Impact of Advanced Fuel Cycles on Geological Disposal in a Clay Formation

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Content

1. Framework
2. Considered fuel cycles
3. Considered repository system
4. Impact on the dimensions of the HLW repository
5. Radiological impact of HLW disposal
   a) Doses in case of expected evolution scenario
   b) Evolution of radiotoxicity and human intrusion doses
6. ILW disposal
7. Conclusions

Framework

- Nuclear Energy Agency
  - 3rd Expert Group on P&T related topics
  - Impact of Advanced Nuclear Fuel Cycle Options on Waste Management Policies
    - ♣January 2003 - October 2005
- European Commission
  - Red-Impact (Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal) Project
    - ♣March 2004 – September 2007

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Considered fuel cycles

- NEA study (10 fuel cycles + 3 variants)
  - Current industrial technology and extensions (4)
  - Partially closed fuel cycles (3 + 1)
  - Fully closed fuel cycles (3 + 2)

Considered fuel cycle scenarios

- Red-Impact project
  - 3 industrial scenarios:
    - A1: the reference scenario: open cycle in PWRs
    - A2: mono recycling of Pu in PWRs
    - A3: multi-recycling of Pu in EFRs
  - 3 innovative scenarios:
    - B1: fast neutron Gen IV scenario: multi-recycling of Pu and MA in EFRs
    - B2: PWRs (50 GWd/tHM) + ADS

Fuel cycle scenarios considered in this paper (6 fuel cycles + 1 variant)

- Scenario 1: ref. scen.: open cycle in PWRs (NEA 1a)
- Scenario 2: mono recycling of Pu in PWRs (NEA 1b)
- Scenario 3: multi-recycling of Pu in PWRs (NEA 2a)
- Scenario 4: mono recycling of Pu in PWRs, MA + Pu from MOX recycled in ADS (R-I B2)
- Scenario 5: Na-cooled FR (R-I B1)
- Scenario 6: gas-cooled FR (NEA 3c-v1)
- Scenario 6a: gas-cooled FR + removal of Cs and Sr from HLW (NEA 3c-v1_Cs,Sr)

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Needed amount of natural uranium

Fuel cycle scenario	Consumption of natural U
	(kg/TWhe)
1	20723
2	18448
3	17935
4	15766
5	106
6	86

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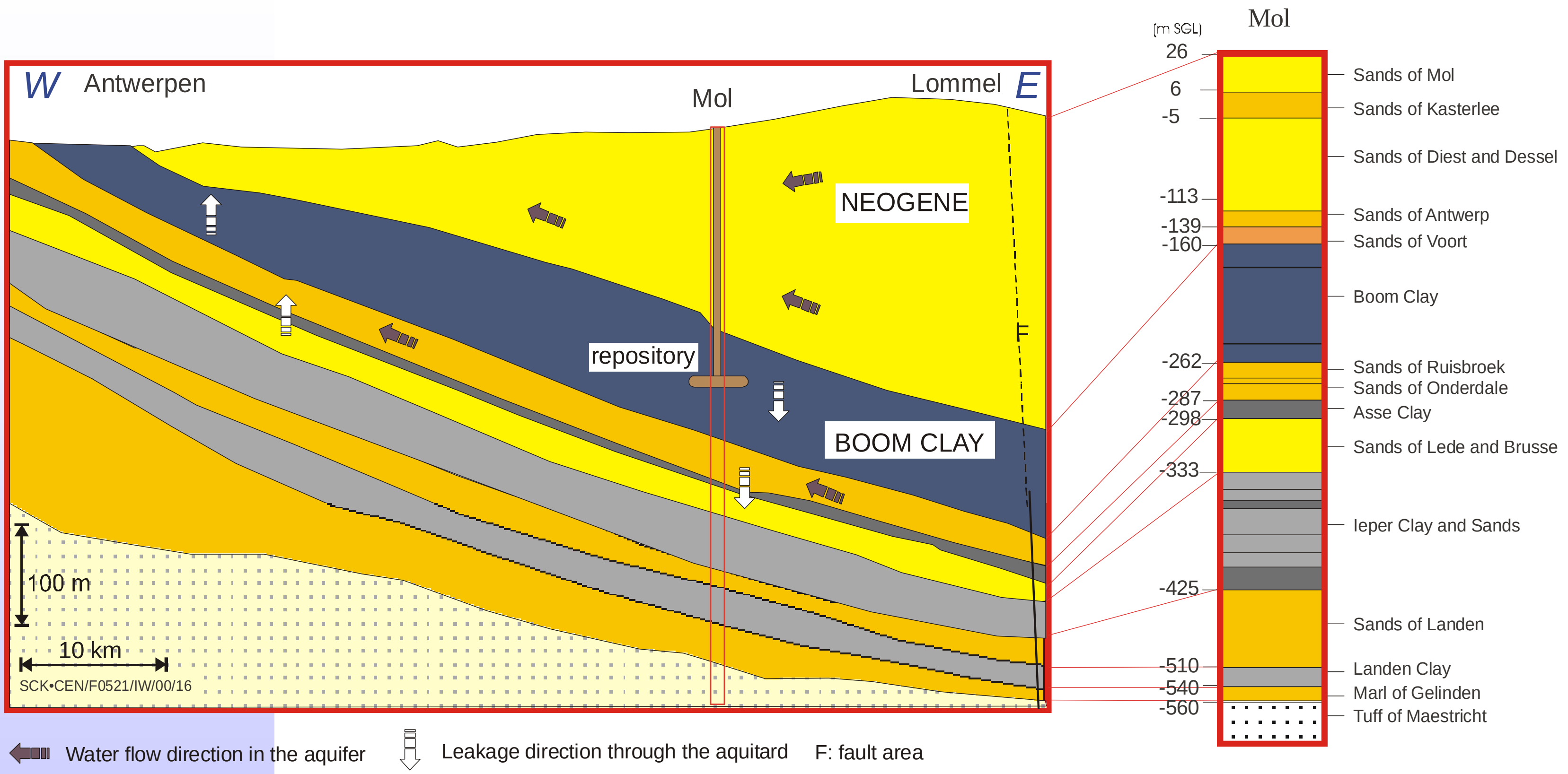
HLW: main assumptions

- Activation products not considered in NEA study
  - large uncertainties for advanced fuel cycles
- Reprocessing losses (NEA study)
  - 0.1% for U and Pu
  - 1% for minor actinides (wet reprocessing)
  - 0.1% for minor actinides (pyro-reprocessing)
  - 1% of Cs and Sr (scenario 6a)
- I-129
  - 0.1% to 1% of I-129 in vitrified HLW
- HLW matrix in case of advanced fuel cycles
  - Not yet known, assumed to have a performance comparable to that of present glass matrices

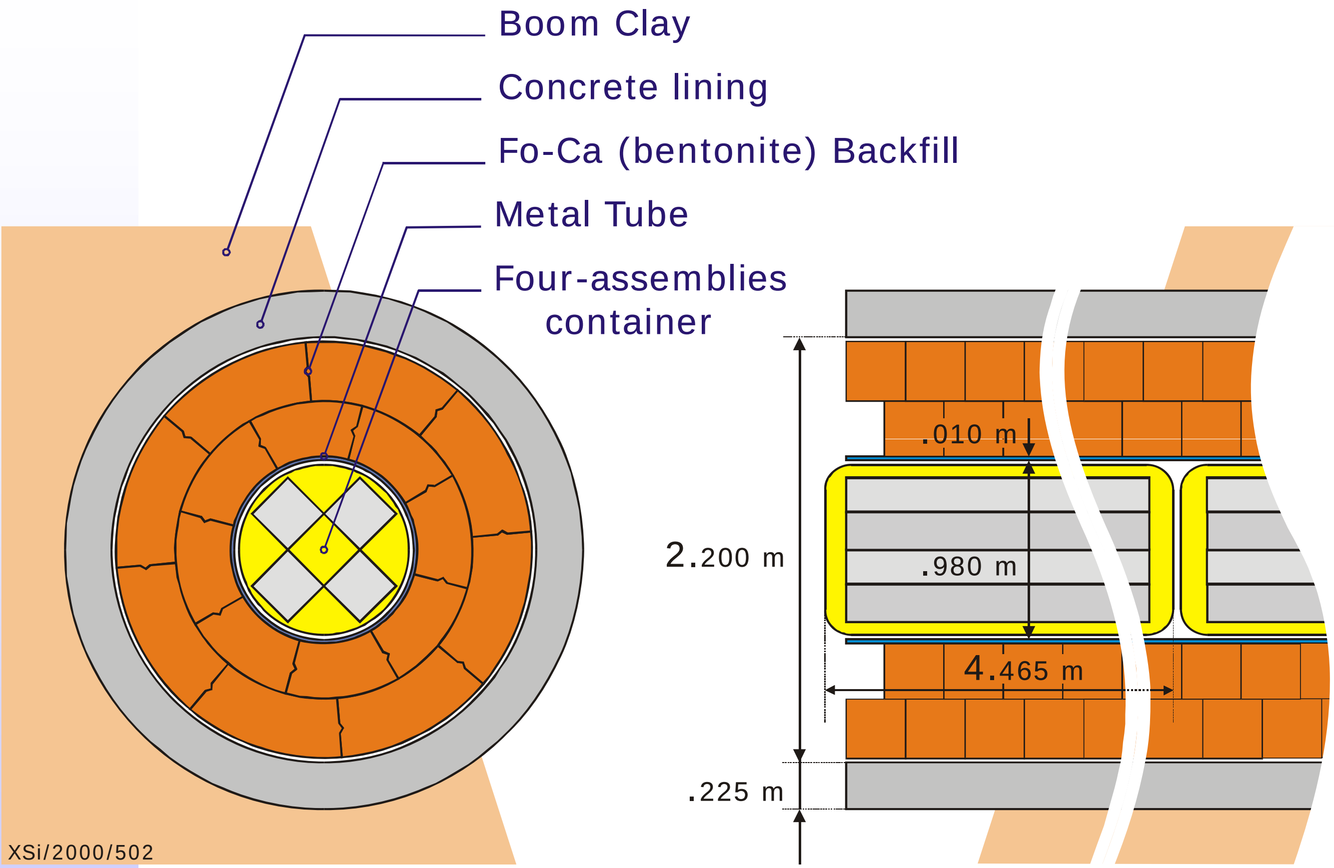
Waste packages

- Spent fuels
  - UOX: 4 assemblies packed in 1 container
  - MOX: 1 assemblies packed in 1 container
- Vitrified HLW
  - 1 HLW canister packed in 1 (short) container

Geological disposal: considered site (clay layer in NE Belgium)



Gallery configuration (UOX)



Impact of thermal output of HLW on disposal configuration

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- Cooling time 50 years
  - after unloading of spent fuel from reactor
- Main temperature limitation
  - temperature at liner / clay interface
    T< 100 °C
    - ♣Linear thermal loading < 300-350 W/m

Thermal output and needed length of disposal galleries

		Fuel cycle scenario						
		1	**2**	**3**	**4**	**5**	**6**	**6a**
SF assemblies	#/TWhe	3.98	0.44	-	-	-	-	
HLW canisters	#/TWhe	-	2.59	3.99	2.50	1.77	1.18	0.70
Cs-waste canisters	#/TWhe							0.22
Thermal output HLW (50 a)	W/TWhe	2110	2031	1997	1051	715	571	12.5
Thermal output Cs-waste (100 a)	W/TWhe							121
Length HLW disposal galleries	m/TWhe	7.03	6.77	6.66	3.50	2.44	2.02	0.75

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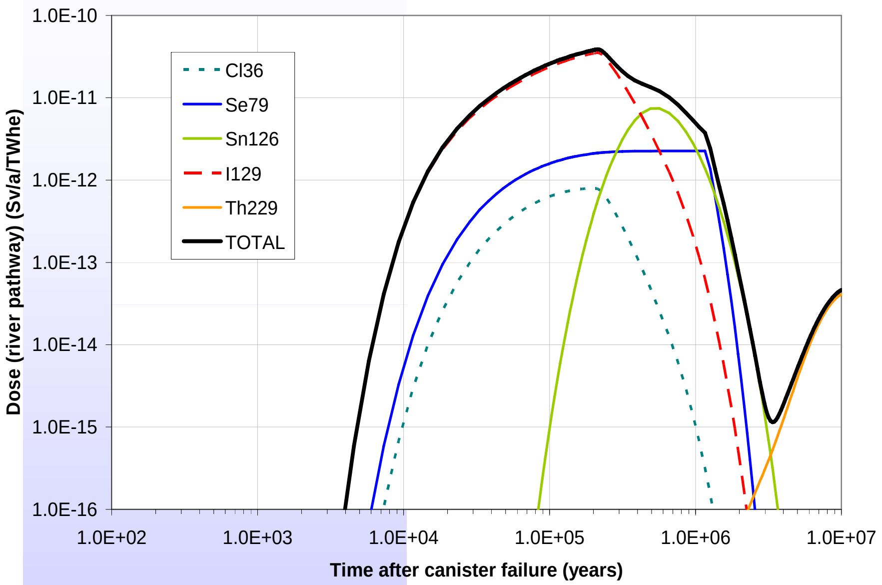
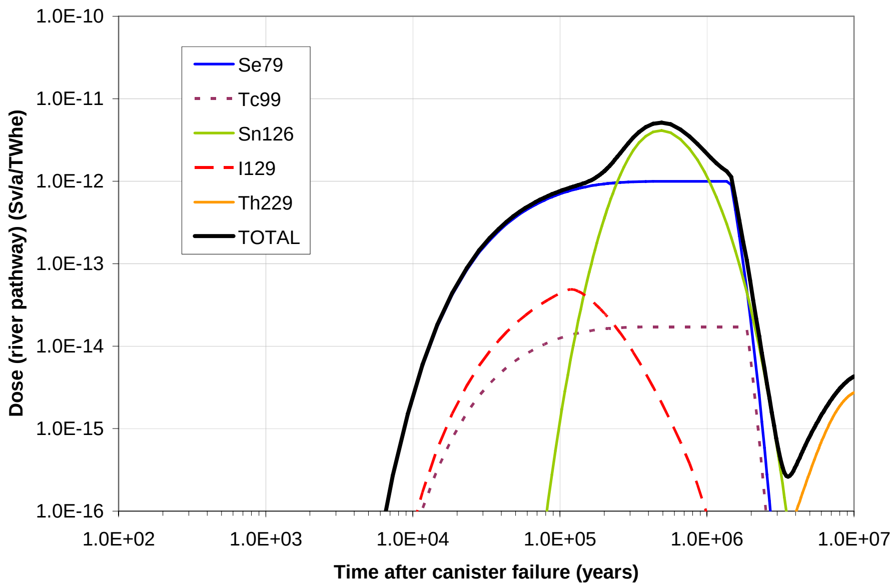
Radiological impact

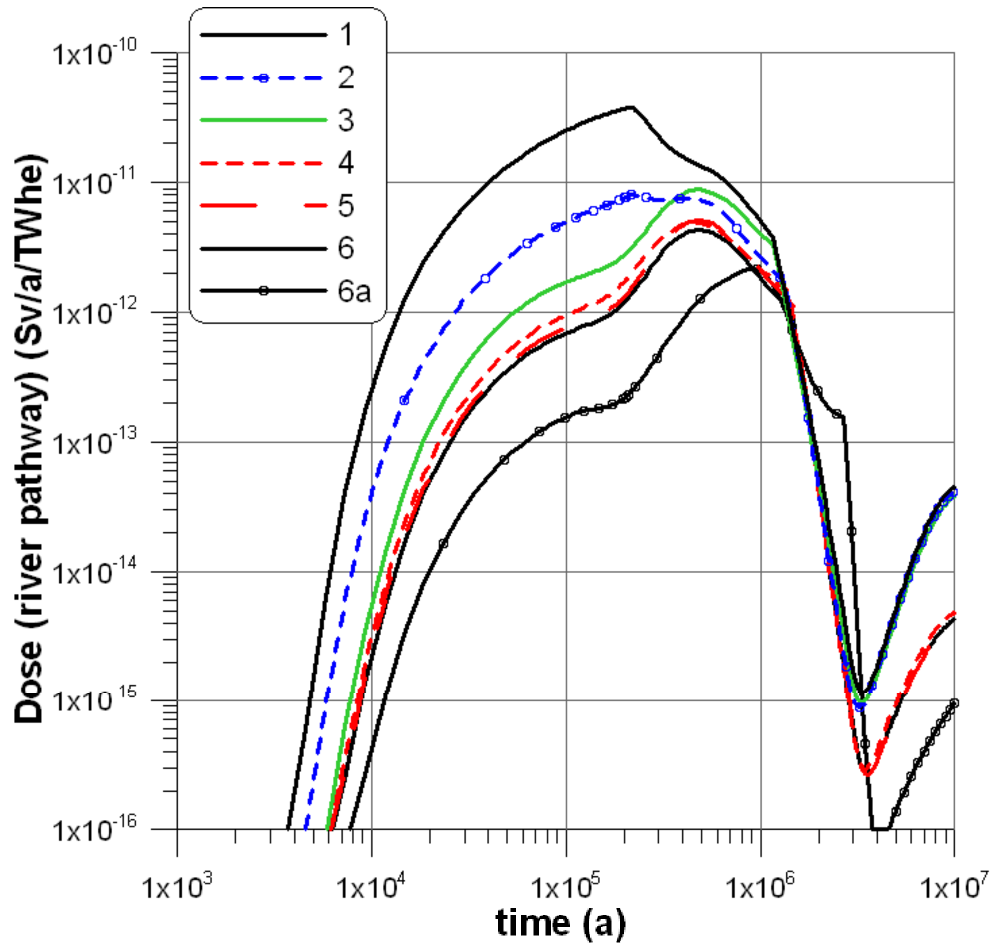
- Expected evolution scenario
  - Container lifetime: 2000 a
  - Main barrier: host clay formation
  - Main processes
    - Waste matrix degradation
    - Solubility limitation (reducing conditions)
    - Diffusive transport through buffer and clay layer
    - Sorption on clay minerals
  - Very small releases of mobile radionuclides into aquifers and biosphere

Calculated doses via river pathway (scenarios 1 and 5)





Calculated doses via river pathway (all scenarios)



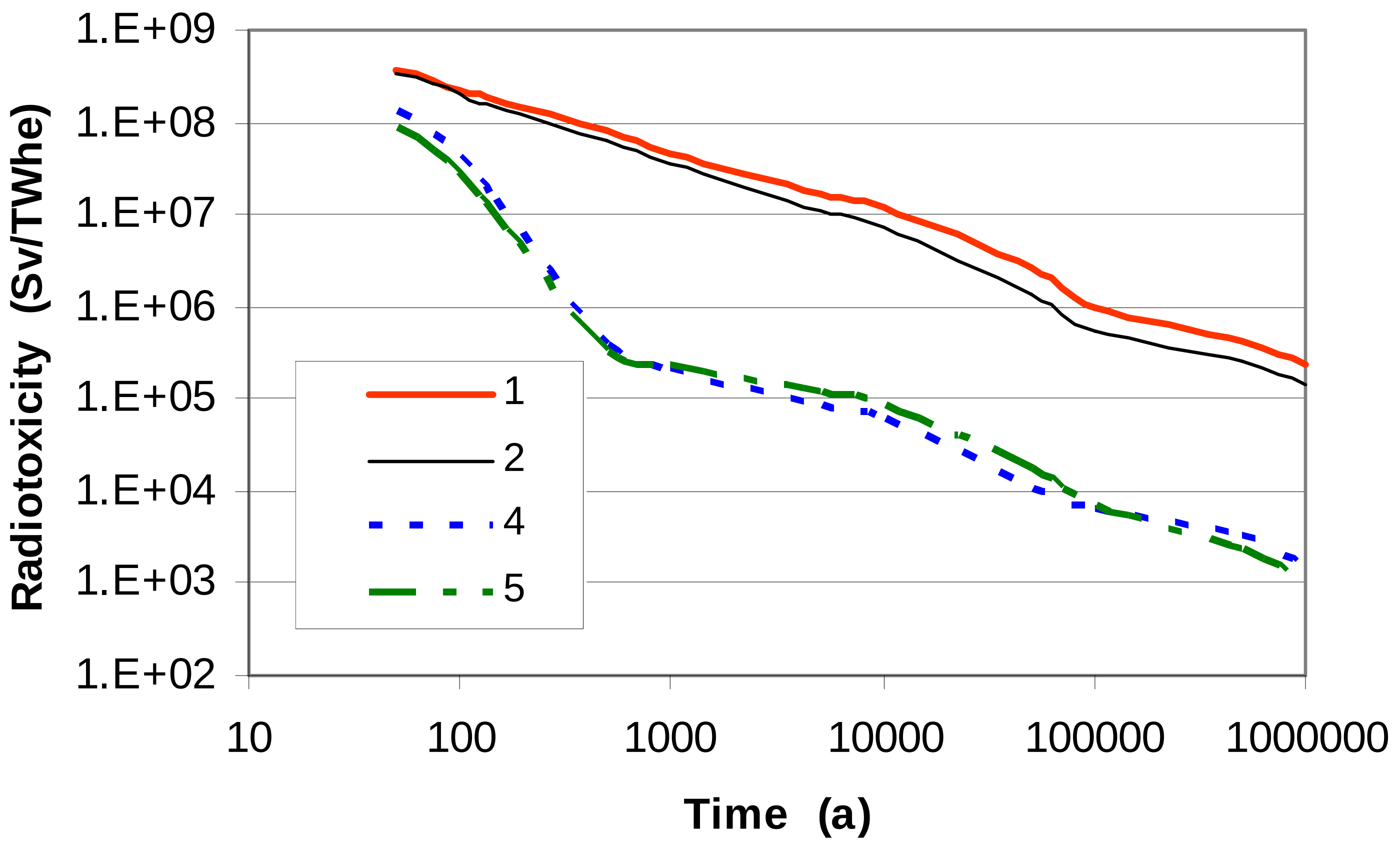
Complementary indicators

- Duration of releases
  - Cumulative radiotoxicity released into biosphere
    - integrated over time (up to 1 million years)
- Human intrusion
  - Radiotoxicity in waste

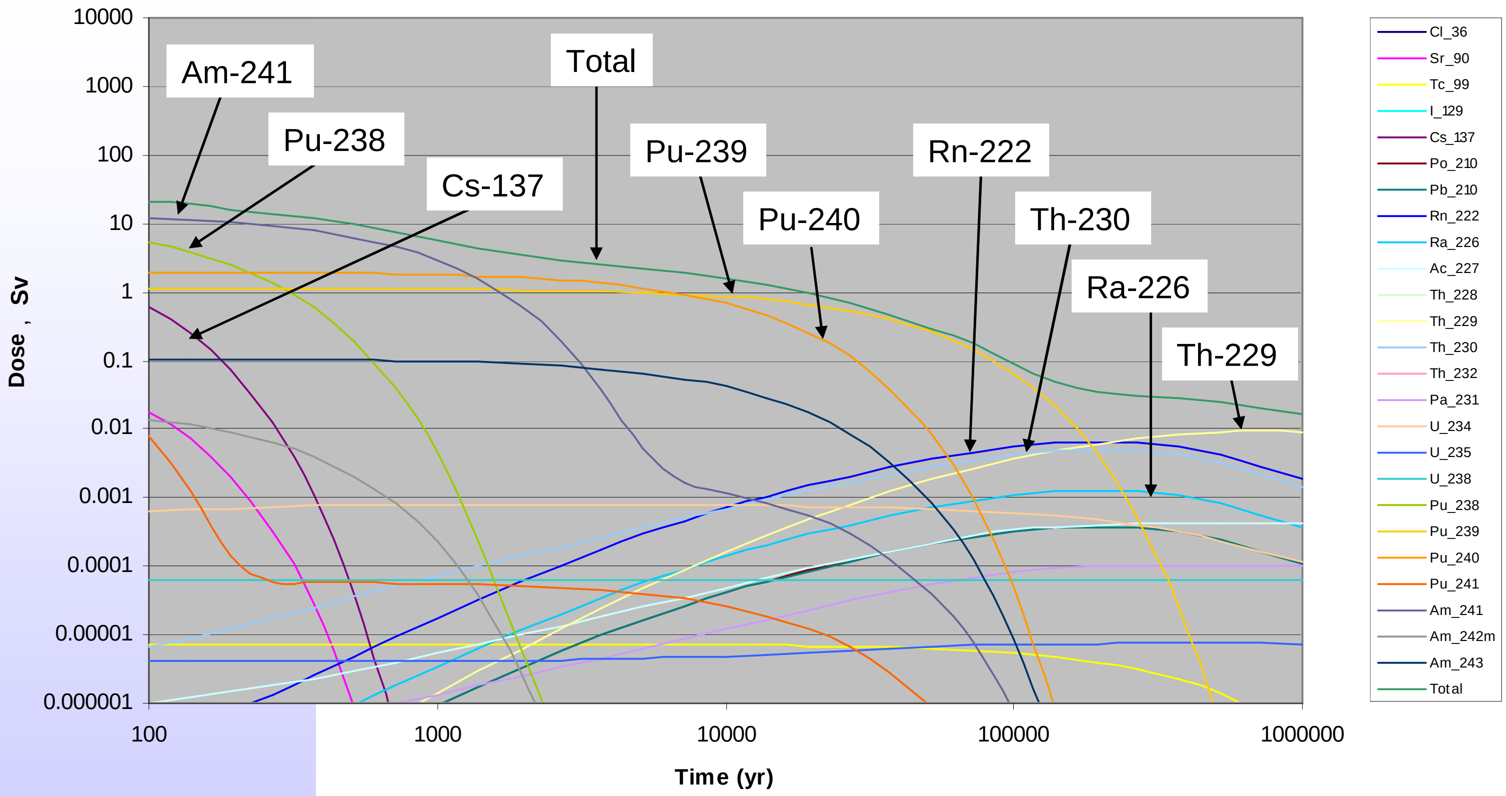
Cumulative radiotoxicity released into biosphere up to 1 million years

Fuel cycle scenario	Cumulative radiotoxicity (Sv/TWhe)
1	724
2	108
3	15.4
4	8.58
5	7.20
6	6.33
6a	2.93

Evolution of radiotoxicity in waste



Dose to geotechnical worker: intrusion into spent fuel repository (scenario 1)



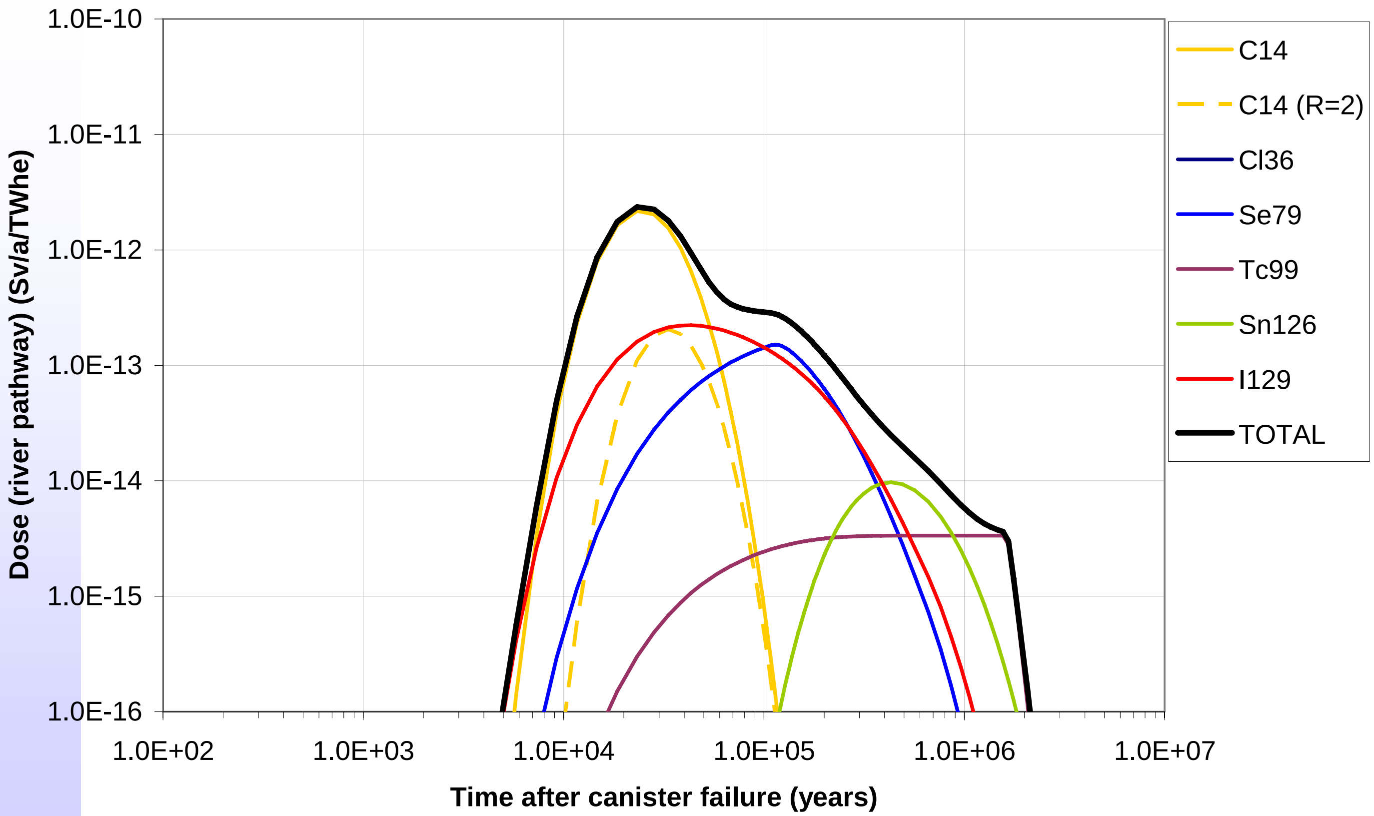
Required isolation times

Comparator / HLW/SF Types	Cigar Lake natural analogue	ICRP 10 mSv intervention level	ICRP 100 mSv intervention level	Radiotoxicity
Scenario 5: HLW	~200,000 a	~40,000 a	~1000 a	~300 a
Scenario 4: HLW from ADS fuel	> 1 Ma	~70,000 a	~13,000 a	~300 a
Scenario 3: HLW	> 1 Ma	> 1 Ma	~70,000 a	~24,000 a
Scenario 1: spent UOX fuel	> 1 Ma	> 1 Ma	~100,000 a	~200,000 a
Scenario 2: spent MOX fuel	> 1 Ma	> 1 Ma	~200,000 a	~90,000 a

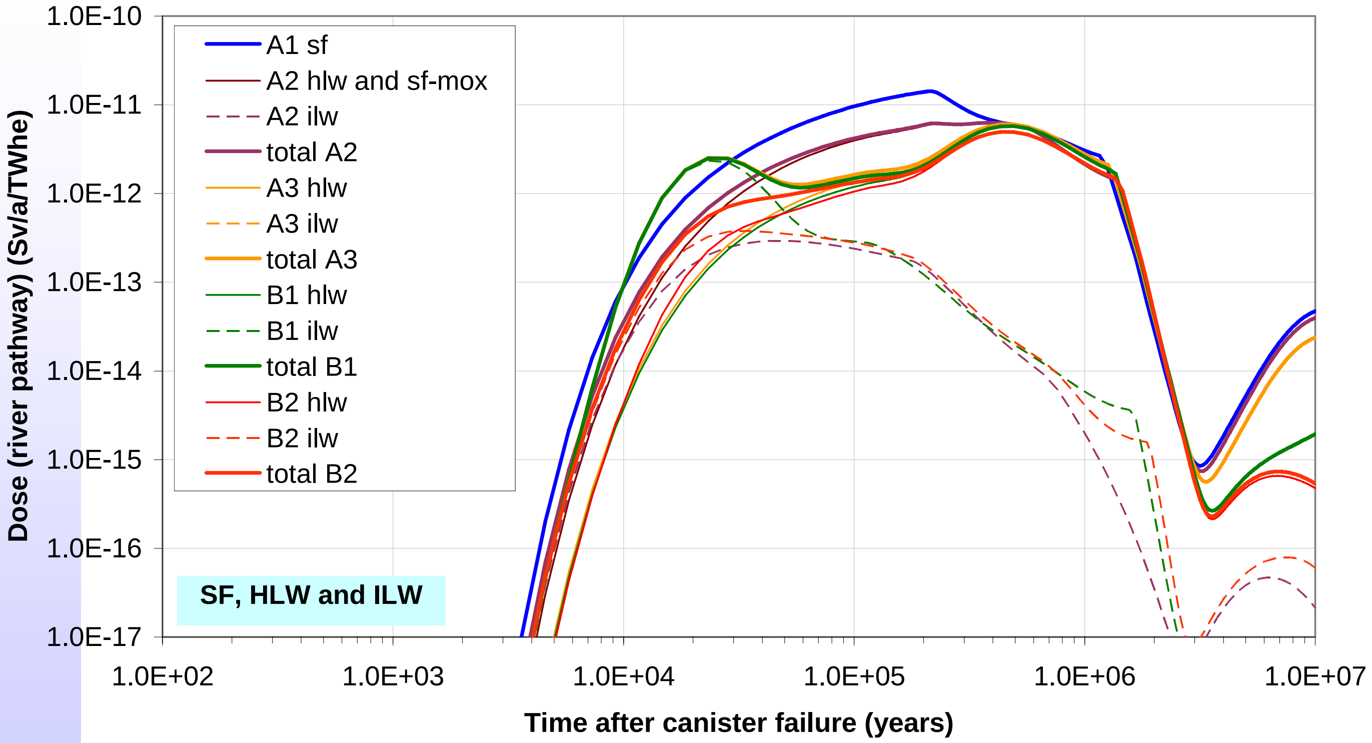
ILW (Red-Impact): number of waste canisters

Fuel cycle		1	2	3	4	5
spent fuel	(assemblies/Twhe)	5.35	0.54	-	-	-
V-HLW	(canisters/Twhe)	-	2.48	2.4	2.66	2.27
ILW-reprocessing	(canisters/Twhe)	-	2.21	4.71	2.93	4.71
ILW- operation	(canisters/Twhe)	-	-	-	0.03	-

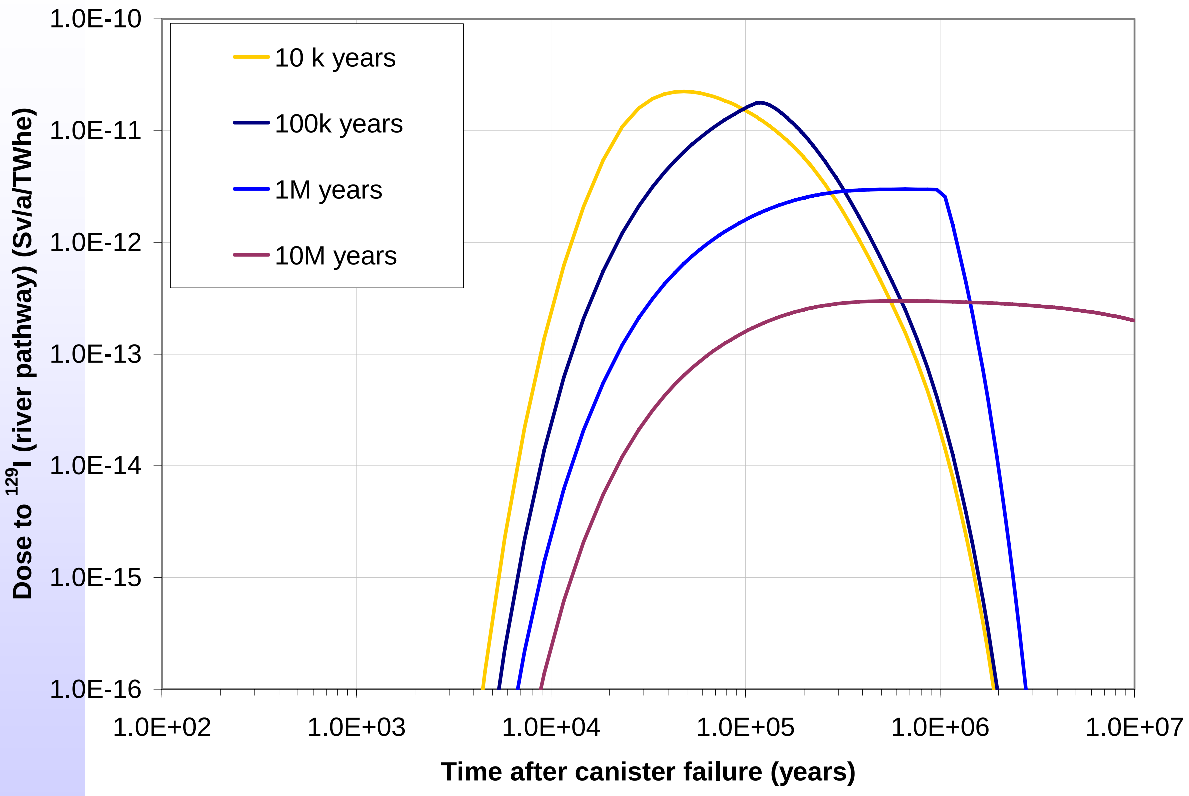
ILW: doses (scenario 5 (B1))



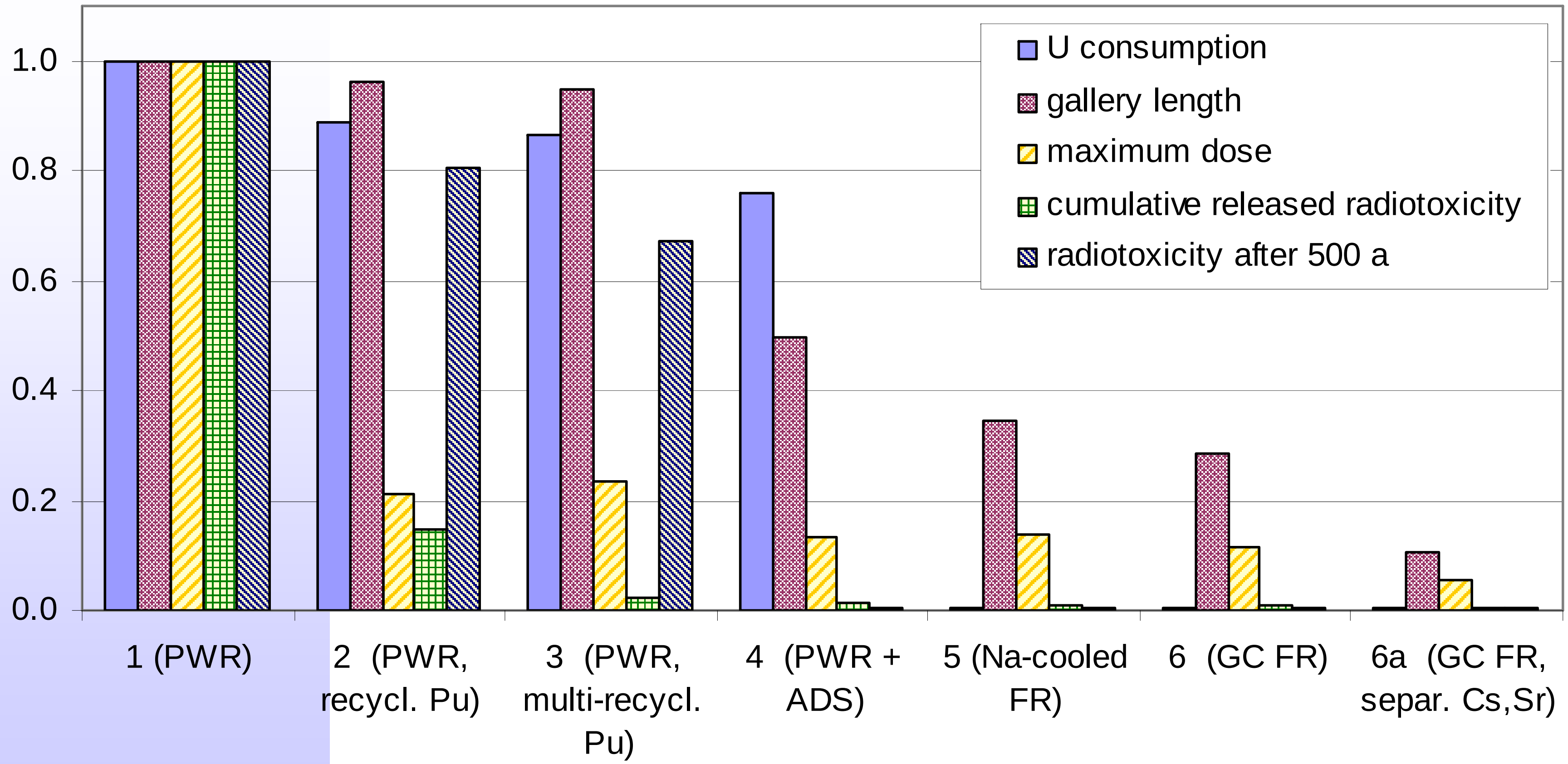
ILW vs. HLW doses



I-waste


1.0E-10
1.0E-11
1.0E-12
1.0E-13
1.0E-14
1.0E-15
1.0E-16
Dose to ^{129}I (river pathway) (Sv/a/TWhe)
10 k years
100k years
1M years
10M years
1.0E+02
1.0E+03
1.0E+04
1.0E+05
1.0E+06
1.0E+07
Time after canister failure (years)

Overview of results



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Conclusions (1)

- Impact on repository dimensions
  - HLW (high thermal output) AFC: reduction of gallery length with a factor 2 to 3.5 (10 or more in case of Cs and Sr removal)
  - ILW: volume comparable with HLW, negligible thermal output
- Radiotoxicity (human intrusion dose)
  - AFC: strong reduction of radiotoxicity after 500 years (transmutation of actinides in ADS or FR)

Conclusions (2)

- Impact on dose
  - Limited: dose is due to mobile fission (and activation) products and not to actinides
  - Depends strongly on amount of disposed ^{129}I
  - AFC: somewhat higher contribution of solubility limits due to more compact disposal configuration
  - ILW doses: non-negligible (10% of HLW)
    - Activation products: e.g. ^{14}C in case of FR
      - Low activation materials needed
  - I-waste: very stable waste matrices (or containers) needed

Limitations

- The presented results were obtained for equilibrium scenarios
  - it may last 100-200 years to reach equilibrium
- How to switch from present fuel cycles to advanced fuel cycles?
  - transient scenarios
    - final disposal: expected waste types have been considered
  - Cm stocks
- How to end advanced fuel cycles?
  - very “hot” spent fuels arise from FR or ADS
  - complete transmutation takes about 150 years

More information

- Paper (clay) will be published in Nuclear Technology (July 2008)
- NEA report (clay, granite, salt, tuff)
  - *Impact of Advanced Nuclear Fuel Cycle Options on Waste Management Policies*
  - published by NEA/OECD in 2006
- Red-Impact project (clay, granite, salt)
  - Synthesis report
    - to be published as a FZJ-report (June 2008?)
  - Web site:

    www.red-impact.proj.kth.se