ANNEX IX.

ADRIA STUDY INPUTS AND DETAILED RESULTS

In this study the benefits from operating at multinational level with the deployment of a fleet of PWRs and subsequently, at a proper time, the one of lead cooled fast reactors (LFRs) are analyzed. To simplify the calculations it is assumed that the installed nuclear capacity is in all cases represented by a generic pressurized water reactor (PWR); moreover, the increase of the installed nuclear capacity in the near term is supposed to be accomplished by PWRs too. After 2040 these fleets of PWRs will be replaced with fast reactors of a particular type, assuming they would become industrially mature by that time. Fast reactors will be lead cooled reactors of a particular type, with core design characterized by a fuel cycle where only fission products and the reprocessing losses are sent for disposal and natural or depleted uranium is added to fuel in each reprocessing cycle. Such lead fast reactor (LFR) could be referred to as "adiabatic reactor" [IX-1, IX-2].

In this annex the input data is presented which is used in the simulations and more detailed results that complete those synthetized in the main report.

In economic analysis it is widely accepted that there is a tight connection between the variation of the gross domestic product (GDP) and the electricity consumption (EC); therefore, a guess of the evolution of the GDP in the countries under analysis is a key to get figures for the EC. It is plausible that, as soon as the present economic crisis will be overcome, the countries from the South East Europe (SEE) will experience a significant increase of their GDP, up to approximately the level of the Western countries. If one assumes an annual increase of 6% for the average GDP in Region I, then it would reach in the year 2050 a per capita GDP level as high as the present average European Union one. Adopting an average ratio between the GDP and the EC similar to that from reference [IX-3], we get an EC annual increase of 3.3%. After the year 2050 it is assumed that this value will decrease to 1% yearly. The same figures are adopted for Region IV, in accordance with the forecast in the IAEA country profile of the Ukraine. For regions II and III a constant annual increase of the electricity consumption of 1% per year until 2100 is assumed in accordance with the most conservative expectations given in reference [IX-4].

TABLE IX-1 shows the input parameters used in models of the reactors and fuel cycles.

TABLE IX-1. KEY PARAMETERS USED IN THE SIMULATIONS.

Pu produced by a PWR (annually)	0.026	tHM/TWhe
Pu in a PWR core	0.513	tHM/ GW(e)
Pu in a LFR core	15.14	tHM/ GW(e)
PWR total mass fuel	78.7	tHM/ GW(e)
PWR LFR total mass fuel	83.4	tHM/ GW(e)
PWR Capacity factor	0.9	-
LFR Capacity factor	0.9	-

TABLE IX-1. KEY PARAMETERS USED IN THE SIMULATIONS (cont.)

Time before is usable the discharged Pu from the LFR	8	year
Time before is usable the discharged Pu from the PWR	8	year
LFR Fuel residence time	5	year
PWR Fuel residence time	4	year
PWR life time	60	year
LFR life time	60	year
Pu needed to start a LFR ([1])	39.4	tHM/ GW(e)
PWR Natural U consumption	25.2	tHM/TW(e)h
PWR Natural U for first core	705.9	tHM/ GW(e)
SWU for a PWR reactor	14.8	tSWU/TW(e)h
PWR fuel output	2.81	tHM/TW(e)h
LFR fuel output	2.06	tHM/TW(e)h
LFR Uranium fraction in fresh LFR fuel	0.8056	-
Pu generated in region 1 before the year 2020	13.8	tHM
Pu generated in region 2 before the year 2020	33.4	tHM
Pu generated in region 3 before the year 2020	12.0	tHM
Pu generated in region4 before the year 2020	54.5	tHM

Figures IX–1 and IX–2 show the evolution of the installed power for PWRs and LFRs in each region for both scenarios. The minor LFRs' power in the non-synergic case is caused by the minor quantity of Pu available to start them, determined by the hypothesis that the second region doesn't install LFRs and therefore Pu generated by the LWRs from the second region remains unused in the deposit.

Figure IX–3 illustrates the evolution of new installed power for both types of reactors, displaying the values added for all the four regions (each region individually follows a similar trend).

[1] A conservative hypothesis is assumed, that Pu needed to start a LFR must be that which is necessary for the first core plus that which is necessary for the refueling until the Pu from the same reactor is available to be used as fresh fuel.

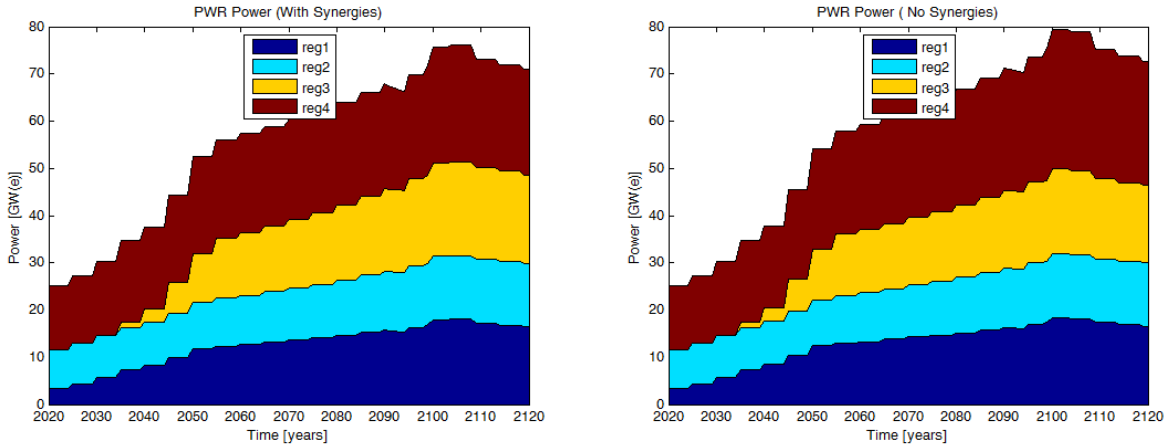

FIG. IX-1. Power evolution for the PWRs in each region in the scenario with synergies (on the left) and the scenario without synergies between the regions (on the right).

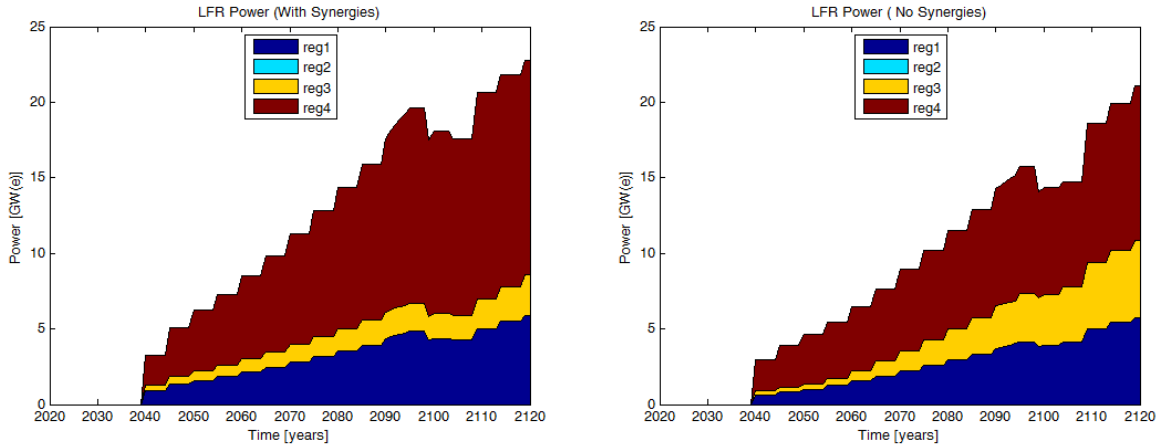

FIG. IX-2.Power evolution for the LFRs in each region for both scenarios.

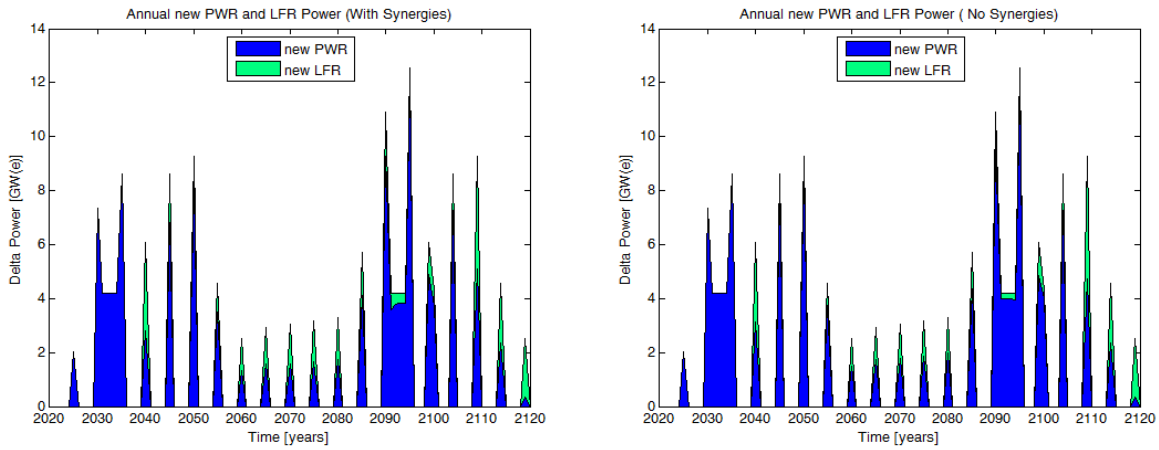

FIG. IX-3. New installed power for both types of reactors (cumulated for all the regions) in the two scenarios.

Figure IX-4 shows the Pu production for each region in both scenarios which was calculated on the basis of the initial stock produced in the years previous to the present simulation.

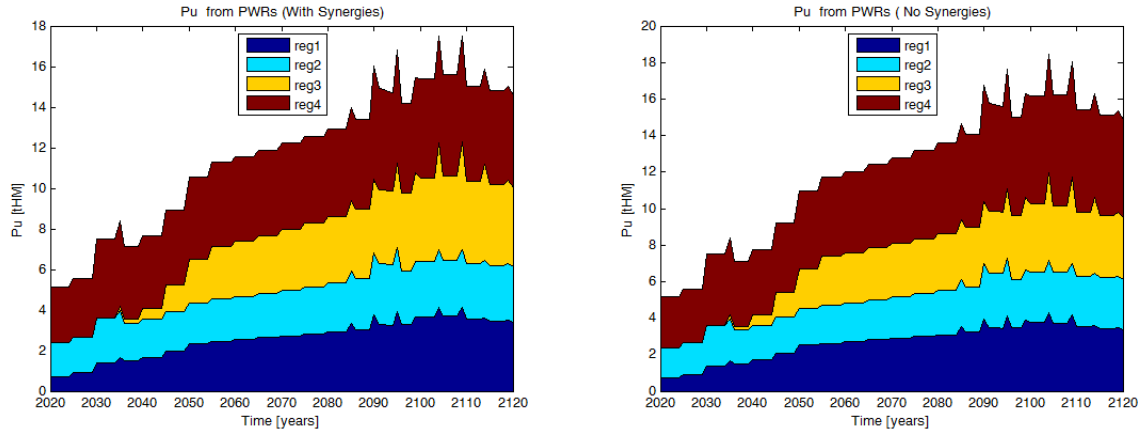

FIG. IX-4. Annual Pu production in each region for both scenarios.

Figure IX–5 shows the cumulated Pu quantity produced by the PWRs, with differences almost not visible between the two cases due to only a slight difference in the PWRs power.

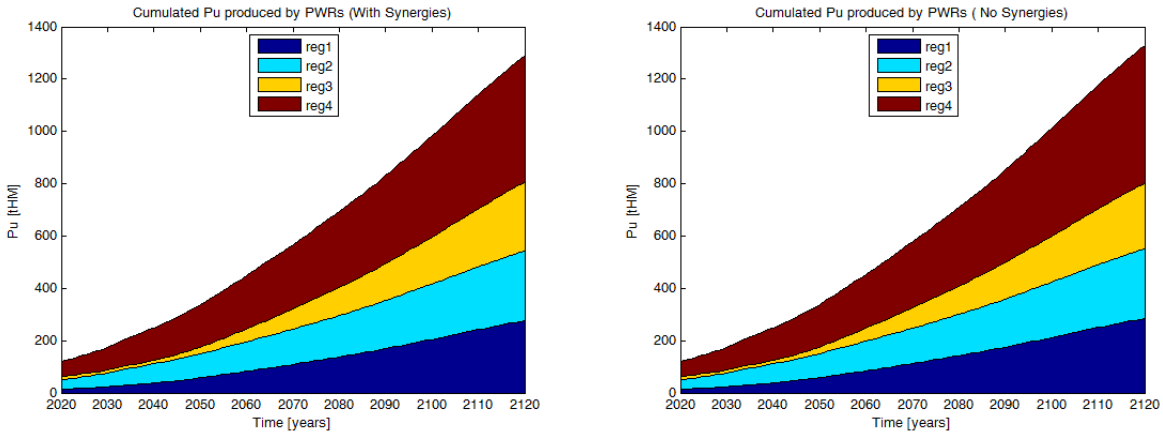

FIG. IX–5. Cumulated Pu production in each region for both scenarios.

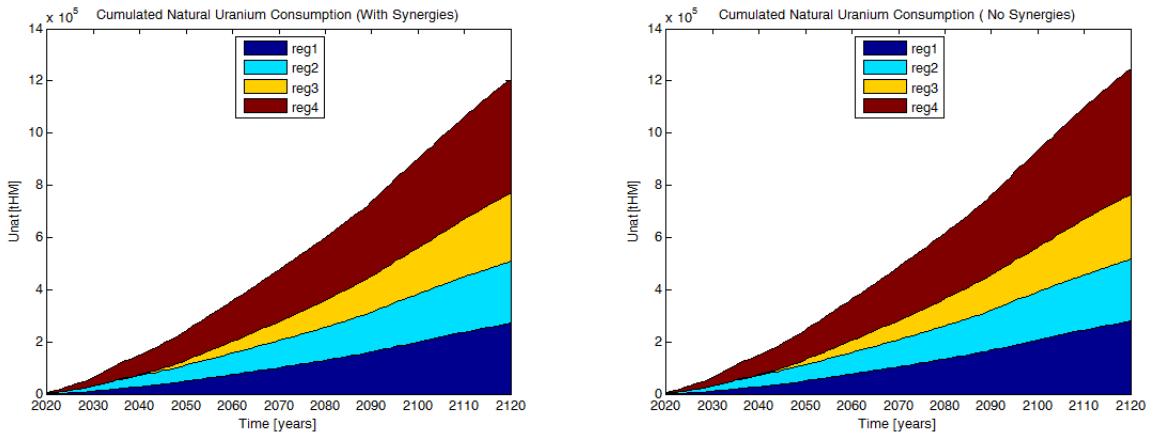

FIG. IX-6. Cumulated natural uranium consumption in each region for both scenarios.

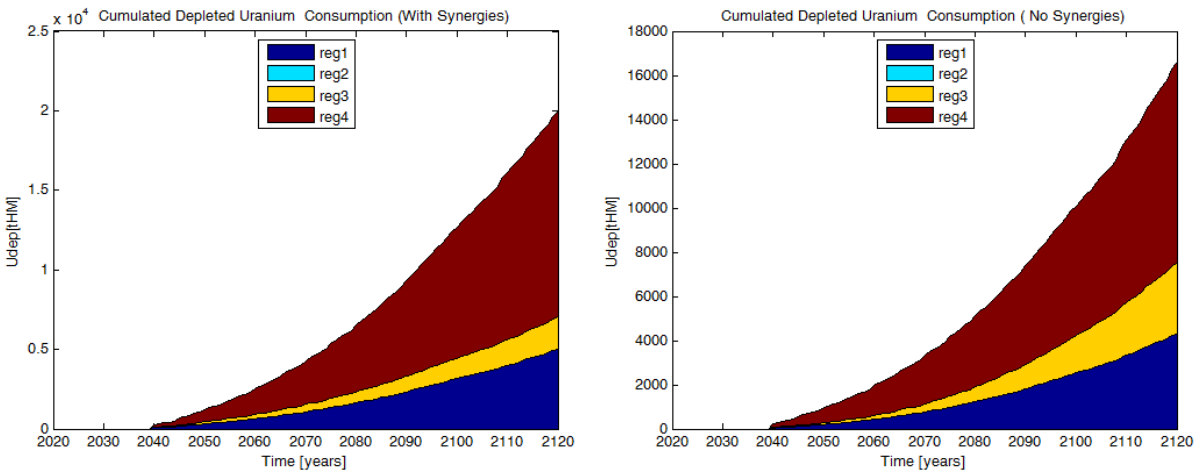

FIG. IX-7. Cumulative depleted uranium consumption by the LFRs in each region for both scenarios.

Figure IX-6 displays the evolution of the cumulative consumption of natural uranium used in PWR fuel. As expected, in the synergic case the values are slightly lower due to the minor installed capacity of this reactor type compared to the non-synergic case. Figure IX-7 shows the depleted uranium used to fuel the LFRs, which is the single extra fuel resource for LFR after the first loading.

The next four figures display the data used to evaluate the expenditures associated with uranium enrichment and SF reprocessing. Fig. IX-8 shows the average annual uranium enrichment demand over a period of ten years. These average values define the facility capacities in each period; as before, the left side of figure refers to the synergic case and the right to the non-synergic one. For the synergic scenario the total enrichment demand for the four regions in annual step and the mean values of this variable in a ten years period are shown. The mean values of the enrichment demand are displayed for the non- synergic case; however, in order to render the figure legible the annual values for each region were not displayed. The mean values over a ten years period displayed in the right part of Fig. IX-8 define the capacity evolution of each one of the four enrichment facilities that function in each region.

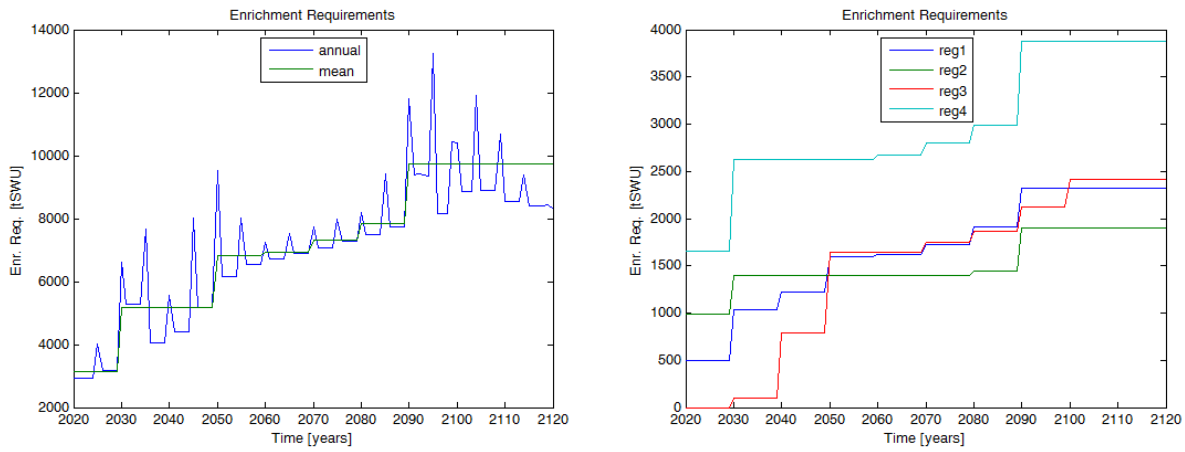

FIG. IX-8. Mean enrichment demand (over a ten year period) for both scenarios along with the curve with the annual values for the synergic case.

Figure IX-9 illustrates the corresponding levelized costs associated with the enrichment demand displayed in Fig. IX-8 for both scenarios, which were calculated on the basis of information from the IAEA progress report on economic data, see Appendix II to the report.

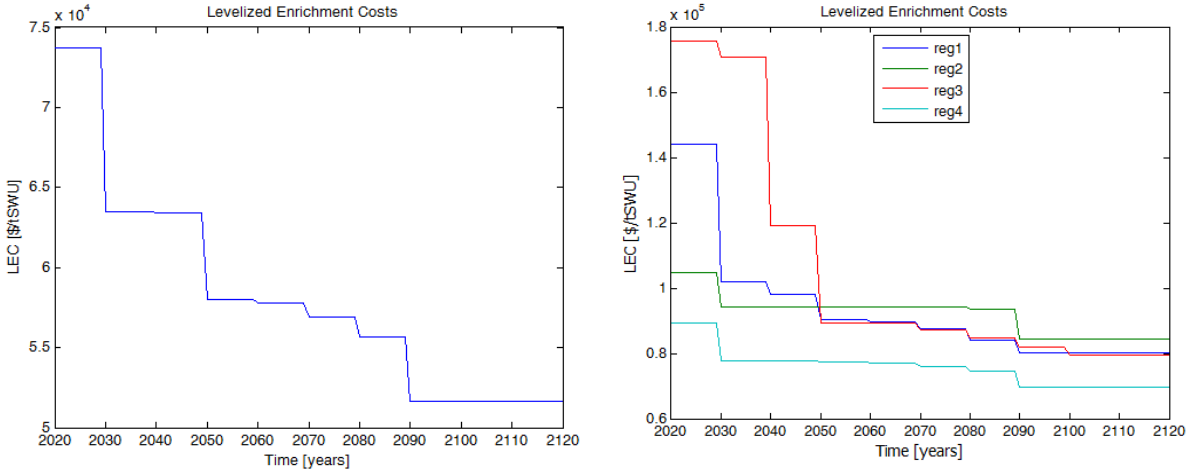

FIG. IX-9. Evolution of the levelized enrichment cost in the common facility of the synergic case (left) and for the facilities of each region in the non-synergic case (right).

These results clearly demonstrate the advantages of the economies of scale when the values obtained in the two cases are compared. In case of each region reprocessing the spent fuel separately, the unitary costs are reasonably higher than in case of all the regions working on it together.

Similar results were obtained for the reprocessing costs as shown in Fig. IX-10 and Fig. IX-11. Noticeable differences were observed in unitary costs between the two scenarios.

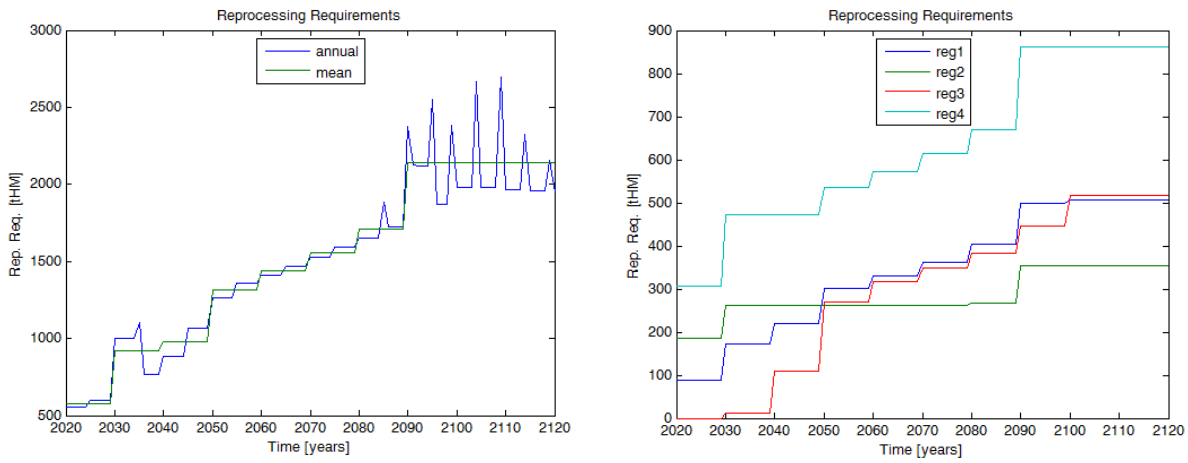

FIG. IX-10. Mean reprocessing requirements (over a ten year period) for both scenarios with the curve with the annual values for the synergic case.

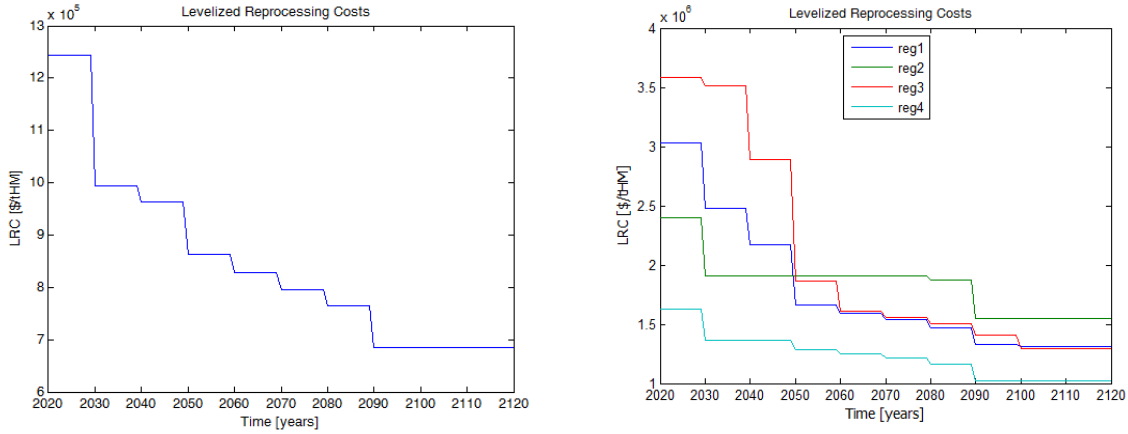

FIG. IX-11. Evolution of the levelized reprocessing cost in the common facility of the synergic case (left) and for each of the facilities in the non-synergic case.

REFERENCES TO ANNEX IX

[IX-1] C. ARTIOLI, G. GRASSO, C. PETROVICH, A new paradigm for core design aimed at the sustainability of nuclear energy, Annals of Nuclear Energy - 01/2010; 37(7), p. 915-922.

[IX-2] C. ARTIOLI, Minor Actinides Transmutation: ADS and Power Fast Reactors, Nuclear 2011, Pitesti (Romania), May 25-27, 2011.

[IX-3] PRICEWATERHOUSECOOPERS et al, REBIS: GIS, vol. 2: Electricity demand forecast, EU CARDS programme for the Balkan region, 2004.

[IX-4] EUROPEAN COMMISSION, Energy Roadmap 2050 Impact assessment and scenario analysis, SEC (2011) 1565 final, European Commission Brussels, 15.12.2011.