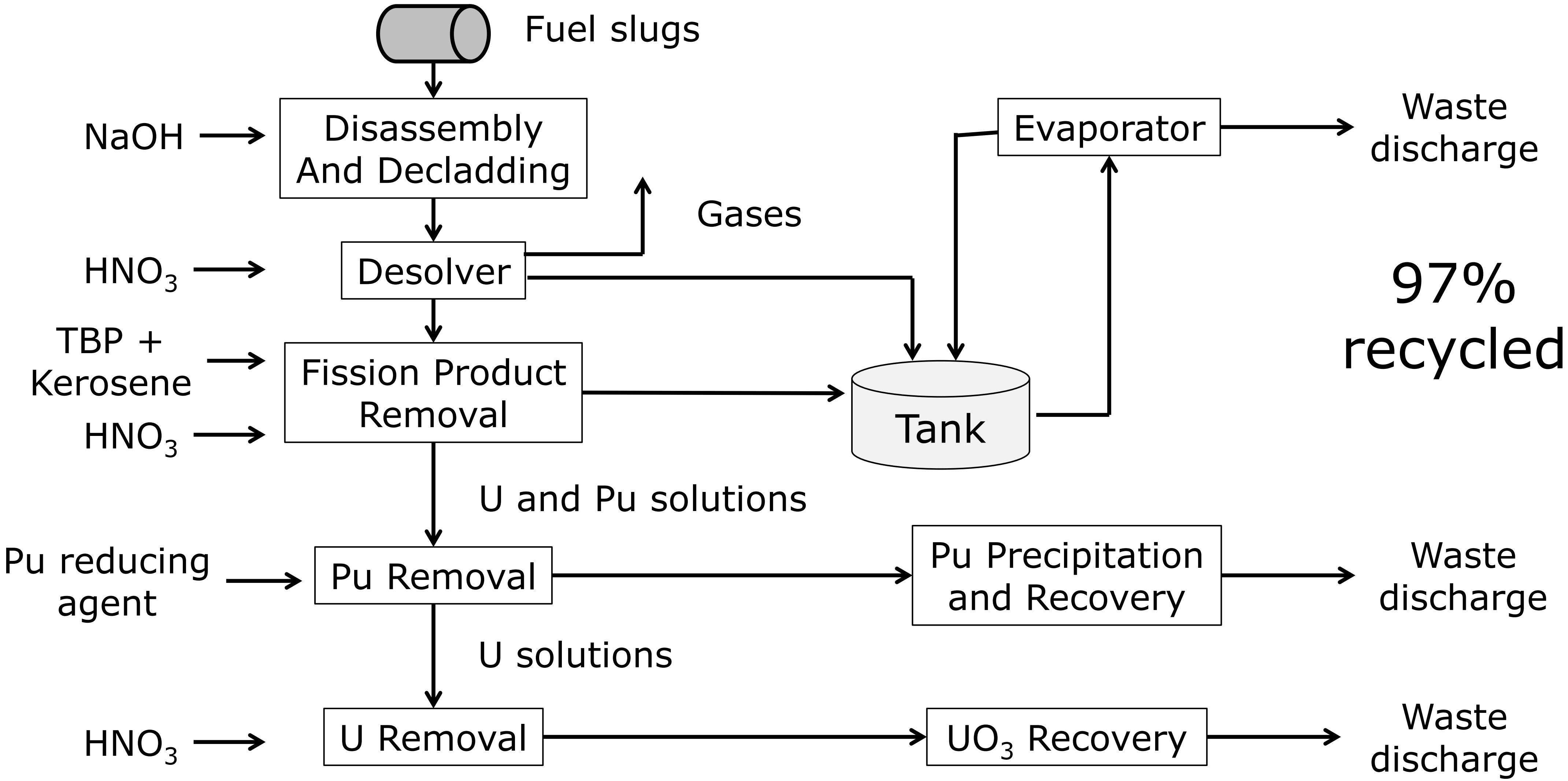
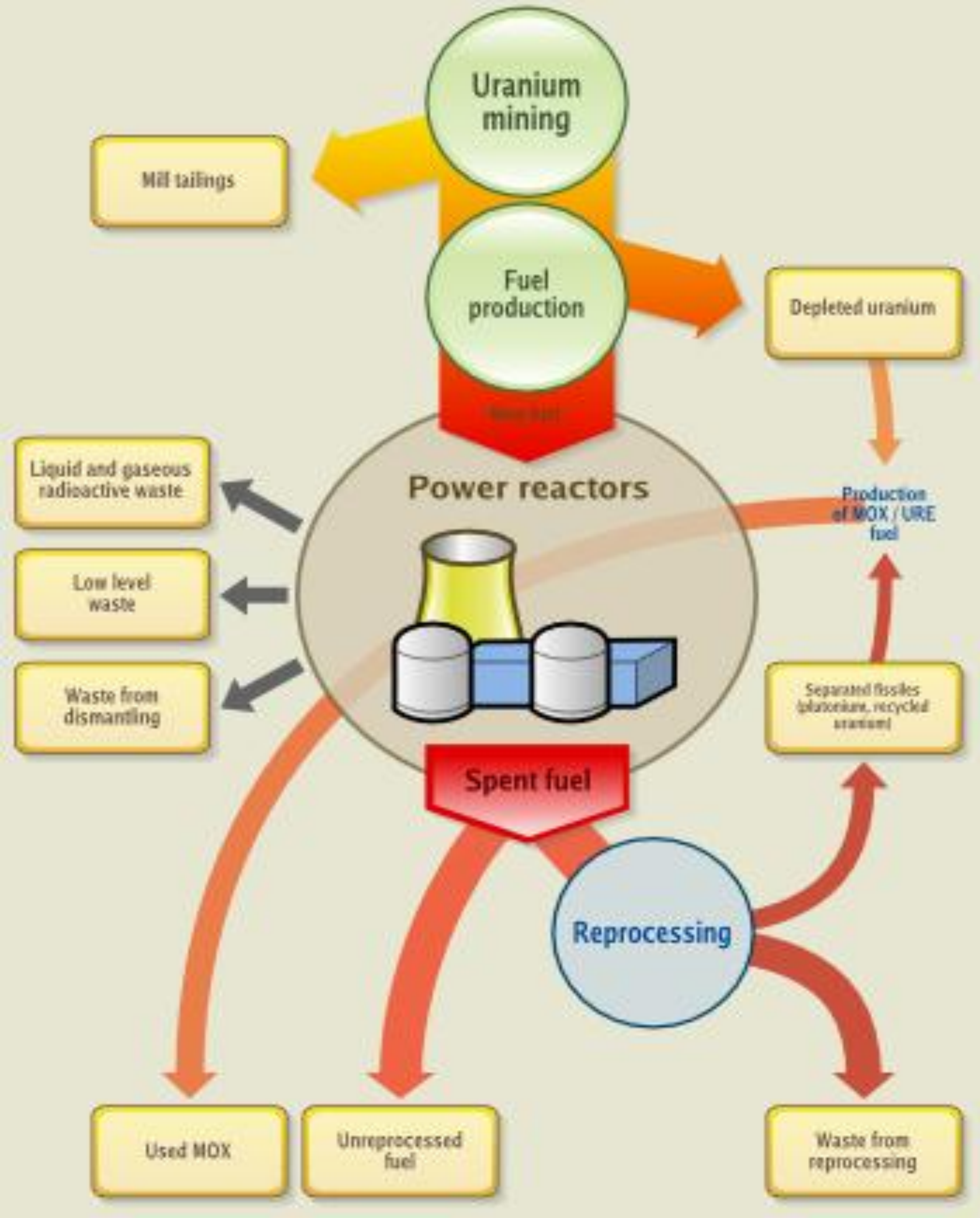
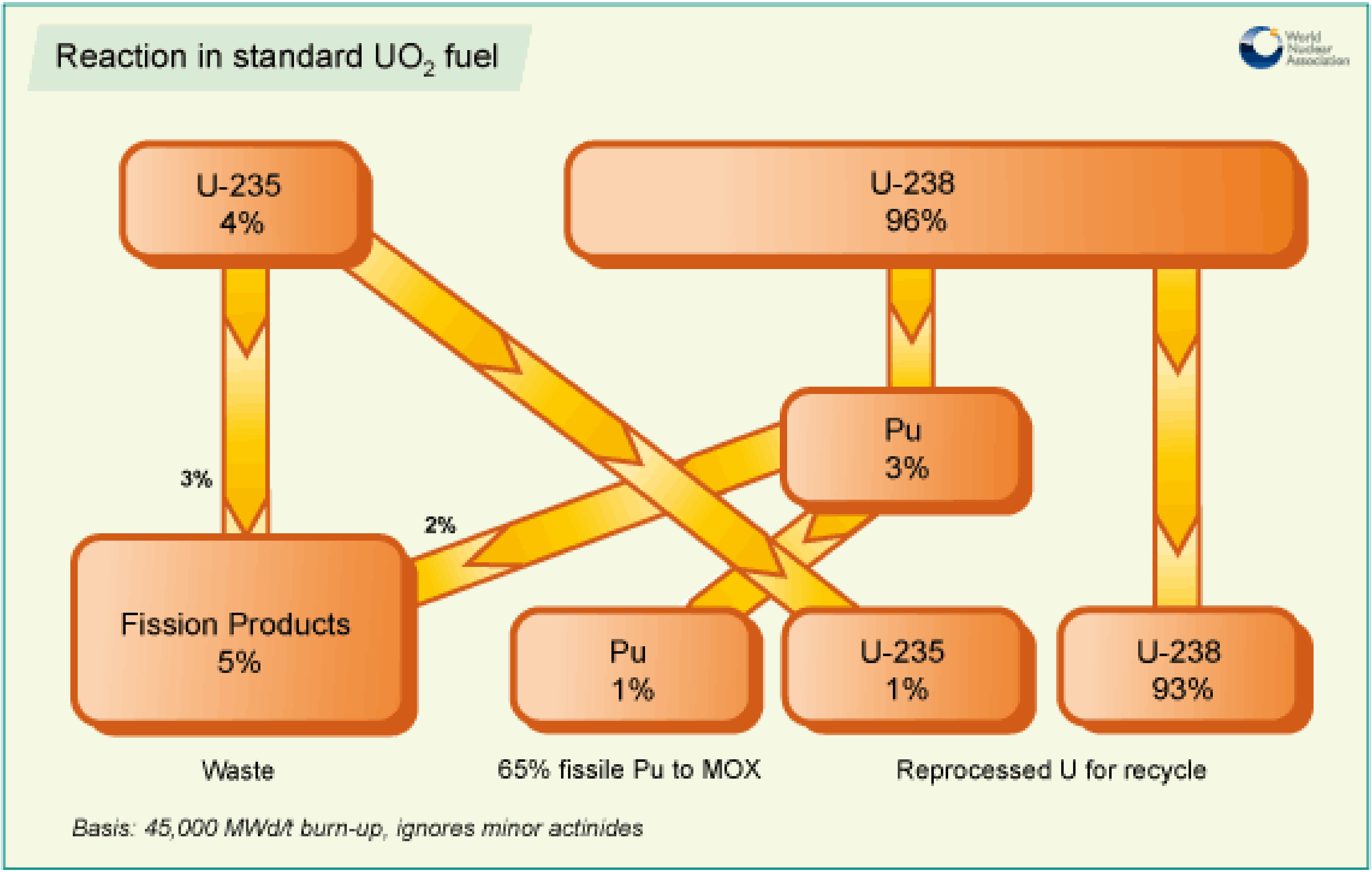
Spent nuclear fuel –
Handling the nuclear waste

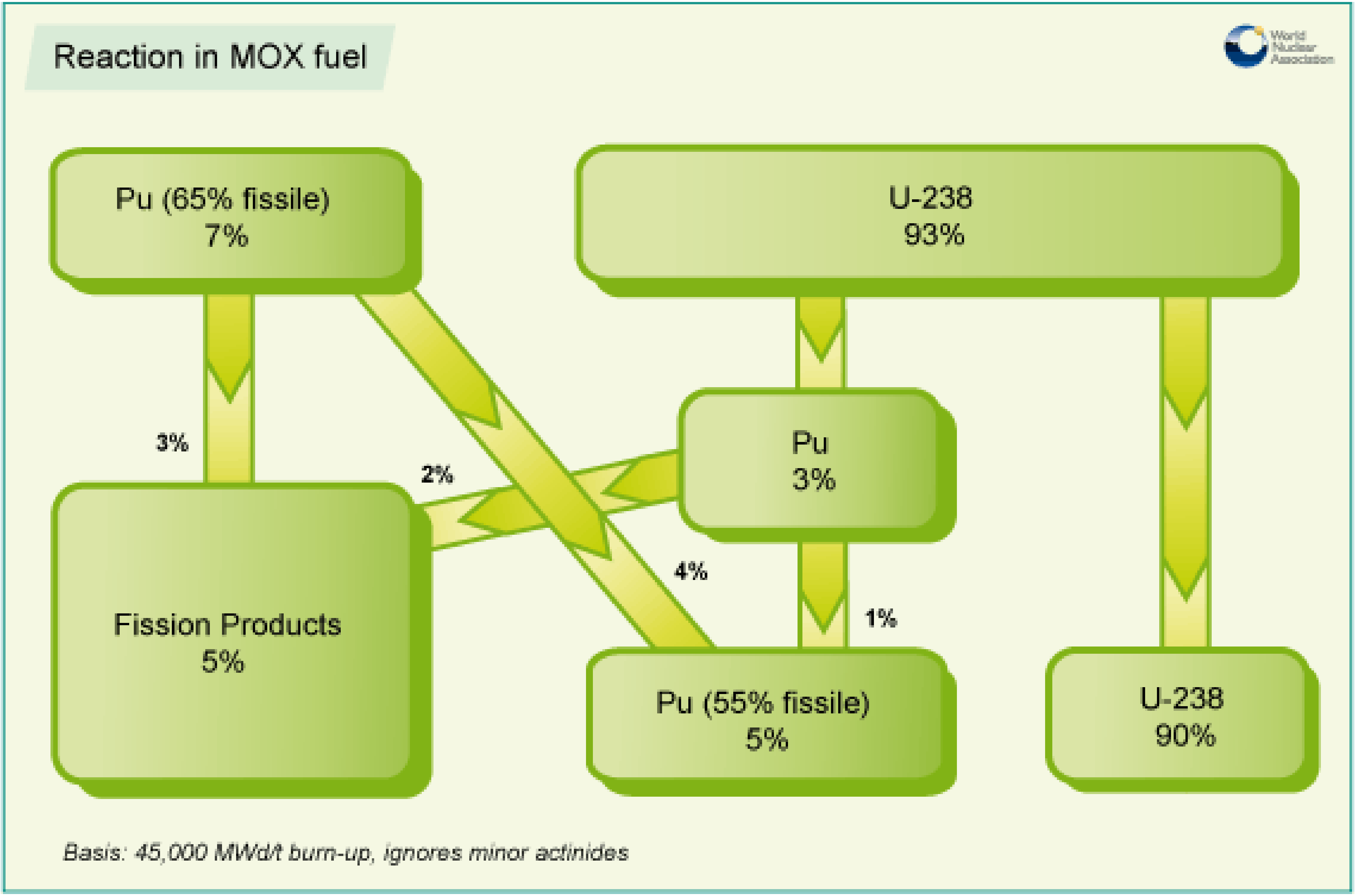

3%
97%
Fission products
Pu
U-235
U-238
3%
1%
1%
95%
97% reusable material
Uranium Fuel
Spent Fuel

Purex Reprocessing of Spent Fuel

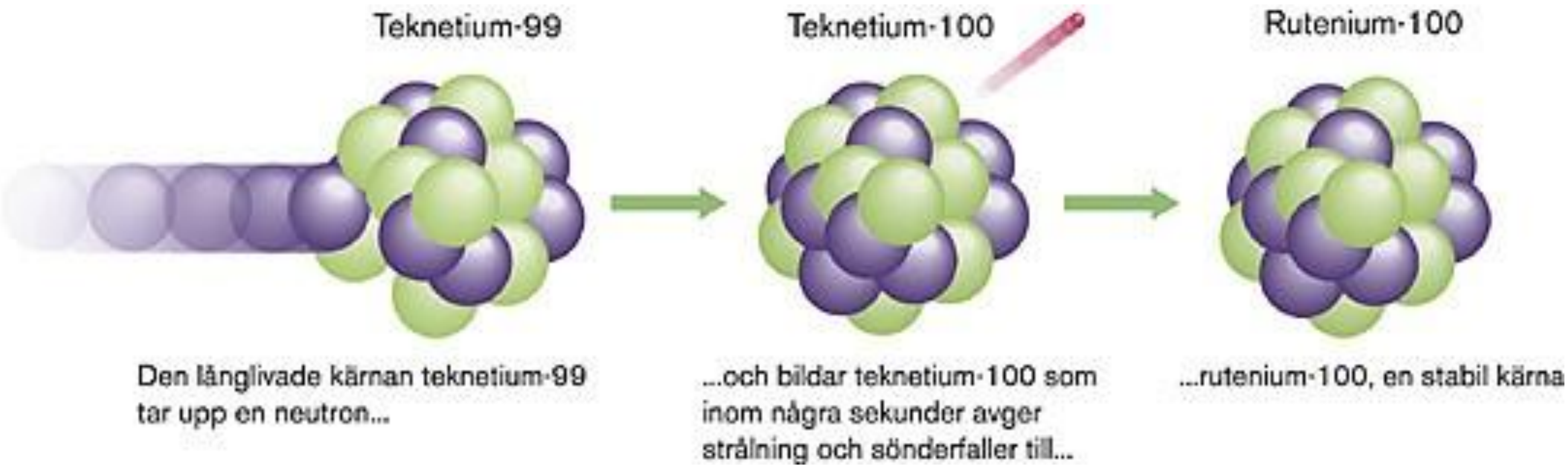



Uranium mining
Mill tailings
Fuel production
Depleted uranium
Power reactors
Liquid and gaseous radioactive waste
Low level waste
Waste from dismantling
Production of MOX / URE fuel
Spent fuel
Reprocessing
Used MOX
Unreprocessed fuel
Waste from reprocessing


Reaction in standard UO_2 fuel
World Nuclear Association
U-235
4%
U-238
96%
3%
2%
Pu
3%
Fission Products
5%
Pu
1%
U-235
1%
U-238
93%
Waste
65% fissile Pu to MOX
Reprocessed U for recycle
Basis: 45,000 MWd/t burn-up, ignores minor actinides

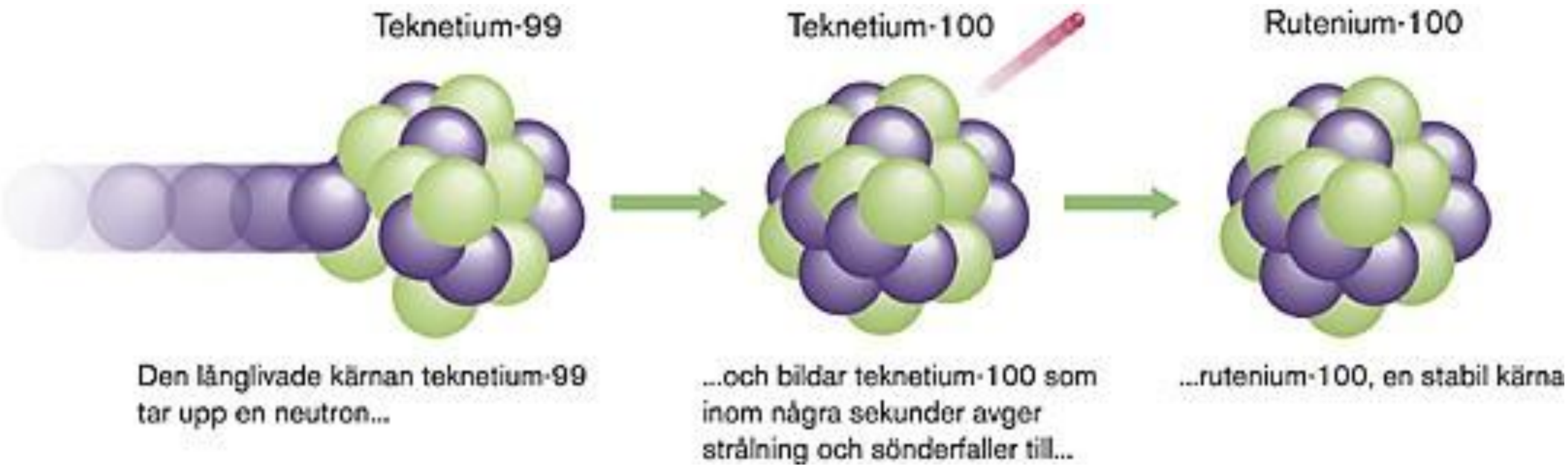

Reaction in MOX fuel
Pu (65% fissile)
7%
U-238
93%
3%
2%
Pu
3%
4%
1%
Fission Products
5%
Pu (55% fissile)
5%
U-238
90%
Basis: 45,000 MWd/t burn-up, ignores minor actinides

Transmutation of actinides in the nuclear waste



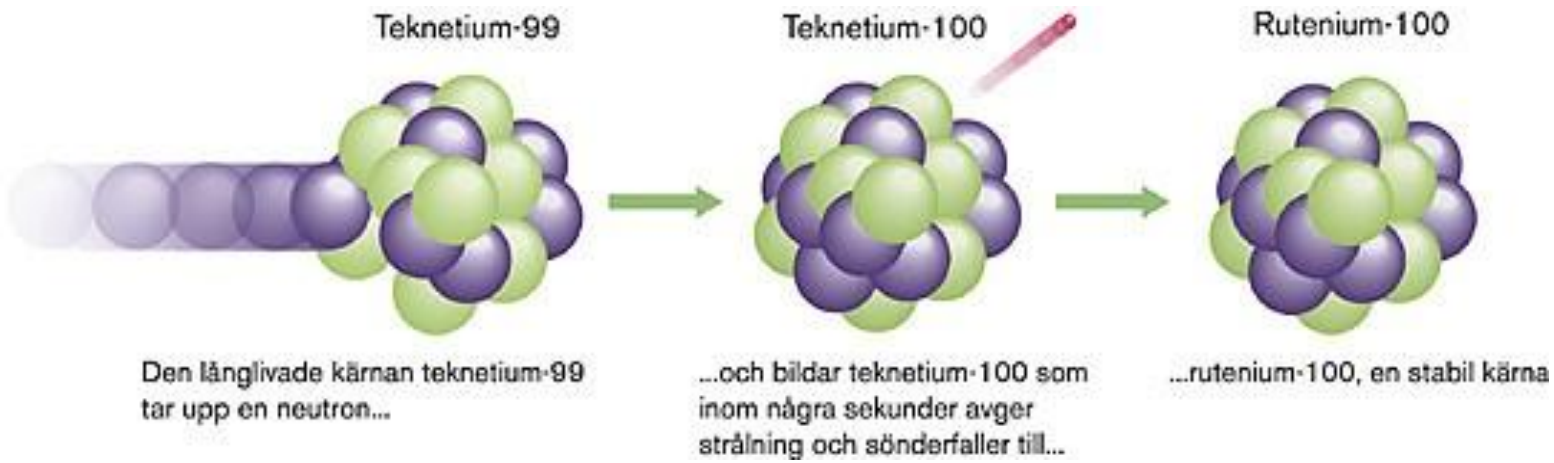
Needs separation in long-lived and short-lived actinides

Transmutation, continued



Tranmutation of actinides such as Pu, Np, Am and Cm could decrease the problems around nuclear waste by reducing the part of long lived isotopes

Transmutation



- Large technical and economical uncertainties
- Transmutation plants will probably be big complex involving several countries
- All long-lived isotopes cannot be eliminated

=> Repositories for spent fuel still needed

Transmutation

- Cs-137 & Sr-90 dominates up to 500 years
- Cross sections low i.e. are not helped by transmutation
- Pu the most important actinide in long time perspective, but can be used again in MOX-fuels for example

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Radioactive waste management

Principles

- Concentrate and contain
- Dilute and disperse
- Delay and decay

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Waste produced in the nuclear industry

Low-level waste (LLW):

Intermediate-level waste (ILW):

High-level waste (HLW):

Countries’ choice of repositories

Sweden – Deep granitic bedrock repository

Finland – Deep granitic bedrock repository

Canada – In Sedimentary rocks, or crystalline bedrock

Belgium – Boom clay, enormous clay natural clay formations

China – So far reprocessing. Prospect of a deep granitic bedrock repository

France – So far reprocessing in Le Hague, but will probably get a deep bedrock repository

Germany – On hold, probably deep waste disposal in salt domes

India – Research on deep bedrock repositories

Japan – Reprocessing a lot of fuel but have decided on a deep bedrock repository

Korea – Envisaged deep geological repository

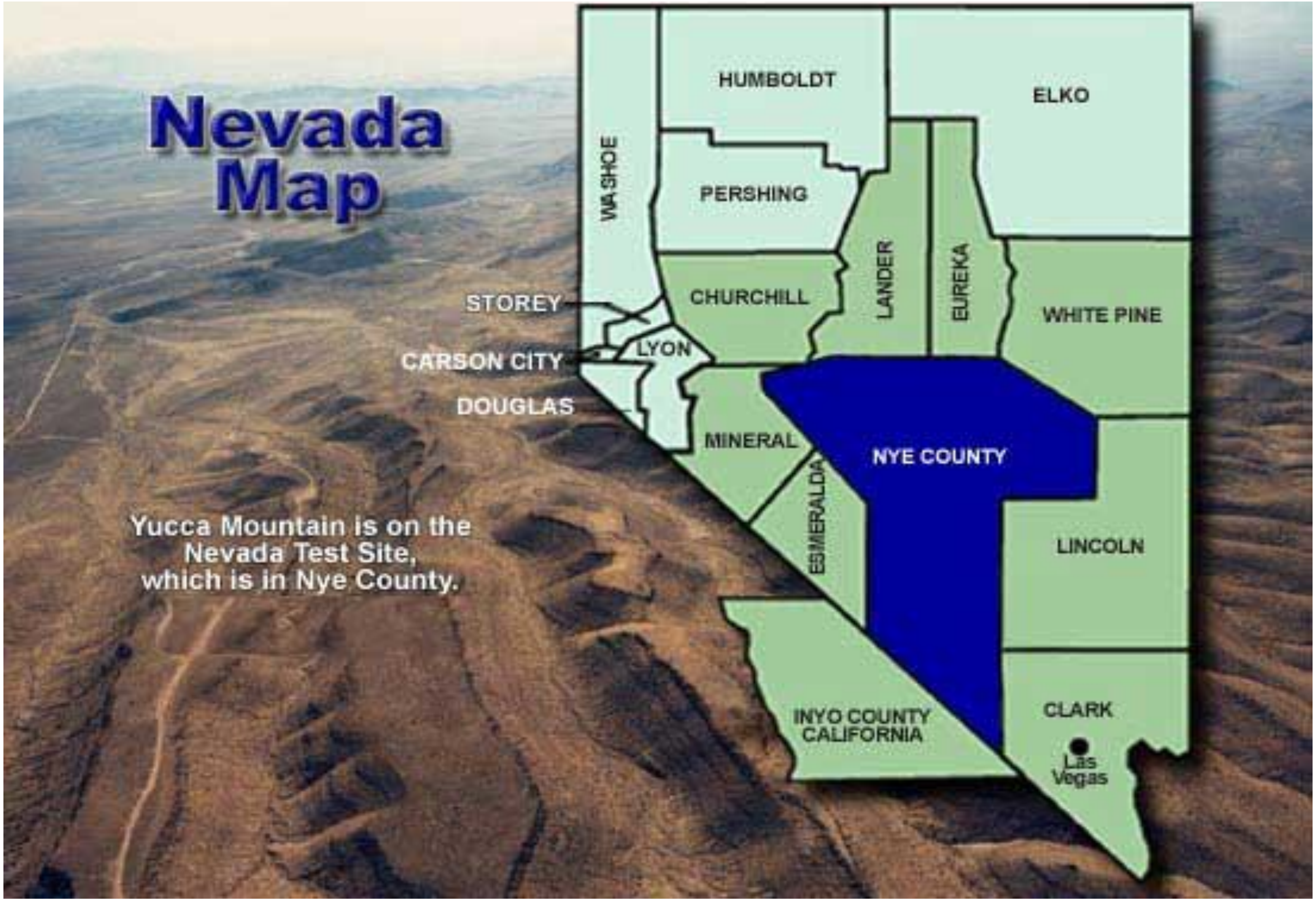
Russia – No waste repository is available, site selections is proceeding in granite in Kola peninsula

Spain – Have research ongoing on deep geological repositories, transmutation and salt domes

Switzerland – Reprocessing and have to decide what to do with waste. Have found sites in clay.

USA – ??

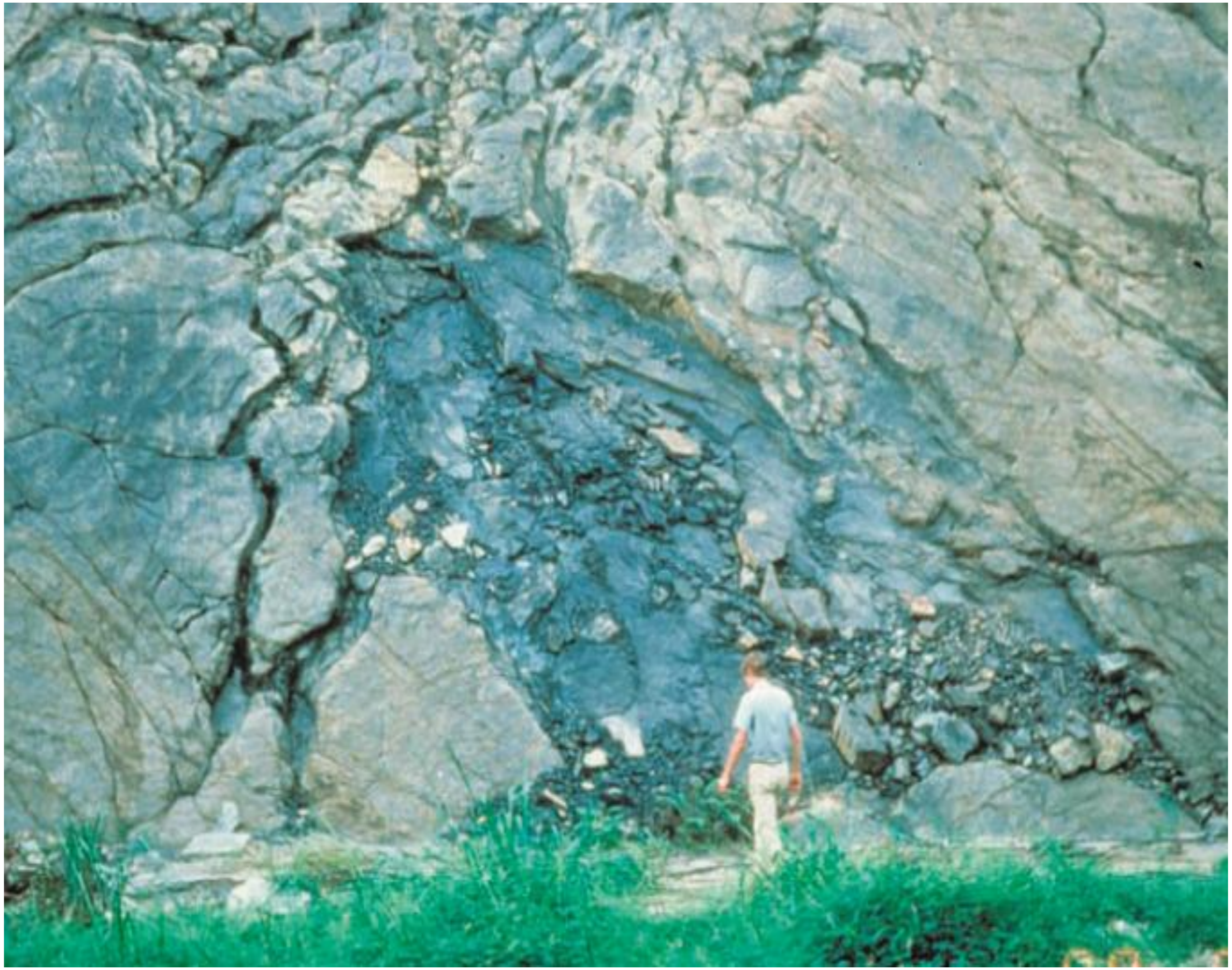
Yucca mountain



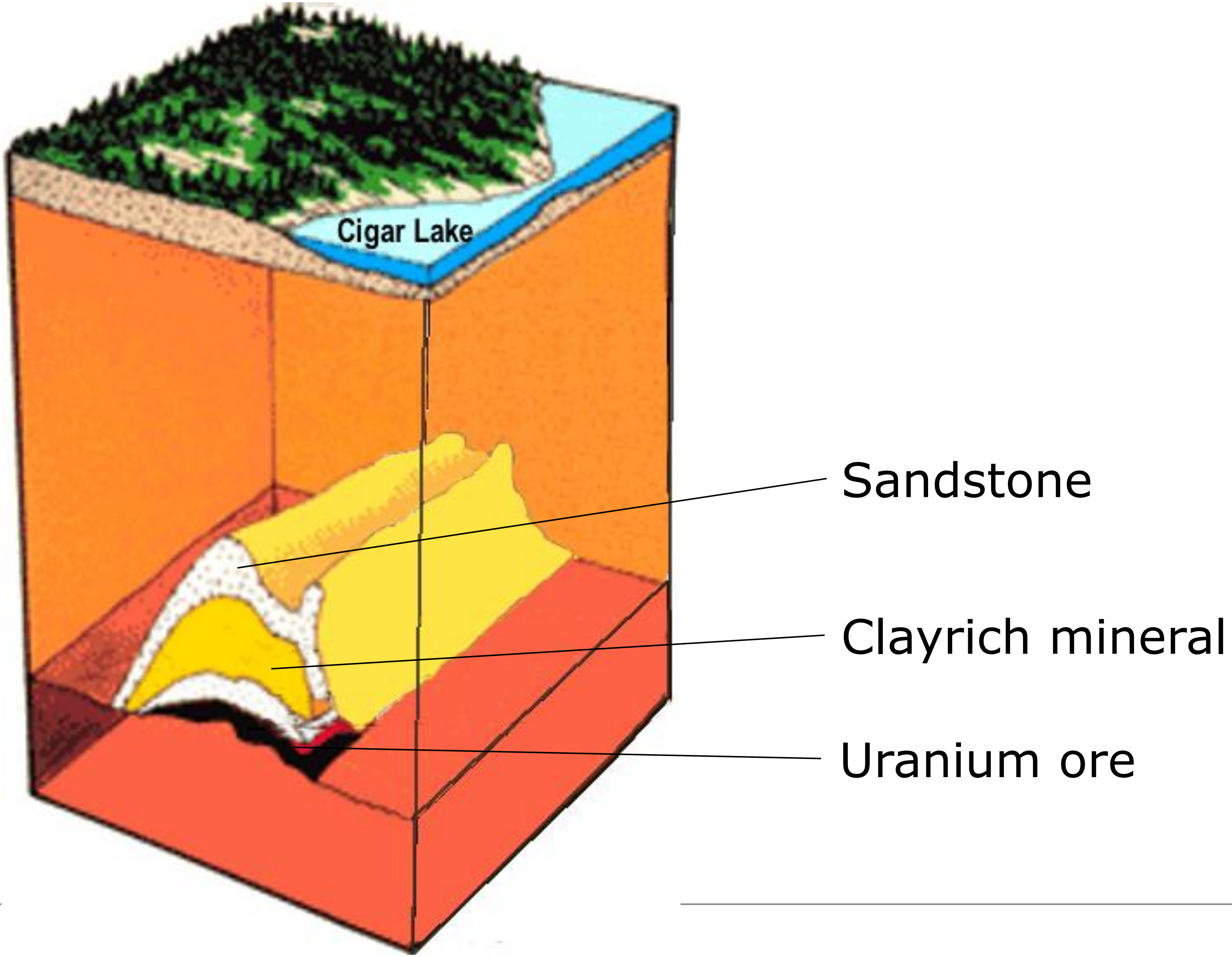
Natural Analogues: Oklo, Gabon

Oklo, Gabon

in West Africa



Natural Analogues: Cigar Lake, Canada



The Swedish concept

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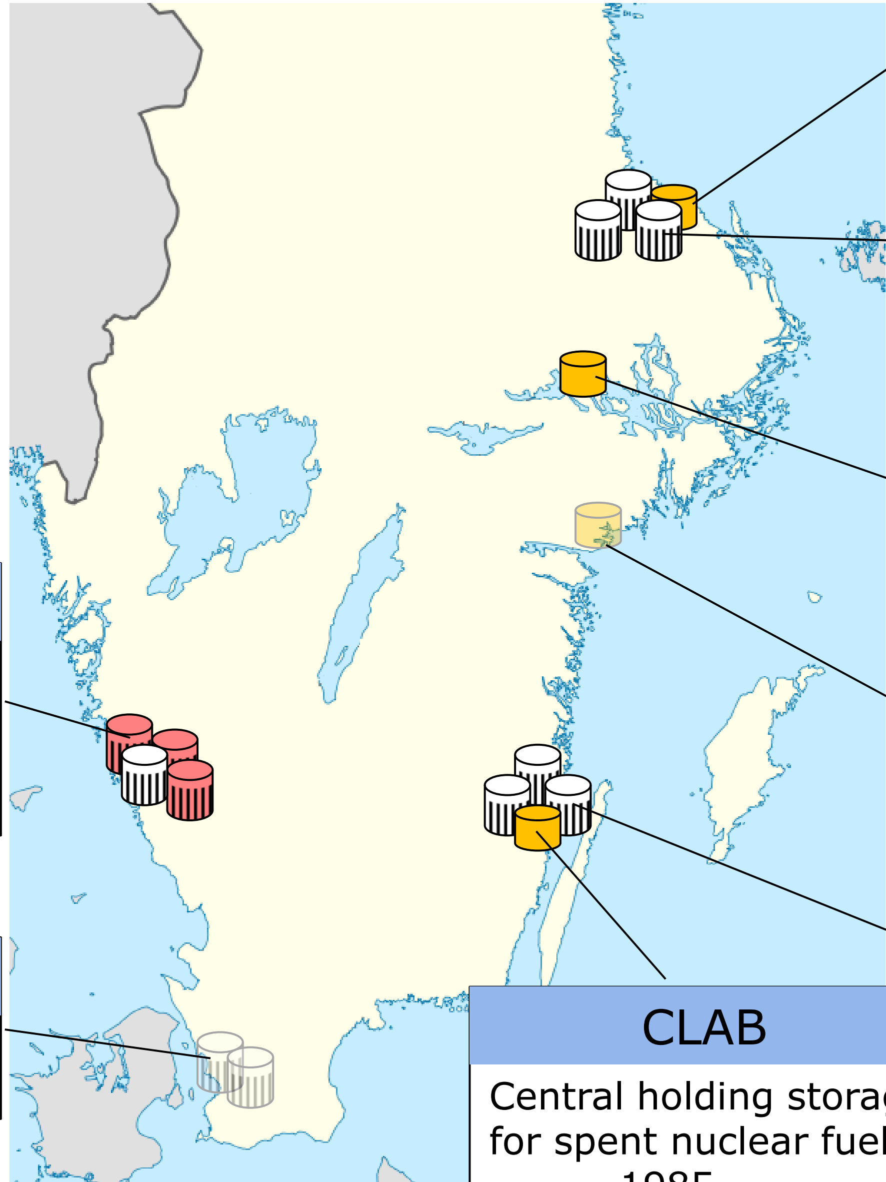
Swedish Nuclear Power System

BWR (ASEA Atom)

PWR (Westinghouse)

Other



SFR

Low- and intermediate level waste repository
1988

Forsmark

FI	1006 MW	1980
FII	1006 MW	1981
FIII	1200 MW	1985

Västerås

Nuclear Fuel Factory
1971

Studsvik

Research reactor
1960 - 2005

Ringhals

RI	860 MW	1976
RII	917 MW	1975
RIII	1045 MW	1981
RIV	960 MW	1983

Barsebäck

BI	615 MW	1976-1999
BII	615 MW	1977-2005

CLAB

Central holding storage for spent nuclear fuel
1985

Oskarshamn

OI	500 MW	1972
OII	630 MW	1975
OIII	1450 MW	1985

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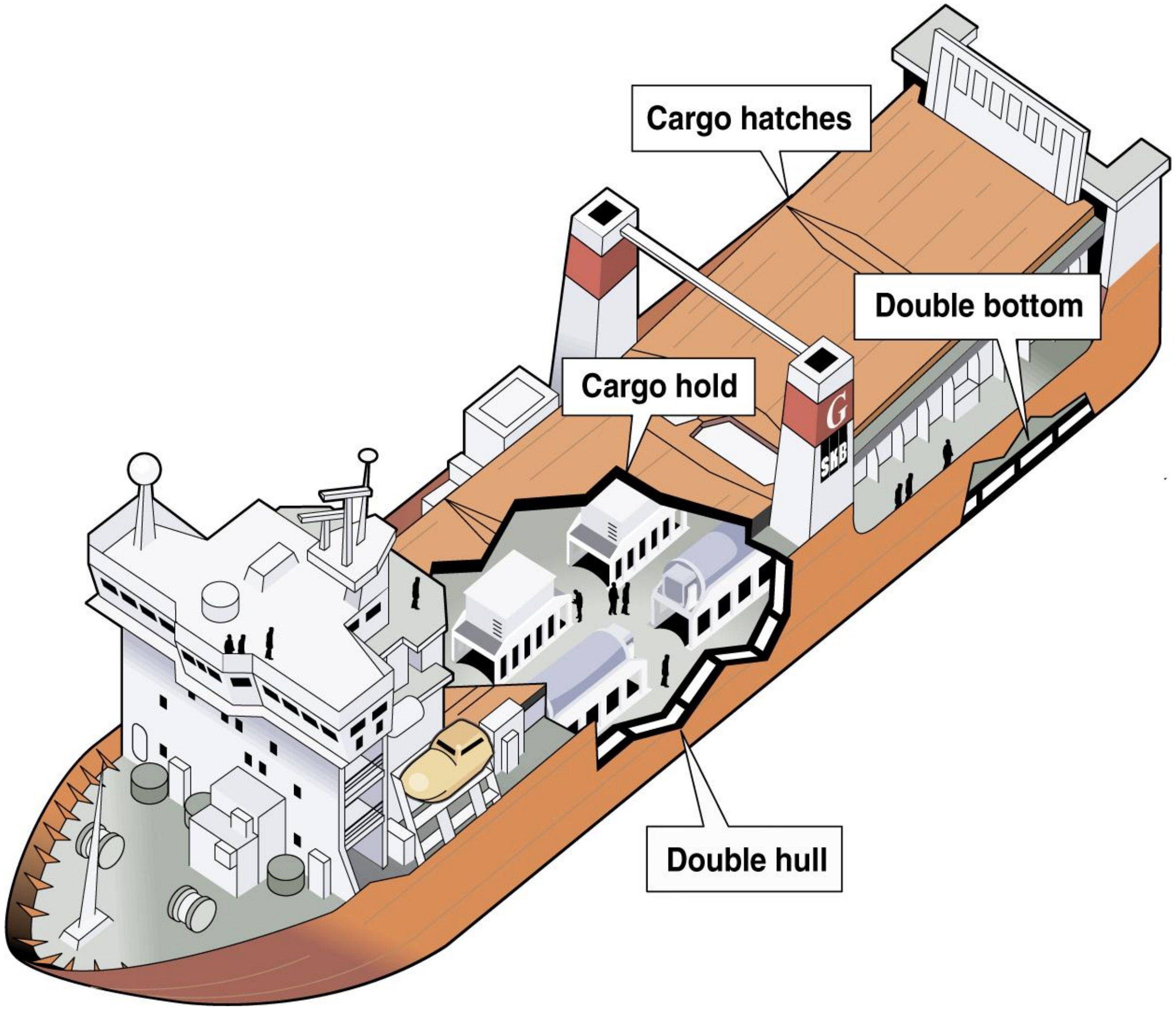
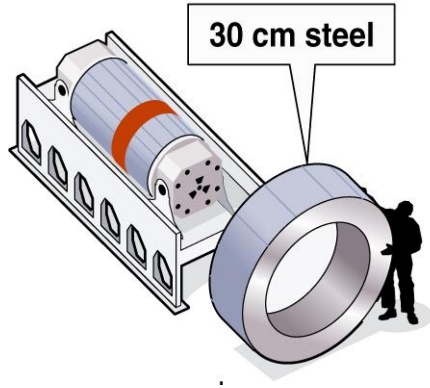
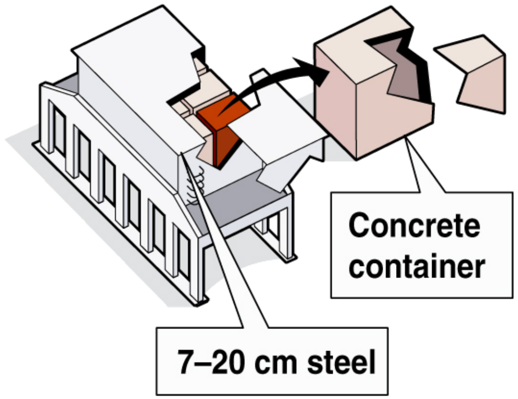
m/s Sigyn



Transport casks





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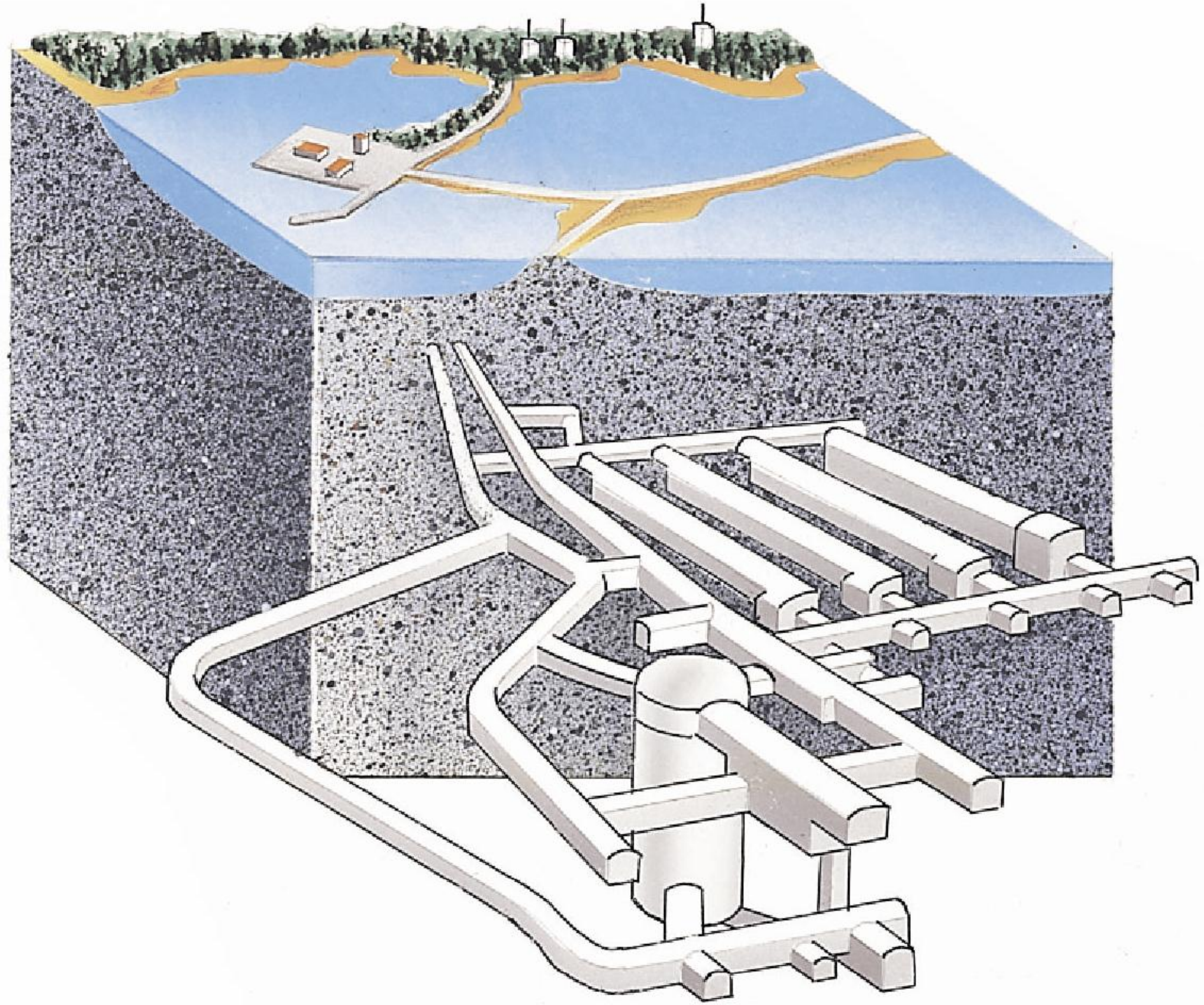
SFR –Final storage of low level waste

- Low active waste from operation of nuclear power plants; clothes, replaced parts from plants, ion exchangers. Also radioactive material from health care, industry and research.
- After 500 years the waste in SFR will not be radioactive
- SFR is built to last 10 000 years
- 2010 SFR was extended from 63 000 m^3 to 200 000 m^3.

SFR –Final storage of low level waste

SFR –Final storage of low level waste



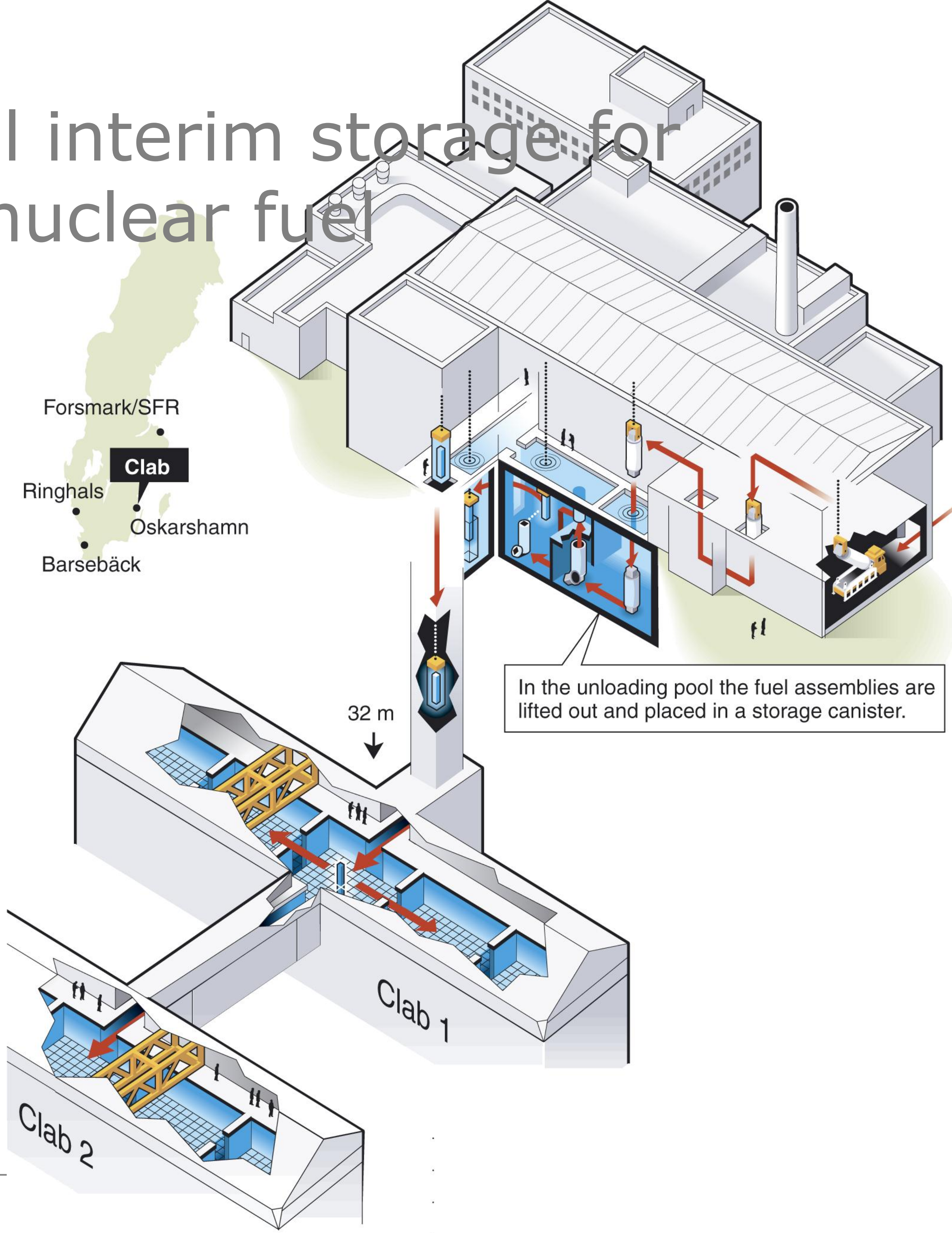
High Level Waste

- The waste is stored at the nuclear power plant for one year. During that year the activity of the waste is reduced by 90%

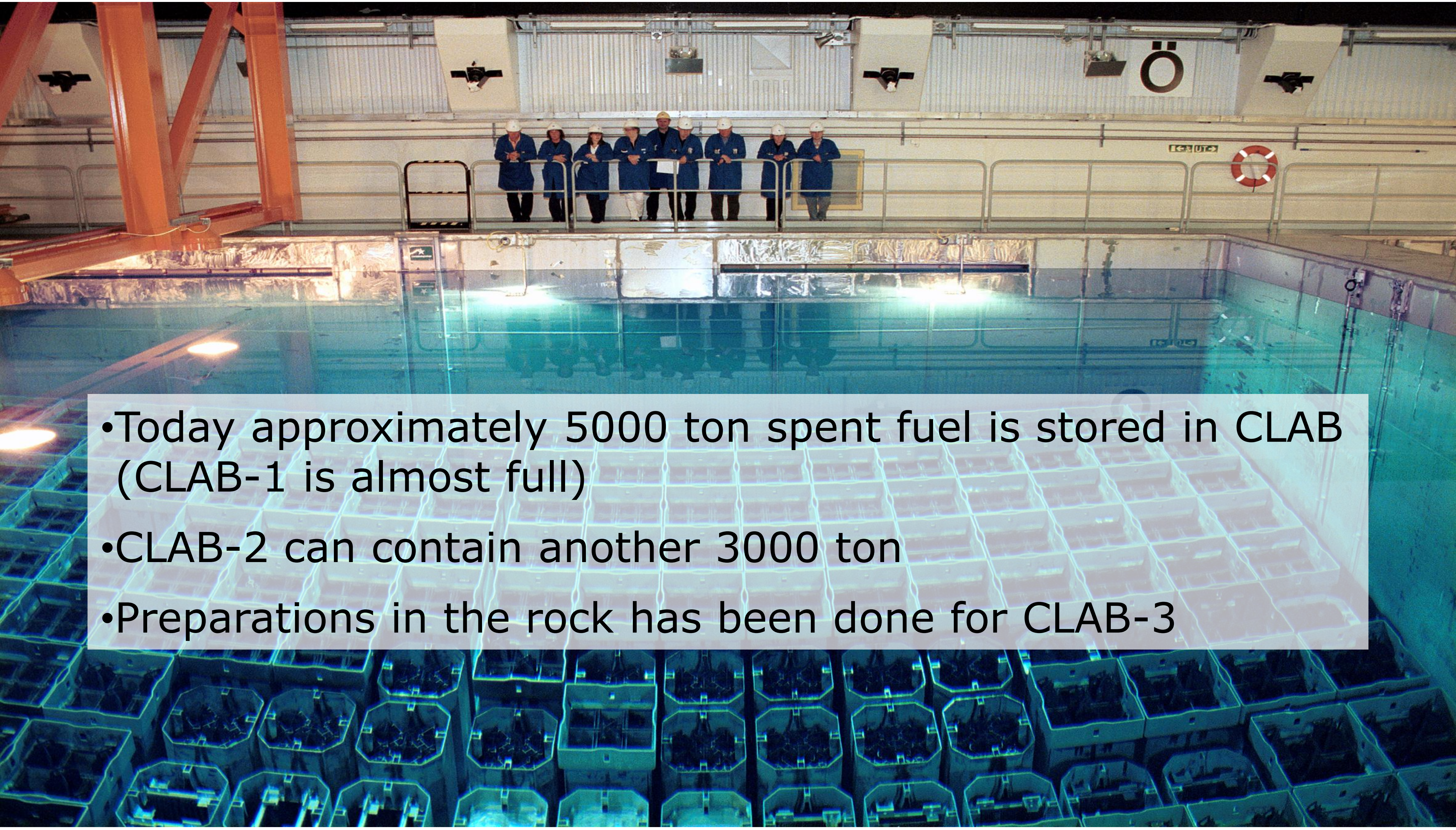
- The waste is transported to CLAB with m/s Sigyn. The waste is stored at CLAB for at least 30 years. During those 30 years the activity is reduced again by 90%.

=> When the waste is placed in the deep repository only 1 % of the original activity remains.

CLAB –Central interim storage for spent nuclear fuel

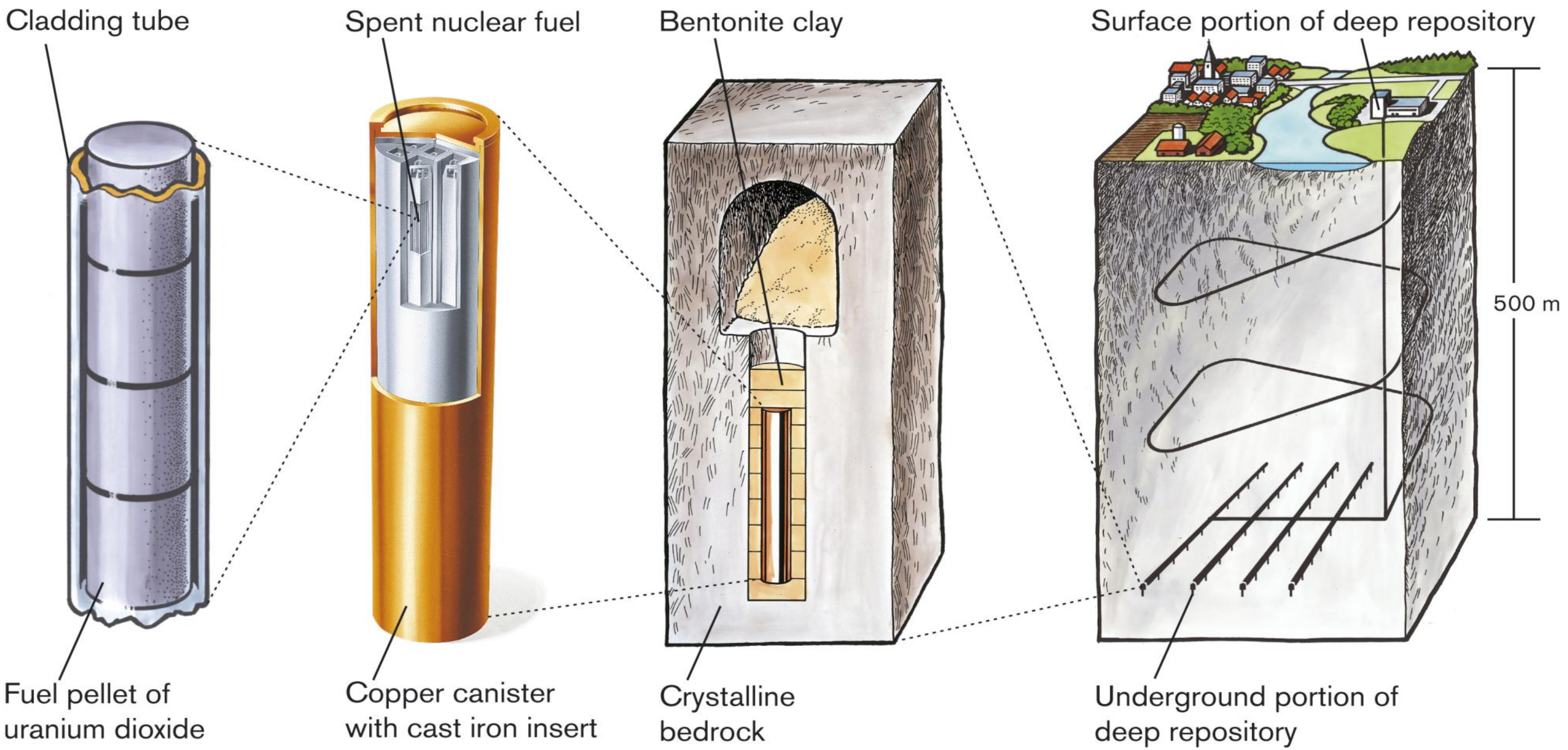


CLAB



- Today approximately 5000 ton spent fuel is stored in CLAB (CLAB-1 is almost full)
- CLAB-2 can contain another 3000 ton
- Preparations in the rock has been done for CLAB-3

KBS-3: The Swedish Concept of Storing Spent Nuclear Fuel



KBS-3: Presumptions

- The repository shall keep the spent fuel from reaching the biosphere for >100 000 years

$\Rightarrow$ All processes need to be extrapolated to extreme times.

$\Rightarrow$ The models must be based on thermodymanically stable processes

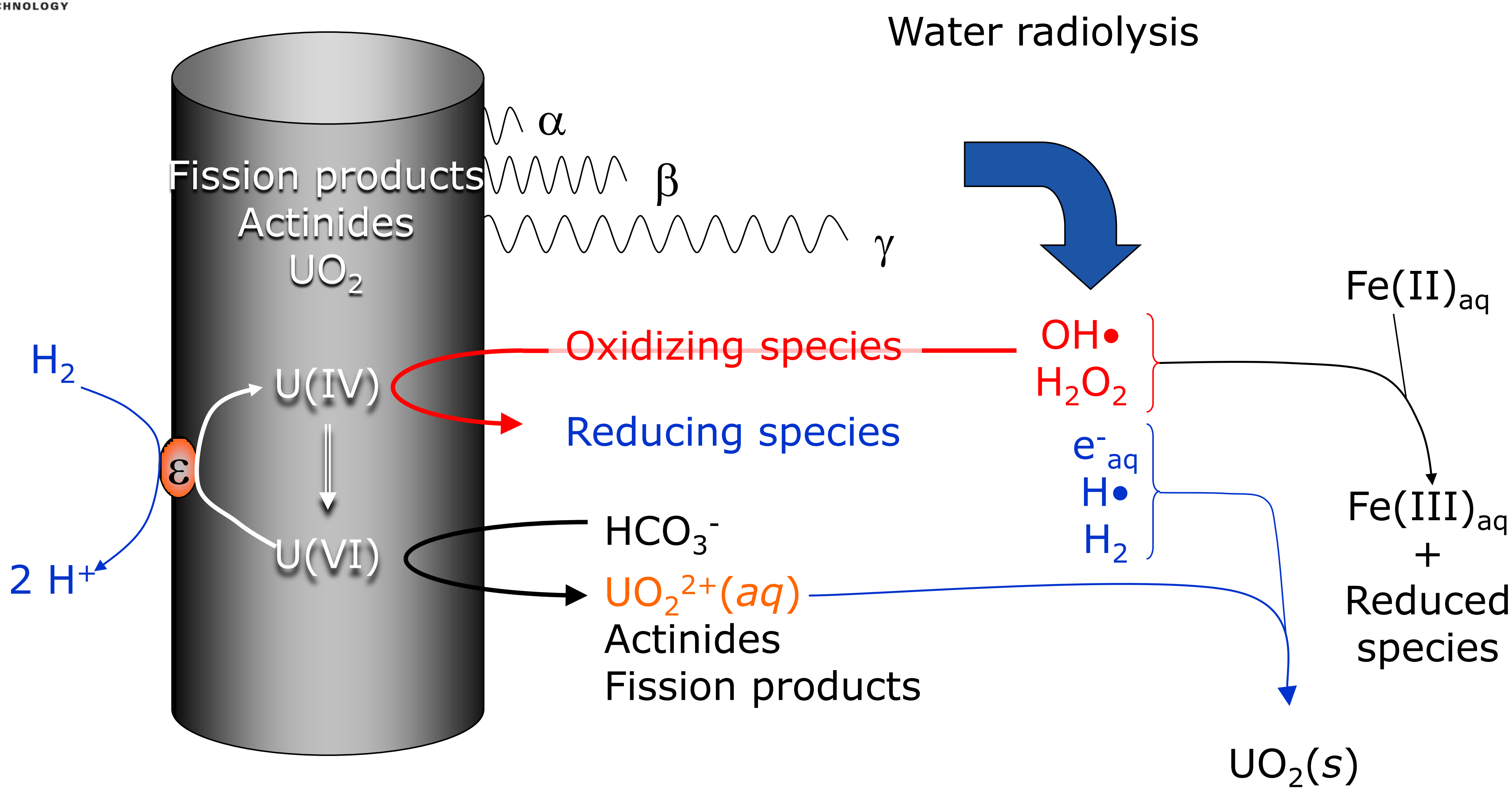
The Fuel itself

The spent fuel is 95% UO_2

Fission products and actinides are all incorporated in the UO_2-matrix
=> The release rate depends on the dissolution rate of UO_2

Under reducing conditions the solubility of UO_2 is very low (10^{-9} M)

Dissolution of the Fuel



The copper canister

Inner cask of cast iron (support) and
5 cm Cu (chemical resistance)

Under reducing conditions corrosion of copper is a very slow process

Recently copper has been questioned as material.

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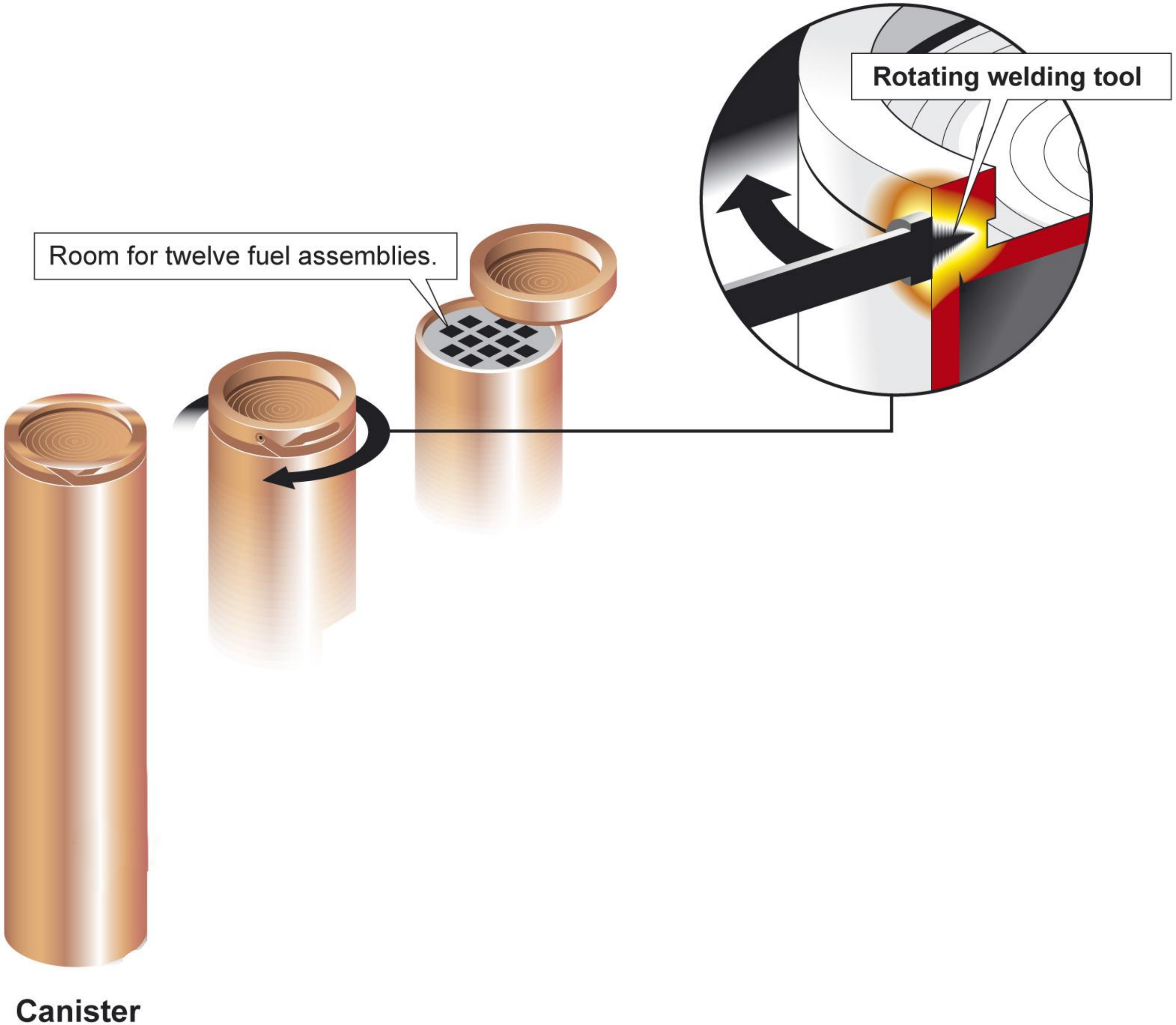
Welding the cap



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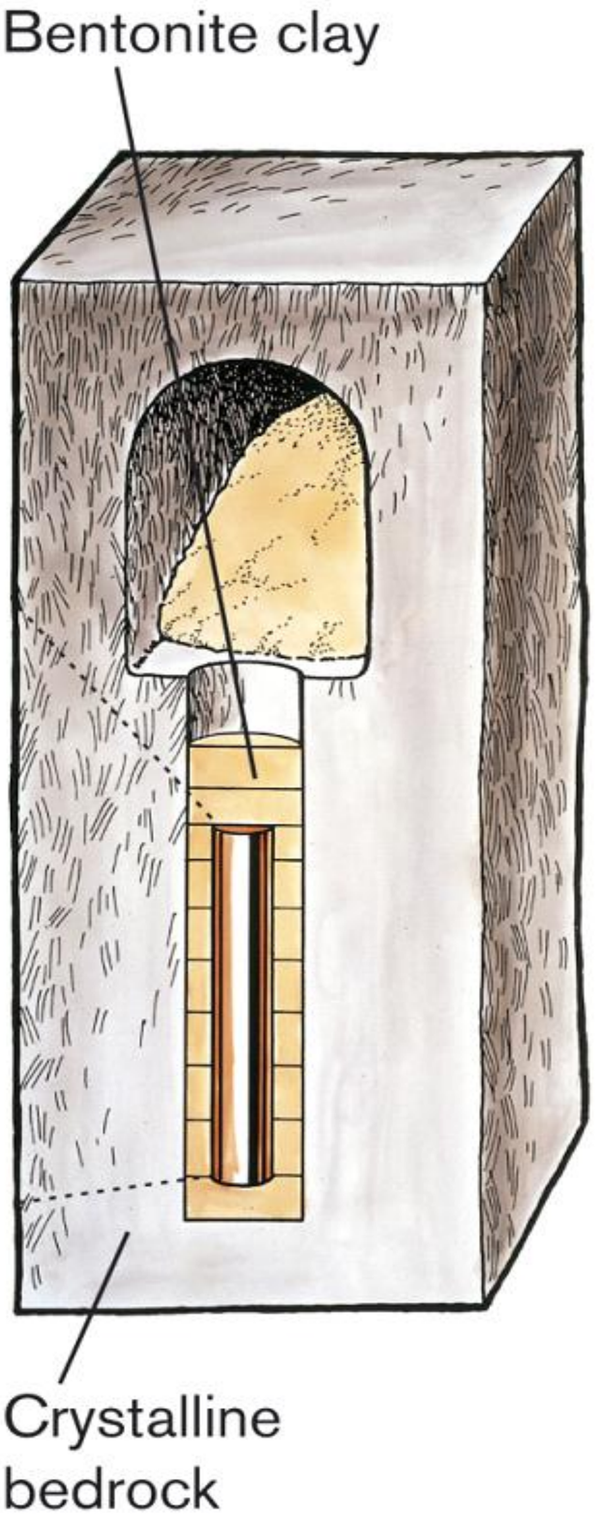
Hultqvist & Szakalos

- Researchers claim that they have performed experiments where Cu corrodes in oxygen-free water
- They claim that the canister may collapse in 1000 years

- If Cu would corrode in oxygen-free water an undiscovered Cu(I)-phase must exist

- Another very recent study suggests that Cu will corrode faster after being exposed to ionizing radiation



Bentonite Clay

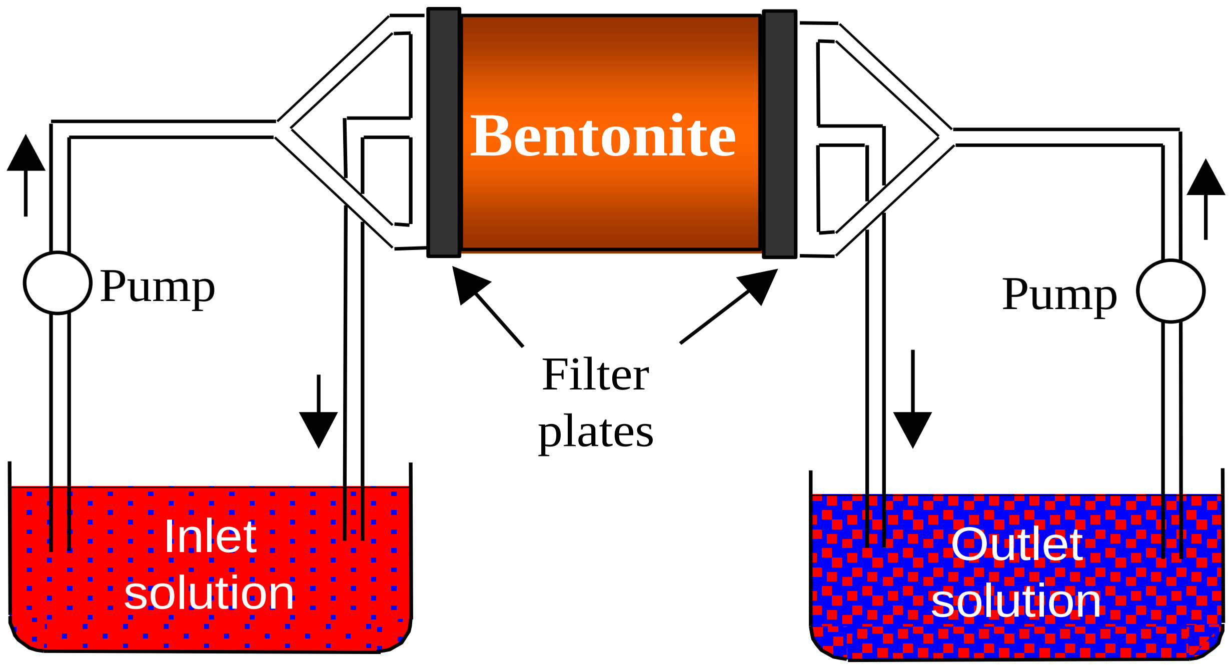
70-80% is montmorillonite

Montmorillonite takes up water and swells (swelling pressures up to 100 bars)

All transport to and from canister will be by diffusion

The clay is a plastic material. It will take up movements in the rock.

Determining transport properties of bentonite clay



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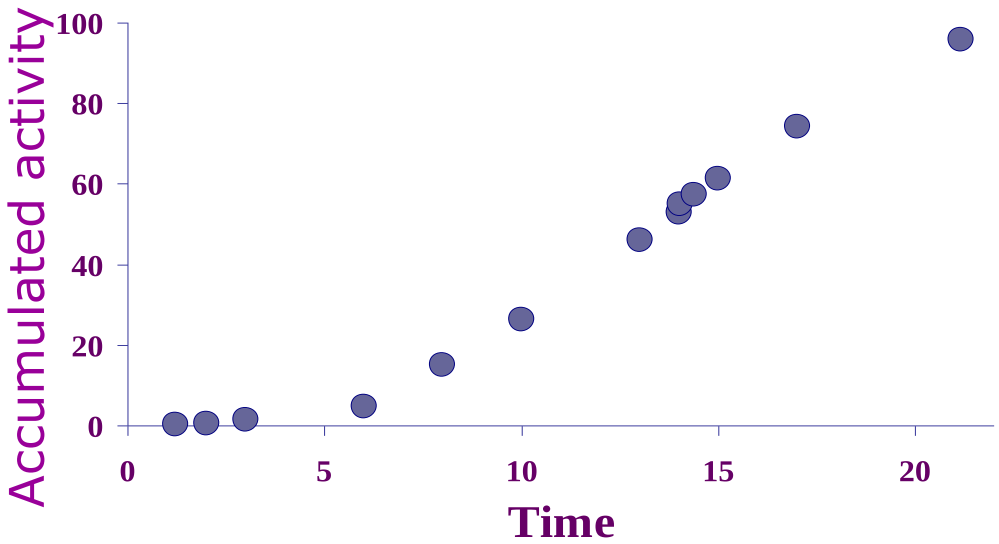
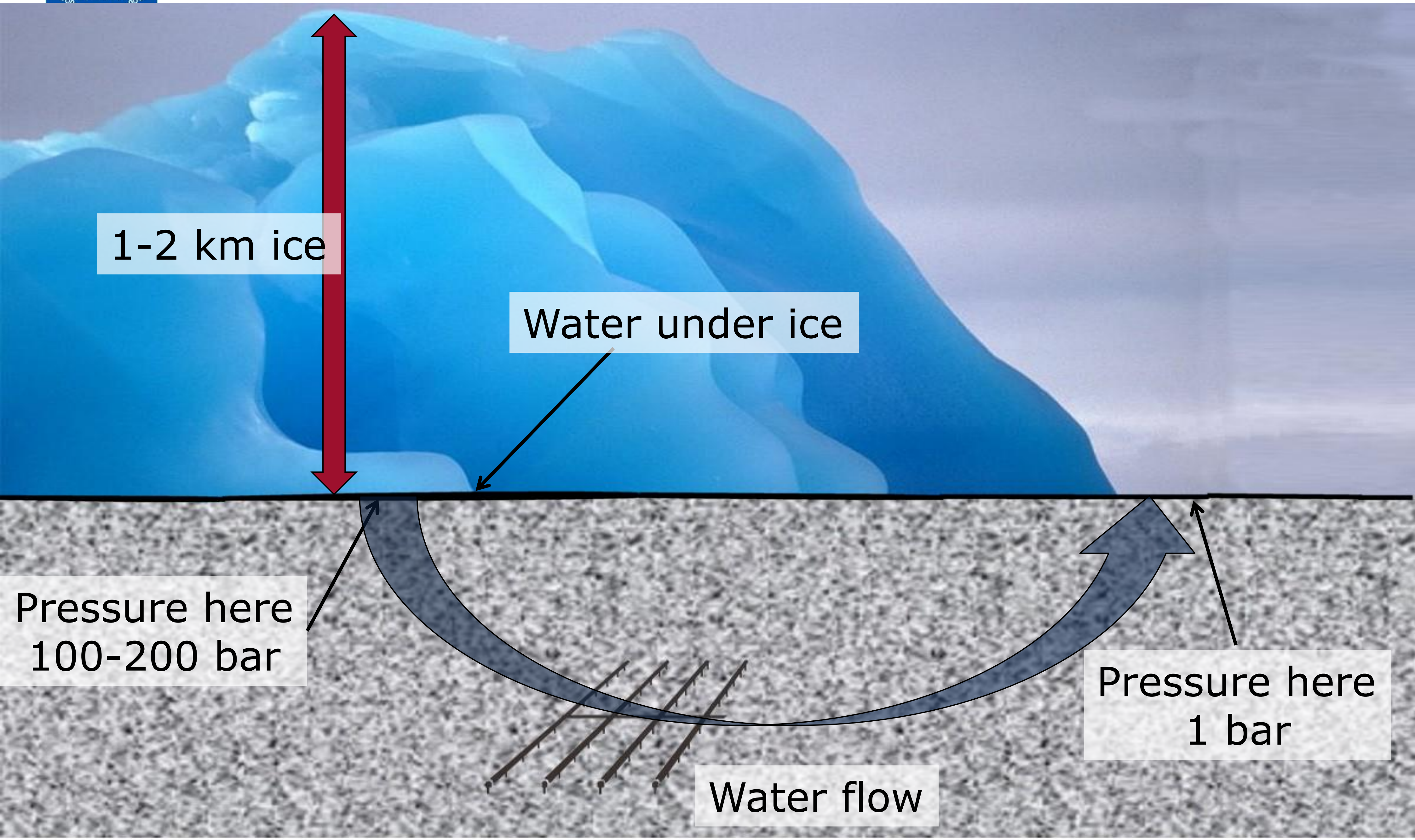
Obtained data



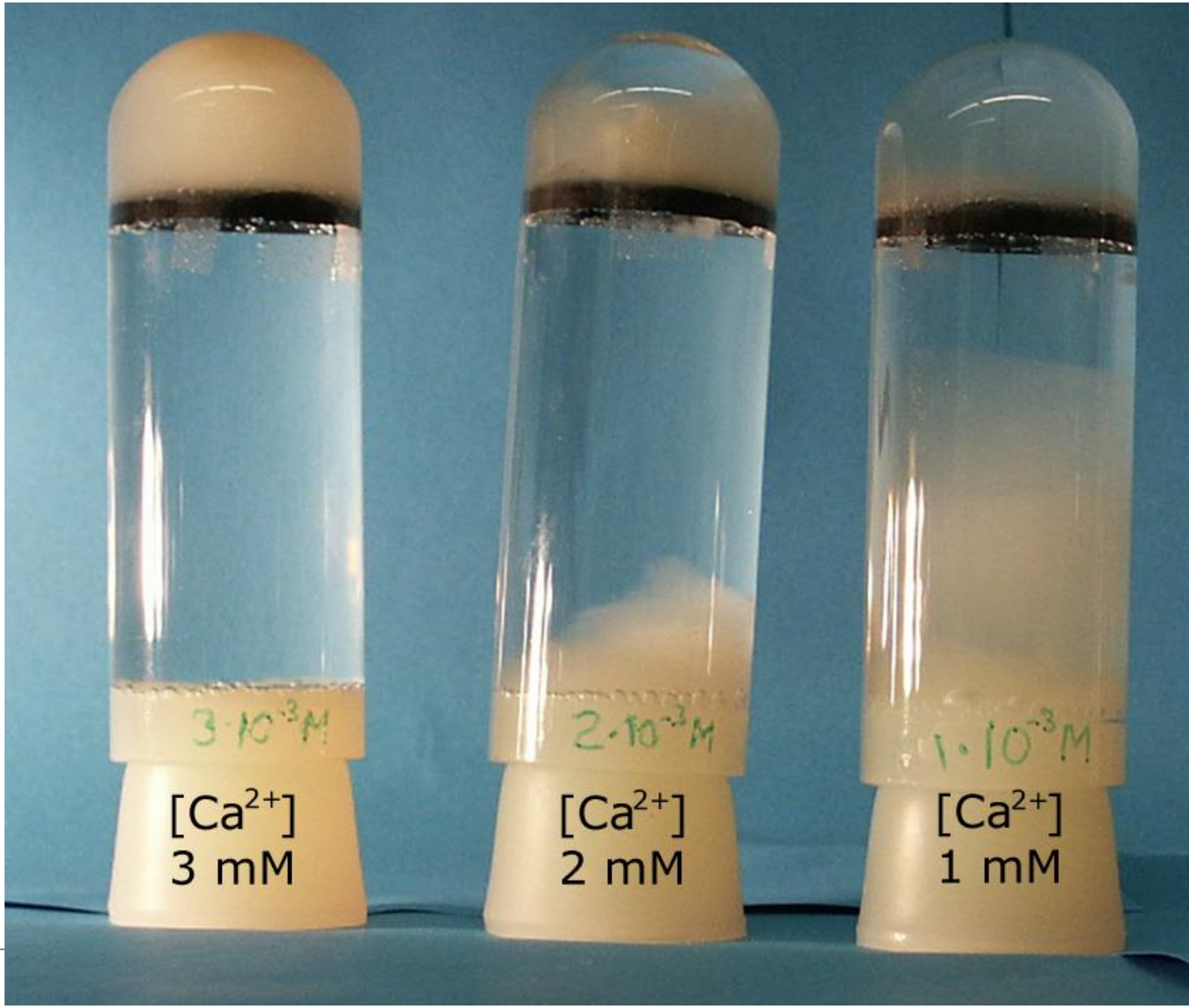
Break-through curve

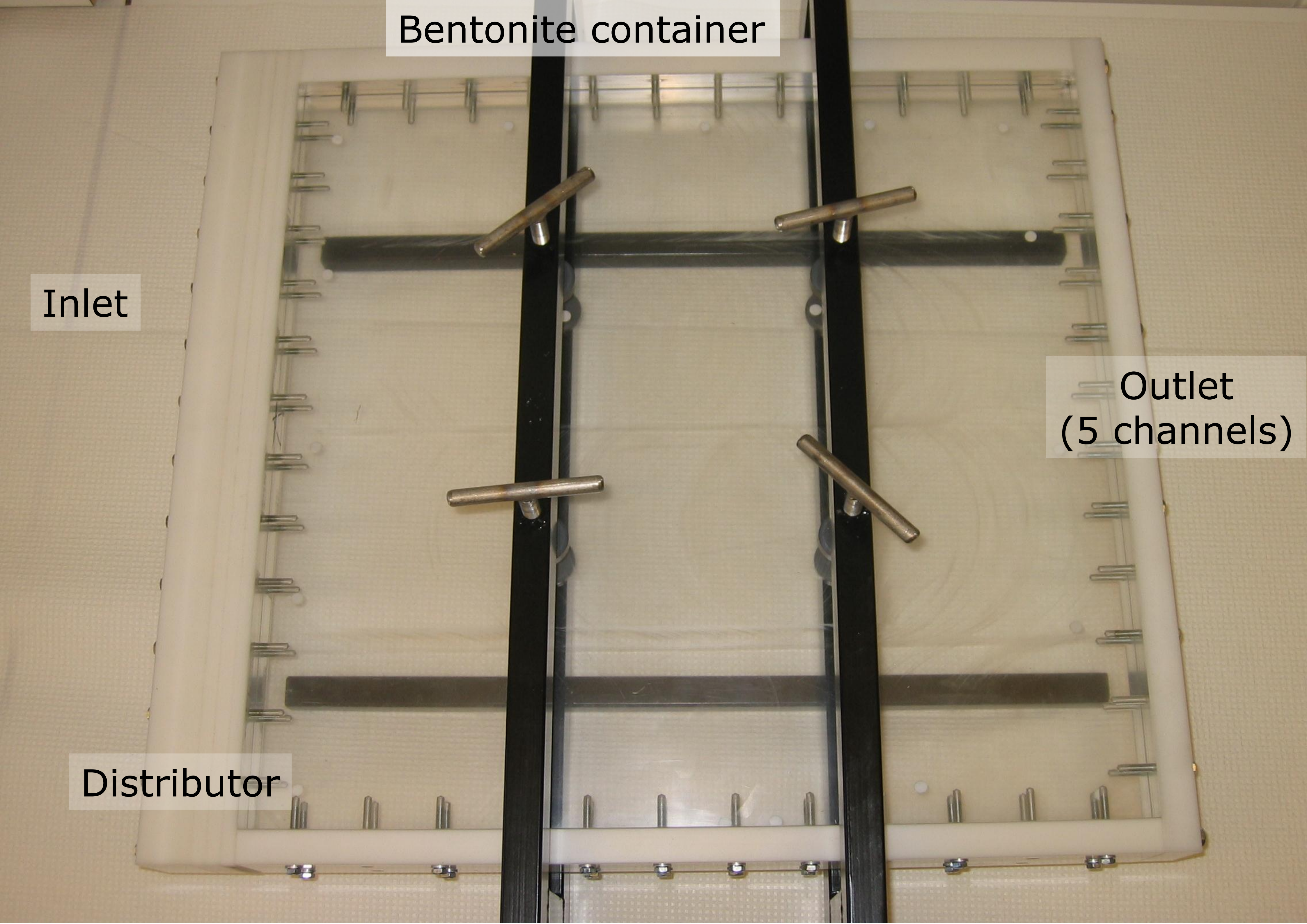
Activity profile in cell

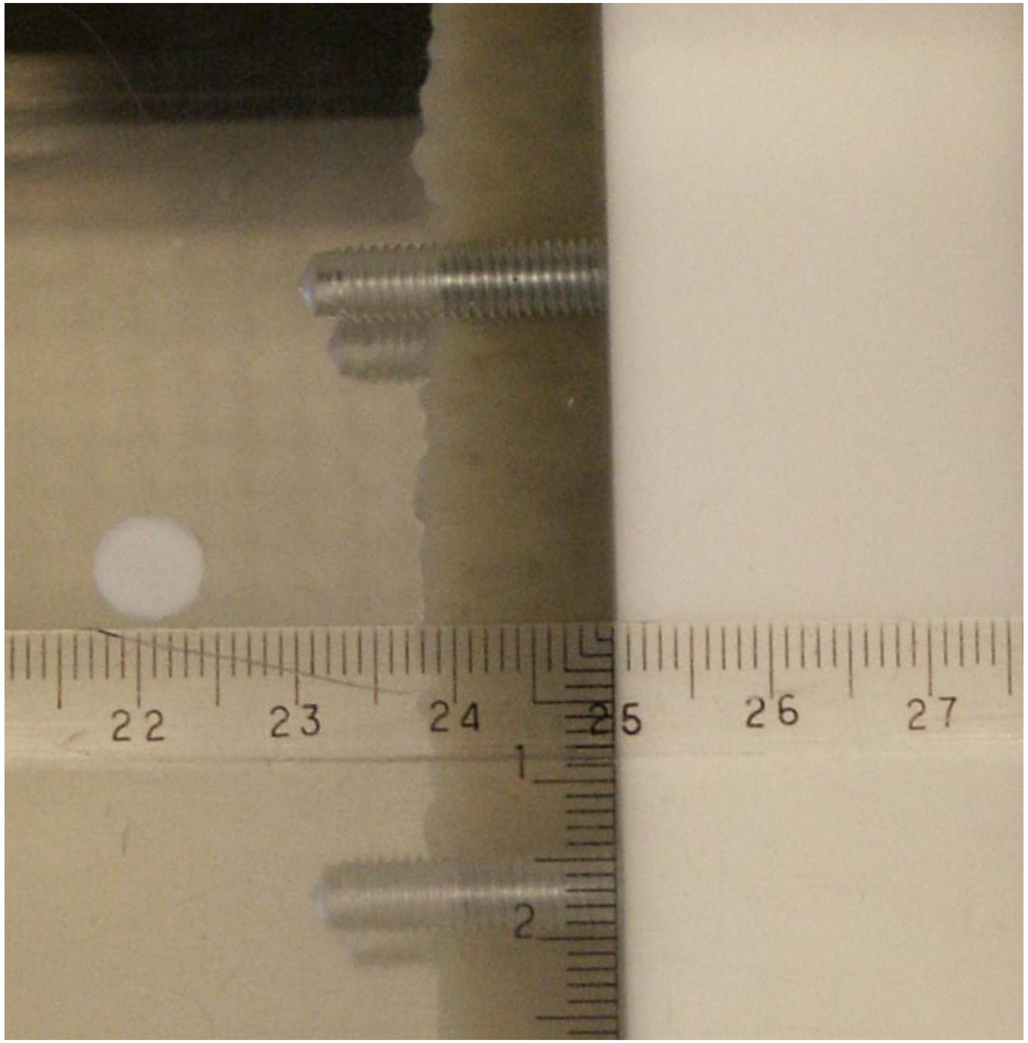
The Ice Age Scenario



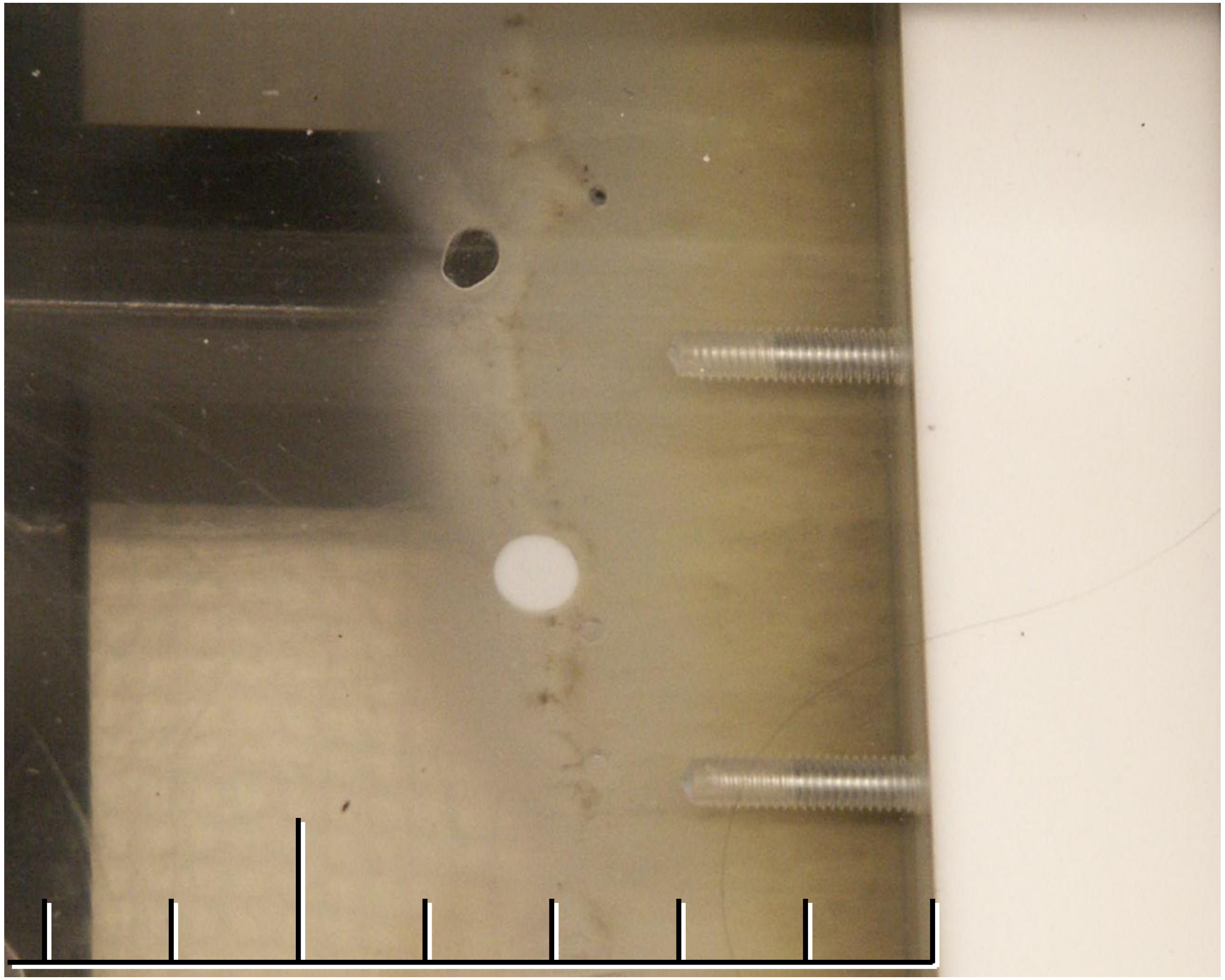
Stability of bentonite vs salinity



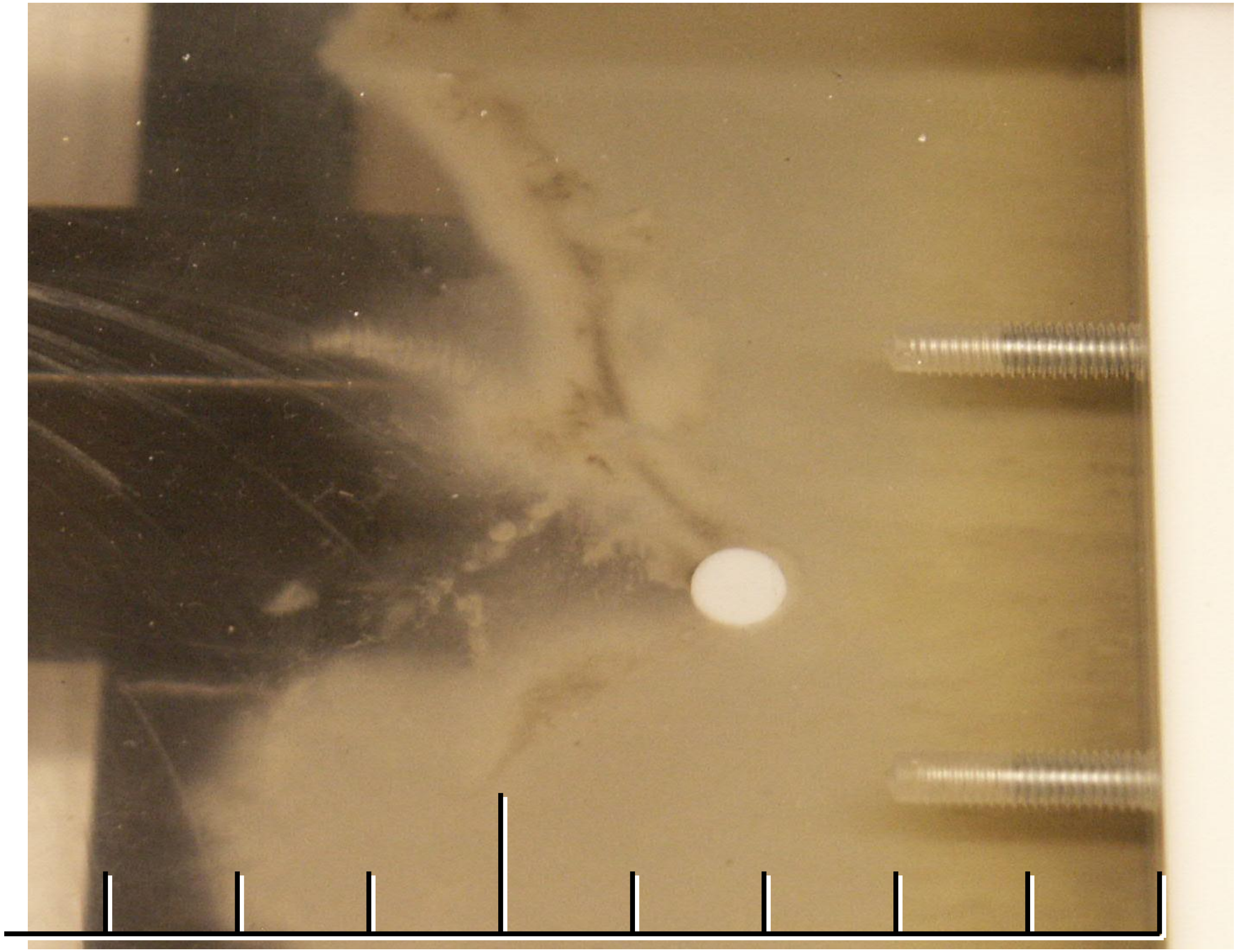

Bentonite container
Inlet
Outlet
(5 channels)
Distributor



After water saturation of clay



After pumping distilled water
in fracture water 4 weeks



After pumping in fracture water 28 weeks

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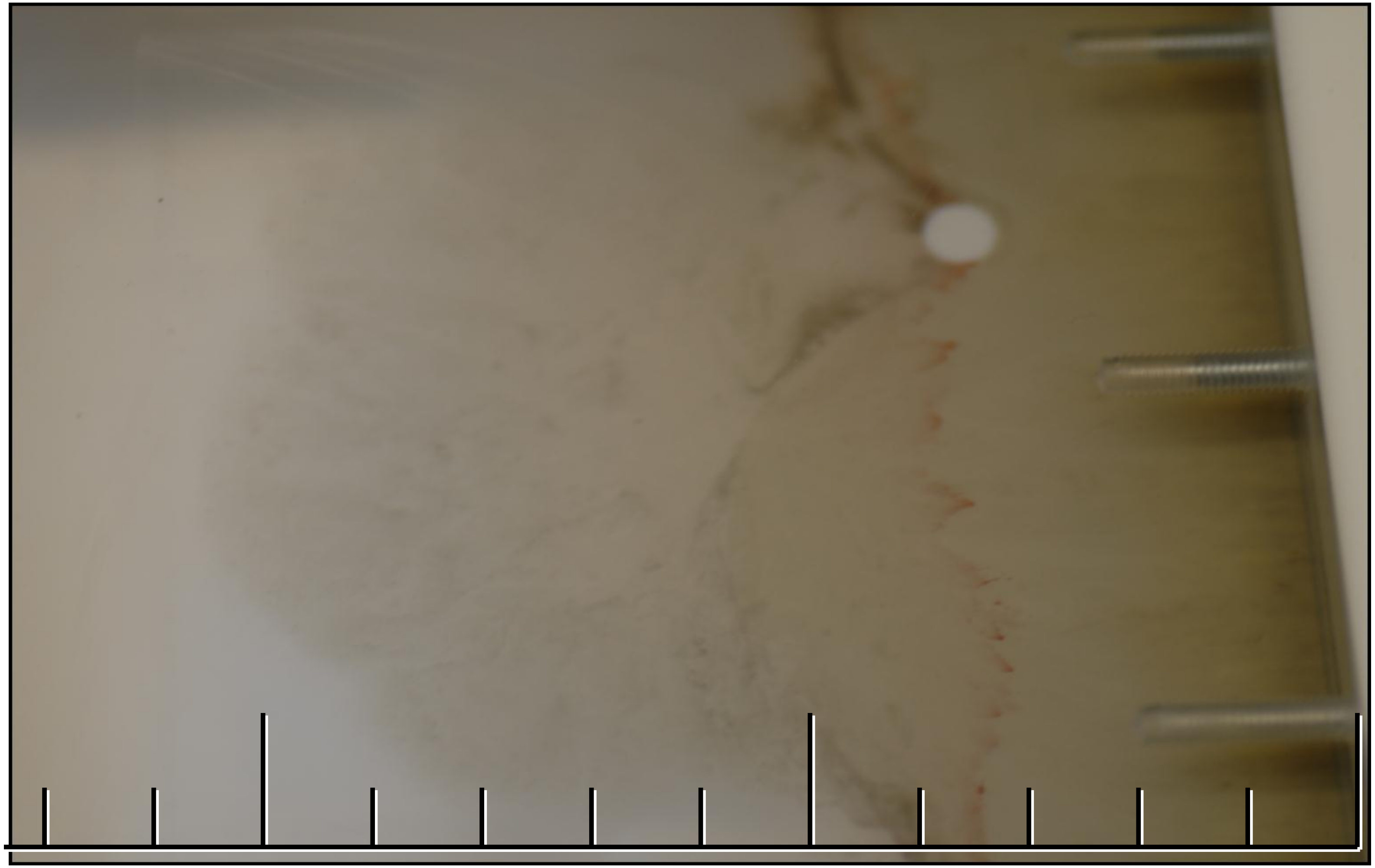
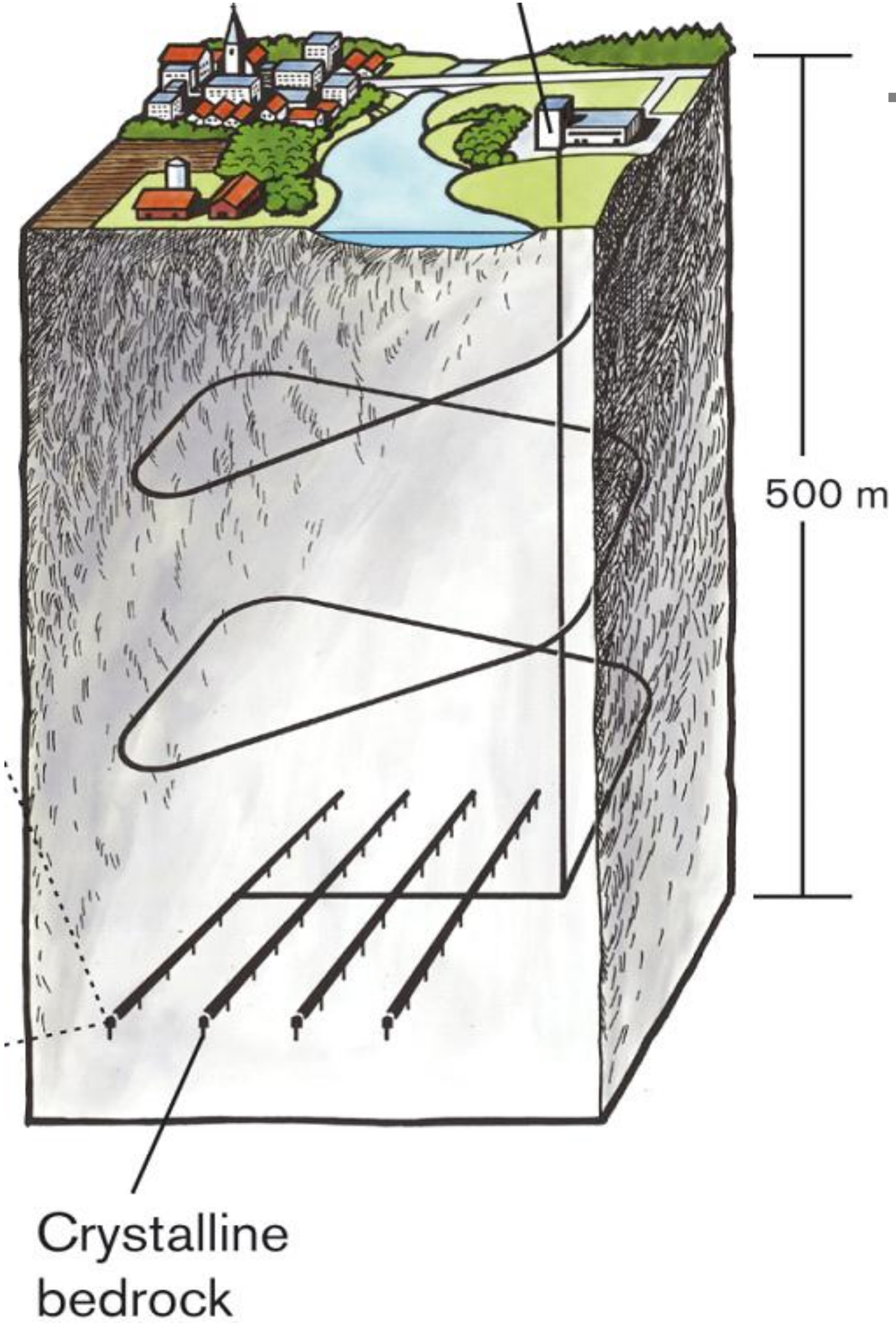


After pumping in fracture water 45 weeks

Conclusion

- Bentonite may disperse if water with sufficiently low salinity penetrates the repository.

- Other studies show that benonite colloids may facilitate faster transport through bed-rock



The Bedrock

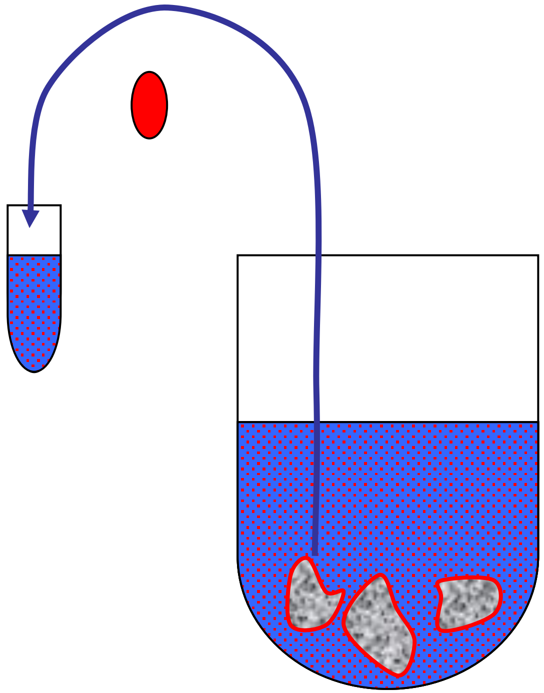
Most radionuclides in the spent fuel are cations.

Most mineral surfaces are negatively charged.

The transport towards the biosphere the cations will be largely retarded by sorption to the bedrock

Sorption properties of the rock

- Determination of Sr-distribution between granite and solution



Water

Add granite

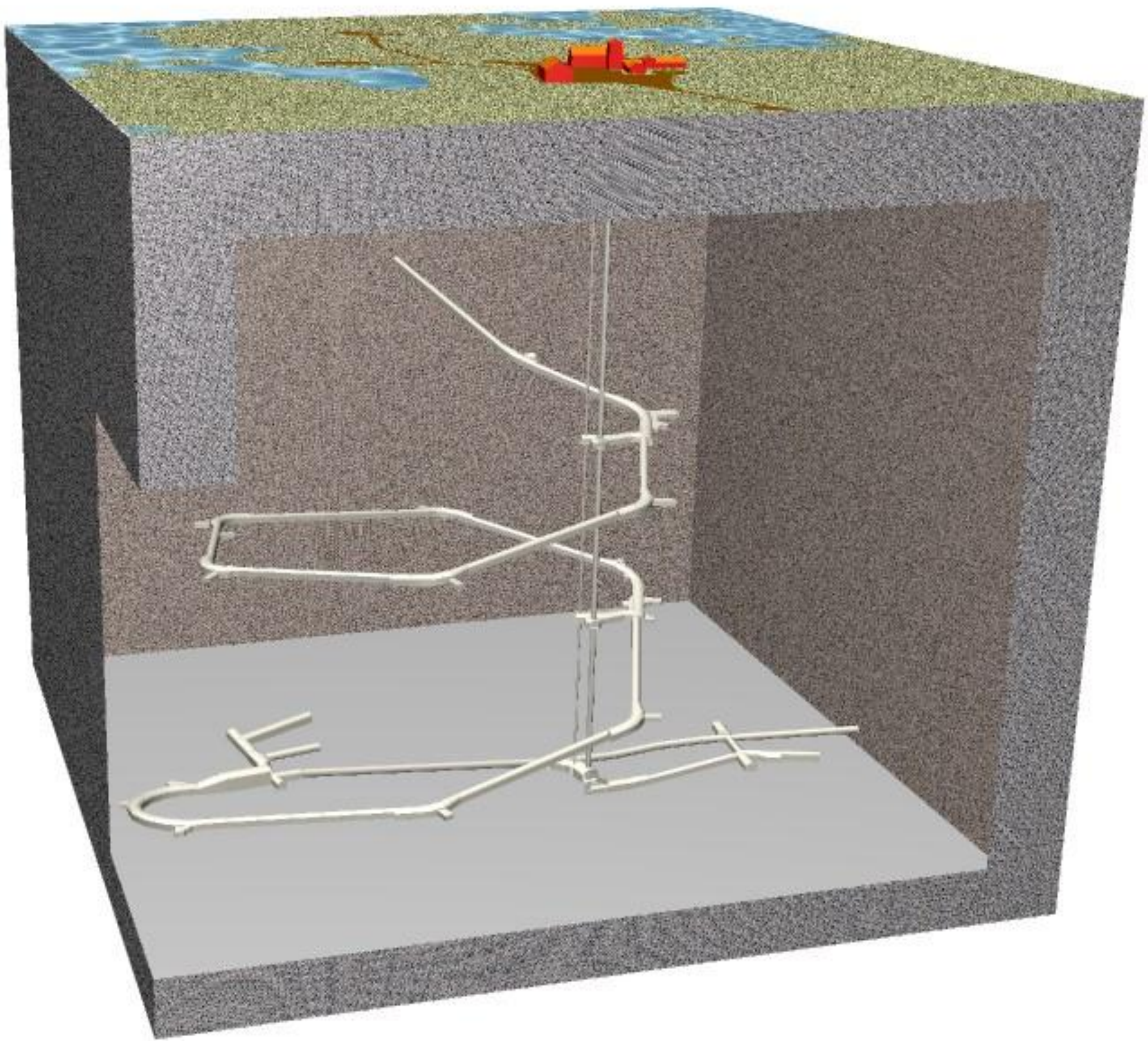
Add tracer (cation to study)

Wait for equilibrium

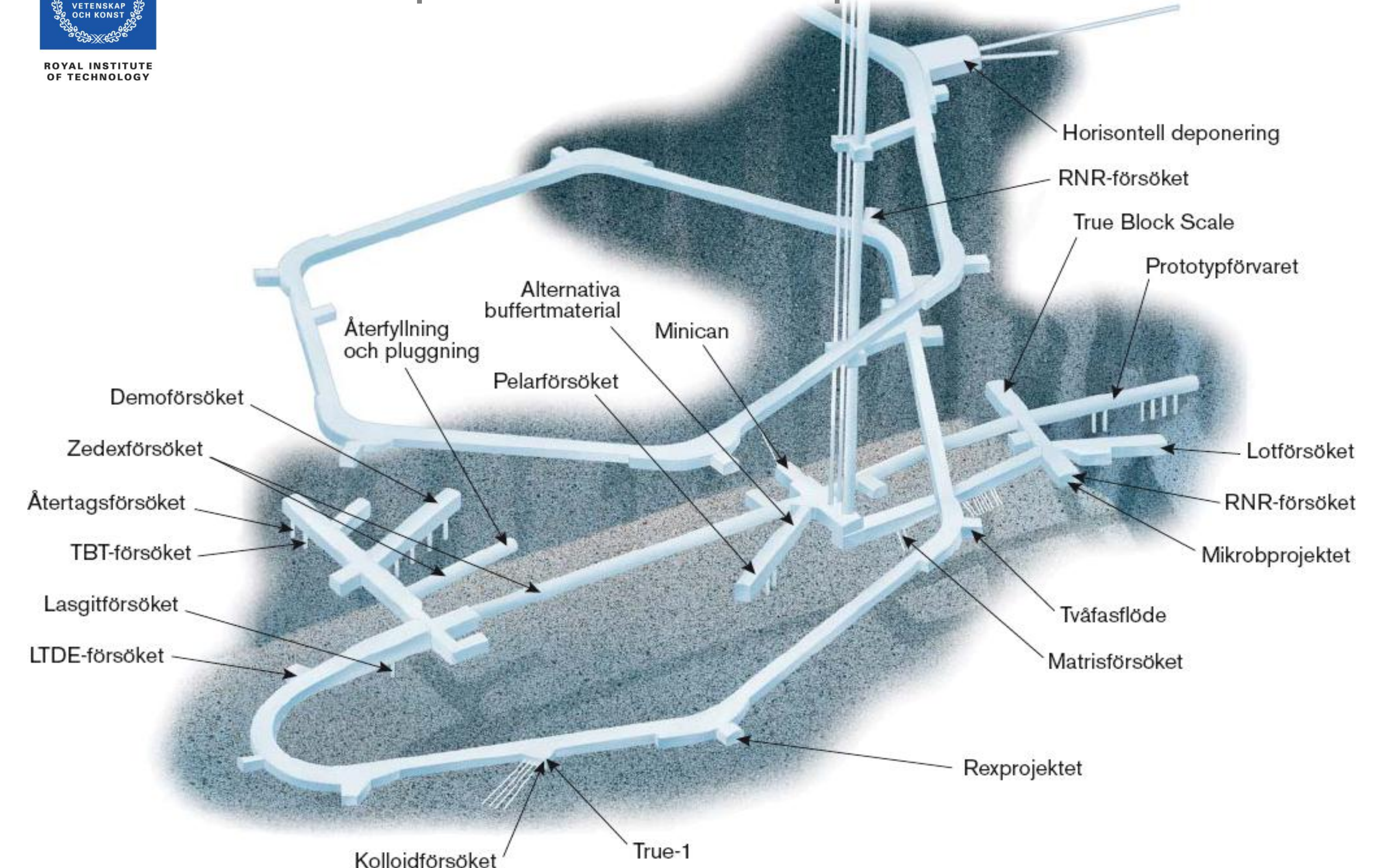
Take sample from solution

Äspö HRL Facility

- Office space for 86 persons
- Main experimental area between 220 and 450 m levels
- Rescue chamber/ conference room on 420 m level
- Hoist and 2 ventilation shafts
- On-line hydro-monitoring system

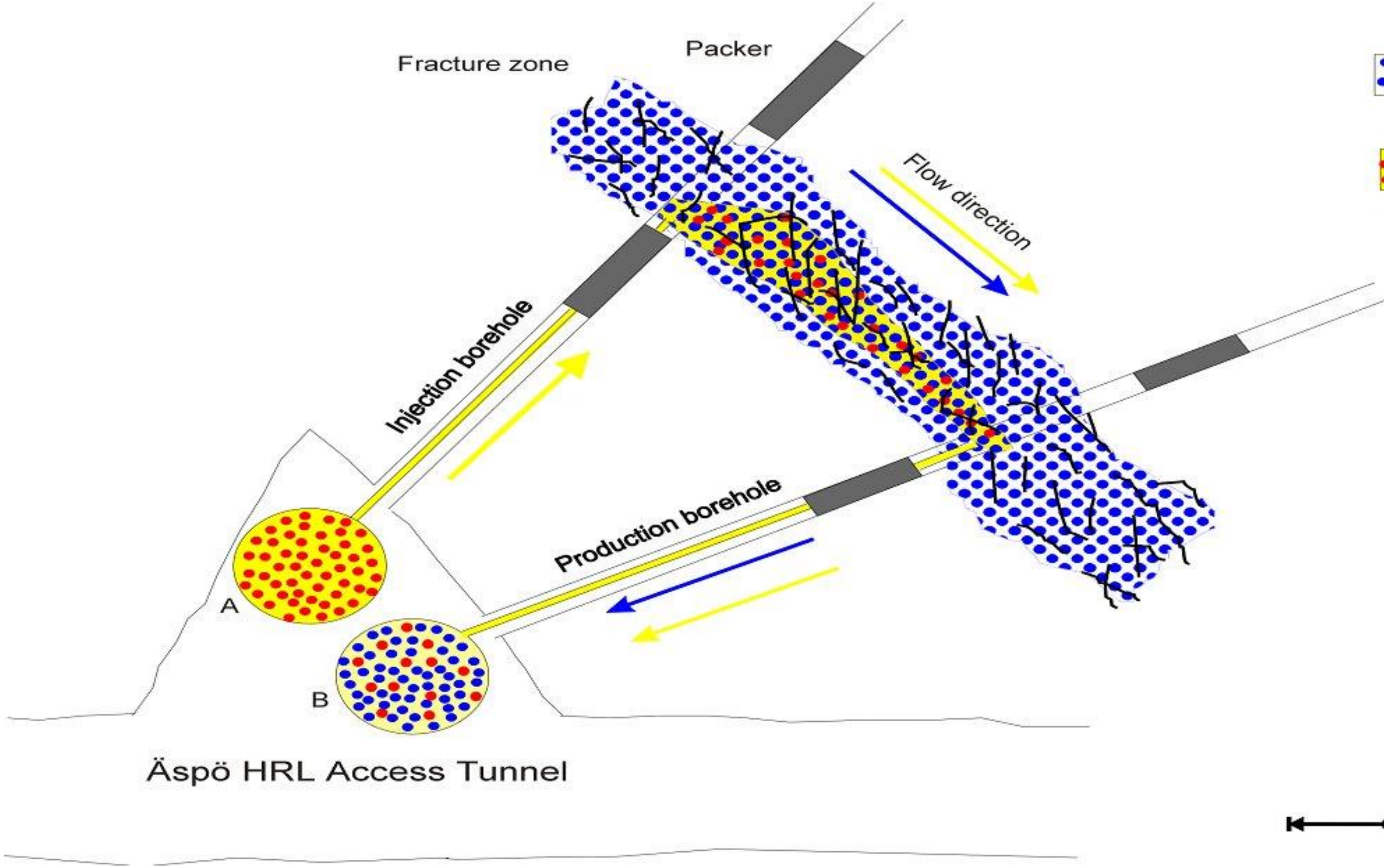


Experiments at Äspö HRL

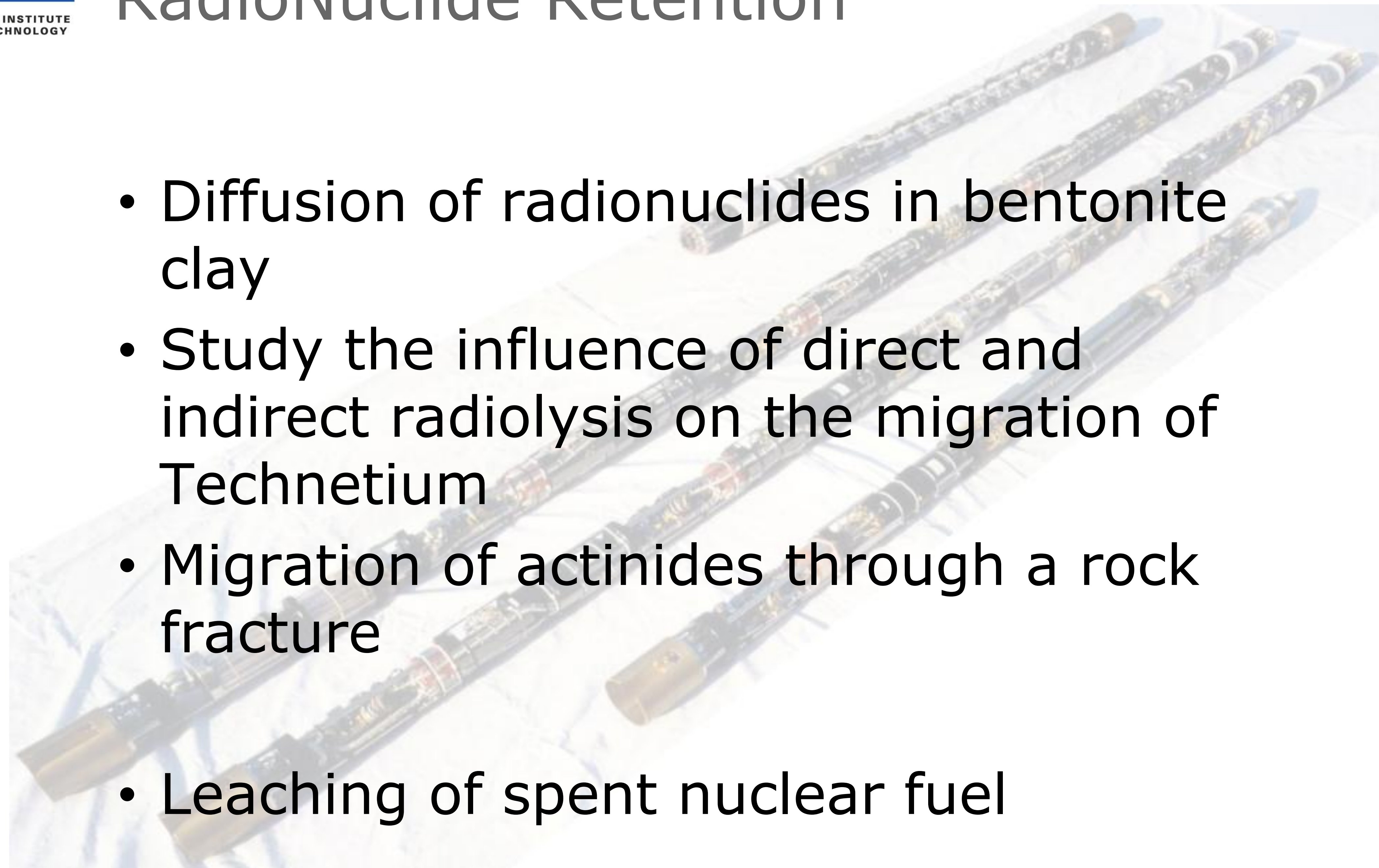


TRUE

Tracer Retention Understanding Experiments



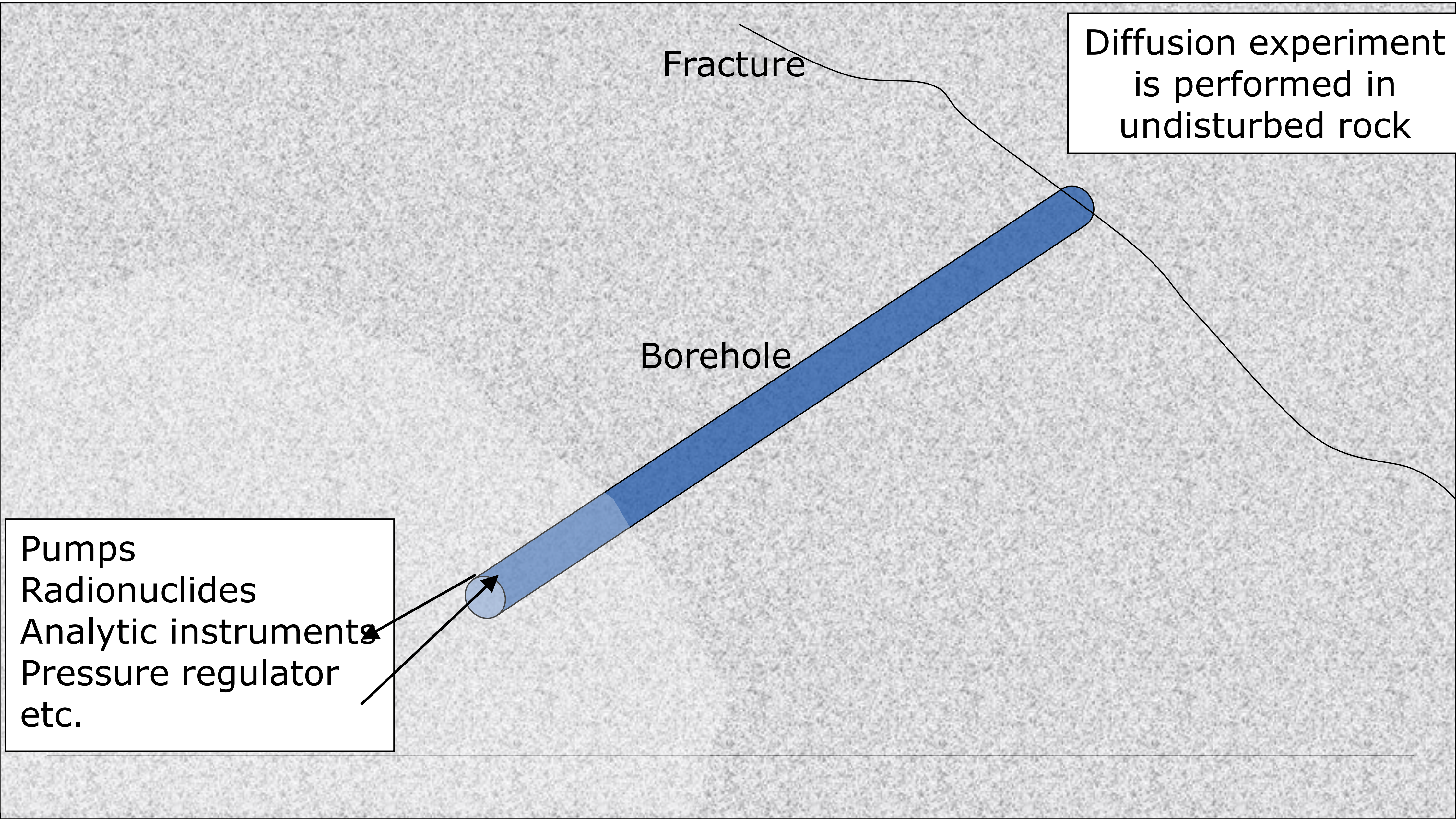
RNR: CHEMLAB
RadioNuclide Retention



- Diffusion of radionuclides in bentonite clay
- Study the influence of direct and indirect radiolysis on the migration of Technetium
- Migration of actinides through a rock fracture
- Leaching of spent nuclear fuel

LTDE

Long Term Diffusion Experiment



LOT
Long Term Test of Buffer Material

Bentonite clay was tested under adverse conditions

In one of the blocks radionuclides were added

The blocks was retrieved and sliced up

The activity profile in the block revealed the diffusional behavior of the radionuclide

Selecting the site

- Pre-studies have been performed in 8 communities
- The first ones were in the Northern part of Sweden; Malå, Storuman, Älvkarleby.
- Later Tierp, Nyköping, Hultsfred, Oskarshamn and Östhammar
- Referendum were held in Malå where the people said no (54%)
- Later politicians in Älvkarleby, Storuman and Tierp said no

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Selecting the site

- Eventually SKB choose Oskarshamn and Östhammar for more detailed site investigations.

- 2010 SKB announced that Östhammar was selected

- Very solid bed rock, few fractures, little water.
  - The bentonite clay will not disperse.
  - Canisters may corrode due to sulphide. This corrosion will be limited with limited water supply
  - Construction will be easier with limited water
- Stress in rock greater in Östhammar but will not influence greatly

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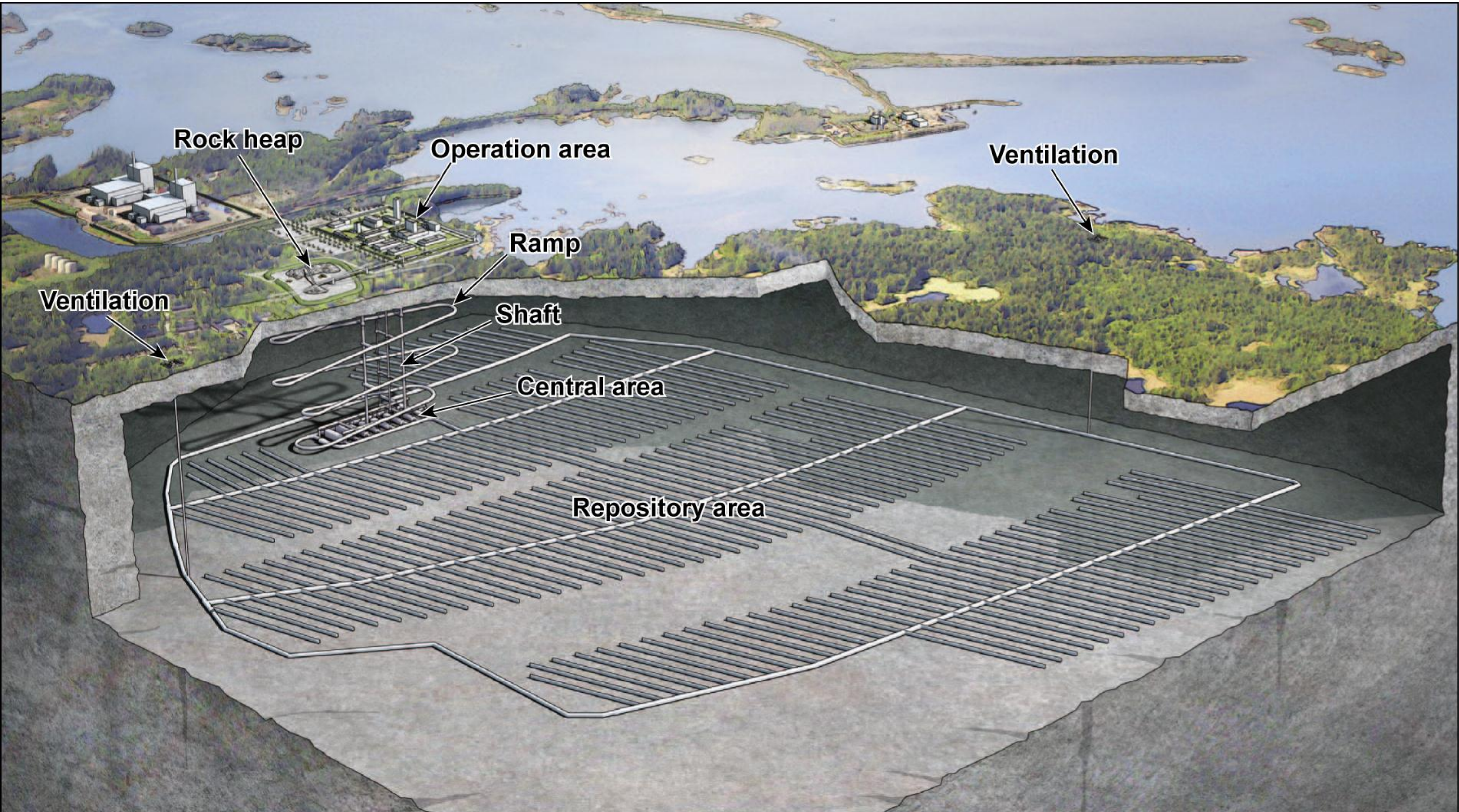
Deep Repository in Östhammar



How much are we talking about?