RED-IMPACT

Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal

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IGD-TP / SNETP Exchange Forum, Prague, 29-30 October 2013

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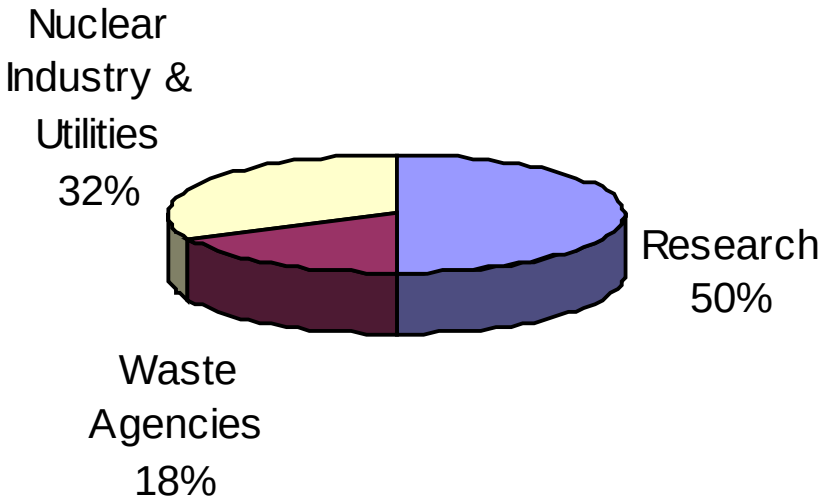
23 partners + 2 subcontractors



EC CONTRACT NO. FI6W-CT-2004-002408

Duration: March 2004 – September 2007

KTH-Sweden: Coordinator

FZJ-Germany: Co-Coordinator

Belgium: BN; SCK-CEN

Czech Republic: NRI; RAWRA

EC: ITU-Karlsruhe

France: Areva ANP, CEA; COGEMA

Germany:FANP; GRS; IER; KKP

Netherlands: NRG

Romania: CITON

Slovakia: DECOM, VUJE

Spain: CIEMAT; EA; ENRESA

UK: NexiaSolutions; NIREX; UC

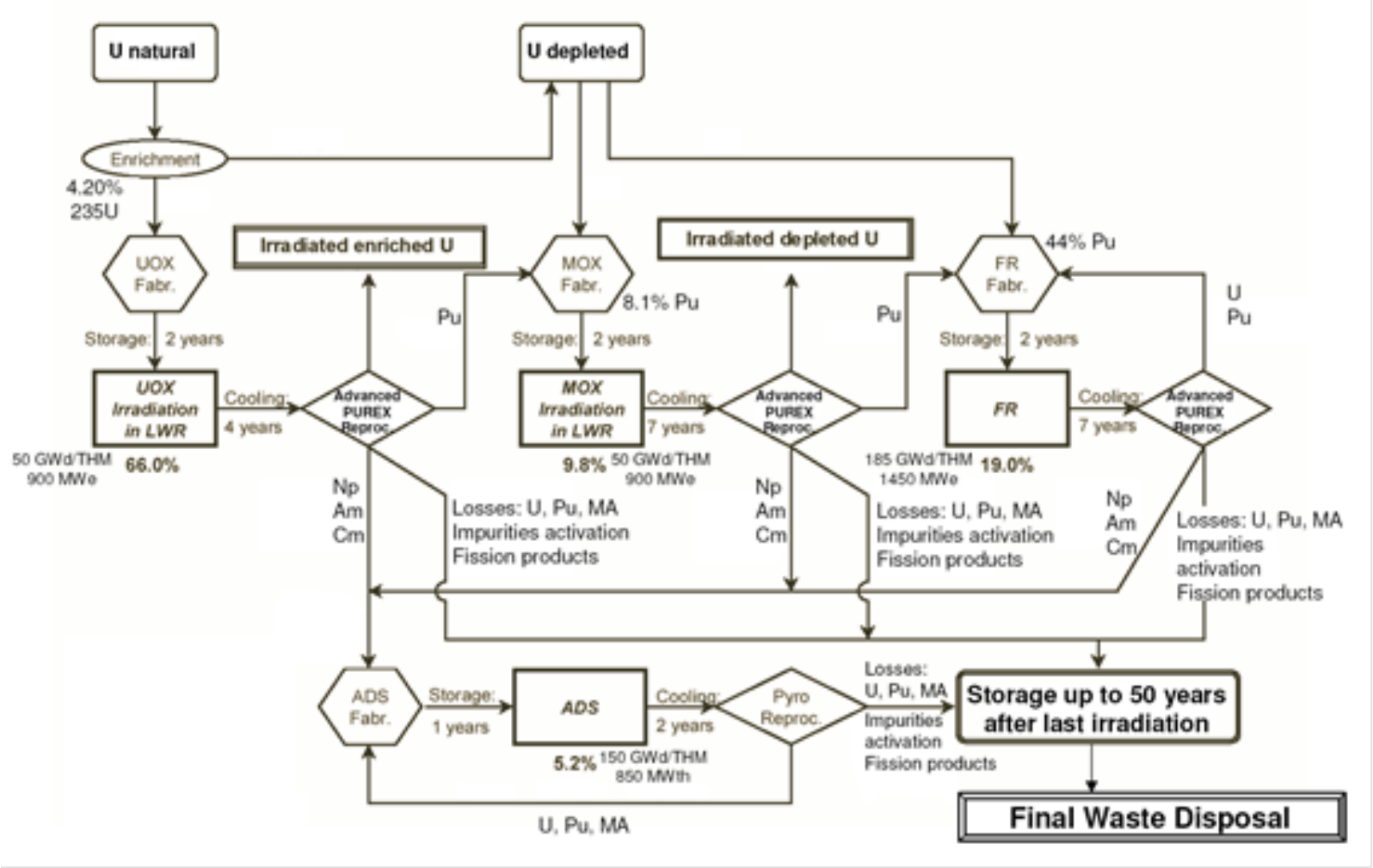
Working procedure

1. Definition of fuel cycle
2. Heavy Metal mass flow
3. Neutronic calculations
4. Mass flow in reprocessing units
   - Actinide losses: 0.1% in HLW, 0.02% in ILW
   - Volatile Activation + Fission Products
     - I: 1% in HLW, 1% in ILW
     - ^{14}C: 10% in HLW
     - Cl: 1% in HLW, 0.2% in ILW
5. Waste inventories
6. Waste disposal analyses
7. Estimation of environmental, economic and social indicators

Investigated Fuel Cycles

- **Industrial scenarios**
  - **Scenario A1: (reference) : once through open cycle with Gen-II / III reactors**
  - **Scenario A2 : mono-recycling of plutonium in Gen-III reactors (+ variants e.g. Th-MOX, IMF, PWR vs. BWR etc.)**
  - **Scenario A3 : Multirecycling of Pu (only) in Sodium Fast Reactors (EFR)**
- **Innovative scenarios**
  - **Scenario B1 : Multi-recycling of Pu & MA in Sodium Fast Reactors (EFR) plus advanced PUREX**
  - **Scenario B2 : multi-recycling of plutonium in Gen-III reactors and burning of Minor Actinides in ADS plus advanced PUREX & PYRO**
  - **Scenario B3 : mono-recycling of plutonium in Gen-III reactors + burning of plutonium in Gen-IV fast reactors + burning of Minor Actinides in ADS including advanced PUREX and PYRO *(reduced efforts)***

Cradle-to-Grave



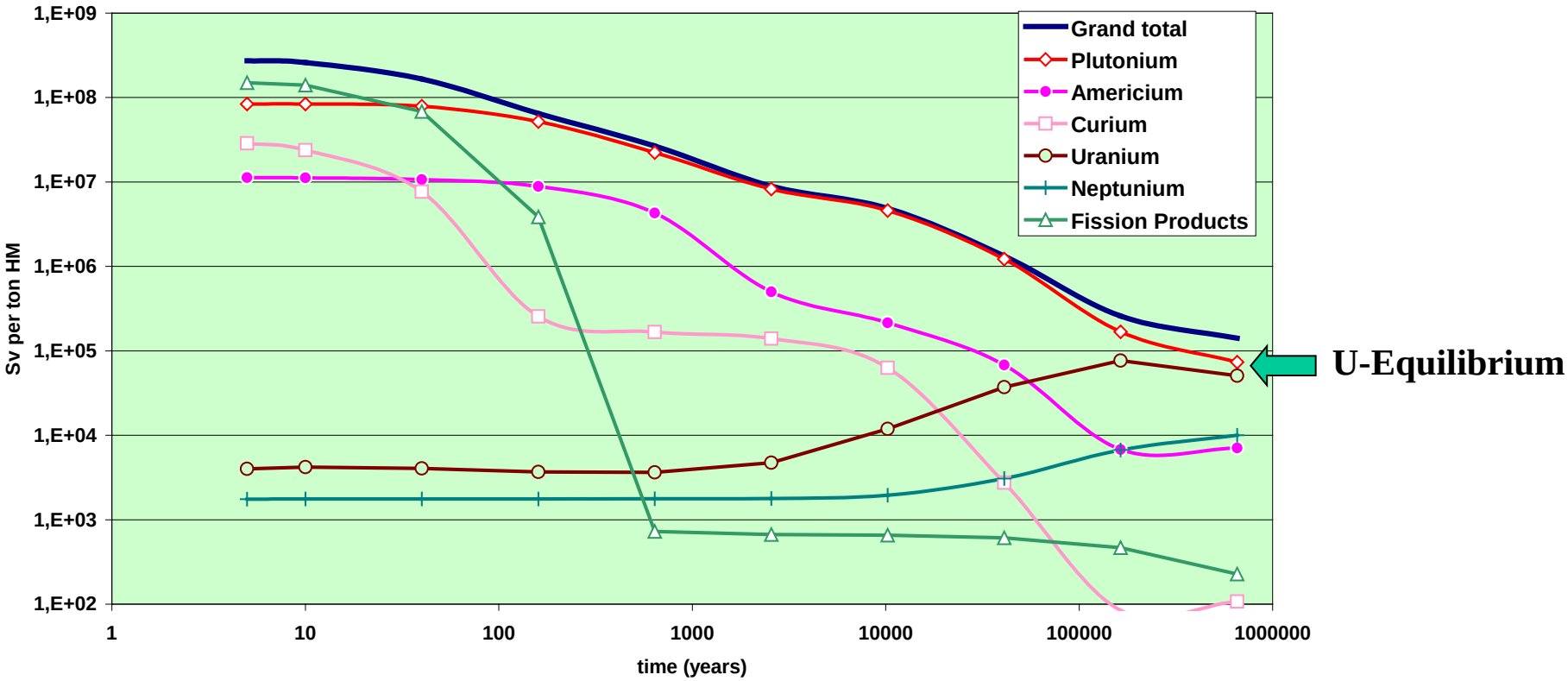
A1: **5.354 spent fuel assemblies / TWh_{el}** **B1**: **1.644 canisters / TWh_{el} ($HLW_{vitr.}$)**

Performance indicators

The indicators have been divided into two major groups:

- **"Technical" indicators related to waste management issues:**
  - **composition of the waste; number of SF-assemblies, number of canisters,**
  - **size of the repository; gallery length *(influenced by heat load)***
  - **long-term performance of the repository system:**
    - **individual annual dose;**
    - **radiotoxicity flux released into the biosphere;**
    - **integrated radiotoxicity flux released into the biosphere.**
  - **Inclusion of ILW**
- **Economic, Environmental and Societal sustainability (EES) indicators**
  - **Production cost & external cost**
  - **Fuel import dependencies, resource consumptions**
  - **Proliferation and terrorist attack resistance**
  - **Health impacts on workers & public in normal operation & accidents**
  - **etc.**

Priorities



Plutonium Management has strongest Impact !

Focus on most important MA !!!

Thermal output and length of disposal galleries (Clay)

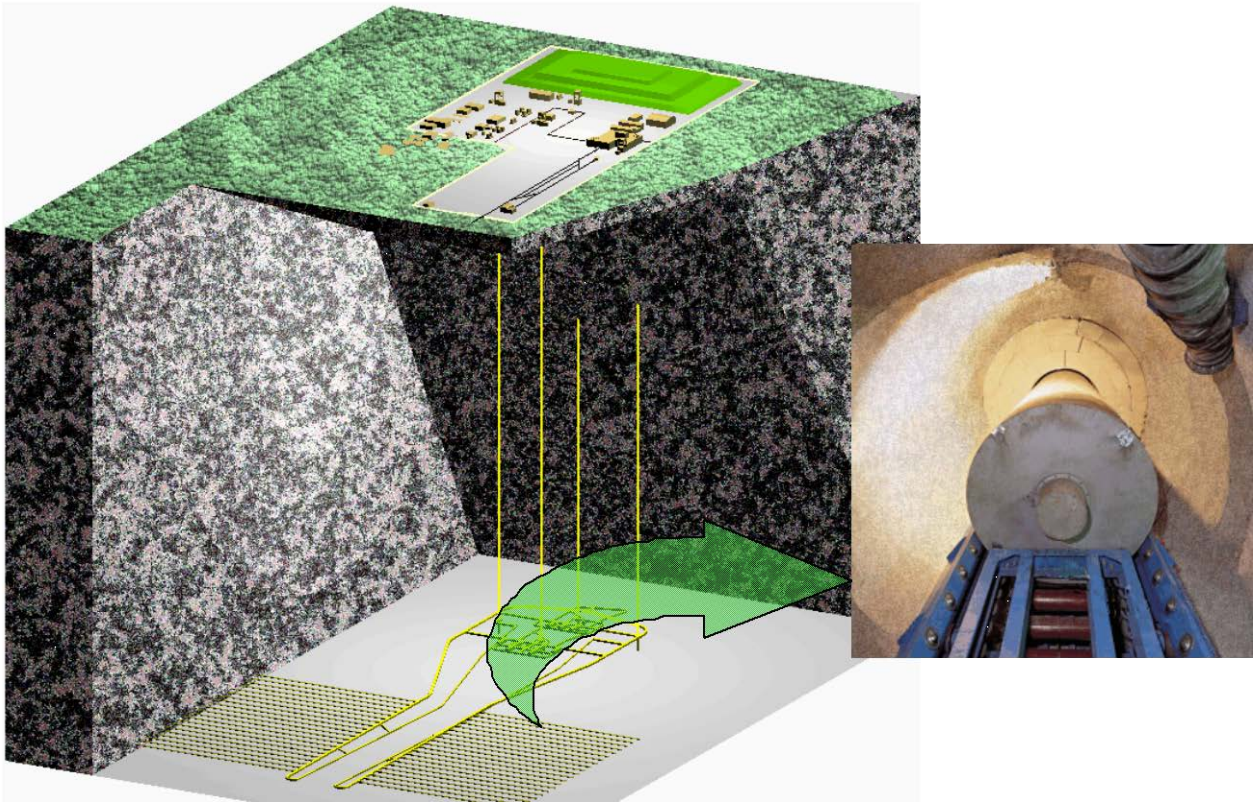
Scenario		Clay: allowable thermal output at disposal time (W/m)	Total needed gallery length (m/TWhe)	Relative needed gallery length (-)
A1		354	5.922	1
A2	A1: LWR-open A2: LWR-Mono A3: SFR-Multi-Pu B1: SFR-Multi-Pu&MA B2: SFR+ADS B3: LWR, SFR+ADS	332 / 376	5.743	0.970
A3		365	3.479	0.587
B2		379	2.895	0.489
B1		379	1.882	0.318
B1-separation of Sr			1.273	0.215
B1- separation of Cs and Sr (Cs-waste disposed after 100 a)			0.439	0.0741

Reduction by a Factor of 3 (A1 vs. B1)

Removal of Cs & Sr would allow further reduction

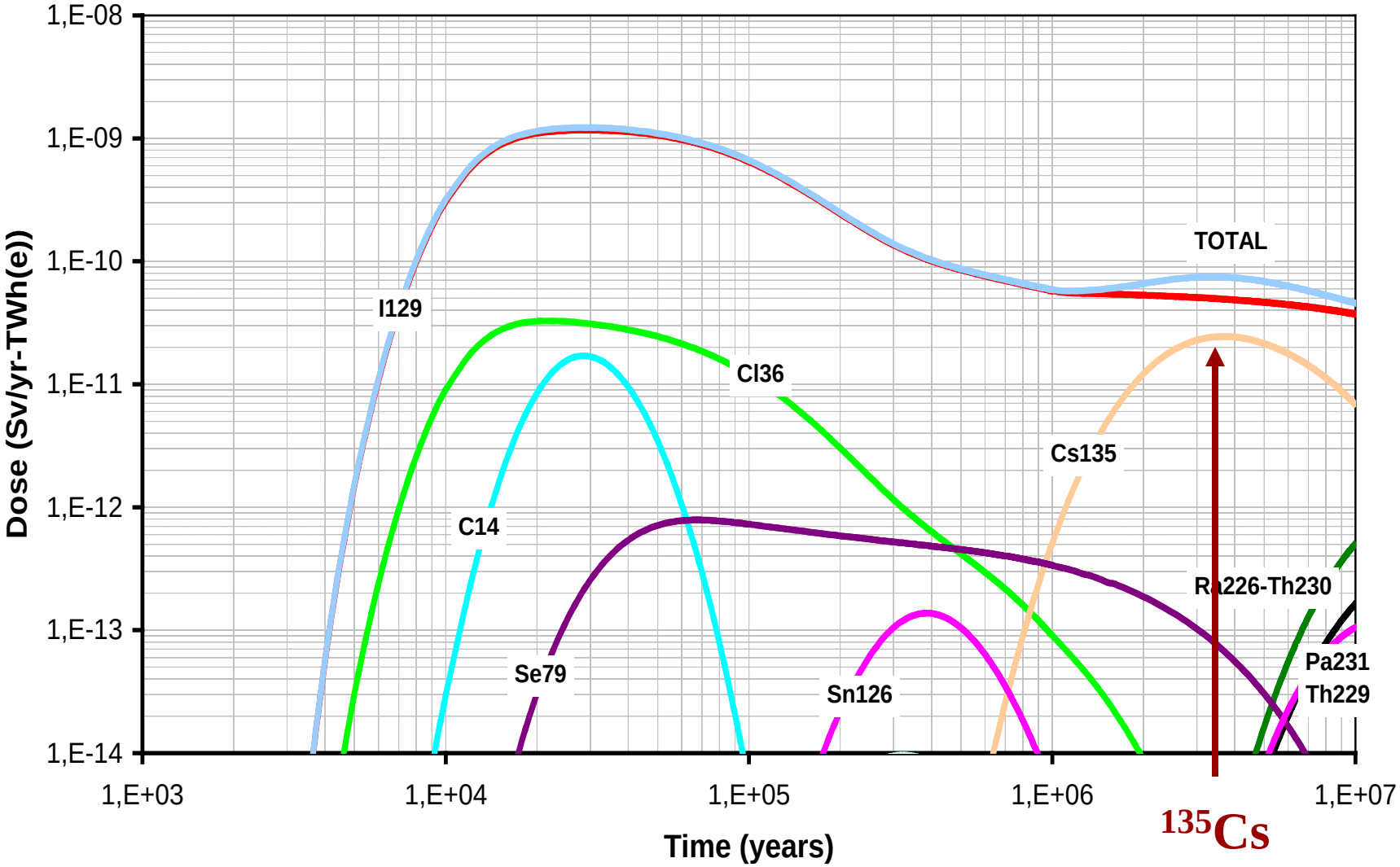
Repository in granite

Concept: Enresa, Spain

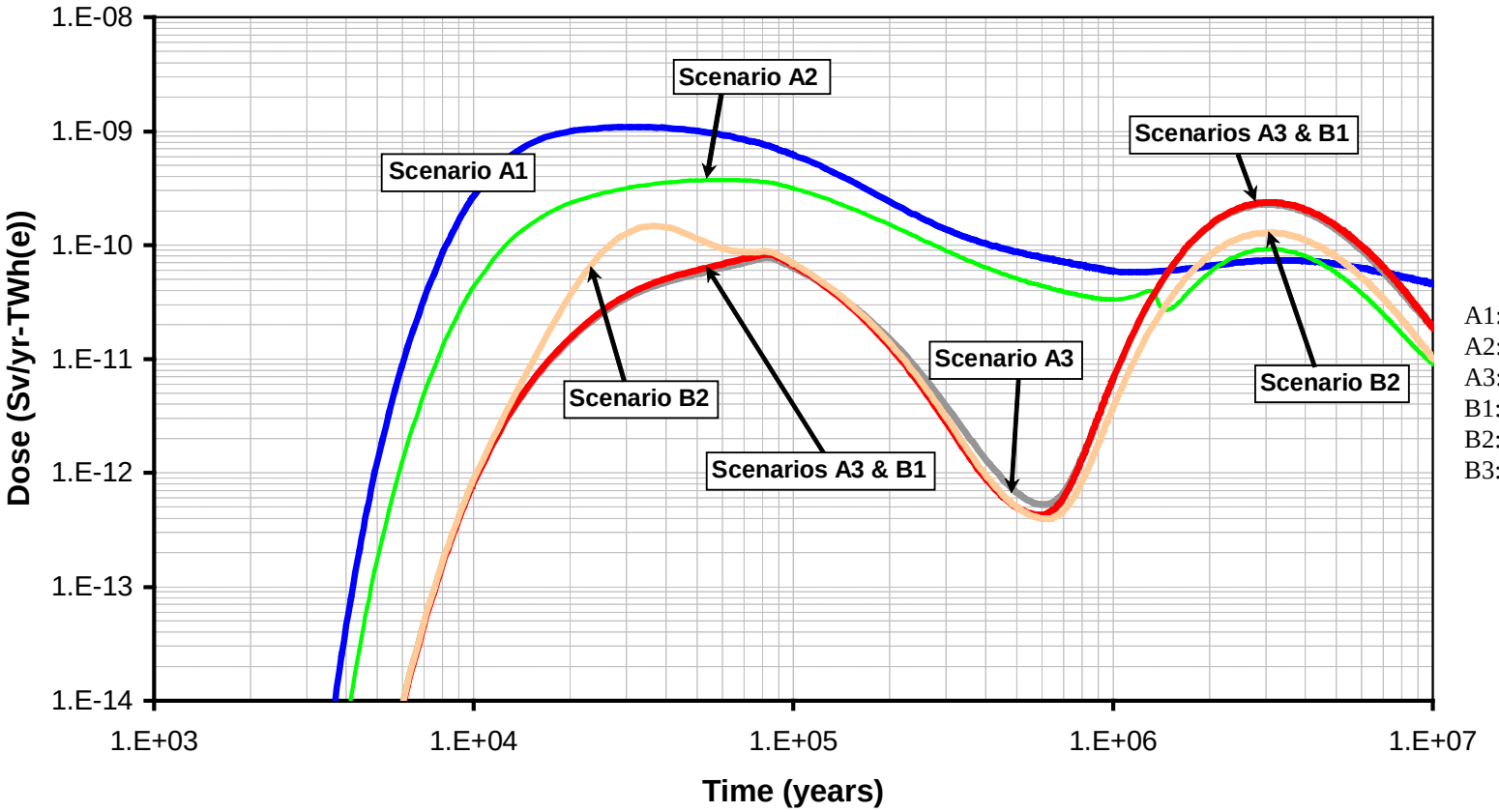


- Bentonite saturated after 20 a, corrosion starts
- Sequential failure of canisters from 1300 to 10000 a
- Average time for H_2O to reach biosphere 8400 a
- **Diffusion and sorbtion retards the transport of many nuclides**
- Release to river (10^6 m^3/a), exposed group use river water

Long-Lived Fission Products dominate Doses (A1 granite)



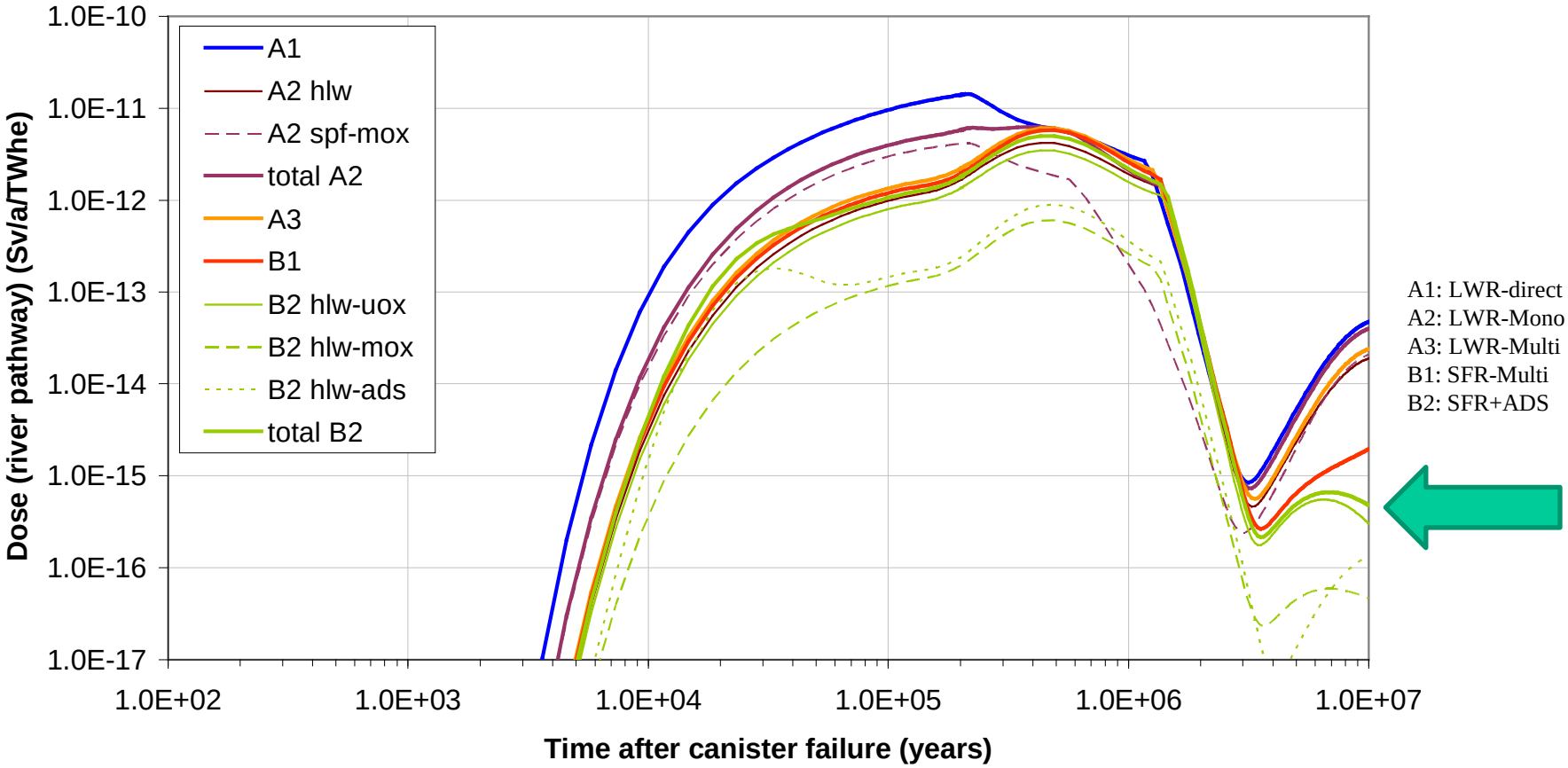
Granite: calculated doses
(all scenarios, Enresa)



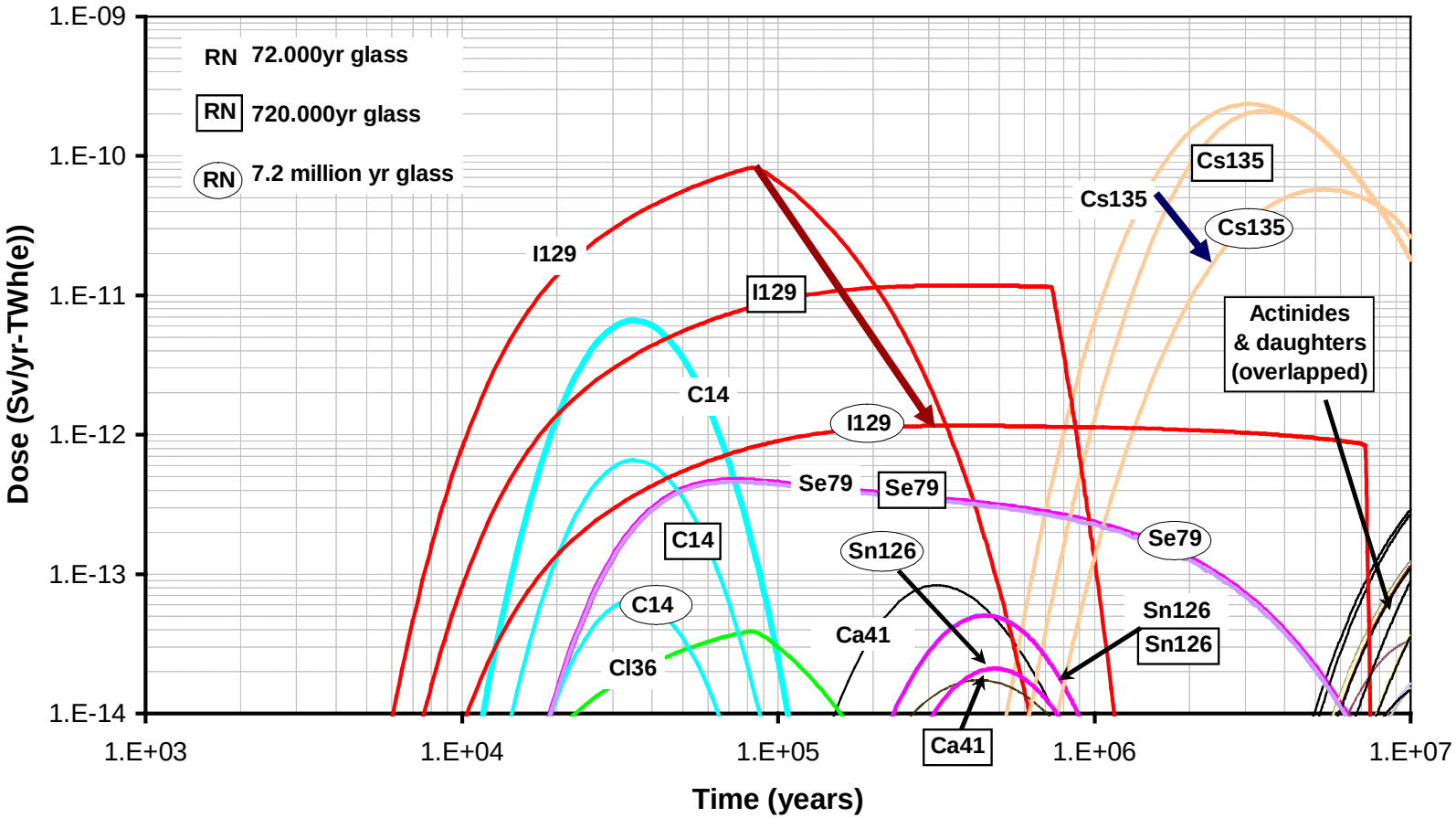
A1: LWR-open
A2: LWR-Mono
A3: SFR-Multi-Pu
B1: SFR-Multi-Pu&MA
B2: SFR+ADS
B3: LWR, SFR+ADS

Differences mainly due to Iodine removal during reprocessing !!!

Calculated doses in Clay
(all scenarios, SCK•CEN)



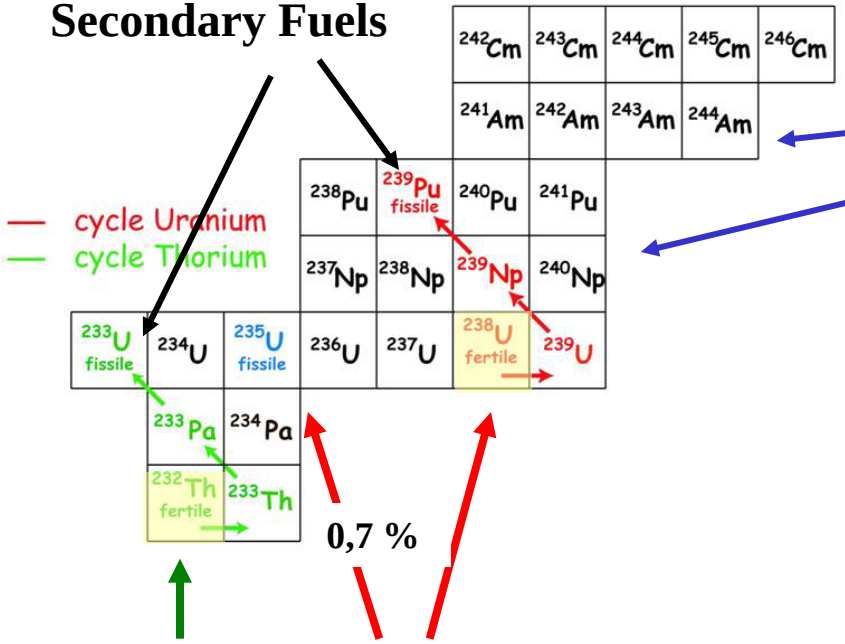
Variant scenarios of B1
(calculated e.g. for Granite)



Impact of waste matrix lifetime

Thorium: Reduction of MA

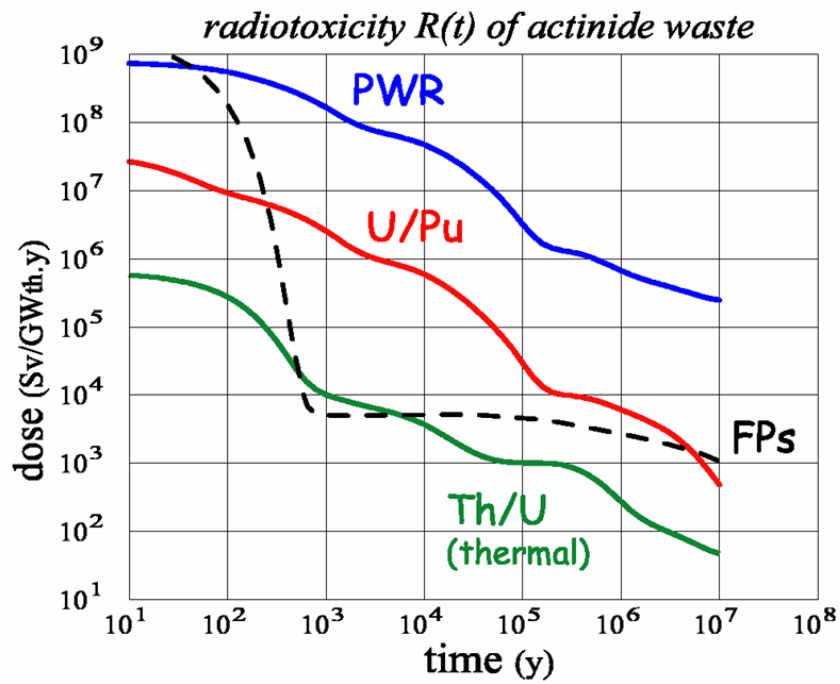
Secondary Fuels



Thorium (3 x more)

Uranium

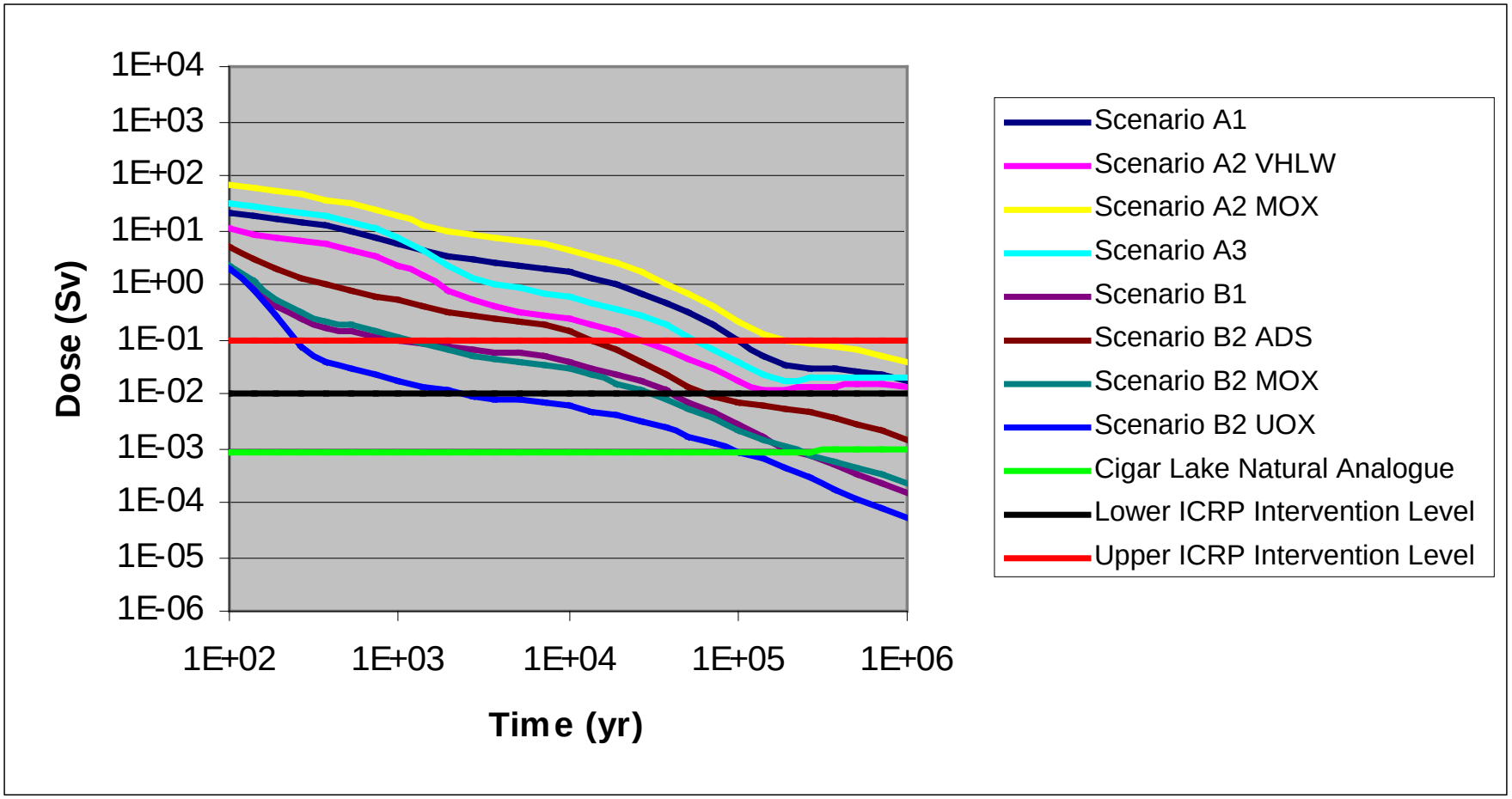
Actinides: Long-term Radiotoxicity !!!



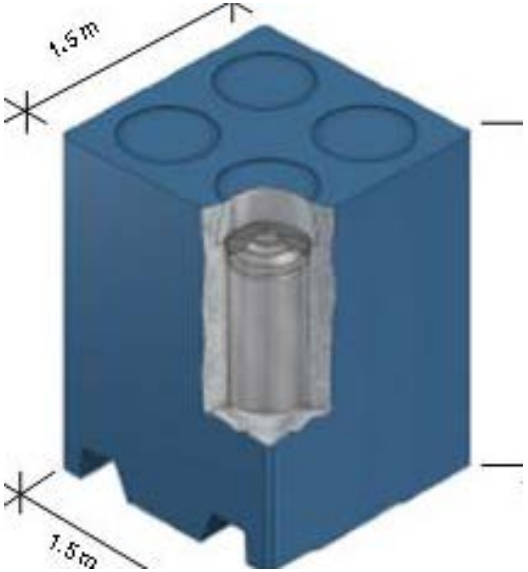
Th/Pu MOX:

2x better Pu/MA consumption !!!

Human intrusion doses
(all scenarios, Nirex)



ILW-Packages



Source:

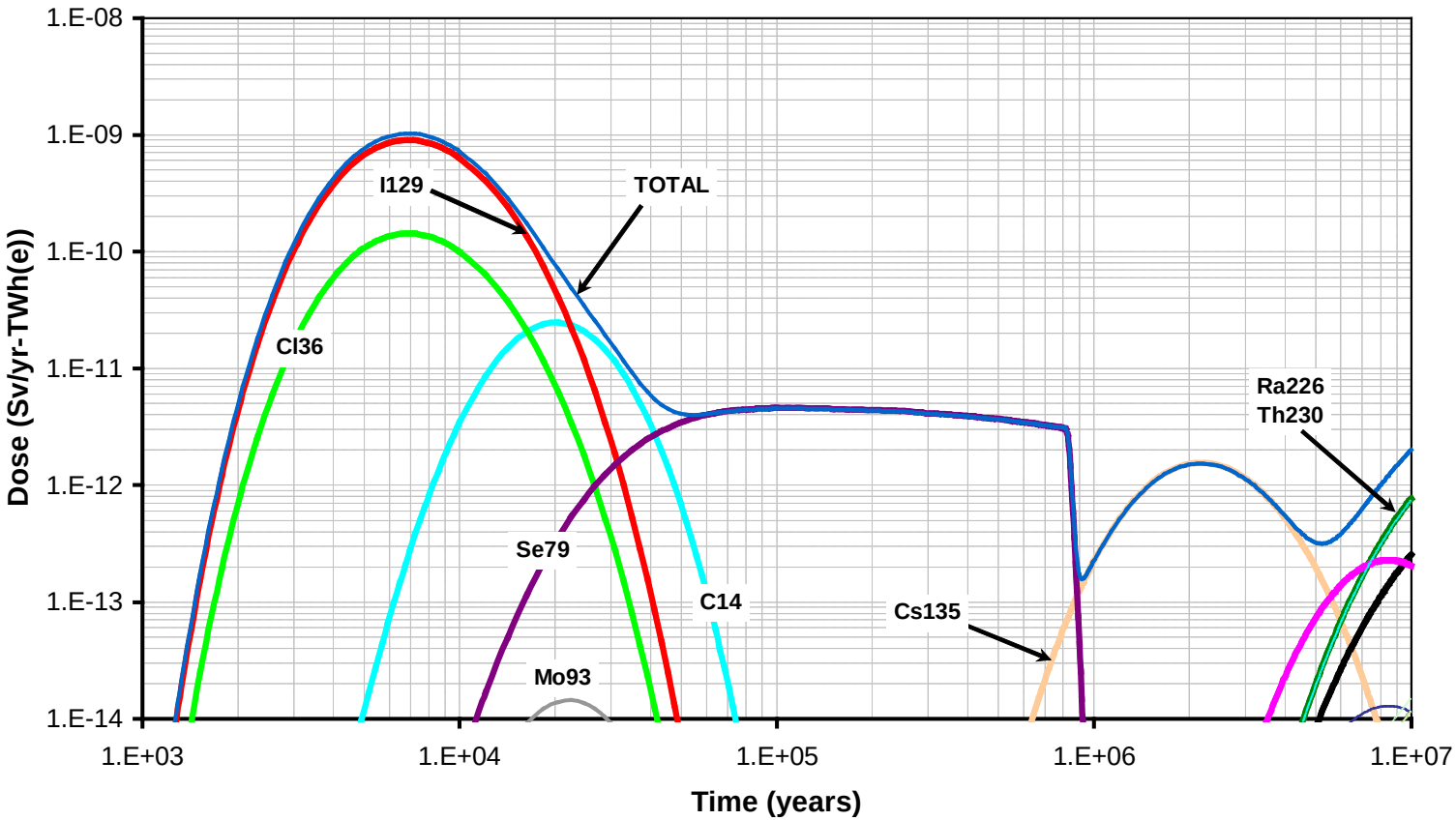
- **Structural Parts of Fuel Assemblies**
  - **End-fittings, chopped claddings, grids etc.**
  - **Core & Blanket**
- **Reprocessing of ADS-Fuel (Zr-Nitride)**
  - **C-14, Cl-36, Nb-94 contents**
  - **Noble metals from Pyro-processing**
- **ADS core components**
  - **Pb-Bi, core support, window, accelerator tube**

For granite repository:

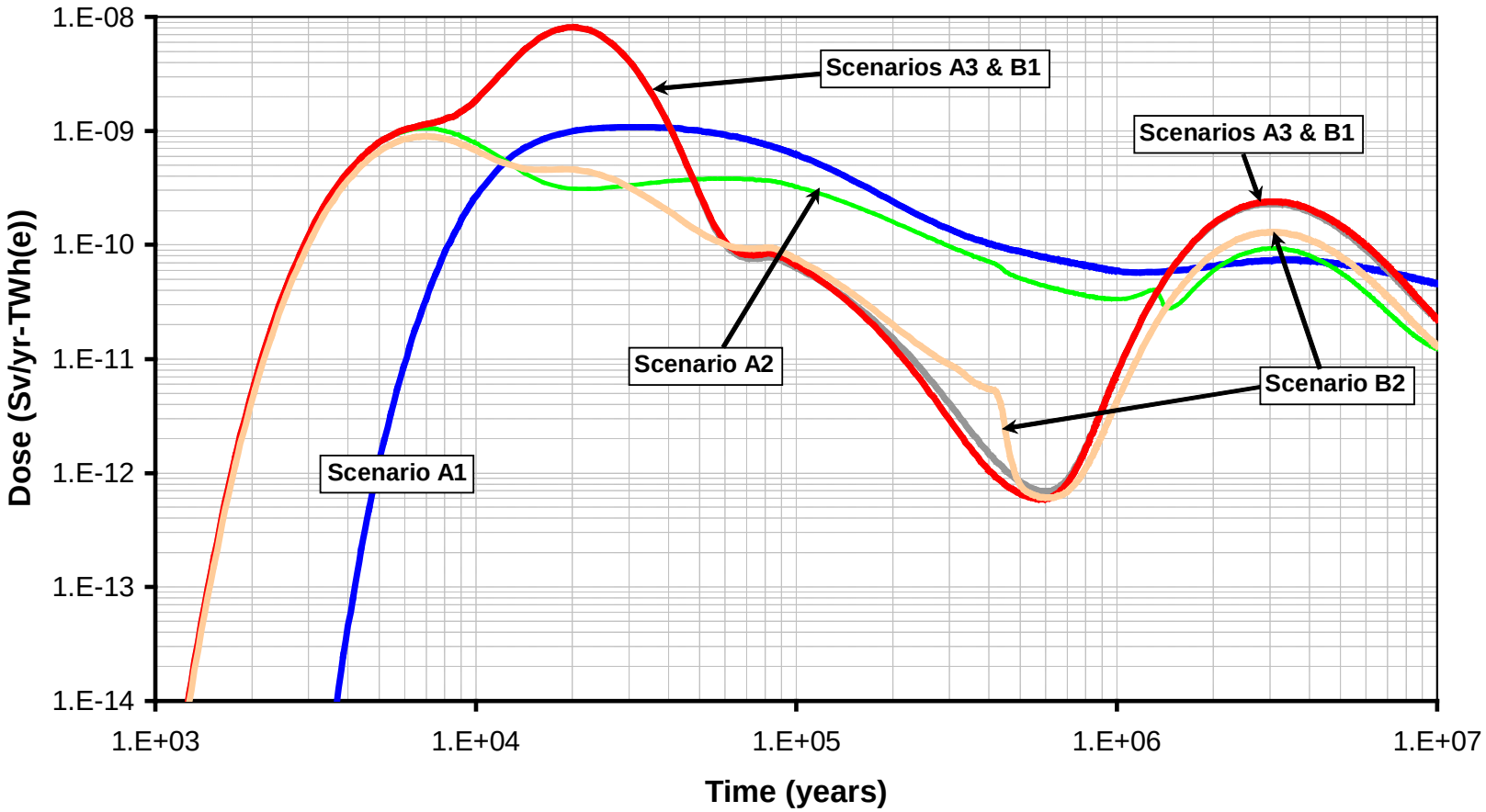
- **Waste matrix less retention**
- **Direct access of ground water**
- **doses start earlier**
- **ILW dominates till 20.000 y**

A1	**0 m^3/TW_eh**
A2	**2,5 m^3/TW_eh**
A3	**5,3 m^3/TW_eh**
B1	**5,3 m^3/TW_eh**
B2	**3,3 m^3/TW_eh**

Calculated doses for ILW in Granite (scenario A2, Enresa)



Doses for HLW + ILW in Granite



Enresa calculation

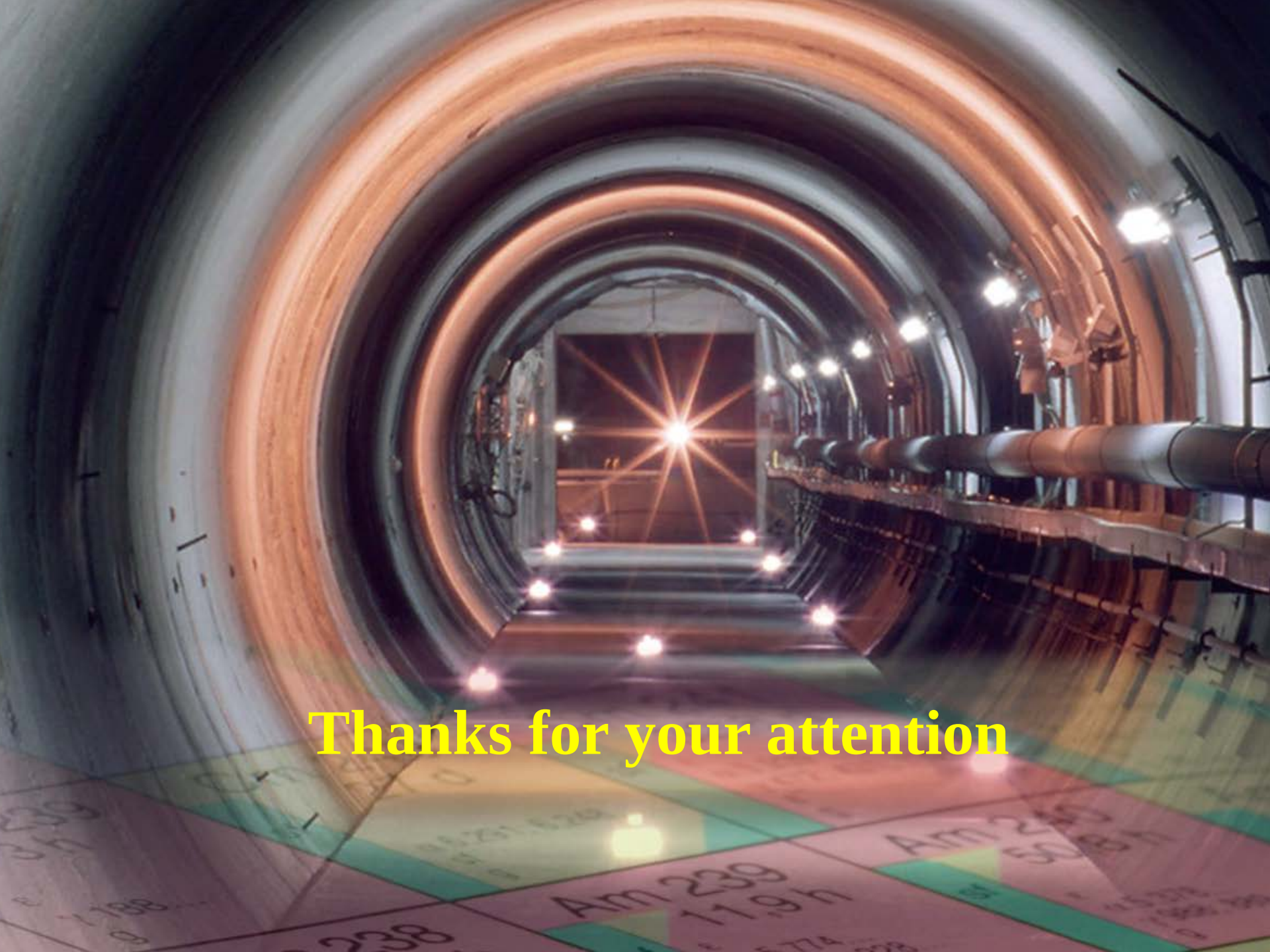
Conclusions (1)

- **P&T Impact on repository dimension**s (heat load)
  - reduction of gallery length with a factor 3
  - a factor 5 in case of Sr separation
  - a factor 10 (or more) in case of ***Cs and Sr separation***
- **P&T Impact on dose**: HLW disposal
  - limited: due to mobile fission and activation products (^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, ^{135}Cs, ^{126}Sn)
  - depends on amount of disposed ^{129}I, ^{14}C, ^{36}Cl vs. discharged volatile isotopes during reprocessing
  - ADS-specific waste to be considered in more detail
- **P&T Impact on Human Intrusion dose**: significant
- **Impact of more stable matrix on dose**: significant

Conclusions (2)

- **ILW Impact on dose**:
  - Granite: ILW doses > HLW doses
    - consider use of low activation materials, add barriers (C-14)
  - Clay: ILW doses < HLW doses
- **Reduced generation of MA:** Th-MOX, IMF vs. Pu-MOX
- **Hetereogeneous recycling & other reactors** **(BWR, HWR, HTR etc.)**
- **Improved Partitioning / Reprocessing:** LLFP, volatile FP
- **Partitioning & Conditioning (P&C):** viable option
- **Cost / Benefit Evaluations:** science / industry dialog
- **Repository/waste package adaptation to P&T waste**

Transition to advanced reprocessing/conditioning: **ASAP**

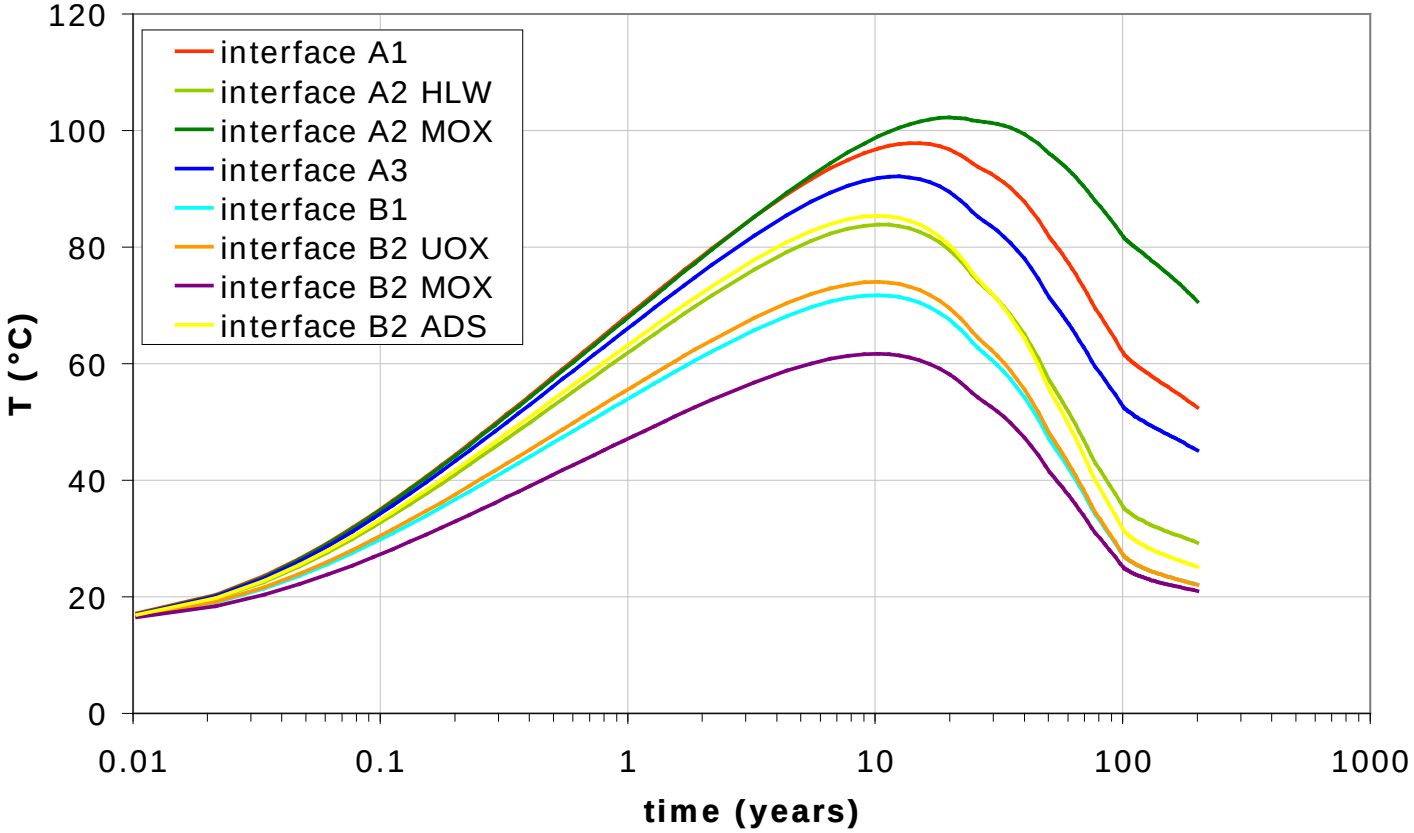


Thanks for your attention

Assumptions

- **A1: reference scenario: open cycle**
  - Burn-up 50 GWd/tHM, UOX : ^{235}U enrichment 4.2%
  - HLW: **5.354 spent fuel assemblies / TWh_{el}**
- **B1: Fast neutron Gen IV & advanced PUREX**
  - Burn-up: core 136 GWd/tHM (axial 15, radial 24)
  - MOX: 23.2% Pu + 2.7% MA
  - Vitrified HLW: **1.644 canisters / TWh_{el}**
- **HLW disposal in 3 host formations**
  - **Granite: ENRESA (Spain),** NRI (Czech Republic)
  - Clay: SCK•CEN (Belgium)
  - Salt: GRS (Germany)

Evolution of temperature

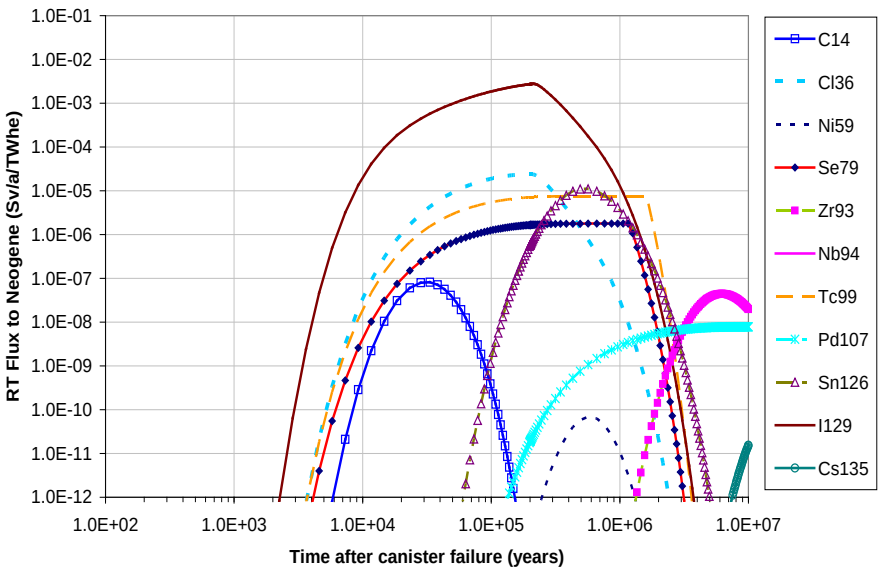


A1: LWR-open
A2: LWR-Mono
A3: LWR-Multi
B1: SFR-Multi
B2: SFR+ADS

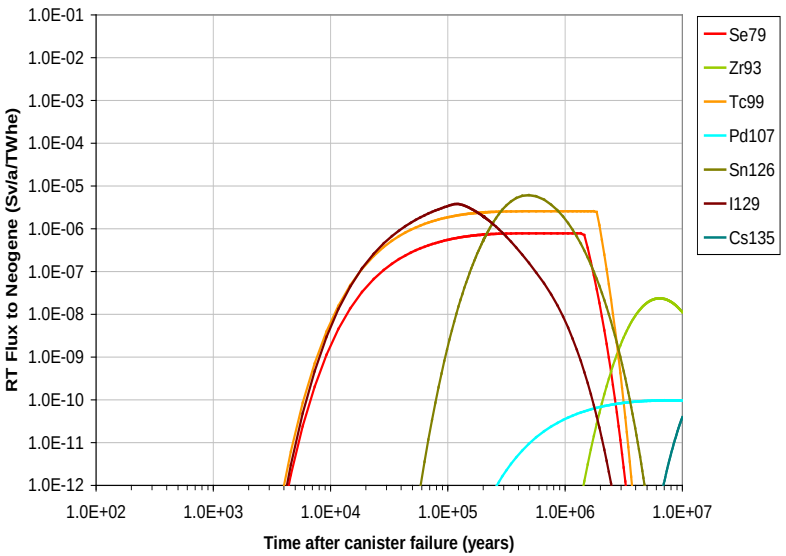
Radiological impact

- Safety functions of repository system
  - Engineered containment
    - Container lifetime (2000 a)
  - Slow release of RNs
    - Waste matrix degradation (100 000 a)
    - Solubility limitation (reducing conditions)
  - Very slow transport
    - Diffusive transport through buffer (and clay formation)
    - Sorption on (clay) minerals
- Small releases of radionuclides into biosphere

Radiotoxicity Fluxes for Clay



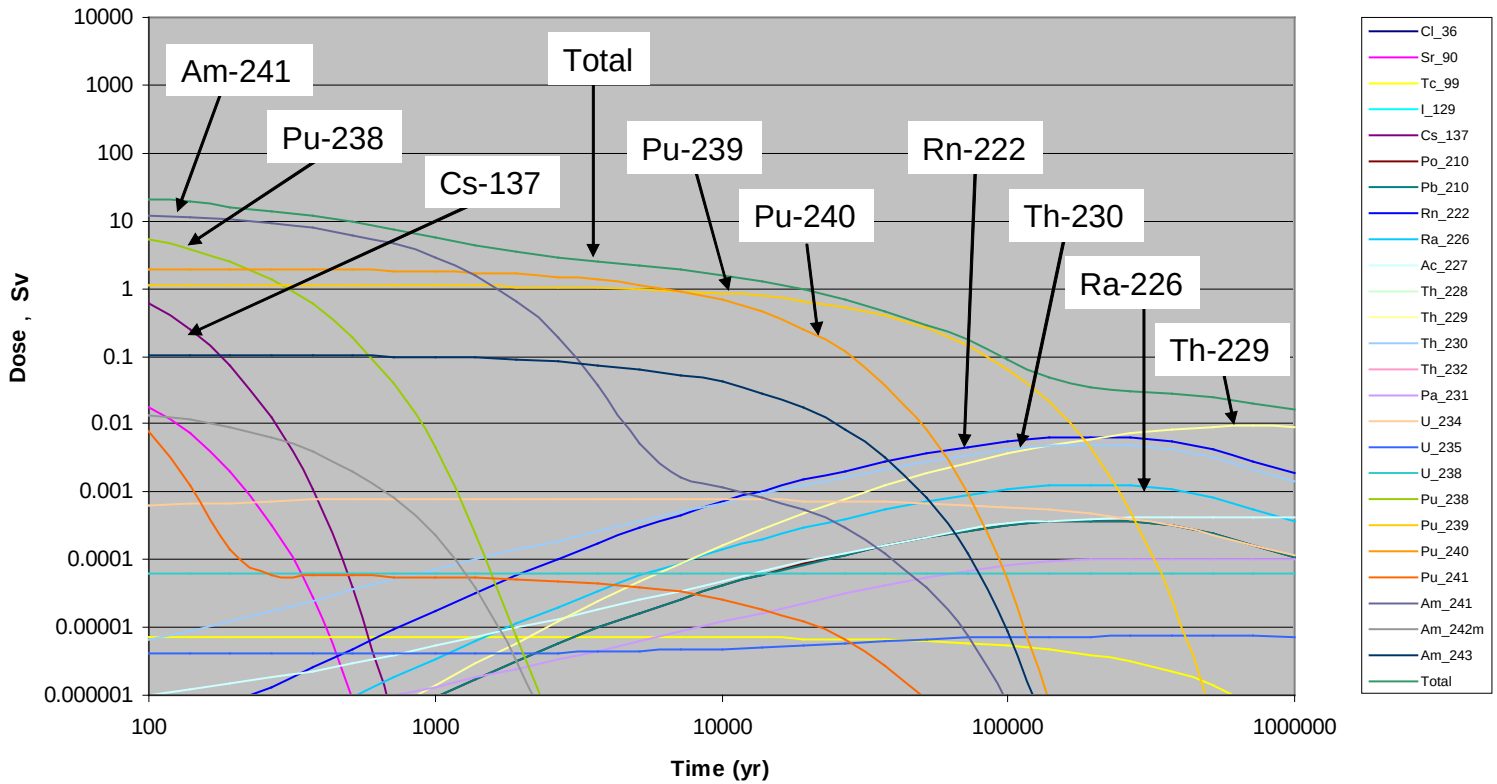
A1



B1

Significant impact of long-lived fission products !
Minor Actinides strongly immobilised !
Strong dependence on solubility limits !

Human intrusion doses
(scenario A1, Nirex)

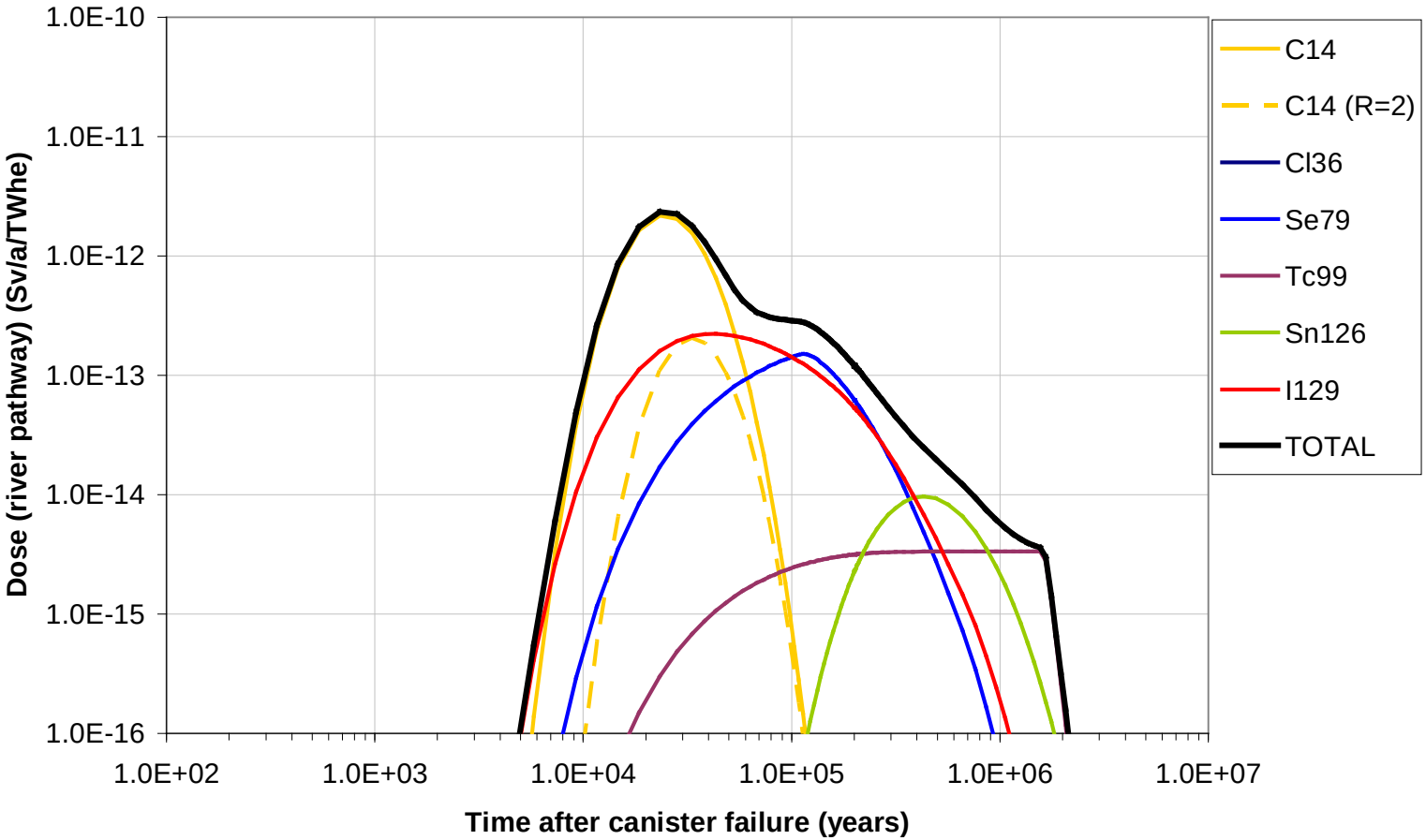


MA dominate Human Intrusion Scenarios

Human intrusion: required isolation times

Comparator / HLW/SF Types	Cigar Lake natural analogue	ICRP 10 mSv intervention level	ICRP 100 mSv intervention level	Radiotoxicity
Scenario B1: HLW	~200,000 a	~40,000 a	~1000 a	~300 a
Scenario B2: HLW from ADS fuel	> 1 Ma	~70,000 a	~13,000 a	~300 a
Scenario A3: HLW	> 1 Ma	> 1 Ma	~70,000 a	~24,000 a
Scenario A1: spent UOX fuel	> 1 Ma	> 1 Ma	~100,000 a	~200,000 a
Scenario A2: spent MOX fuel	> 1 Ma	> 1 Ma	~200,000 a	~90,000 a

ILW: calculated doses in Clay
(scenario A3, SCK•CEN)



Doses for HLW + ILW in Clay
(all scenarios, SCK•CEN)