RED-IMPACT – Progress report

IMPACT OF PARTITIONING, TRANSMUTATION AND WASTE REDUCTION TECHNOLOGIES ON THE FINAL NUCLEAR WASTE DISPOSAL

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Representing the Red–Impact Project : Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal.

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- Nexia Solutions, Sellafield, UK
- Forschungszentrum Juelich GmbH, Germany
- + 17 other members of RED-IMPACT

Outline

- Red-Impact Partners
- Objectives of Red-Impact
- Project Structure
- Studied scenarios
- Assumptions
- Indicators
- Results and Conclusions
- Added on values

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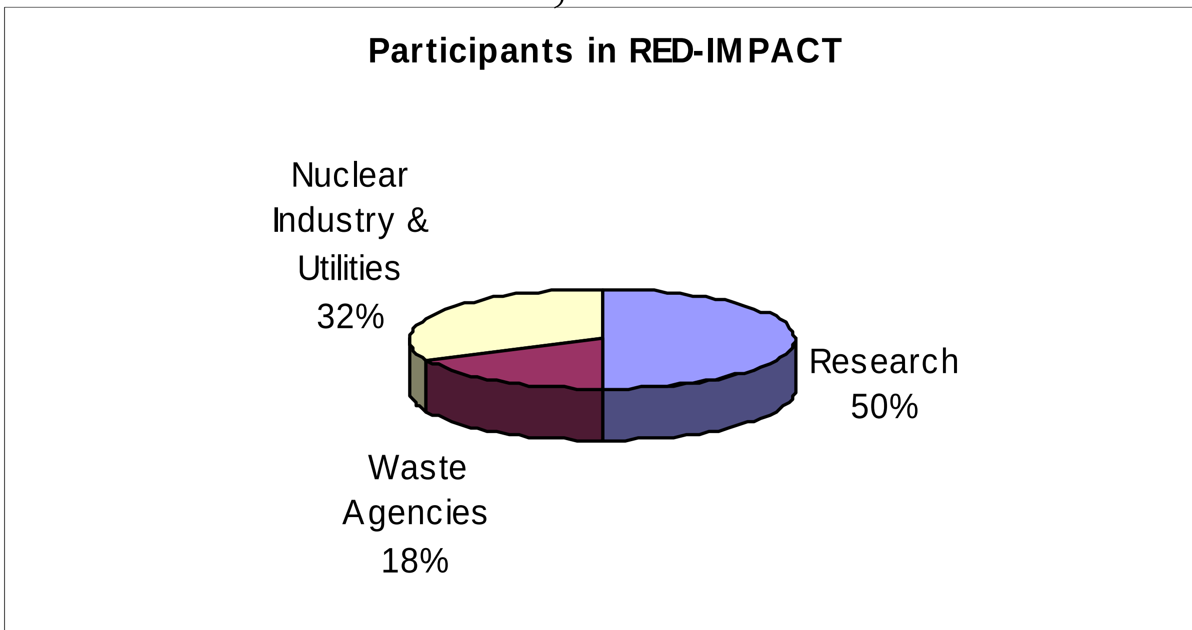
Partners of RED-IMPACT

A unique consortium of research institutes, waste agencies and industrial partners

23 partners + 2 subcontractors, 11 countries



RED-IMPACT participants

RED-IMPACT website : http://www.red-impact.proj.kth.se/

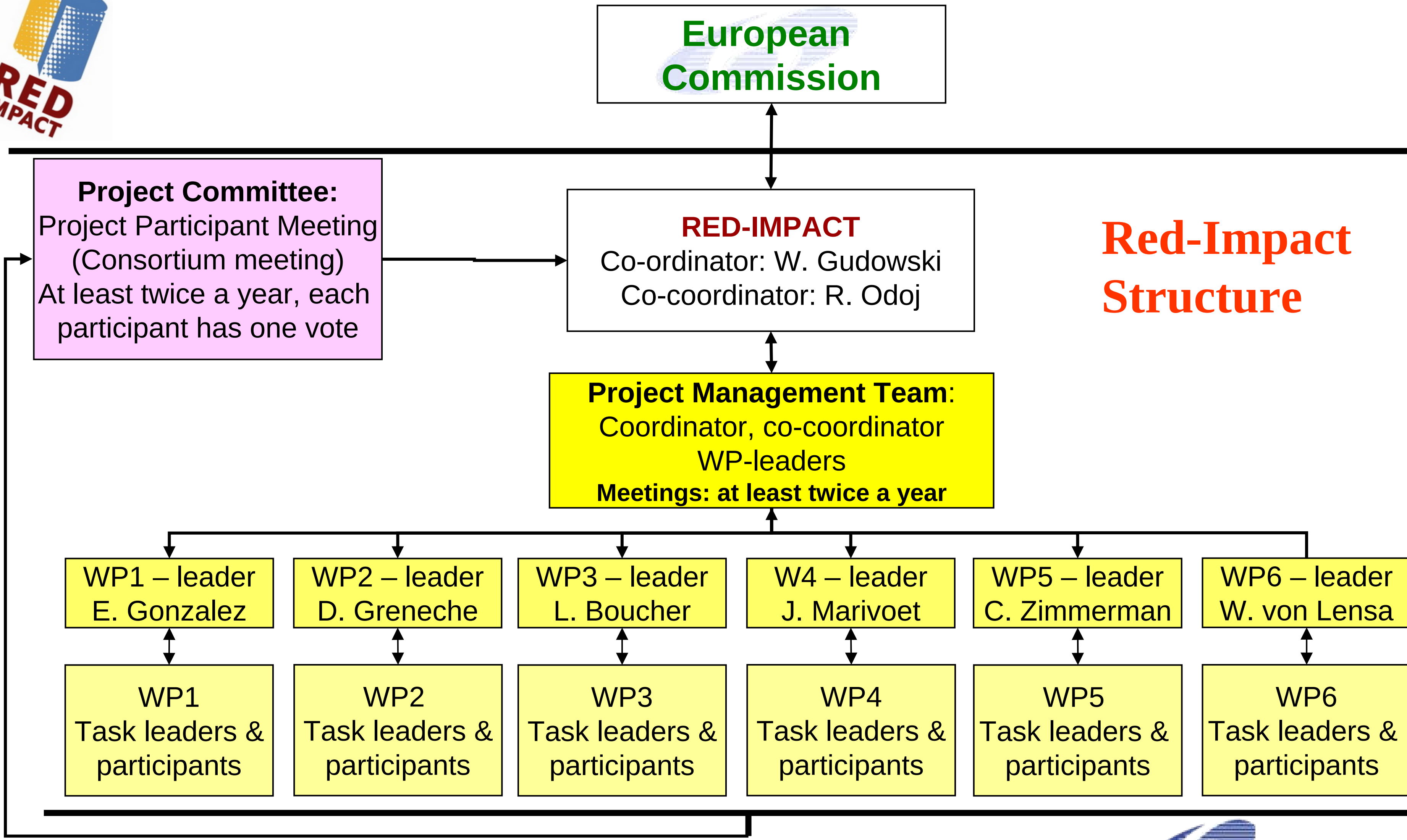
The objectives of RED-IMPACT project – Why do we want to do transmutation:

- Assess the effects of P&T on geological disposal and waste management.
- Assess Economic, Environmental and Societal Costs/benefits of P&T.
- Disseminate results of the study to stakeholders (scientific, general public and decision makers) and get feedback during the study.
- Iterate and refine the work based on stake-holders' feedback to achieve full impact of this study on the implementation of the waste management policy of the European Community.

Red-Impact: six workpackages

- **WP1**: Review of waste management and transmutation strategies, selection of fuel cycles scenarios
- **WP2**: Feasibility of the industrial deployment of selected scenarios and their impact on waste management
- **WP3**: Assessment of waste streams, waste features, leach resistance, heat generation, reprocessing capability etc for selected fuel cycles.
- **WP4**: Assessment of the benefits and costs of P&T/C in advanced fuel cycles for waste management and geological disposal.
- **WP5:** Economic, environmental and societal assessment of fuel cycle strategies
- **WP6:** Synthesis and dissemination of results to stakeholders

Red-Impact Structure



Set of fuel cycles to assess

Starting point: NEA/OECD report: "Accelerator-Driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles. A Comparative Study" (2002).

The fuel options taken into account were:

- *the standard reference UO_2 fuel with a ^{235}U enrichment 4.2% with a final average burn-up of 50 GWd/tHM;*
- *mixed oxide fuels (UO_2/PuO_2), with a high burn-up of 50 GWd/tHM;*
- *high Pu content MOX fuel (~ 30 w%) in fast reactors, with a burn-up of 150 GWd/tHM;*
- *mixed Th/Pu fuels with a burn-up of 60 GWd/tHM or inert matrix fuel (IMF)-Pu fuel (instead of thorium), where the inert matrix can be based in the CER-CER concept (Pu diluted in ceramic material) or in the CER-MET concept (takes advantage of higher conductivity of metallic matrices);*
- *the mixture of MA inside MOX fuels or the use of target rods diluted into an inert of partially fertile matrix;*
- *the coated particles, with a fissile kernel and several layers of pyrolitic carbon as pressure resistant envelope and gas diffusion barriers, with a burn-up such as about 600 GWd/tHM.*

• *The chemical reprocessing options considered were the aqueous partitioning system (PUREX, TRUEX, UREX, THOREX, DIAMEX and SANEX processes) and the pyrochemical partitioning system, able to handle fuels with high content in Pu and MA.*

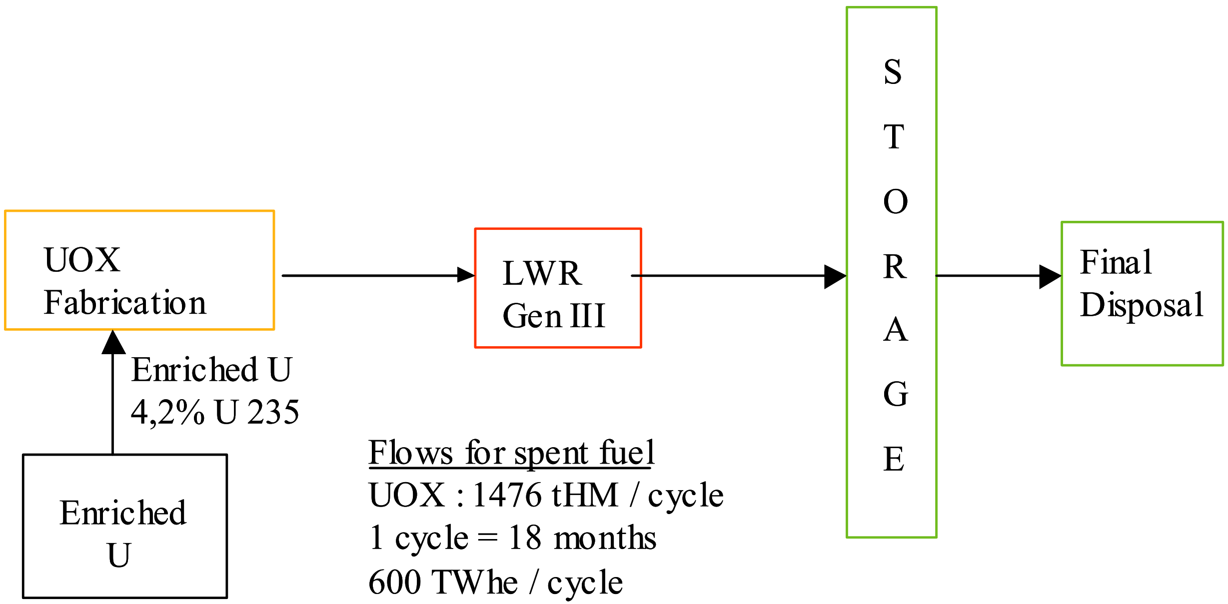
Six basis scenarios are considered for the evaluations

- Three "industrial" scenarios:
  - A1. Reference scenario. Open cycle
  - A2. Near term scenario. Plutonium single recycling in LWR with standard MOX
  - A3. Fast reactor with infinite recycling of Plutonium with "standard" MOX

Three long-term scenarios :

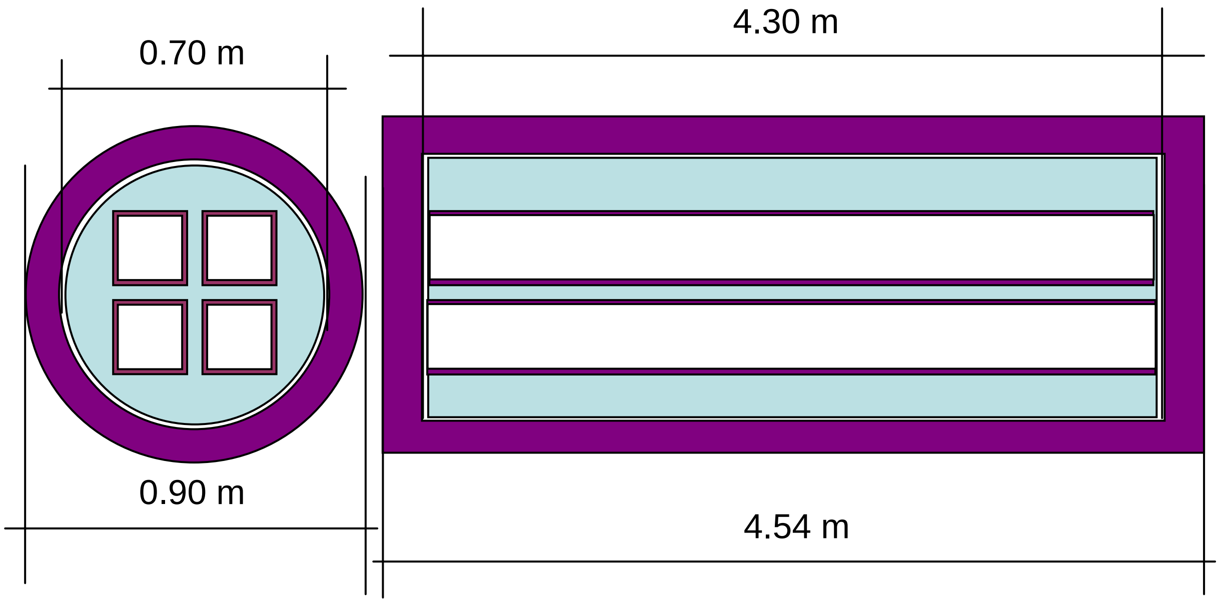
- B1. Gen IV scenario: infinite recycling of Plutonium and Minor actinides in fast reactors.
- B2. Simplified double strata: LWR + ADS.
- B3. Double strata + Fast reactors + ADS.

Scenario A1 - Reference

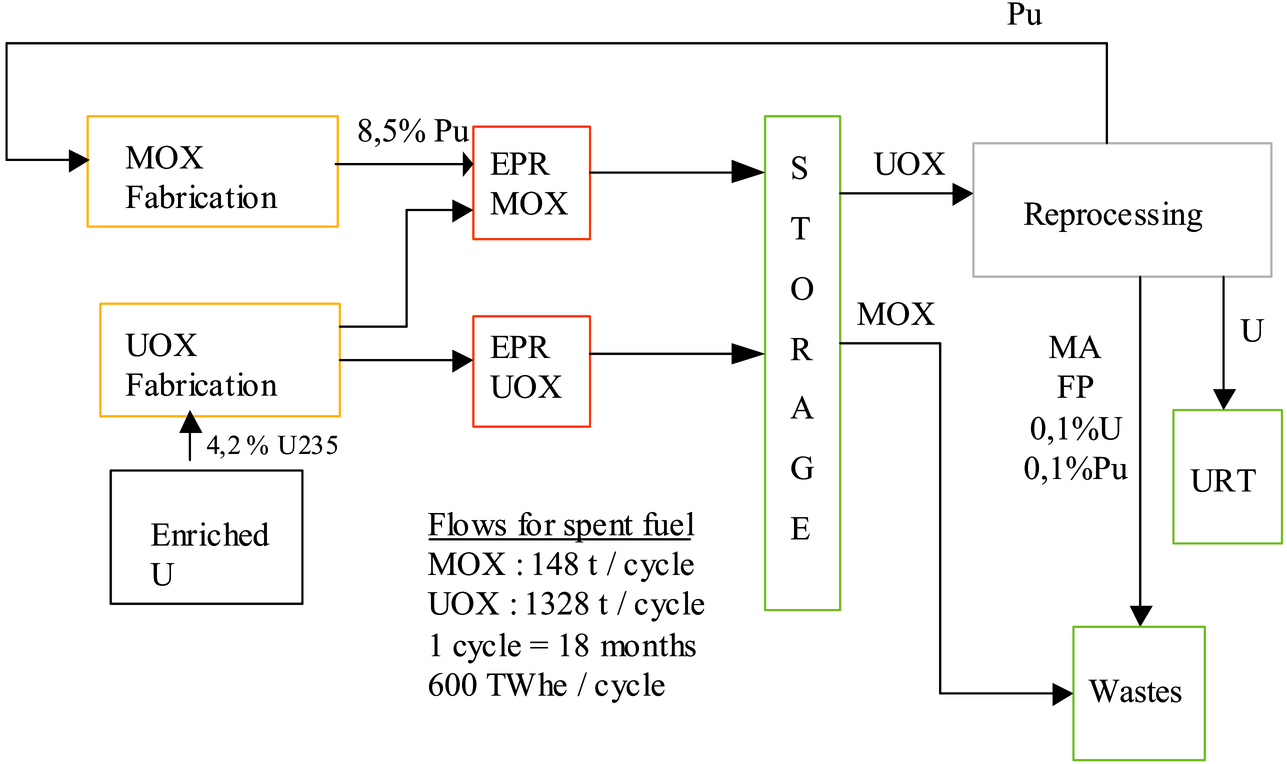


<u>Flows for spent fuel</u>
UOX : 1476 tHM / cycle
1 cycle = 18 months
600 TWhe / cycle

Scenario A1: Waste Package for 4 UOX spent fuel assemblies

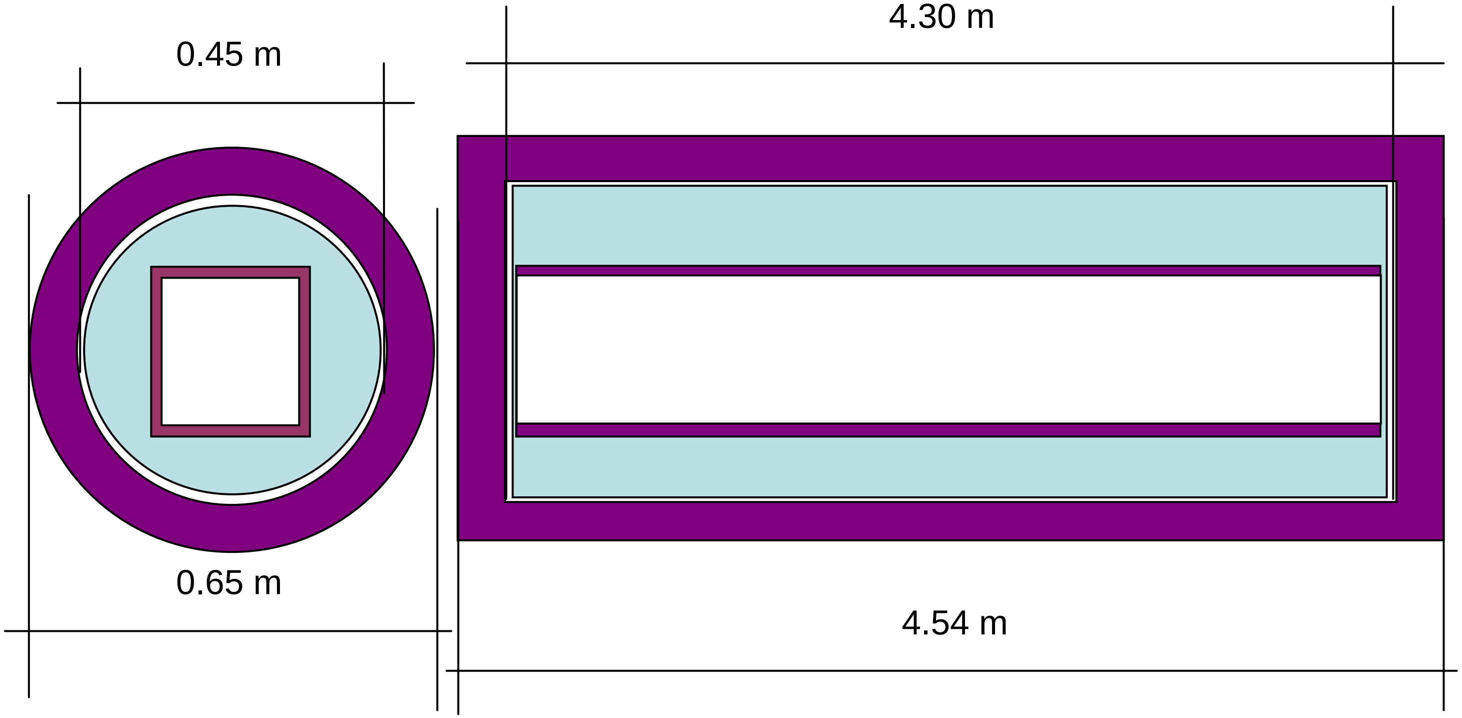


Scenario A2: mono-recycliging of plutonium in LWRs



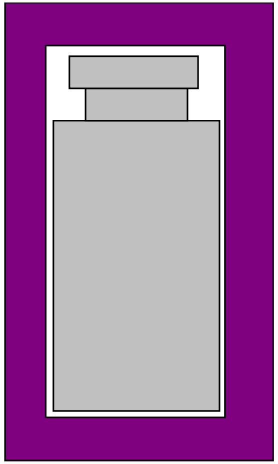
Flows for spent fuel
MOX : 148 t / cycle
UOX : 1328 t / cycle
1 cycle = 18 months
600 TWhe / cycle

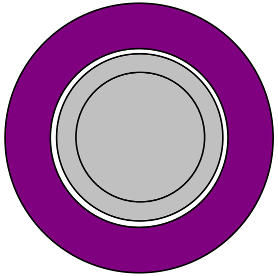
Scenario A2: Waste Package for 1 MOX spent fuel assembly



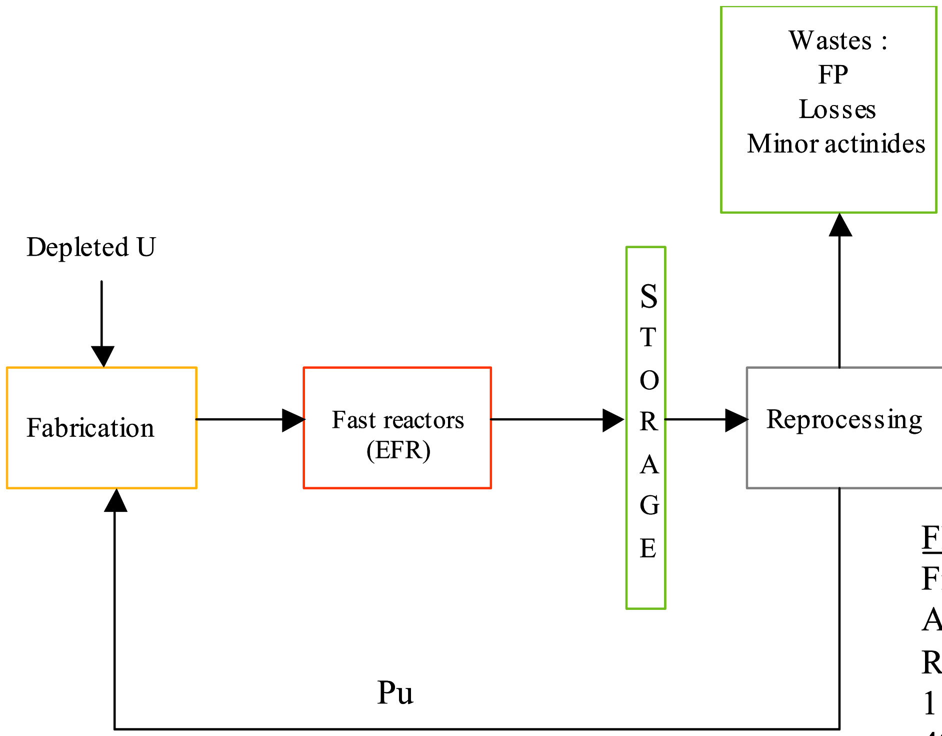
Universal Canister (scenarios A2, A3, B1, B2 and B3)

Material	Stainless Steel (C: 0.15%; Cr: 24%; Ni: 13%)
Physical dimensions:	
- Length	1 338 mm
- External Diameter	430 mm
- Wall thickness	5 mm
Mass:	
- Total	492 Kg
- Empty	80 Kg
Volume:	
- External	175 l
- Internal	170 l
- Vitrified Waste	150 l



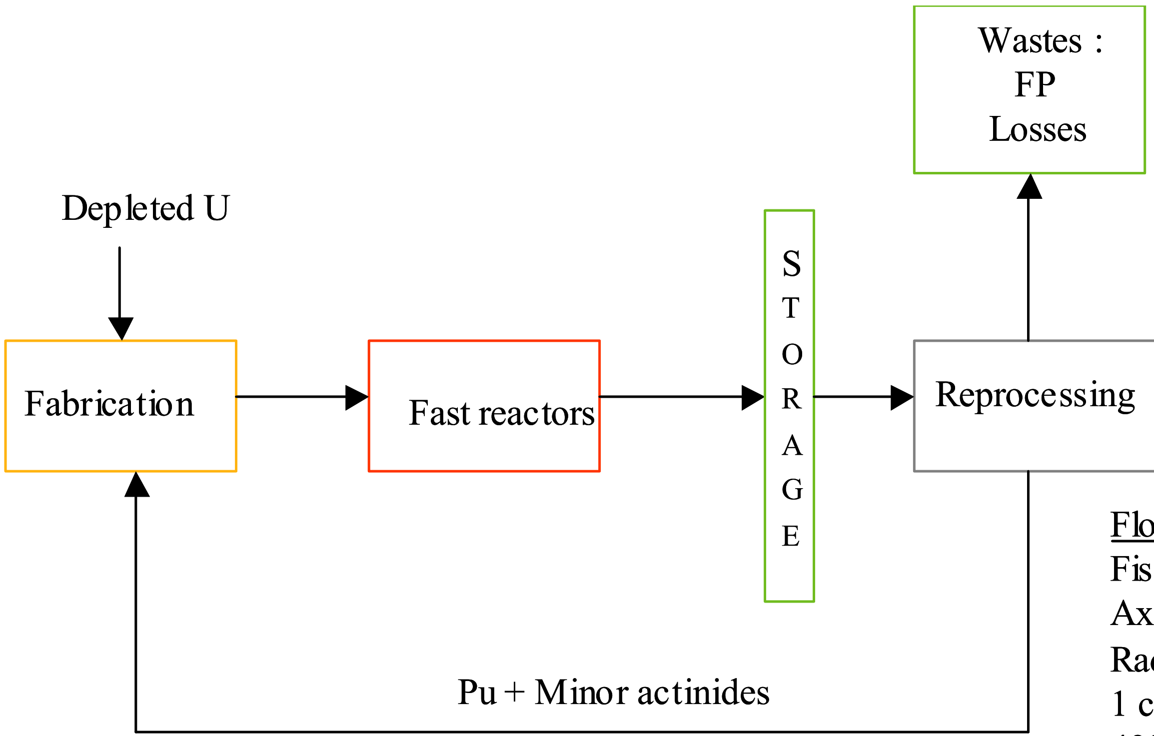


A3: “Industrial” scenario, infinite recycling of Plutonium with “standard” MOX.



<u>Flows for spent fuel</u>
Fissil : 348 tons / cycle
Axial blankets : 151 tons / cycle
Radial blankets : 71 tons / cycle
1 cycle = 14,6 months
493 TWhe / cycle

Scenario B1: Fast Neutron – Gen IV scenario



<u>Flows for spent fuel</u>

Fissil : 348 tons

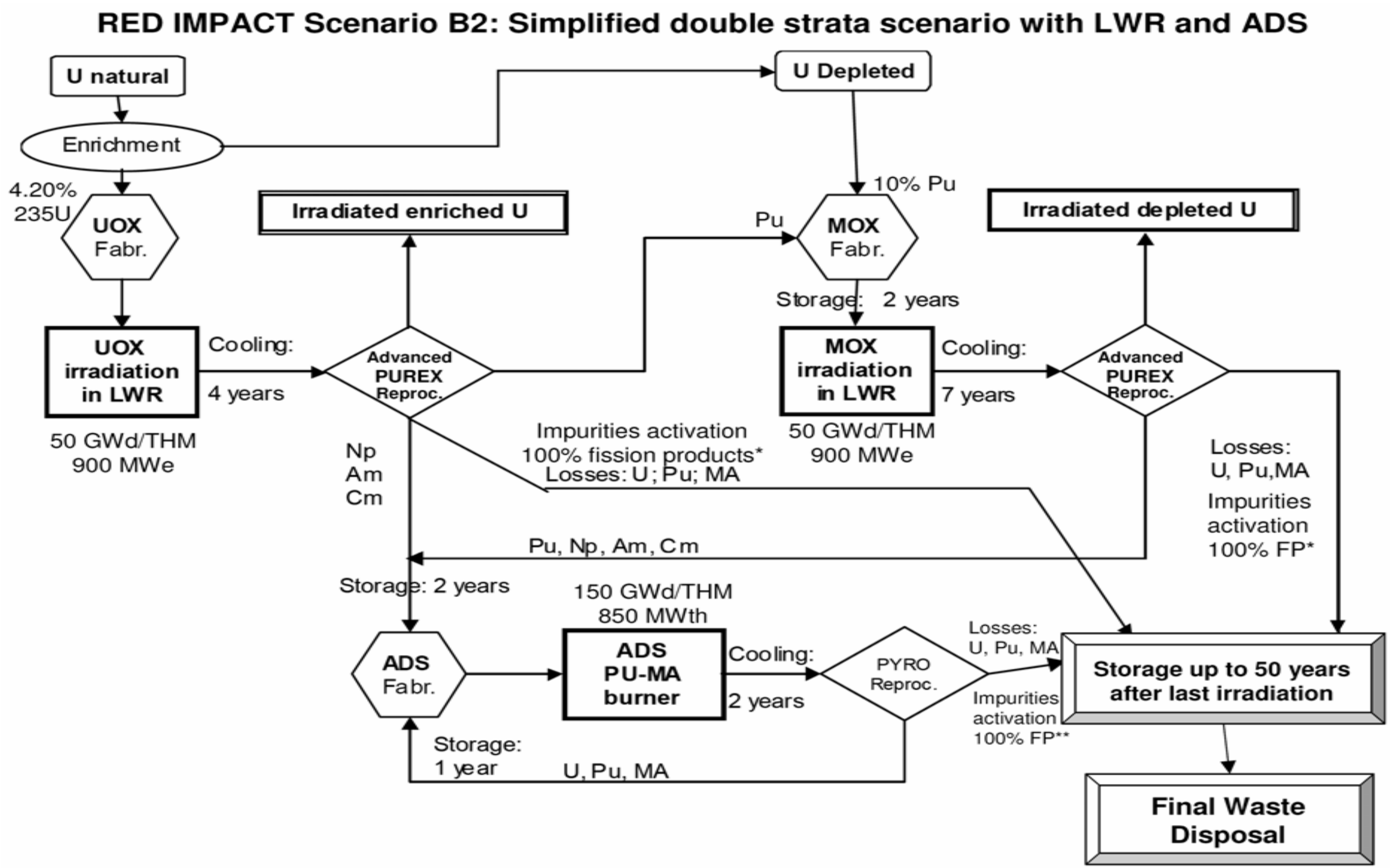
Axial blankets : 151 tons

Radial blankets : 71 tons

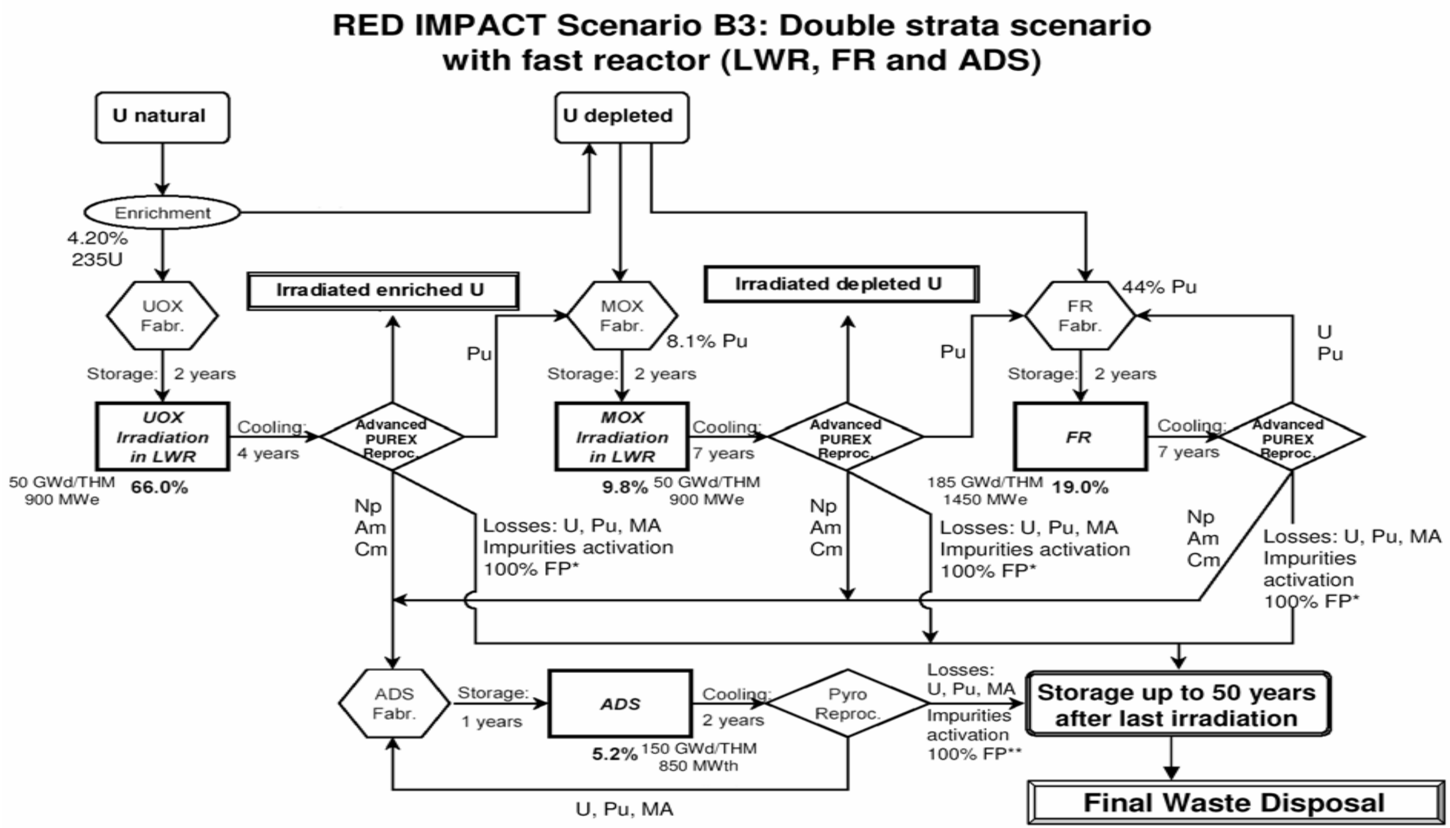
1 cycle = 14,6 months

493 TWhe / cycle

Scenario B2 : Simplified “double strata” scenario with LWR and ADS



B3 – Double Strata Scenario with LWRs, FRs, ADS



Maturity of technologies

Scenari o	Description	Technologies needed (excepted final repository)	Year of availability
A1	Once through fuel cycle in Gen II & III reactors	None	Available
A2	Mono-recycling of Pu in Gen III reactors	None	Available
A3	Multi recycling of Pu in Sodium Fast reactor	Fabrication and reprocessing of MOX fuel for FNR	2020
B1	Mono recycling of Pu in Gen III reactor + Burning of Pu and MA in ADS	Partitioning ADS transmuter and associated fuel cycle	2050 (QG)
B2	Mono-recycling of Pu in Gen III reactor + Multi recycling of Pu in Gen IV Reactor + Burning of MA in ADS	Partitioning FNR and associated fuel cycle ADS transmuter and associated fuel cycle	2050 (QG)
B3	Multi recycling of U, Pu and MA in Gen IV reactors	FNR and associated fuel cycle (including MA)	2050 (QG)

Considered hydro-metallurgical processes, their goal and the state of the art

Objective	Process	Status
Separation of U, Pu, FP+MA	PUREX	Industrial-scale process
Separation of U, Pu+FP+MA	UREX	Industrial feasibility
MA partitioning, one-extraction-cycle process	DIDPA process, SETFICS, PALADIN	Scientific feasibility
An+Ln co-extraction	TRUEX, DIAMEX, TRPO	Technical feasibility
An, Ln separation	TALSPEAK, CTH, SANEX, CYANEX, ALINA, BTP	Technical feasibility
Am, Cm separation	SESAME, Am precipitation	Technical feasibility
I, Np, Tc recovery	Advanced PUREX	Industrial feasibility
Cs and/or Sr recovery	Calixarenes, titanic acid	Technical feasibility

Pyroprocessing (necessary mainly for ADS recirculation schemes)

- Involve several techniques such as : volatilization, liquid-liquid extraction using non-miscible metal-metal phases or metal-salt phases, electro-refining in molten salt, fractional crystallization, etc.
- Lack of reliable technical data. Assumptions and qualified guesses needed!

Reprocessiong assumptions

		SCENARIO											
		A2	A2.b		A3	B1	B2			B3			
REPROCESSING TYPE		Stand. PUREX	Stand. PU RE X	Stand. PUREX	Stand. PUREX,	PYRO	Adv. PUREX	Adv. PUREX	PYRO	Adv. PUREX	Adv. PUREX	PYRO	PYRO
REPROCESSED FUEL		UOX (PWR)	UOX (PWR)	MOX (PWR)	Blankets + Fissile Core (FR)	Blankets + Fissile Core (FR)	UOX (PWR)	MOX (PWR)	ADS	UOX (PWR)	MOX (PWR)	MOX (FR)	ADS
ACTINIDES to HLW	U	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Pu	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	MA	1	1	1	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
FISSION PRODUCTS to HLW	Noble Gases	0	0	0	0	0	0	0	0	0	0	0	0
	Iodine	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Noble Metals	1	1	1	1	0	1	1	0	1	1	0	0
	Others, including volatile (Cs, Br) and partially soluble (Mo, Tc and Sb)	1	1	1	1	1	1	1	1	1	1	1	1
ACTIVATION PRODUCTS (Fuel Impurities) to HLW	All, including volatile (H, C, N, F and Cl), etc.	1	1	1	1	1	1	1	1	1	1	1	1
Zr and N (ADS fuel matrix) to HLW		-	-	-	-	-	-	-	0	-	-	-	0
MASS of HLW to Universal Canister		40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.	40 Kg +Impu.

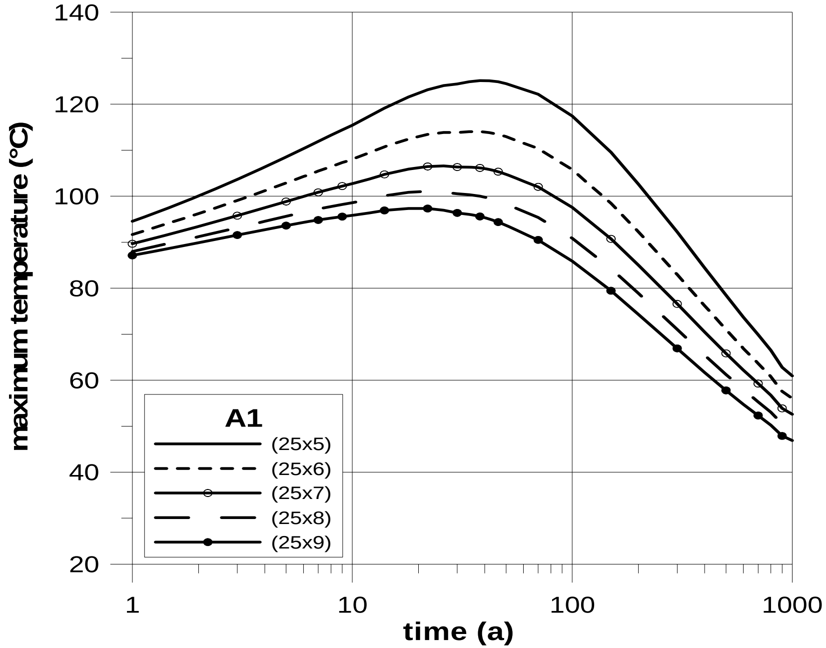
3 Different Geological Disposal Models

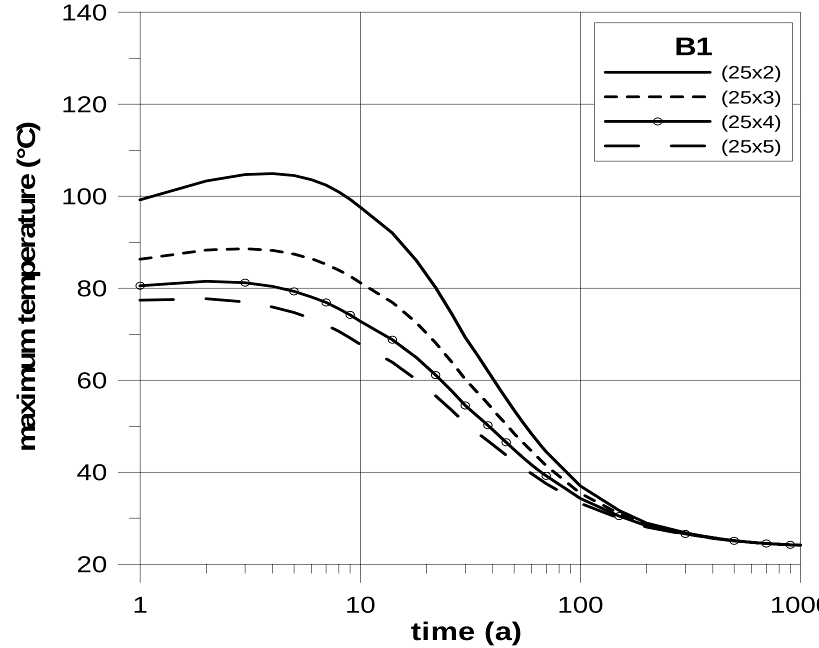
- Granite (e.g. Swedish, Spanish, Czech models)
- Clay (Belgium)
- Rock Salt Formation (Germany)

Samples of results:

Granite:

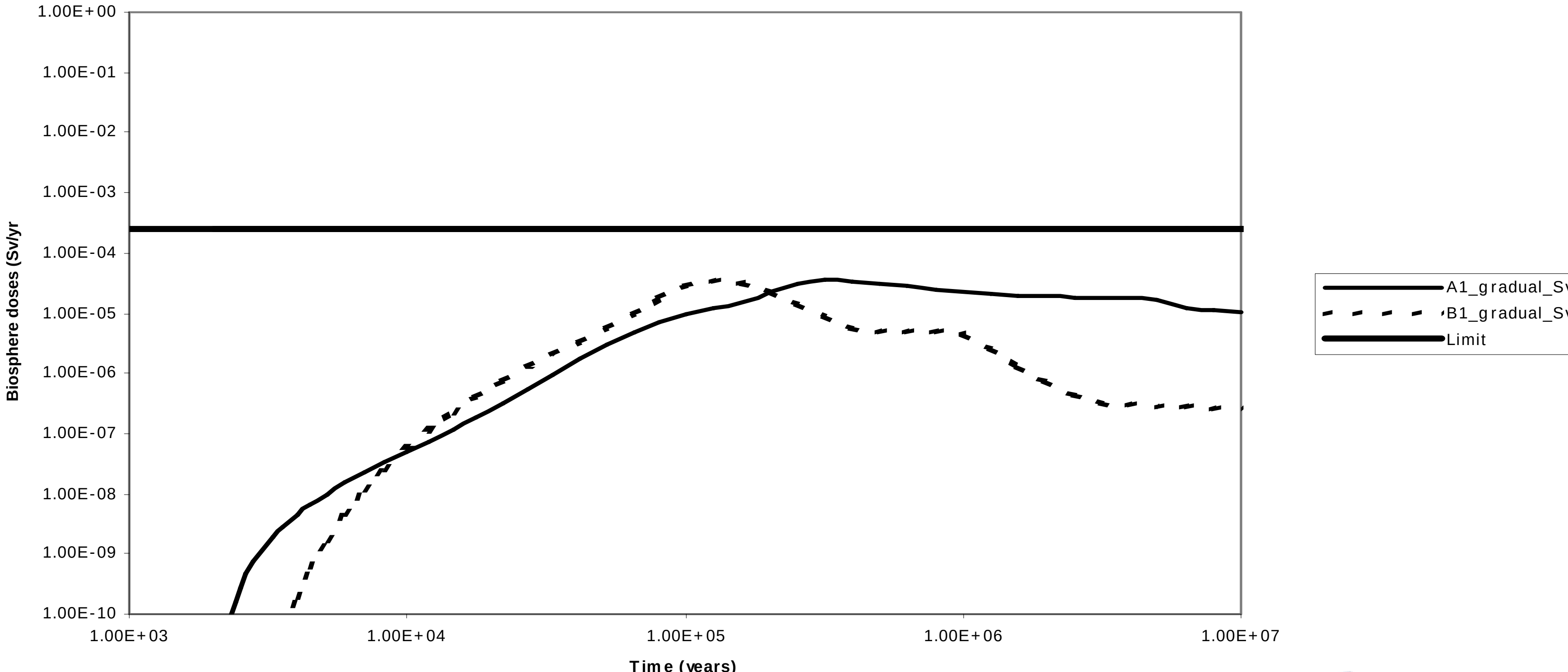
Evolution of maximal temperature at the surface of the canisters calculated for scenarios A1 and B1





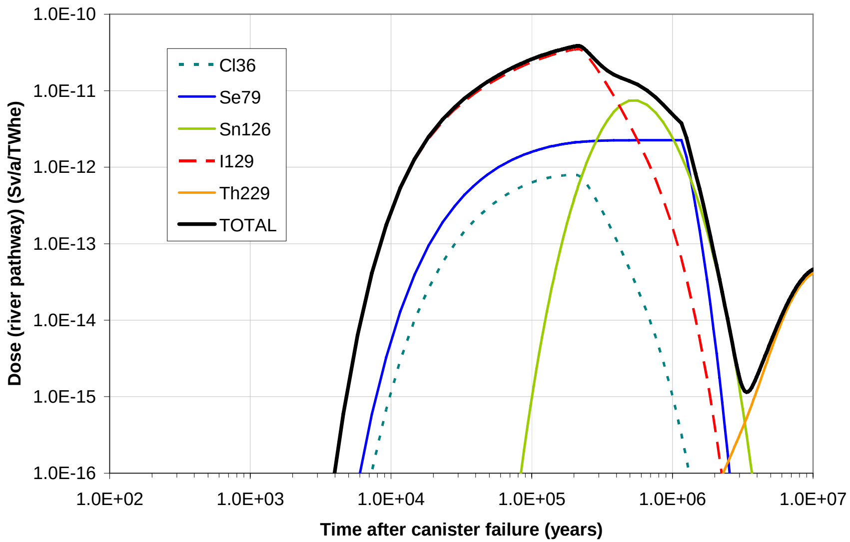
Granite

Comparison of biosphere doses from A1 and B1 scenarios (instant failure of canisters)

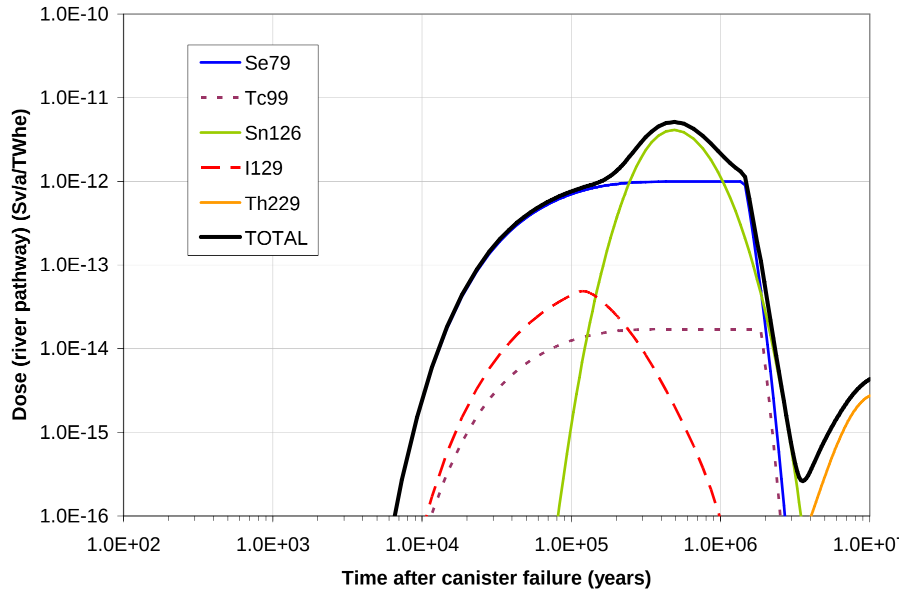


Clay: Dose via the river pathway per TWh_e

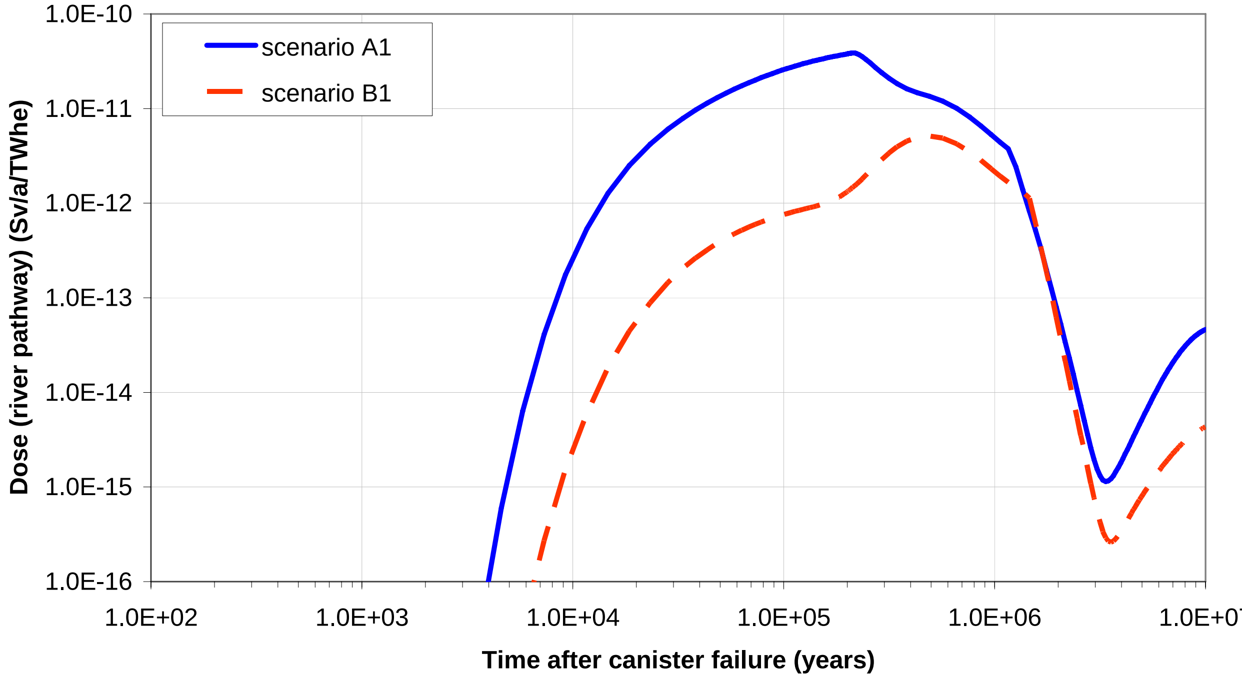
A1



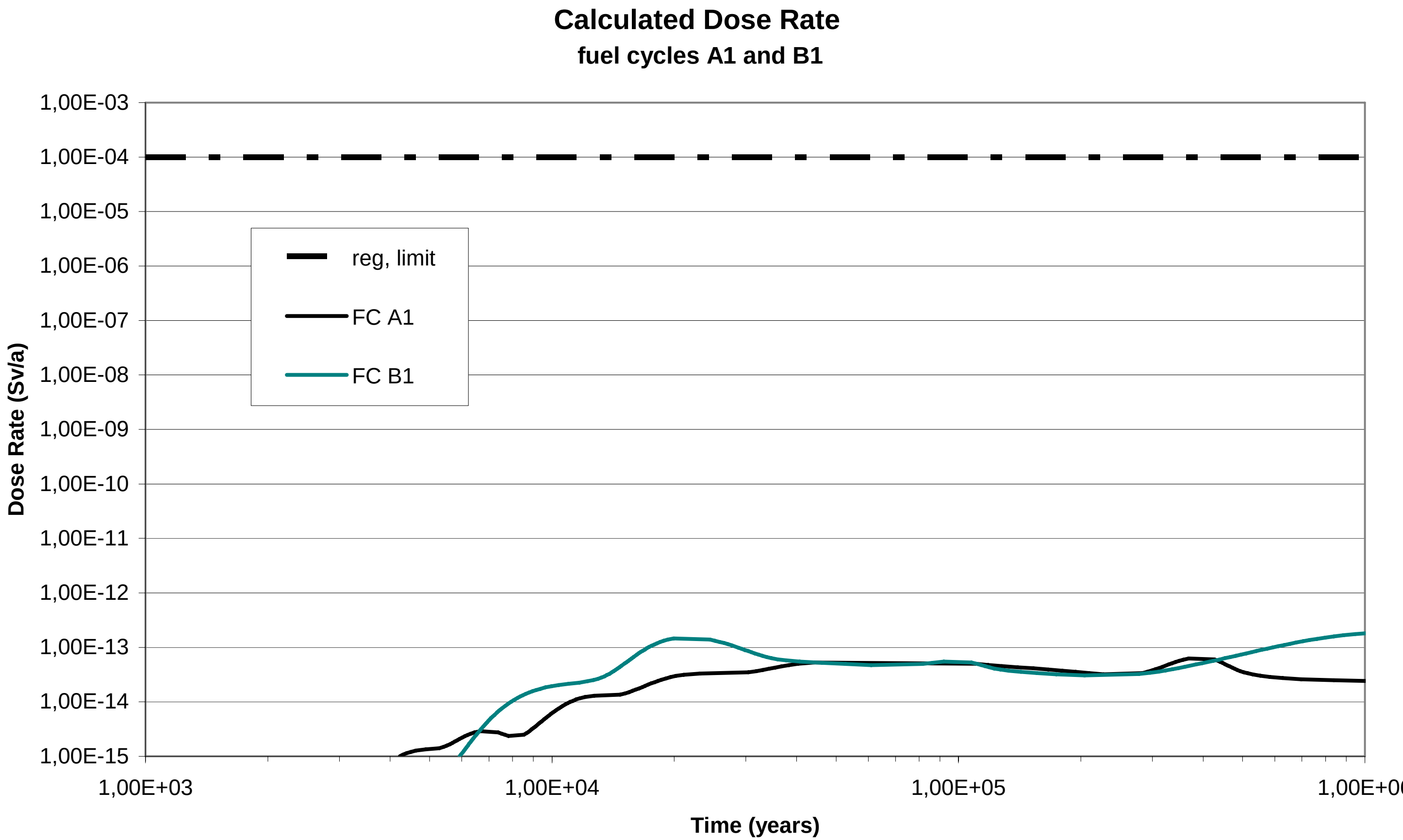
B1



Clay: Total doses via the river pathway per TWh(e) calculated for scenarios A1 and B1



Salt: dose rate for possible releases coming from waste of fuel cycle A1 and B1

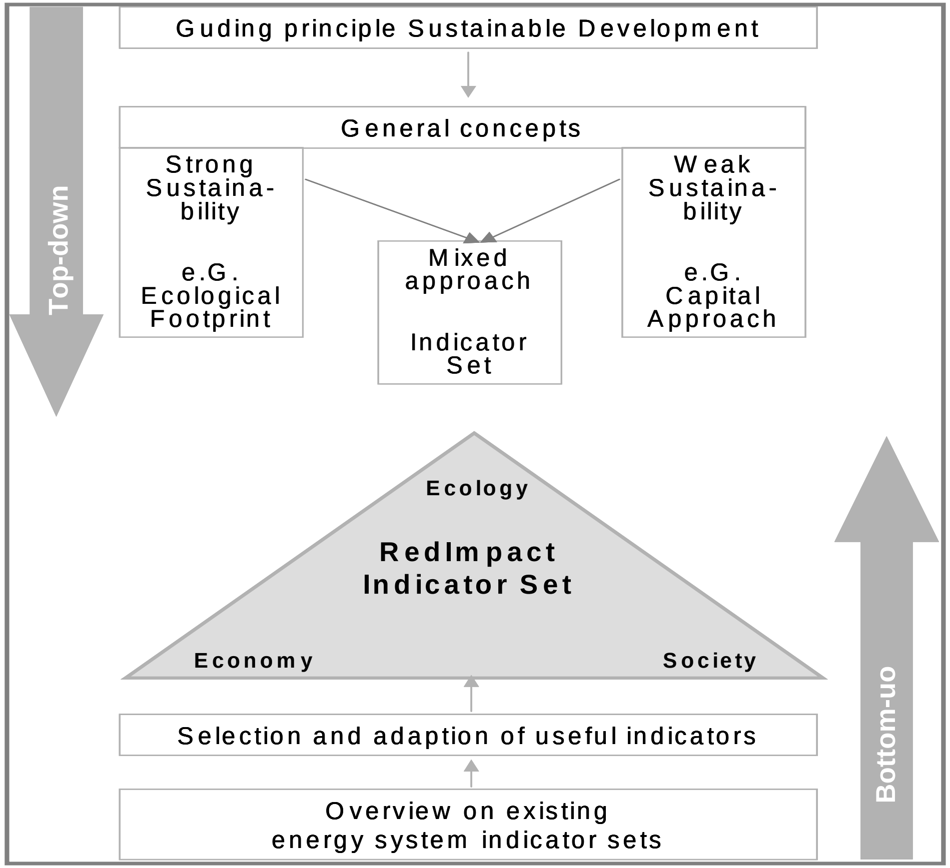


Performance indicators

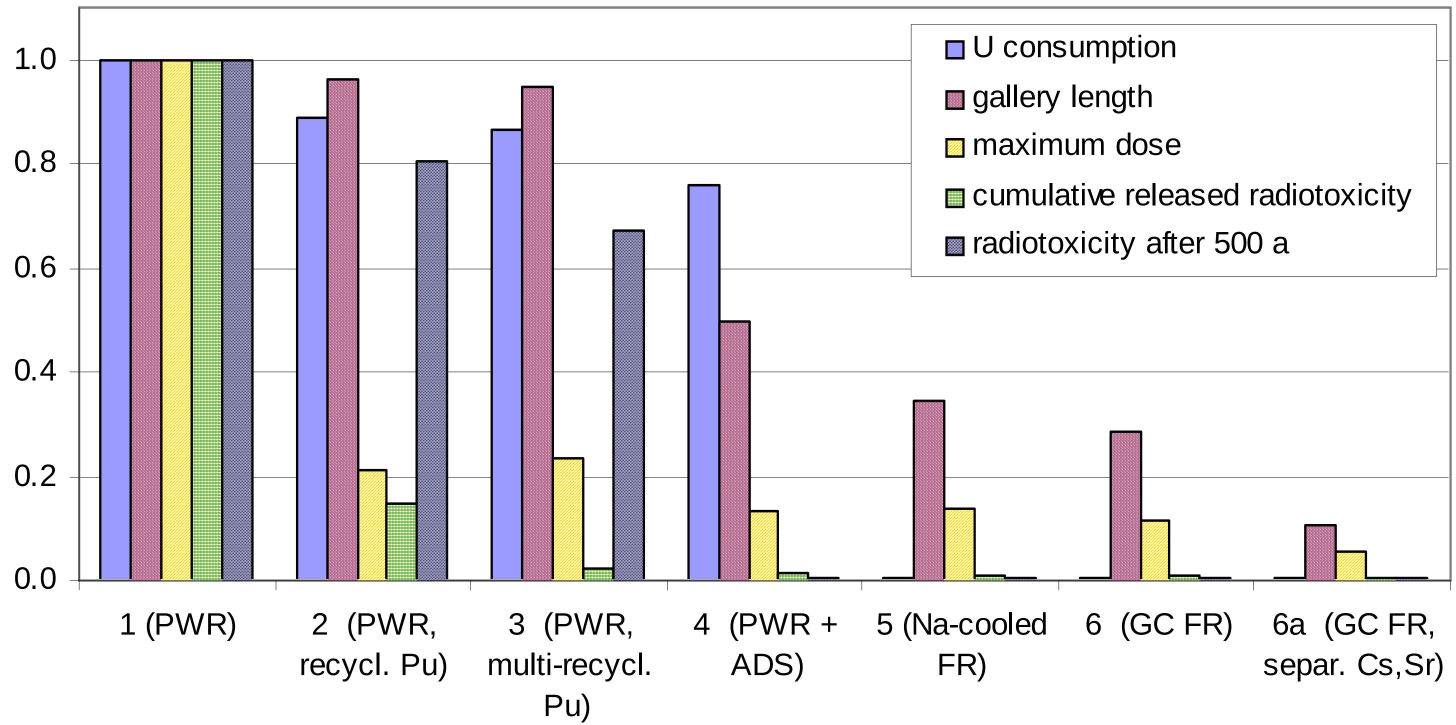
The indicators have been divided into two major groups:

- "Technical" indicators partioned into three groups:
  - indicators based on the composition of the waste;
  - indicators related to the size of the repository;
  - indicators related to the long-term performance of the repository system:
    - individual annual dose;
    - radiotoxicity flux released into the biosphere;
    - integrated radiotoxicity flux released into the biosphere.
- Economic, environmental and societal/sustainability (EES) indicators

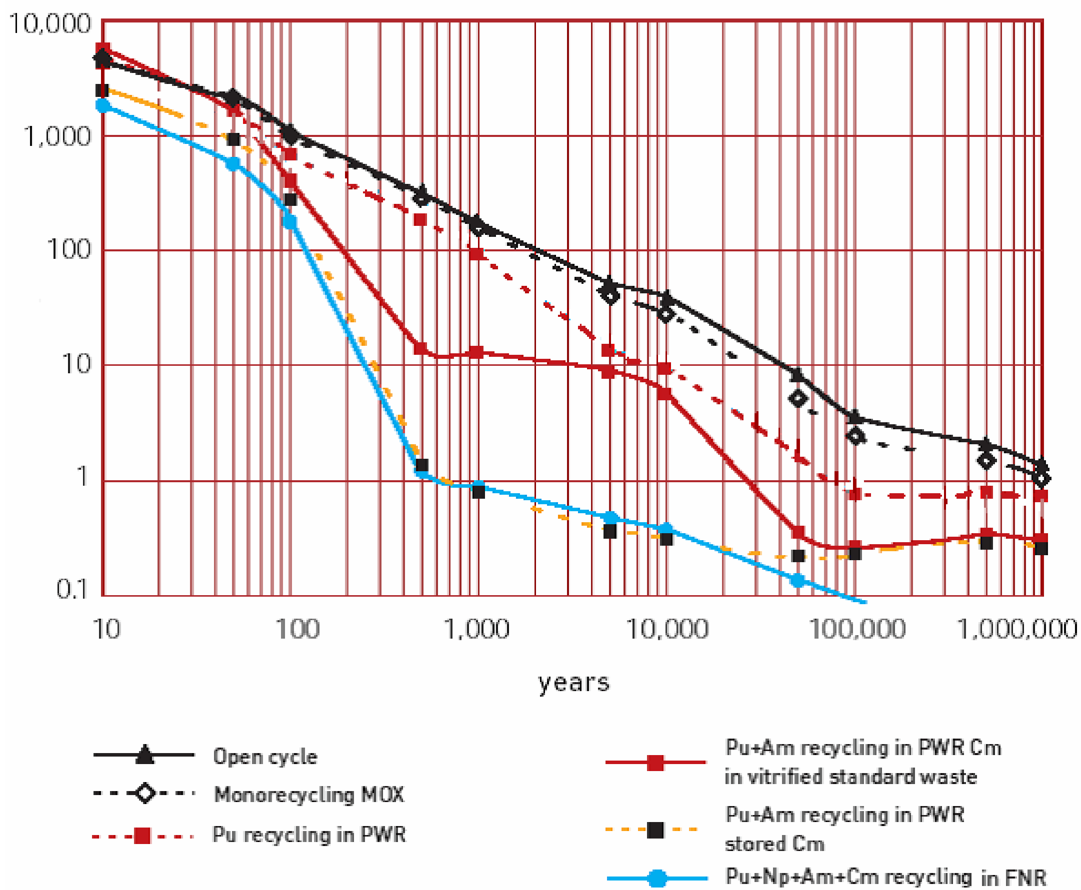
Sustainability Indicators Identification



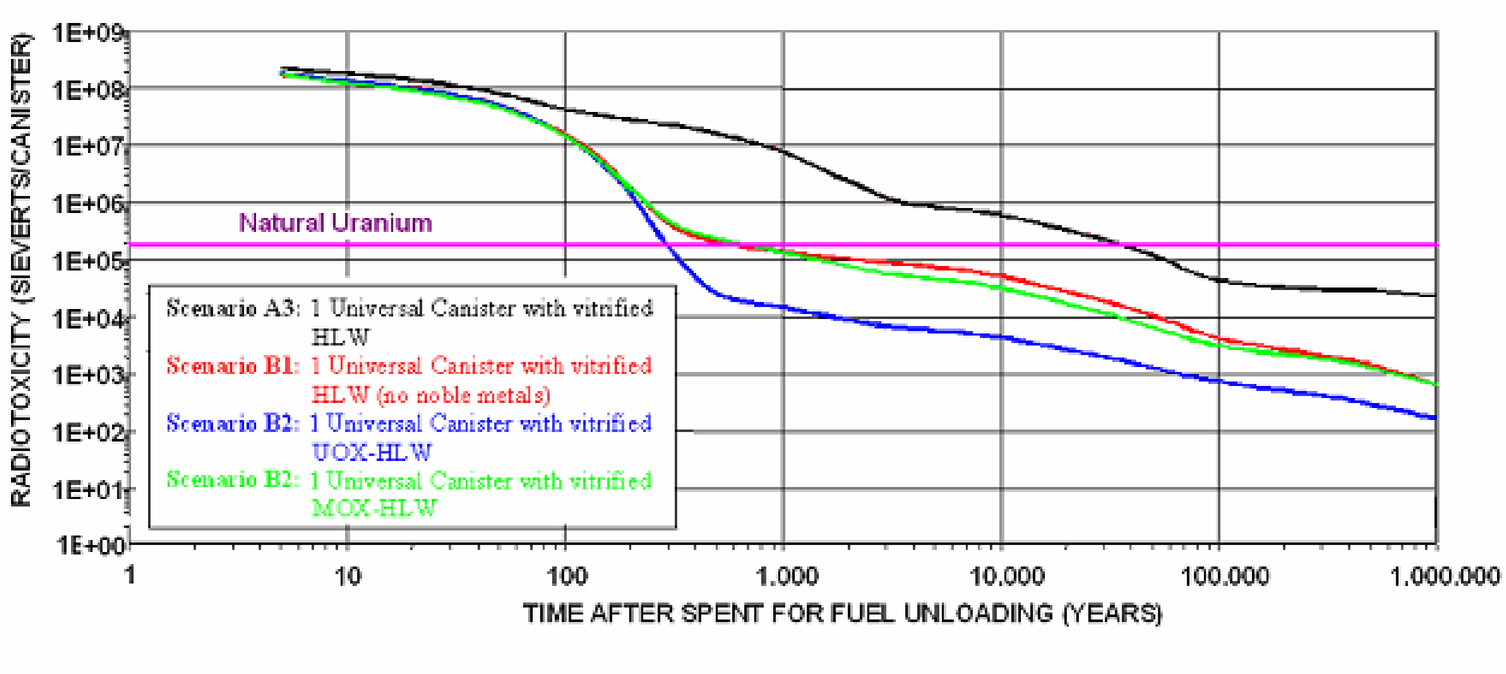
Comparison of different fuel cycle strategies in terms of radiological and disposal aspects



Decay heat per TWhe as a function of time in a repository for different fuel cycles



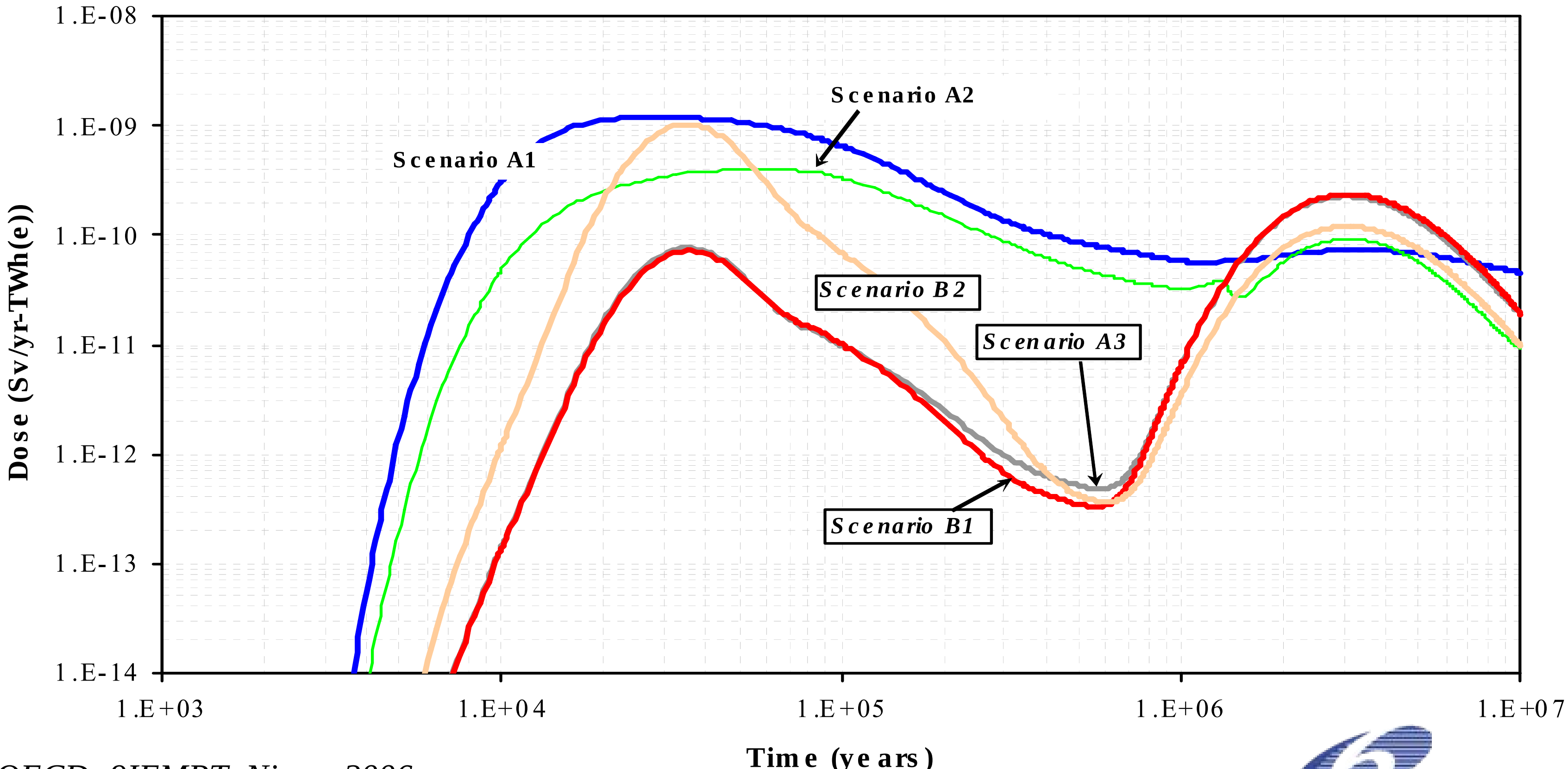
Ingestion radiotoxicity after disposal for different scenarios



Impact of fuel cyle on waste quality for disposal

	Scenarios							
	A1	A2		A3	B1	B2		
Waste form	UOX	MOX	Glass	Glass	Glass	UOX-Glass	MOX-Glass	ADS-Glass
Waste package external length (m)	4.54	4.54	1.6	1.6	1.6	1.6	1.6	1.6
Waste Volume (m^3/TWh(e))	3.8	0.8	1.3	1.3	1.2	1.06	0.13	2.2
Waste Volume per scenario (m^3/TWh(e))	**3.8**	**2.14**		**1.3**	**1.2**	**3.44**		
Waste packages/TWeh	1.33	0.54	2.5	2.4	2.3	2	0.24	4.2
Thermal power at disposal time (W/package)	1564	1549	486	529	314	420	331	31

All scenarios – Radiological Impact: Normalised Annual Dose (Sv/a TWh$_e$)



RedImpact Final Goal: Acceptance and Decisions through understanding

- The RED-IMPACT project follows a multi-disciplinary approach by federating different technical and scientific areas such as specialists from **reactor technology**, **fuel cycle evaluation**, **reprocessing (partitioning)**, **waste management, disposal issues, economical assessment and social science** with regard to public and market acceptance aspects. P&T is not understood only as a very future option but as a strategy which can be stepwise implemented already starting:
  - in the short term by making use of existing reactors and fuel cycle facilities,
  - via more advanced reactor systems (Gen III & Gen IV), fuels, reprocessing & conditioning technologies, in the mid term,
  - towards very ambitious special waste transmuter systems like ADS together with the related partitioning techniques, in the long term.

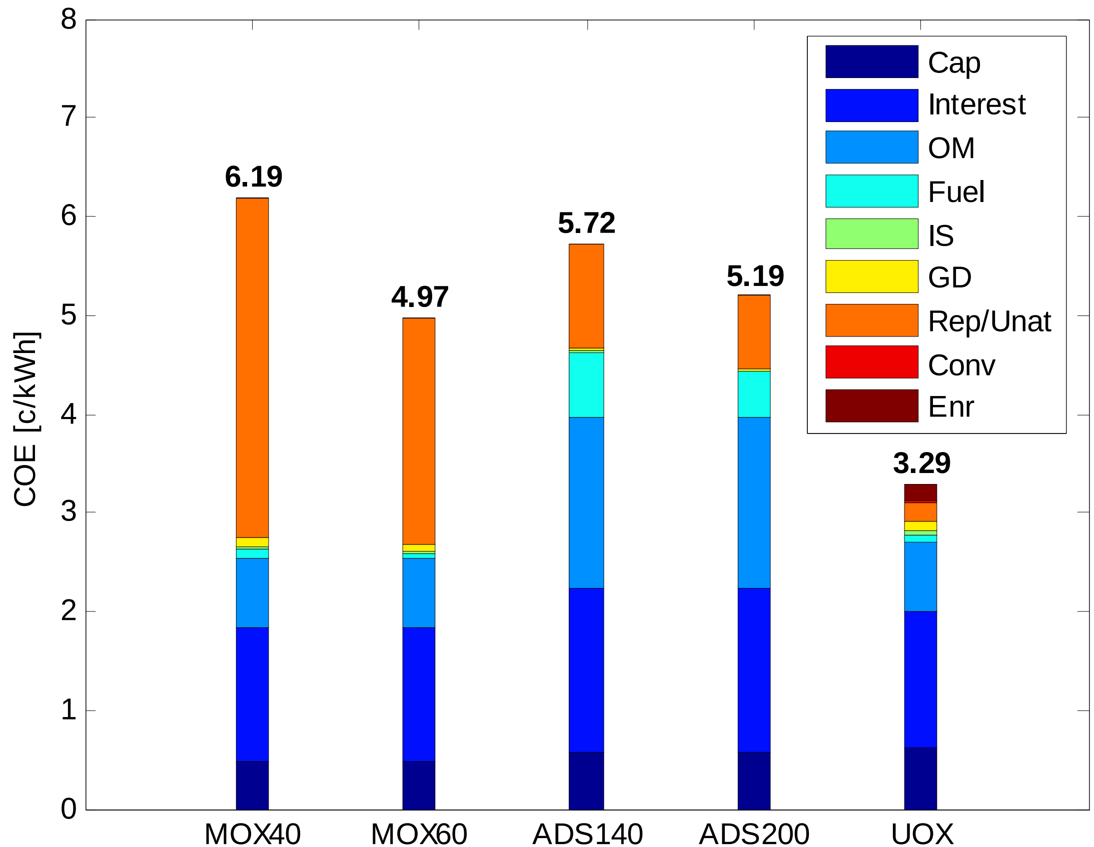
RedImpact Final Goal: Acceptance and Decisions through understanding

- Fuel cycle senarios with their boundary conditions have been well defined. Methodology and assessment tools have been agreed and **well benchmarked**. Most of the calculations are in the final stage and an interim report summarizing the first results has ´been prepared.
- The project provides recommendations for the implementation of pragmatic P&T strategies under different political environments following general sustainability criteria to improve public acceptance

Added on values 1:

- Subtask: Nuclear Spent Fuel Management Scenarios for Sweden:
  - Phase out with direct disposal
  - Burning plutonium and minor actinides as MOX in BWR
  - Burning plutonium and minor actinides as MOX in PWR
  - Burning plutonium and minor actinides in ADS
  - Combined LWR-MOX plus ADS

Cost of electricity comparison for various scenarios with 40, 60, 140, and 200 GWd/tHM of burnup



Added on values 2:

- New Fuel Cycle Anlaysis and OPTIMIZATION (RED-IMPACT)code under development at KTH:
  - Best possible physics – generation of dedicated one-group data libraries for each specific case
  - Matrix method
  - Simulation of the whole fuel cycle from FRONT-FRONT to Back-End inluding legacy of existing waste
  - Regional solutions as an option
  - Economical calculation
  - Uncertainty analysis
  - Very advanced graphical interface