FUEL CYCLE SYNERGIES AND REGIONAL SCENARIOS

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Summary

- **Regional fuel cycle scenarios definition**
- **Scenarios 1 and 2: results**
- **Comparison between regional scenarios 1 and 2 and the case without P&T**
- **Scenarios 3 and 4: parametric studies and results**
- **Summary on the four scenarios and perspectives**

The scenarios consider two groups of countries:

Group A is in a stagnant or phase-out scenario for nuclear energy and has to manage his spent fuel, and especially the Plutonium and the minor actinides (MA).
However, it is also considered the possible nuclear renaissance in some of the countries of this group.

Group B is in a continuation scenario for the nuclear energy and has to optimize the use of his resources in Plutonium for the future deployment of fast reactors.
The deployment of Fast reactors can be envisaged from ~2040. If it is delayed, there is need to manage MA inventory increase.

Scenario 1 and 2: **P&T within a double strata approach**

- **deployment of a number of ADS shared by the two groups of countries.**
- **The ADS will use the Plutonium of the Group A and will transmute the minor actinides of the two groups.**
- **The Plutonium of the Group B is continuously recycled in PWRs.**

The main objective of this scenario is to decrease the stock of spent fuel of countries of Group A down to ~0 at the end of the century, and to stabilize both Pu and MA inventories of Group B.

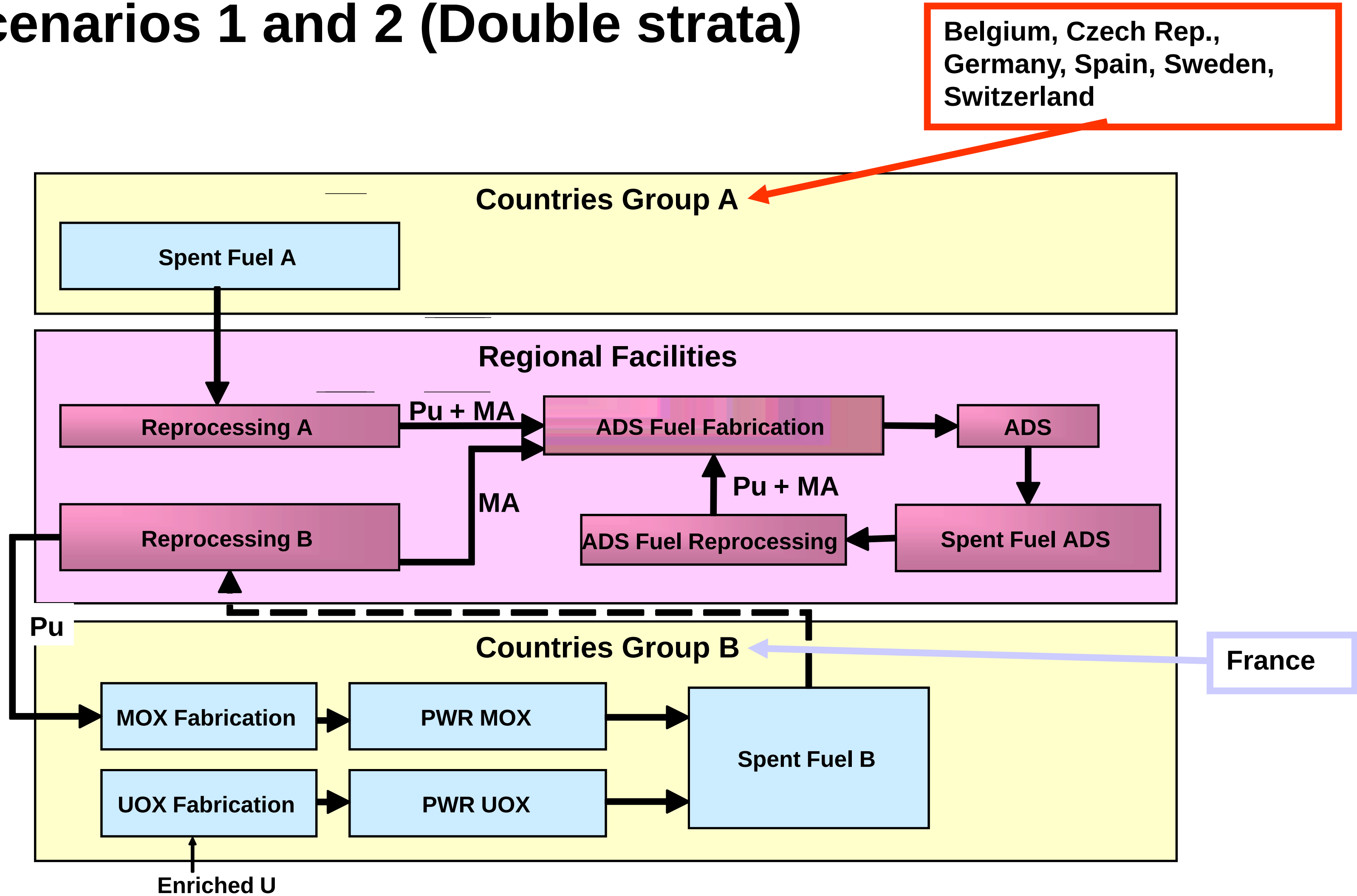
Scenario 3 and 4: Sustainable development of nuclear energy

- **deployment of fast reactors in Group B countries. These fast reactors are deployed with the Plutonium of the two groups and recycle all the minor actinides.**
- **A variant is considered to account for nuclear renaissance in some countries of Group A**

The main objective of this scenario is to decrease the stock of spent fuel of Group A down to 0 at the end of the century and to introduce Gen-IV fast reactors in Group B, starting, e.g., in 2035.

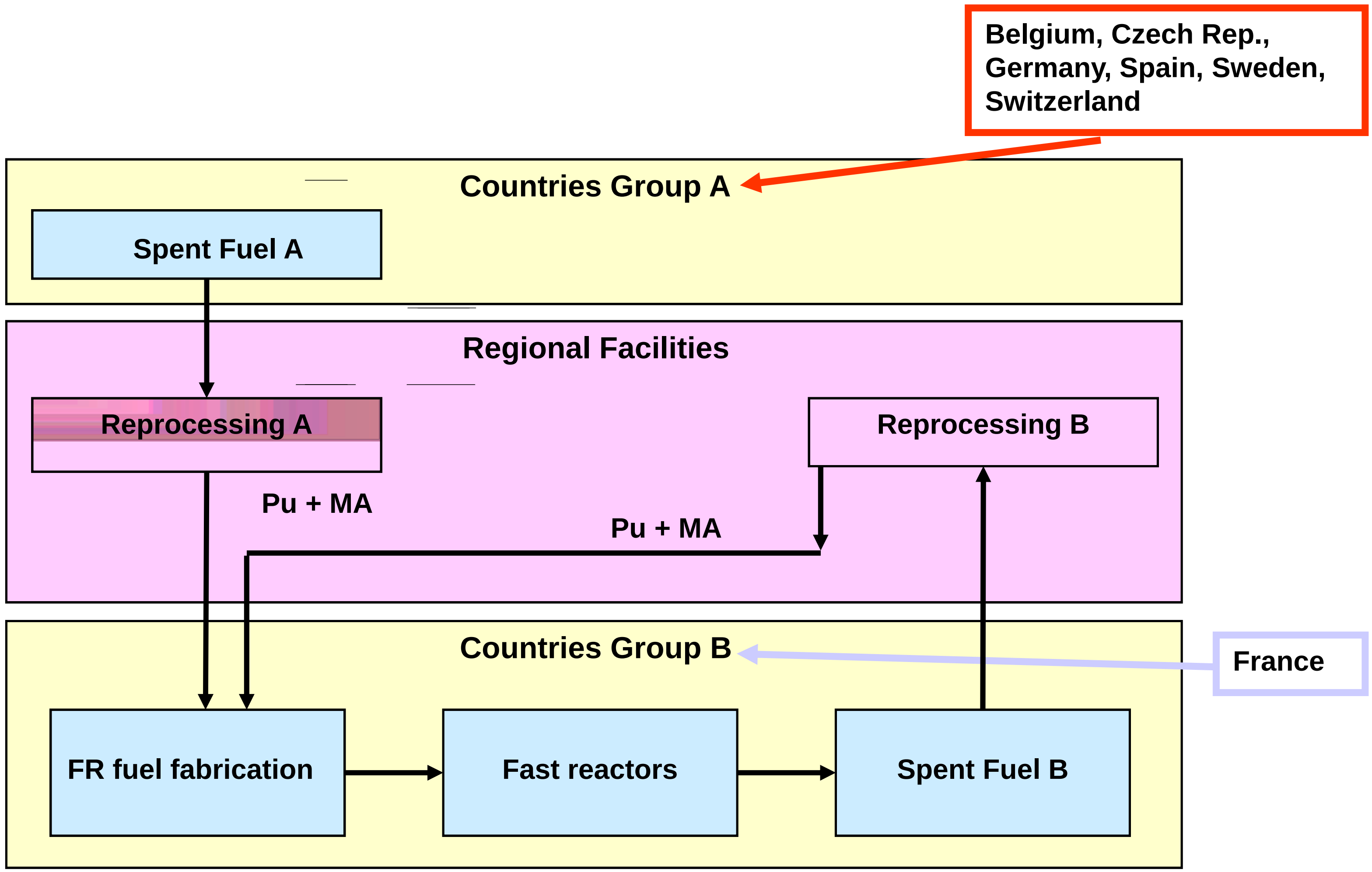
Also: find out if and how many NPP could be deployed in Group A

Scenarios 1 and 2 (Double strata)



Scenario 1: Pu monorecycle in country B
Scenario 2: Pu multirecycle in country B

Scenarios 3 and 4: Sustainable development of nuclear energy



Scenario 3: Fast reactors only in country B

Scenario 4: Some countries of Group A restart nuclear with FR

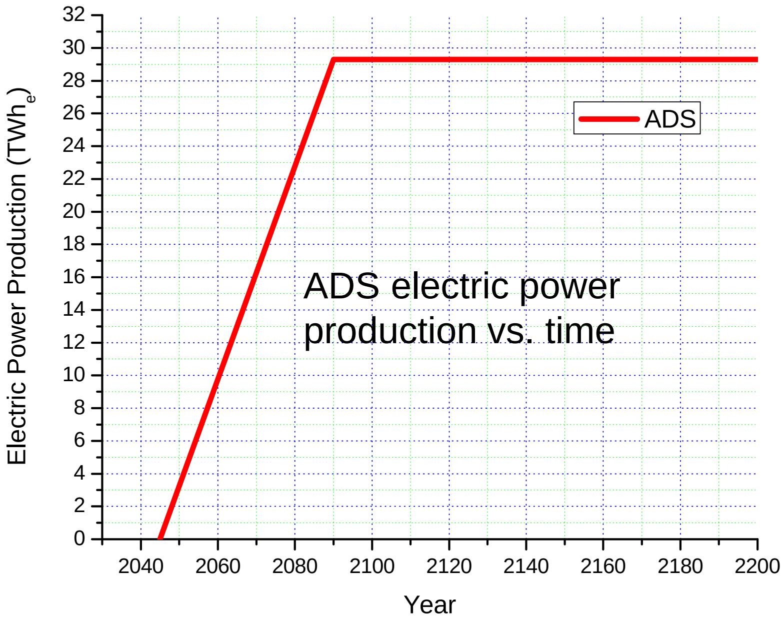
Summary on Scenarios 1 and 2

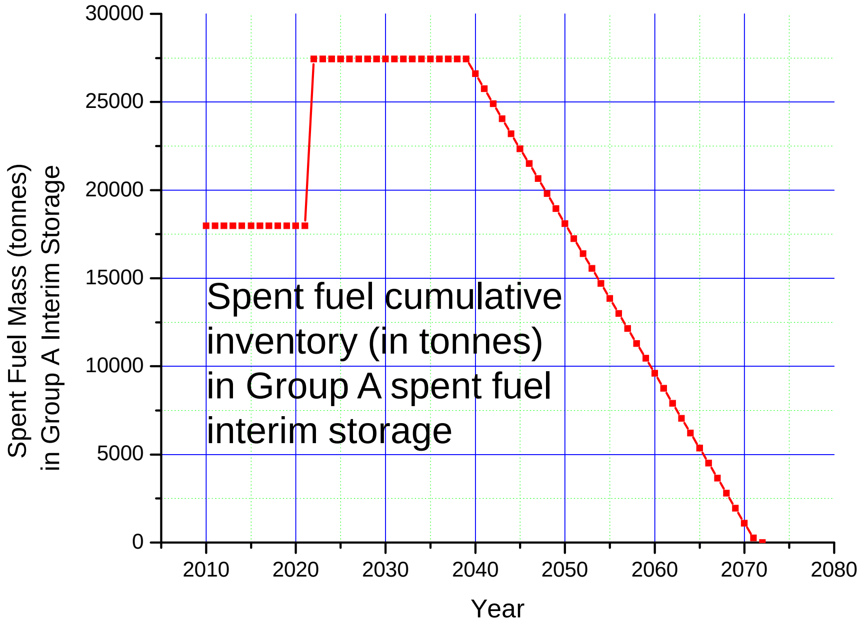
- **The spent fuel stock of Group A can be decreased, as required, down to 0 by 2100 : all the fuel was reprocessed by that date.**

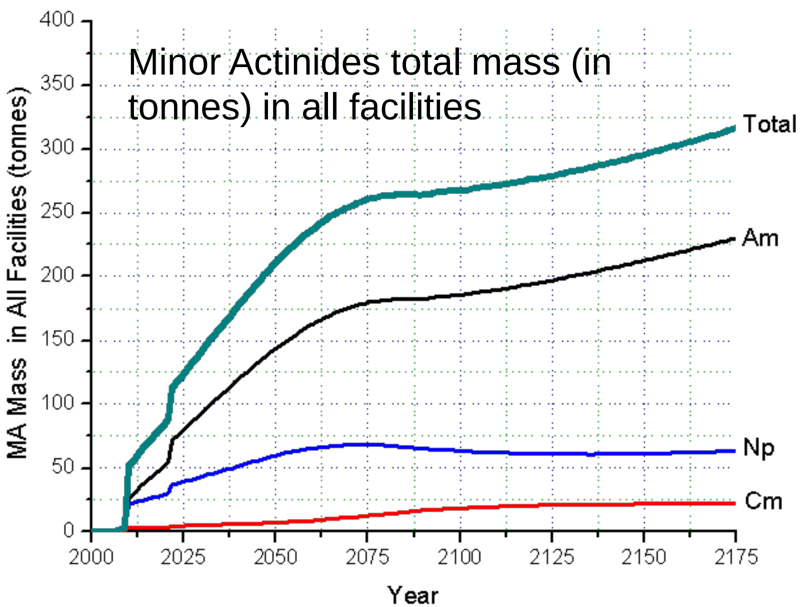
- **In *Scenario 1* the Pu mono-recycle option implies that the reprocessed plutonium is kept in order to be successively transferred to fast reactor plutonium stock for successive use in Group B. The final plutonium inventory available in *Scenario 1* at 2100 for Fast Reactors fleet will be 840 tonnes.**

- **In order to stabilize the MAs production from Group B, the required number of ADS of the EFIT type (~400 MW_{th}) was determined to be *25* units for *Scenario 1*, and *27* for *Scenario 2* (due to plutonium multi-recycling and consequently higher MA generation).**

- **The results of the *Scenario 2* simulation show that the plutonium main stock inventory of Group B is stabilized starting from 2100 at ca. 100 tonnes, while the total inventory increases slightly vs. time due to accumulation of “bad quality” plutonium coming from the MOX multi-recycling.**







Scenario 1 results

As for the Regional facilities:

- A total reprocessing capacity of 3700 tonnes per year (t/y) is needed in the case of *Scenario 1* and of 3300 tonnes in the case of *Scenario 2* : 850 t/y for ADS reprocessing plant, 850 t/y for Group A spent fuel legacy, and 2000 t/y for Group B in *Scenario 1*, 1600 t/y for Group B in *Scenario 2*.

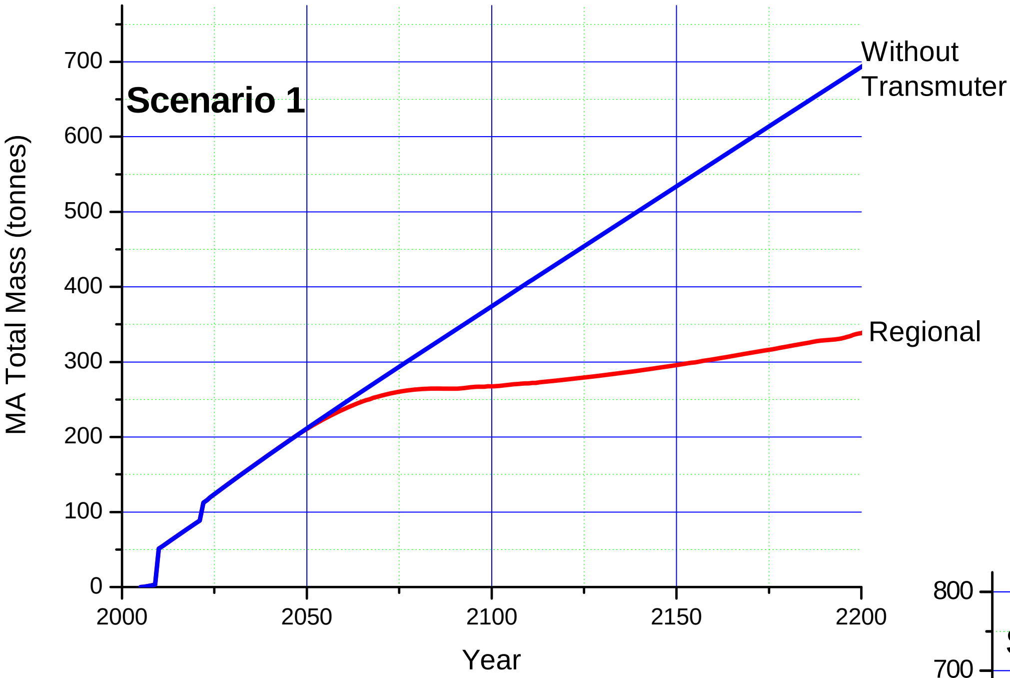
- The PWR fuel reprocessing capacity required for *Scenario 1* is about 18% higher than the one today available in France, while the ADS reprocessing facilities have obviously to be developed and deployed in the future.

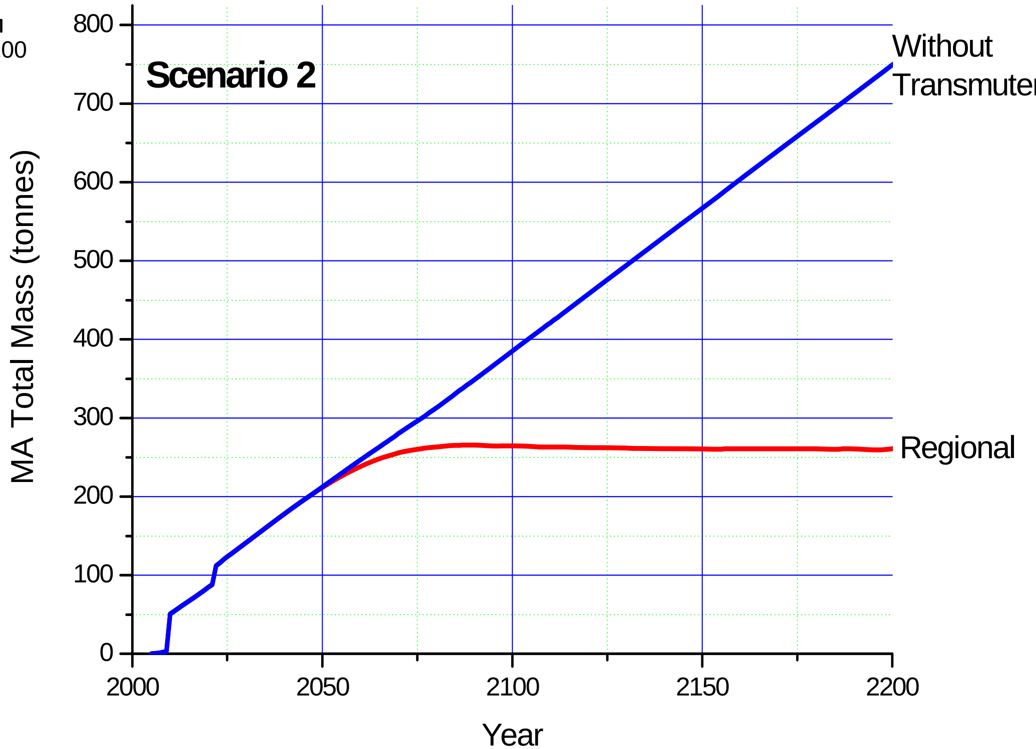
- In *Scenario 1* the annual capacity of fuel fabrication plants should be: 1000 t/y for UOX, 100 for MOX, and 30 for ADS.

- In *Scenario 2* the needed fabrication capacity is : 690 t/y for UOX, 390 for MOX, and 40 for ADS. The total capacity is quite similar in the two cases considered, while only MOX/UOX fabrication capacities proportions are sensibly different (respectively, 1 : 10 and 1 : 1.77).

- EFIT type design offers potential benefits in regional Scenarios, but it seems not suitable for phasing-out nations implementing a P&T strategy in isolation, because its transmutation performance was focused on MA.

Comparison between regional scenarios 1 and 2 and the case without P&T





Summary on Scenarios 3 and 4

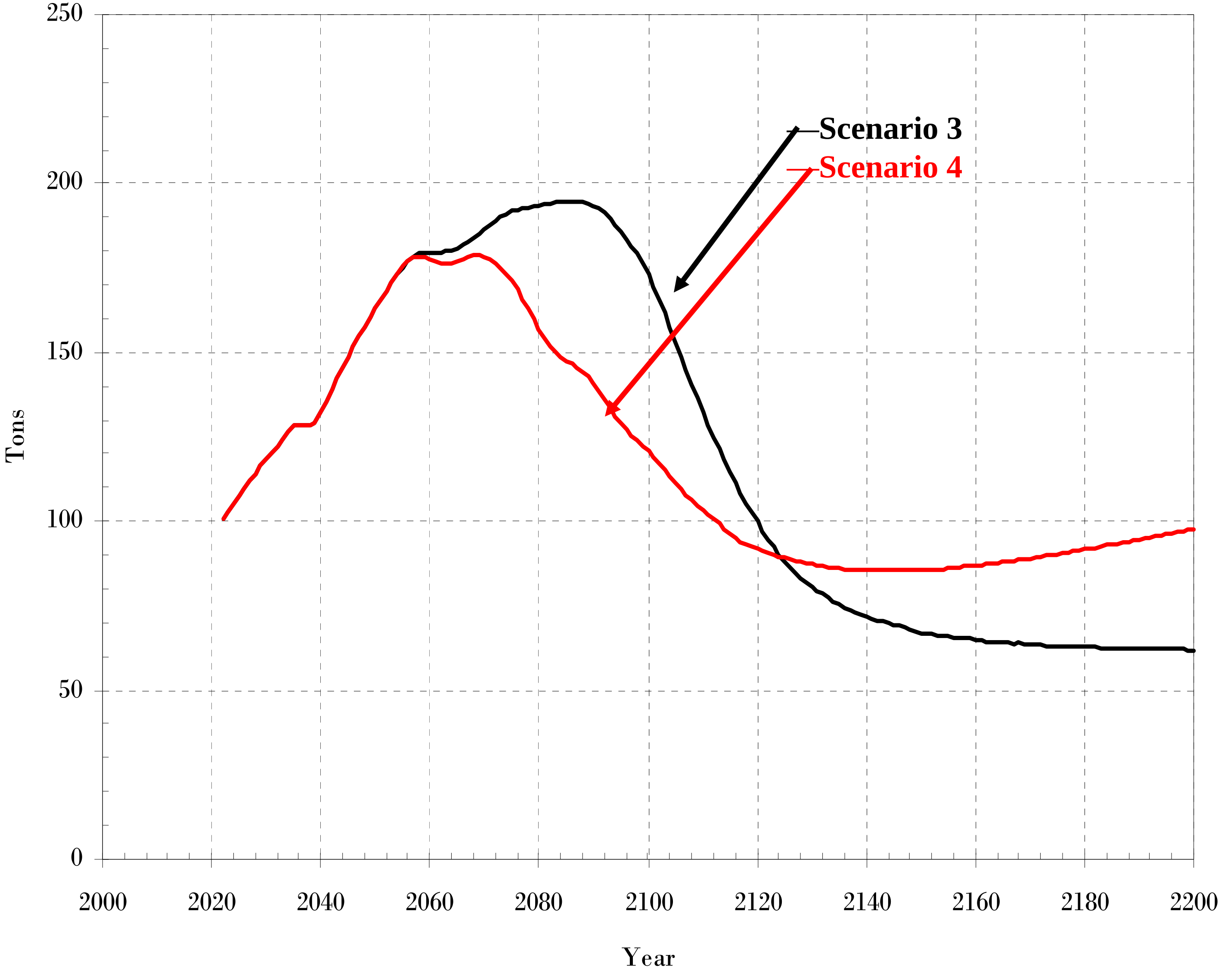
- The major result of the scenarios 3 and 4 has been to show the possibility to manage the Pu and MA of several countries through a regional approach with fast reactors either burners or breeders, depending on the strategies applied in the countries.

- It could be important to use the flexibility of a Fast Reactor and the reversibility from burner to breeder. This would allow to make the transition from burner to breeder configurations for the Fast Reactors (all or part of them), at a specific point in time. This feature can allow to tune future strategies at a regional level, that account both for sustainability and for waste minimisation.

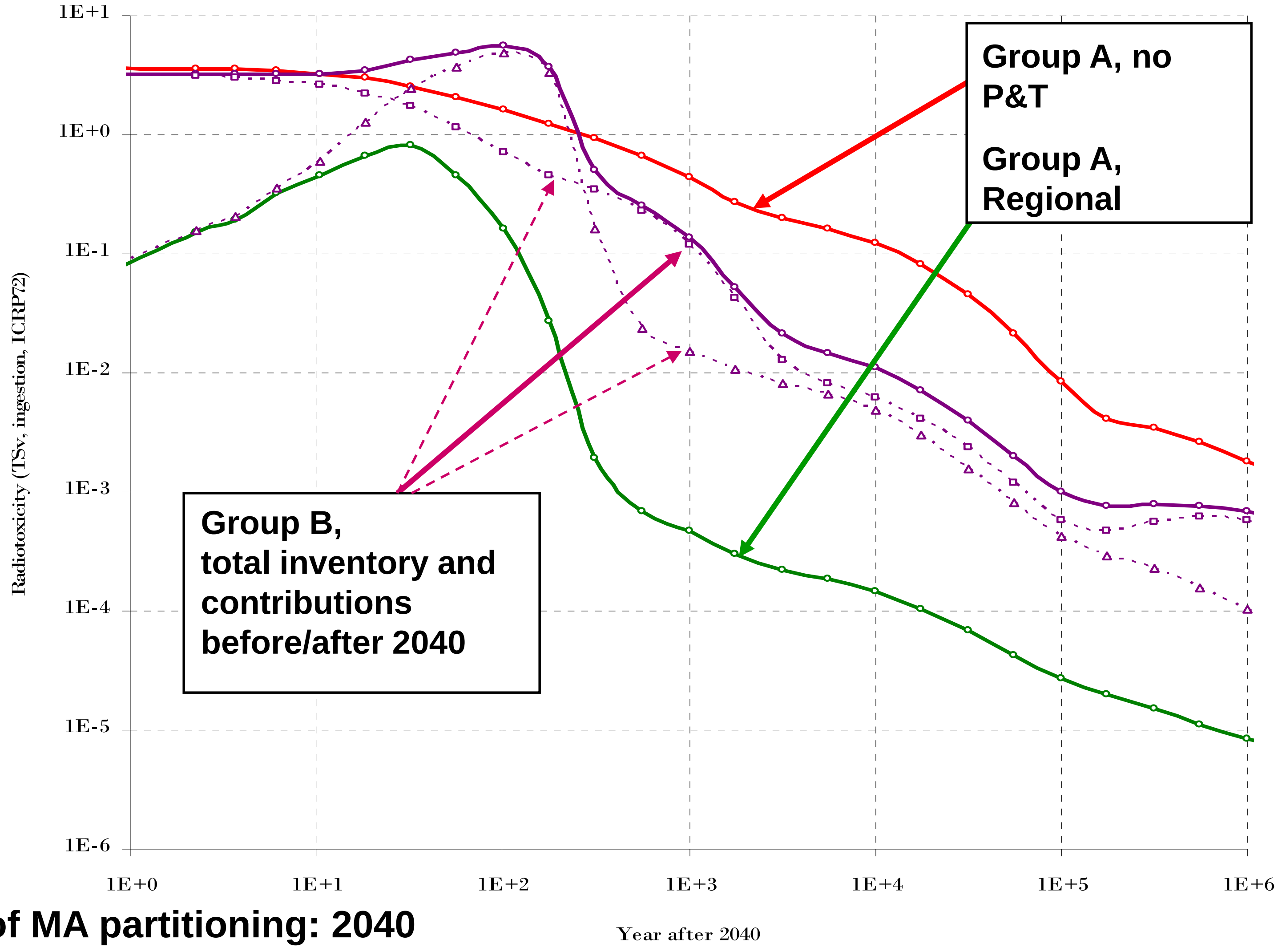
- A significant reduction of the radiotoxic inventory of the High Level Waste is obtained for both group of countries, even in the case of a restart of nuclear energy in the group A. Same trend for decay heat in the repository.

- It has also been pointed out that the optimisation of Scenarios depends, as expected, by a number of parameters, and, among them, parameters that characterize the fuel cycle (cooling times etc) are particularly significant and will have to be investigated in detail.

Minor Actinide inventory in the cycle



Cumulated radiotoxic inventory of the HLW in the Groups A and B for the Scenario 3. The HLW accounted are the waste produced between 2010 and 2200.



Beginning of MA partitioning: 2040

Overall summary and perspectives (1/3)

- **Regional strategies can in principle provide a framework for implementation of innovative fuel cycles, with appropriate share of efforts, accounting for proliferation concerns and resources optimisation.**

- **The indications obtained so far underline that if, e.g. Fast Reactors with homogeneous recycle of not-separated TRU are envisaged, there is the need to optimise the fast reactor characteristics (e.g. the conversion ratio), and the fuel cycle characteristics (e.g. the fuel out-of-pile cooling time), in order to meet the potentially different objectives of different countries within a regional area.**

- **In the present study, we did not investigate the impact of introducing critical Fast Reactors using heterogeneous recycle of MA, and this can be the object of future studies. However, the potential limitations in terms of maximum allowed amount of MA that can be loaded in a target and the potential absence of fertile blankets, can reduce the flexibility of Fast Reactors, as discussed above, that allows to cope with a range of objectives within a regional area.**

Overall summary and perspectives (2/3)

- **Another relevant finding of the study is related to the characteristics of the ADS chosen to transmute MA in Scenarios of the "double strata" type.**

- **In fact, most ADS design studies, envisage a fuel loading and a transmutation potential mostly adapted to "MA", and not "TRU", consumption.**

- **Then, this type of ADS is more apt to be used in a "regional" Scenario where different countries with different objectives do share resources, facilities and spent fuel inventories in order to minimise wastes. In the case of a country committed to a stagnant or decreasing use of nuclear energy that would decide to deploy P&T for waste management in "isolation" an ADS consuming MA and Pu would be needed.**

Overall summary and perspectives (3/3)

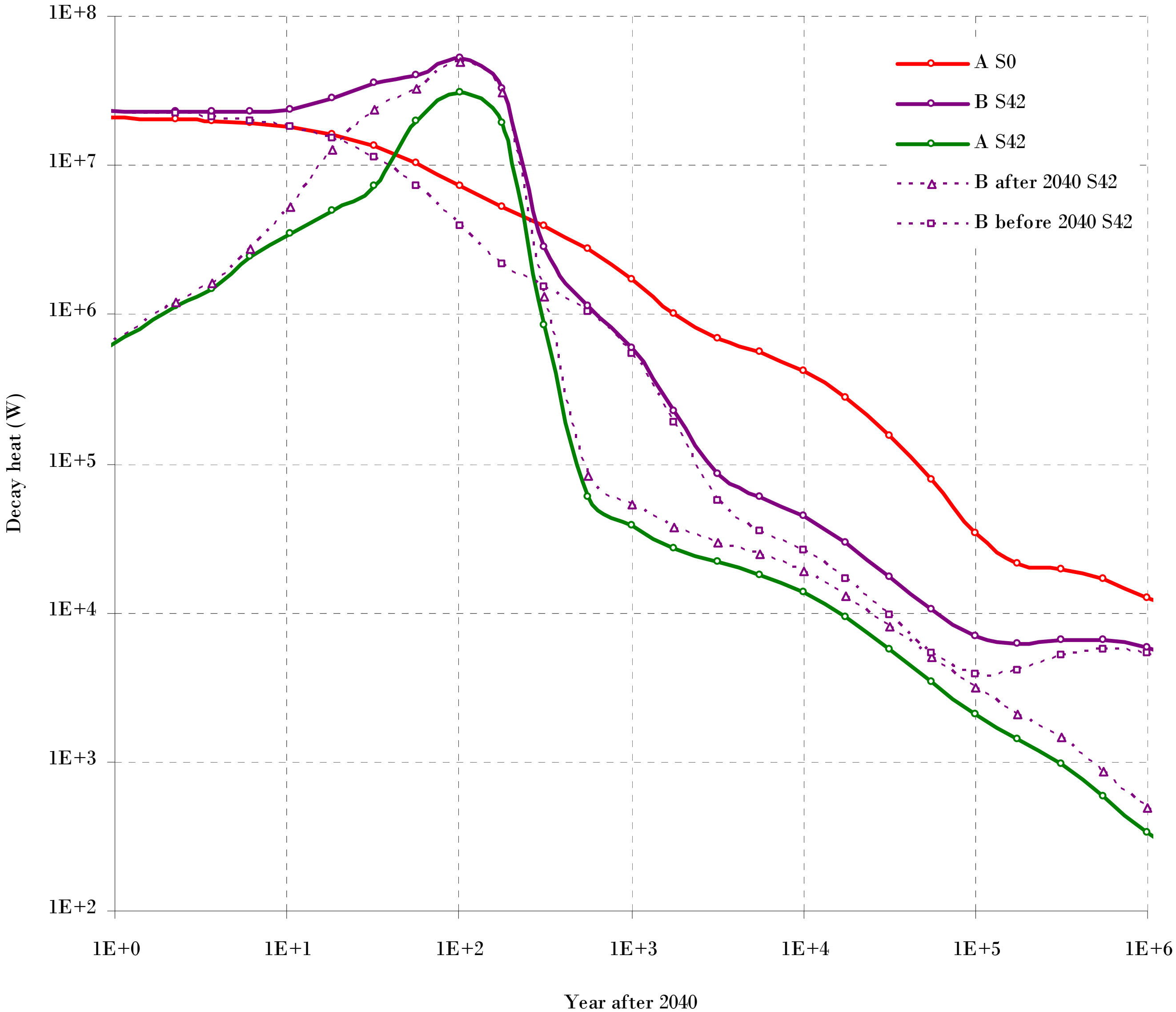
- **In this respect, an interesting addition to the present study would be the introduction of a critical "burner" fast reactor (i.e. with a conversion ratio in the range 0.5-0.8) in Scenarios 1 and 2.**

- **As far as the impact of the implementation of P&T at a regional level, the results of the Scenario studies indicate that the expected beneficial potential of P&T, i.e. reduction of the radiotoxicity in a repository to the level of the radiotoxicity of the initial ore after few hundred years, and the reduction of the heat load in the repository (more than one order of magnitude), applies to whole region, providing a potential significant benefit to all the countries of that region (e.g. Europe), despite their different policies in terms of nuclear energy.**

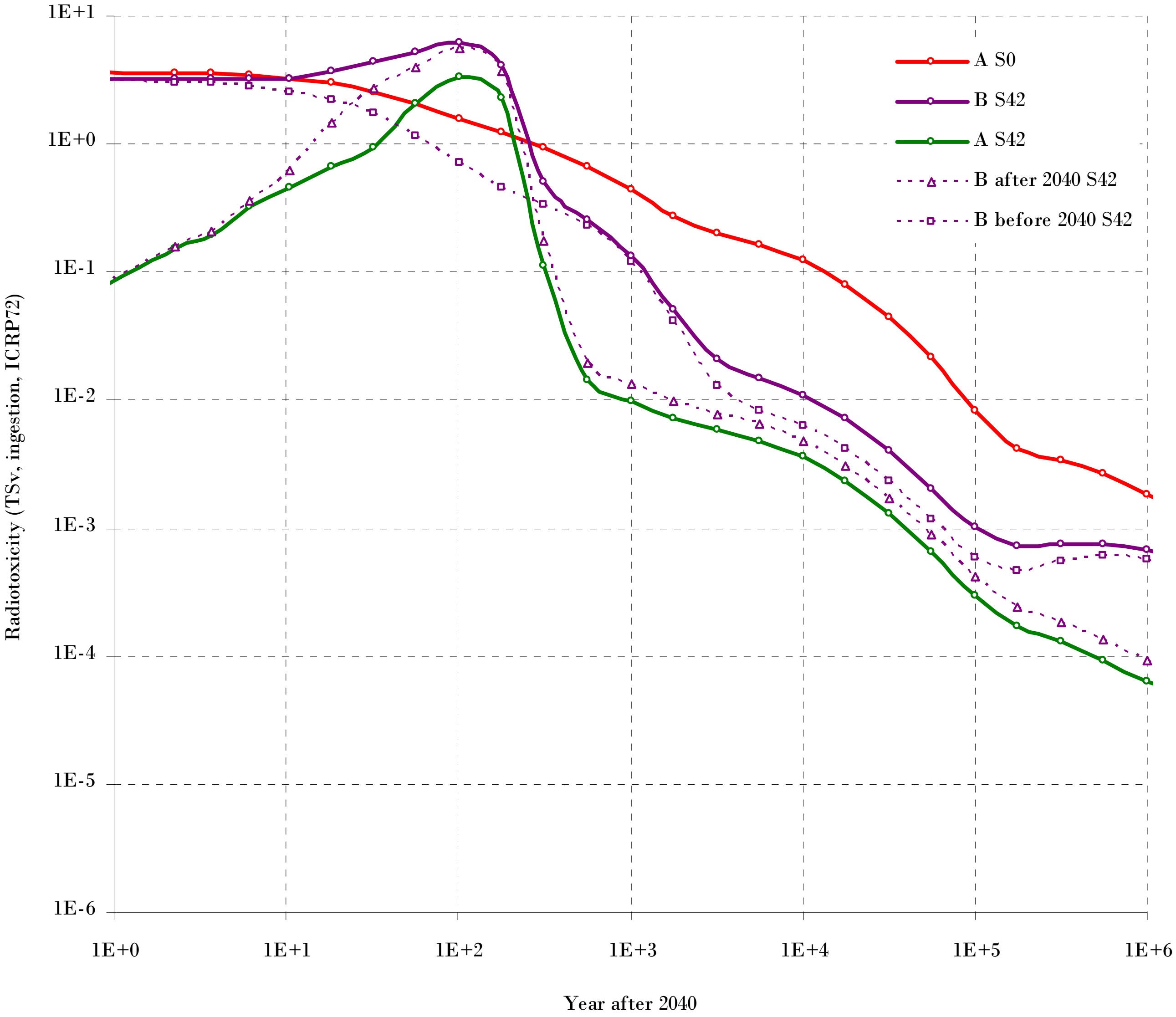
- **Moreover, the present studies have shown the potential of a regional strategy in order to favour a nuclear "renaissance" in some countries.**

- **Further studies will obviously be needed, in particular in order to investigate practical issues (like fuel transport etc) and institutional issues which will be without doubt very challenging.**

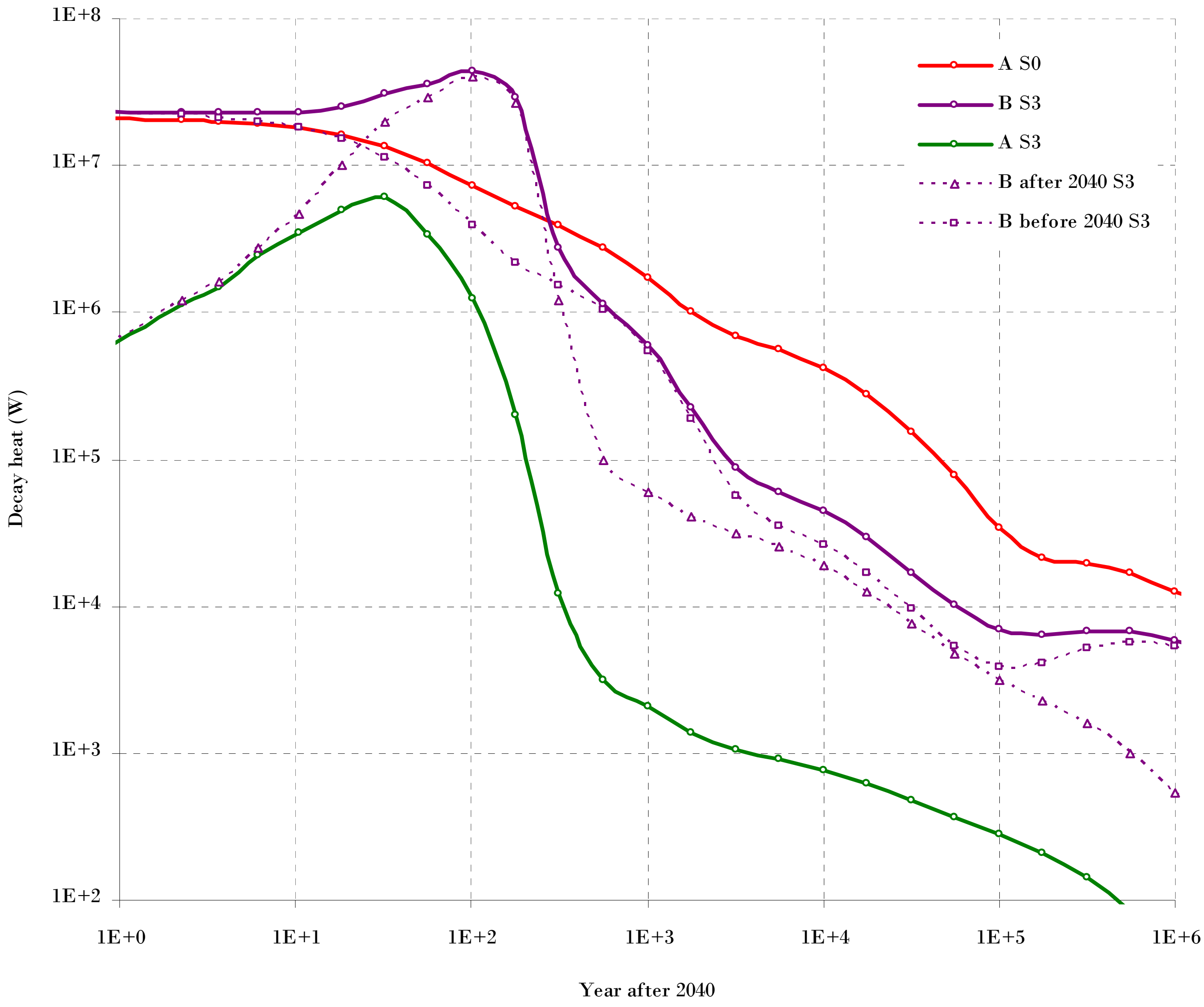
Back-up



A S0
B S42
A S42
B after 2040 S42
B before 2040 S42
1E+8
1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
Decay heat (W)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Year after 2040



1E+1
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Radiotoxicity (TSv, ingestion, ICRP72)
Year after 2040
A S0
B S42
A S42
B after 2040 S42
B before 2040 S42



1E+8
1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
Decay heat (W)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Year after 2040
A S0
B S3
A S3
B after 2040 S3
B before 2040 S3