ANNEX IV.

"EU27 SCENARIO" WITH THE EXTENDED USE OF THE REGIONAL FUEL CYCLE CENTRE COMPOSED OF THE LA HAGUE AND MELOX FACILITIES

The first set of synergies presented by the Scenario family A (see Chapter 2 of the report) has mostly been based on "EU27 nuclear energy system scenarios" given that the EU27 at large presents a diverse, technology mature and rather constant nuclear reactor park already exposed to a growing used fuel inventory starting to saturate available (pool) interim storage capacities [IV-1 – IV-3].

Five different nuclear energy system scenarios for EU27 were analyzed including the introduction of SFRs such that the whole set of these scenarios provides the reader an overview of the impacts such different nuclear reactor parks would induce and allowing for interpolation/interpretation of the results for other nuclear energy system futures as they would realize over time.

In each of the five scenarios, the analysis starts from today's installed nuclear energy system in EU27 essentially composed of LWRs and gradually introducing new LWRs and sooner or later also SFRs accompanied by a deployment of necessary fuel cycle facilities. Two nuclear energy demand scenarios are considered, i.e. a low and a high nuclear energy demand reflecting assumptions taken by other authoritative energy market analysis studies.

This study falls within the framework of Task 1 "Evaluation of synergistic collaborative scenarios towards sustainable nuclear energy systems – nuclear fuel cycle synergies".

The nuclear energy system scenarios are as follows:

1. *Scenario LWR + EPR[1] OTC:*
    a. This first scenario assumes the gradual shut-down of the existing LWRs in EU27 assuming an average 50 years technical lifetime of these nuclear power plants. Gradually, new generation LWRs, in this case assumed EPR[2]-like LWRs, are introduced to match the nuclear energy demand.
    b. While not reality today, both the existing reactor park as the new EPRs are in this scenario assumed to operate in a once-through fuel cycle mode. The purpose of this scenario, despite other practices already in place in EU27, is to provide an upper envelope of spent fuel arising and thus transuranics inventory in the fuel cycle and disposed waste. In addition, various countries in EU27 and maybe as well in the future do use the once-through cycle mode for current LWRs due to a variety of reasons covering economic and societal motivations.
2. *Scenario LWR + EPR UOX/MOX:*
    a. While not pretending to mimic exactly today's partial recycle of separated plutonium by use of MOX in existing LWRs, this scenario shows the use of partially MOX-fuel loaded LWRs and EPRs assuming the reprocessing of all spent fuel (SF) discharged from LWRs and EPRs and the recycle of the

[1] The use of EPR doesn't impose/consider that only EPR's would be built in EU. It's more a representation of Gen-III LWRs being introduced replacing the former Gen-II LWRs.

[2] EPR was formerly known as "European Pressurized Reactor" and "Evolutionary Power Reactor", but more recently the AREVA group of companies – the designer – refers to it just as "EPR"; EPR is a Generation III pressurized water reactor (PWR).

separated Pu in MOX in part of the installed nuclear power plants (or via a partial MOX-load in all nuclear power plants).

b. Once more, this scenario is not identical to today's situation but extends the strategy of MOX-use to a full use of Pu mono-recycling in EU27' nuclear energy system, indicating the change in fissile material inventories and waste arising.

3. *Scenario LWR + EPR UOX/MOX + SFRs:*

a. TRU-management may also be undertaken by fast reactors as many other studies have already indicated and this scenario therefore serves part of a simplified scenario (more part of Family "B") of introducing SFRs to serve this TRU-burning mission.

IV-1. SCENARIO LWR + EPR OTC

The amount if disposed LWR+EPR fuel is shown in Figs IV-1 and IV-2 (for low and high nuclear energy demand scenario variants respectively) as a distribution based on the distributions assumed for the input-variables, i.e. specifically the burn-up and cooling time of the LWR and EPR fuels.

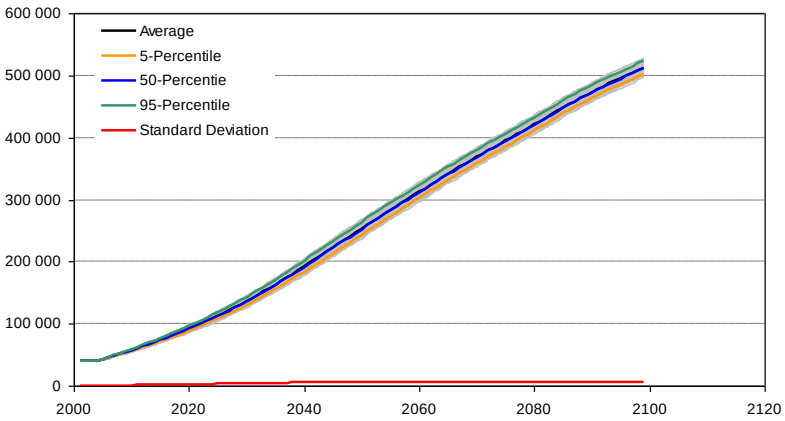


FIG. IV-1. Distribution of disposed LWR+EPR SF (tHM) for low nuclear energy scenario variant.

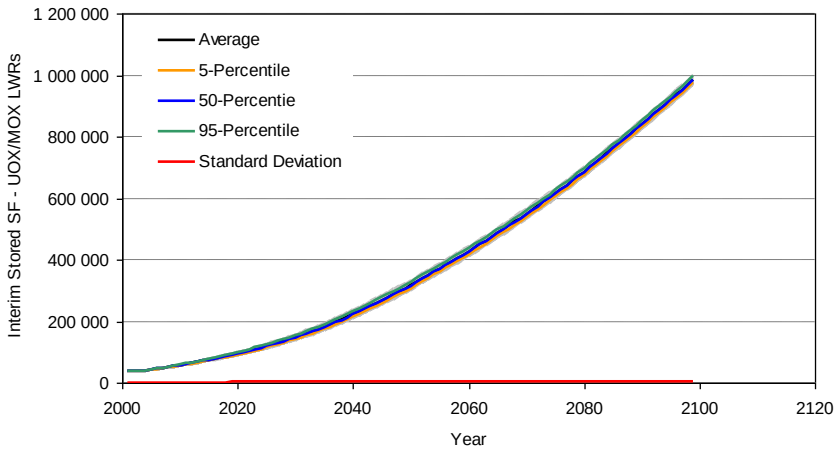


FIG. IV-2. Distribution of disposed LWR+EPR SF (tHM) for high nuclear energy scenario variant.

Both figures show the rather small variation of the disposed SF for the BU and interim cooling times assumed for the LWR and EPR UOX-fuels.

The amount of TRUs in-pile and out-of-pile (and out-of-repository) are shown in the Figs IV-3 and IV-4 for the low and high nuclear energy demand scenario variants respectively. As the park composition gradually becomes essentially EPR-like LWRs dominated and given the rather narrow range of BU-values assumed for the UOX-fuel burnups, the distribution of TRU In-Pile remains rather narrow as can be seen from the Figs IV-3 and IV-4.

Comparable narrow distributions are shown for the cumulative U_{nat} usage (i.e. amount of U_{nat} used by scenario from 2005 till end of century) and the annual enrichment needs, respectively shown in Figs IV-5 and IV-6 for the low and high nuclear energy demand variants.

The relative straightforward relation between the varied input-variables burnup and cooling time for the UOX-fuels and the output variables considered in this analysis is clear from the figures below. No additional detailed analysis of sensitivity analysis was therefore undertaken given the limited conclusions this may entail. A more comparative analysis of all scenarios including this first scenario is provided in the conclusions section within this report.

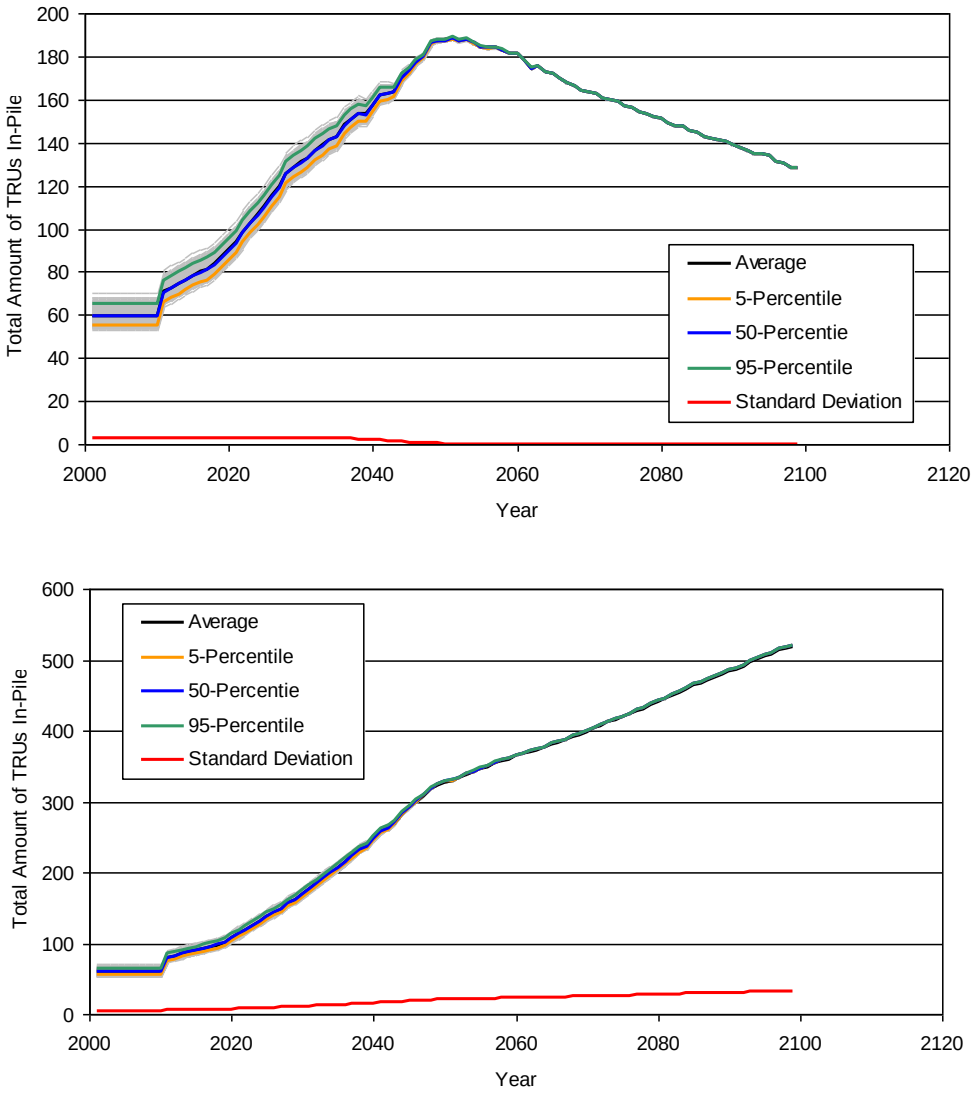


FIG. IV-3. TRU in-pile (tHM) distributions for the low (above) and high (below) nuclear energy demand variants.

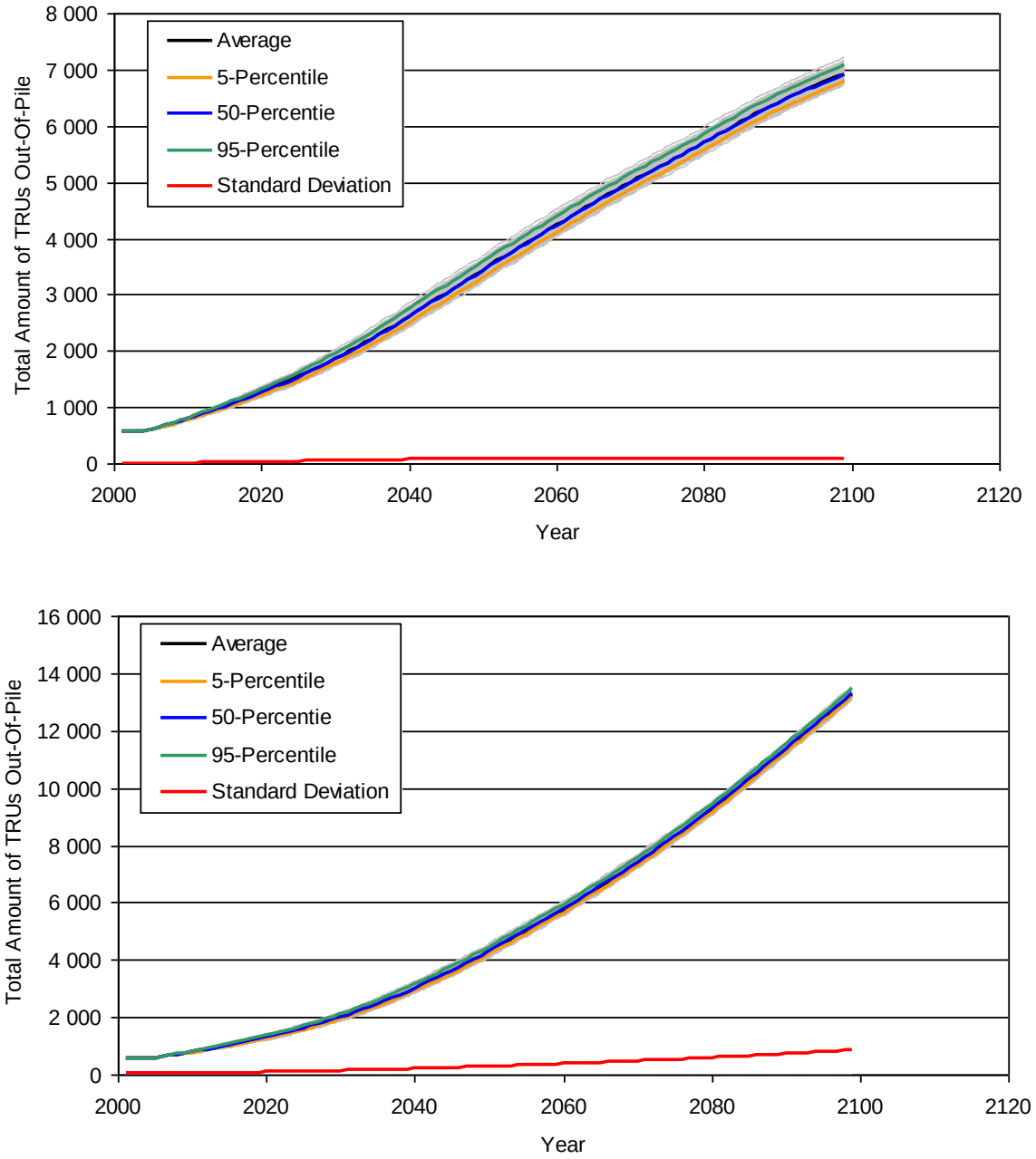
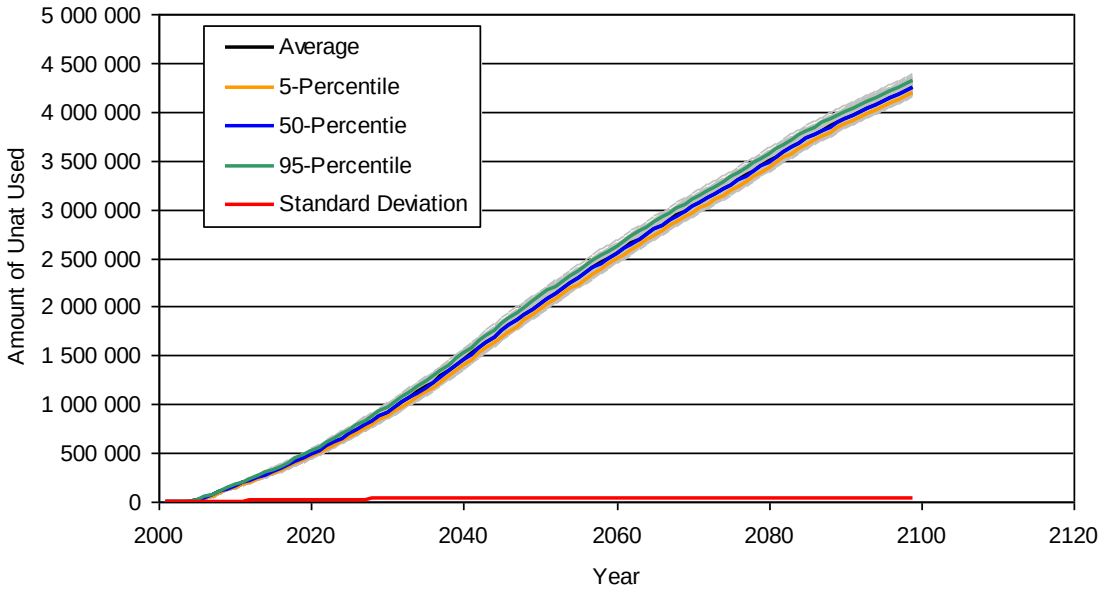


FIG. IV-4. TRU out-of-pile (tHM) distributions for the low (above) and high (below) nuclear energy demand variants.



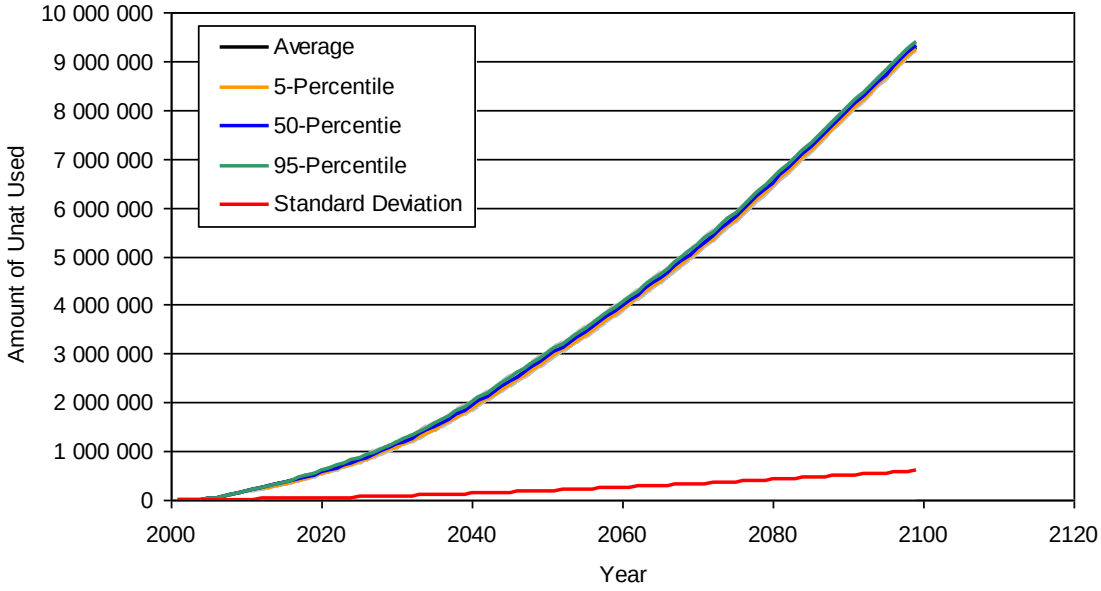


FIG. IV-5. Cumulative U_{nat} (tHM) used for the low (above) and high (below) nuclear energy demand scenario variants.

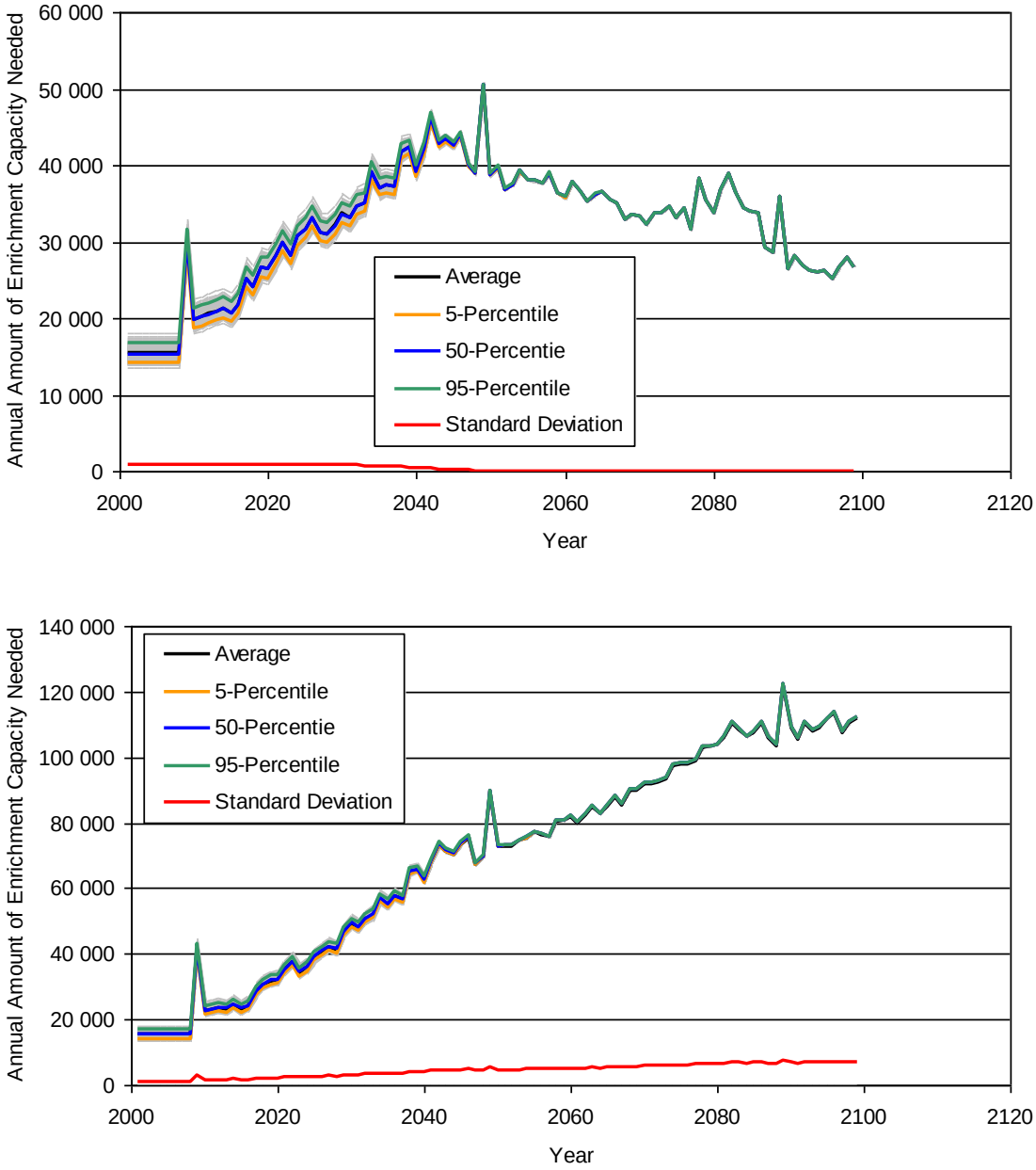


FIG. IV-6. Annual enrichment needs (kSWU/year) used for the low (above) and high (below) nuclear energy demand scenario variants.

IV-2. SCENARIO LWR + EPR UOX-MOX

A comparable sensitivity/uncertainty analysis is undertaken for this scenario though only for the high nuclear energy demand scenario variant.

The distribution of the amount of SF is shown in Fig. IV-7 as a result of the various burn-up and interim cooling times assumed for the UOX and MOX fuels discharged from the LWR and ERPs. The much wider distribution in interim and disposed SF clearly is due to the differences in burn-ups and cooling times assumed. The outliers of this distribution, i.e. beyond about the 90 percentile, do include cases where the nuclear energy demand cannot be met due to too long cooling times and thus reduced separated Pu availability to feed the MOX-fabrication plants and thus allowing to load fresh MOX-fuel in the EPRs.

The total volume of disposed waste (m^3) is shown in Fig. IV-8. Volumes are assumed here in order to show the difference between the estimated volumes of waste given the

difference in SF versus HLW packing that may be envisaged for SF and HLWs depending on the type of fuel being disposed of or waste arising from the reprocessing of these fuels.

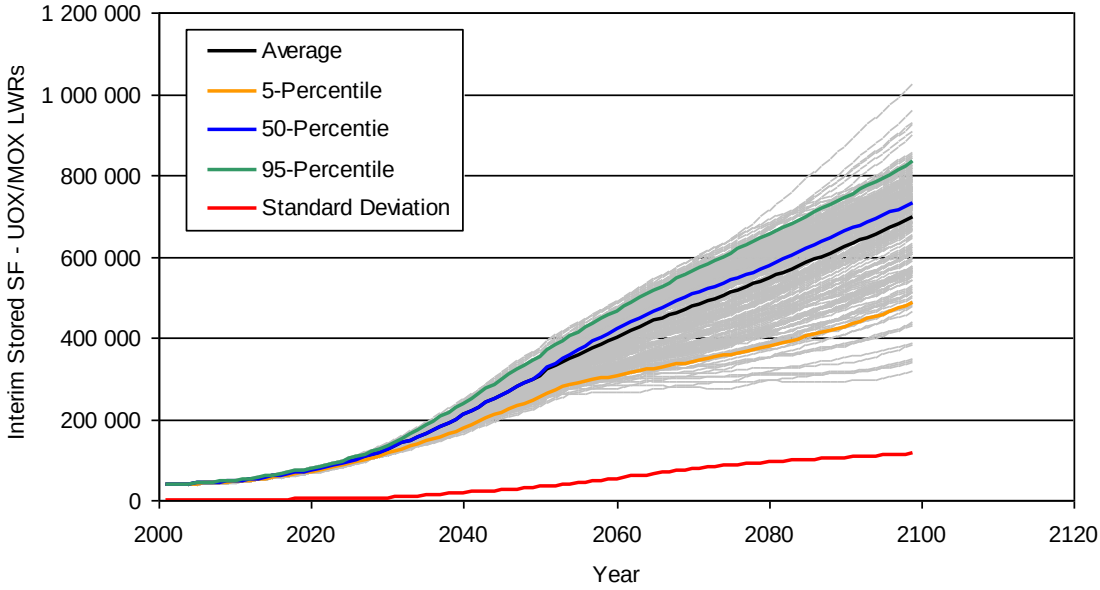


FIG IV-7. Interim stored SF (tHM) for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

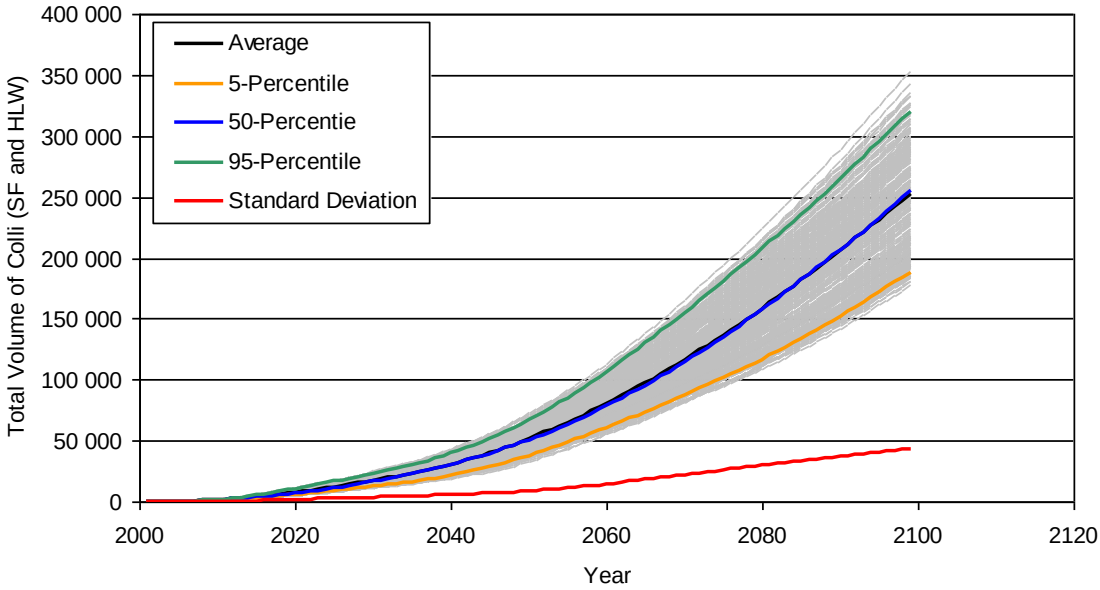


FIG. IV-8. Volume of disposed waste (m^3) for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

The total amount of TRUs In-Pile and Out-of-Pile are shown in Figs IV-9 and IV-10 respectively. Again, the wider distribution due to the differences in working inventory versus In-Pile amount of TRUs due to differences in burn-ups and interim cooling times are obvious. The lower than about ten percentile cases result in a shortage of nuclear energy supply due to too long interim cooling times and thus reduction of separated Pu available for MOX-fabrication and thus loading in the EPRs. Obviously, though not considered in the scenario

analysis in this report, this could be circumvented by reducing the fraction of MOX-loaded EPRs as well.

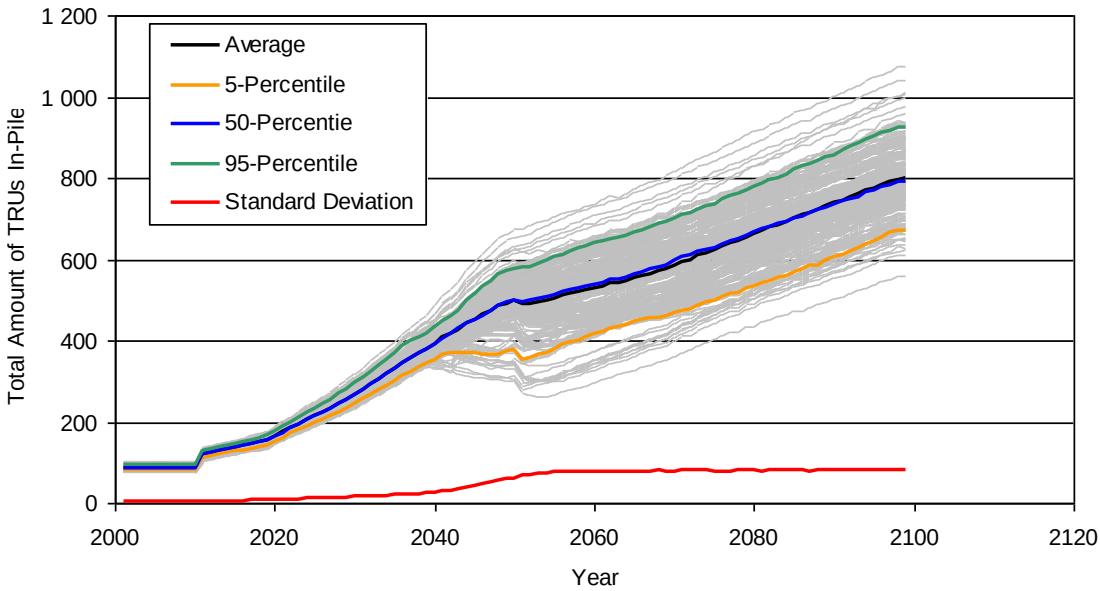


FIG. IV-9. TRU in-pile (tHM) amounts for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

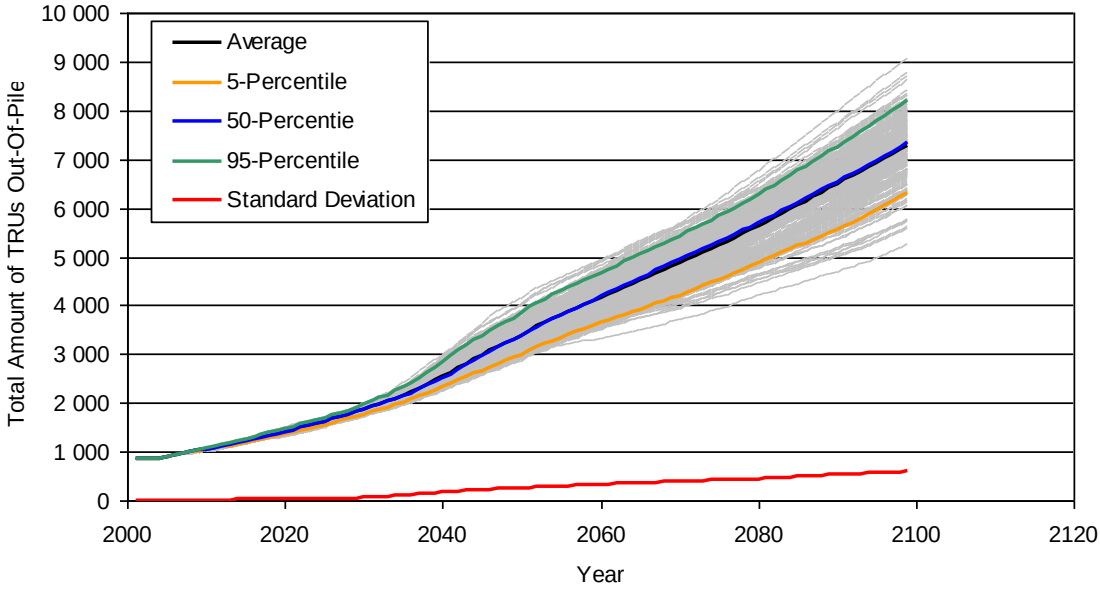


FIG. IV-10. TRU out-of-pile (and out-of-repository) (tHM) amounts for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

The impact on amount of HLW arising from the reprocessing of the discharged UOX from LWRs and EPRs is shown in Fig. IV-11. Especially the cooling time has a high importance here as any long cooling time results in a late reprocessing and thus delayed arising of HLWs as can be seen from the Fig. IV-11. The total amount of TRUs in disposal,

i.e., in the disposed MOX-fuel and in the HLW (as from Fig. IV-11) are shown in the Fig. IV-12.

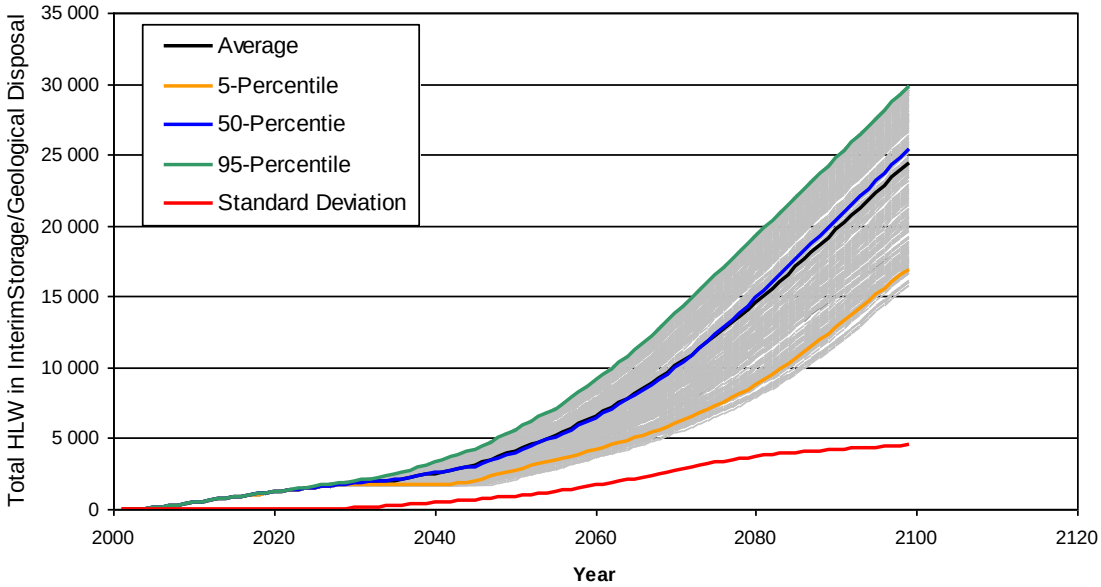


FIG. IV-11. HLW amounts (tHM) for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

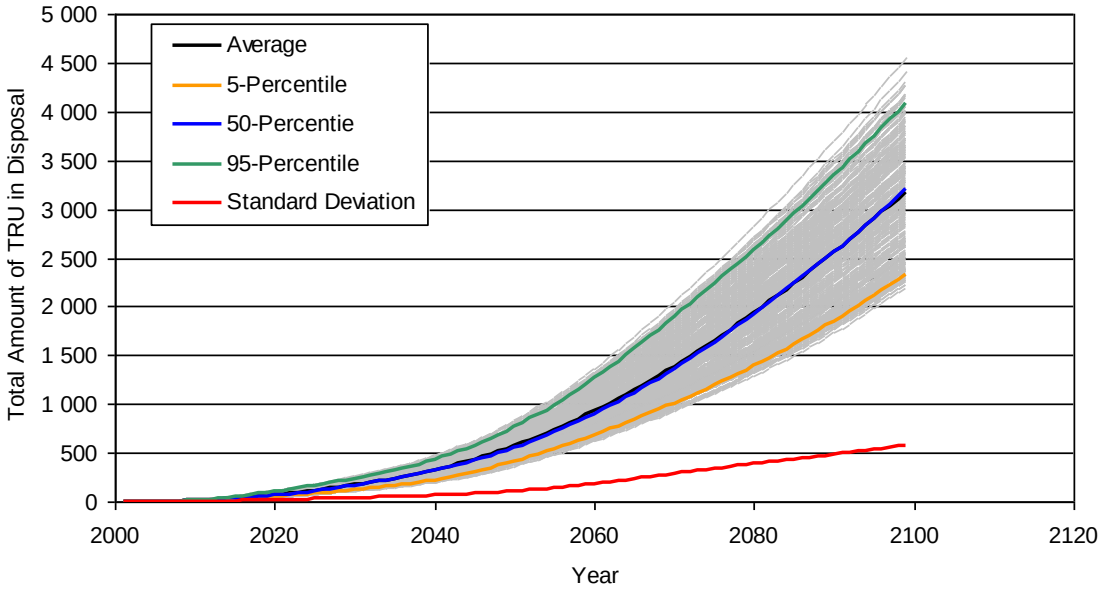


FIG. IV-12. Total amount of TRUs (tHM) in disposal for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

The cumulative amount of natural uranium U_{nat} used by this scenario as function of the sampled burn-ups is shown in Fig. IV-13. Here, the cooling time does not have a direct impact as this amount of U_{nat} is only based on the fresh fuel demand for the evolving reactor park. Though, if the cooling time becomes too long, and thus the requested nuclear energy demand may not be met, a reduced U_{nat} evolution is spotted due to a slower than necessary

deployment of nuclear power park. The annual enrichment needs, again essentially as function of the sampled burn-ups for the UOX/MOX fuels, is shown in Fig. IV-14.

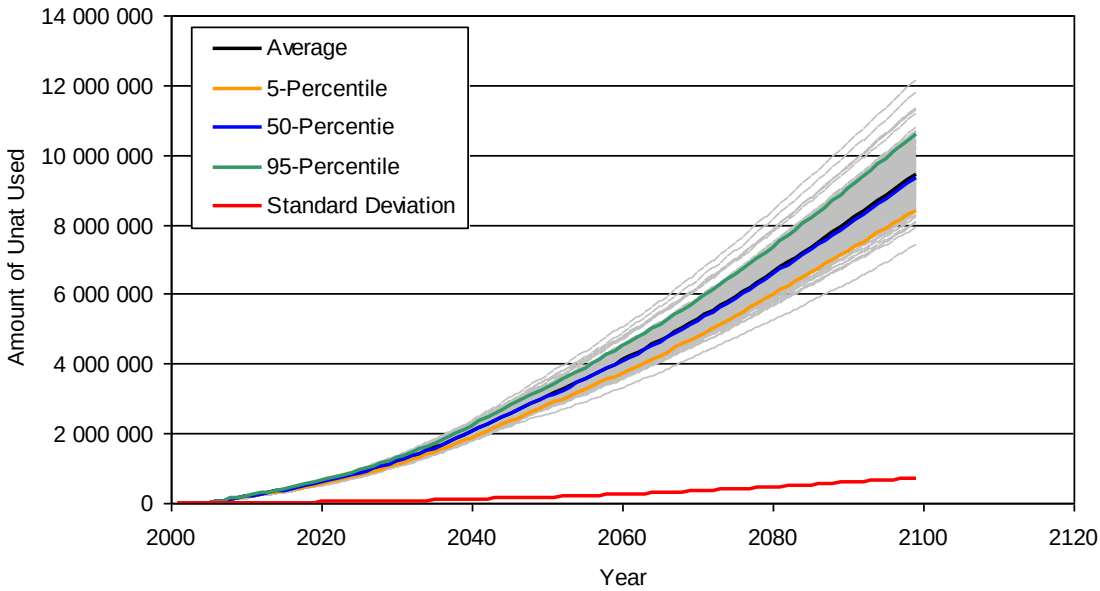


FIG. IV-13. Total amount U_{nat} used (tHM) for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

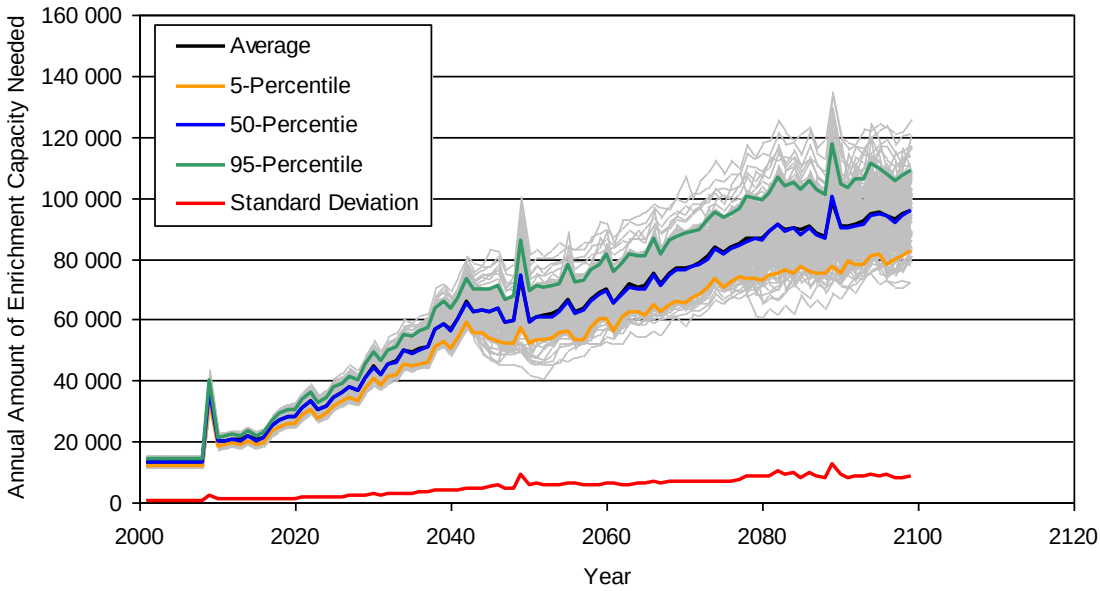


FIG. IV-14. Annual enrichment capacity needed (tSWU/year) for the LWR + EPR UOX-MOX in high nuclear energy demand scenario variant.

Within these scenarios, not each of the EU27 countries will embark on EPR MOX-use and therefore synergies can be considered where a recycling platform, as Sellafield and La Hague were and where La Hague still is, provides the fuel cycle services to many of the EU27-countries. The previous figures show the gain in SF/HLW-arising from such scenarios and thus the reduced geological disposal volume or surface required.

REFERENCES TO ANNEX IV

[IV-1] EUROPEAN COMMISSION, Energy Roadmap 2050, COM(2011) 885/2, Brussels, Belgium (2011): http://www.roadmap2050.eu/

[IV-2] COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES, CEA News # 26, Partitioning and transmutation of long-lived radioactive elements, 2013: www.cea.fr/english_portal/library/cea_news

[IV-3] COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES, CEA News # 28, Nuclear fuel makes the rounds, 2014: http://www.cea.fr/english-portal/library/cea-news/cea-news