Immediate Dismantling of a Large Fleet of LWR NPPs: Consequences for Spent Fuel and Waste Management – 16027

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ABSTRACT

The experience feedback shows that the complete dismantling of one Light Water Reactor (LWR) unit is an activity now globally well under control (reactor pressure vessel and its internals removal and cutting included). However some specific industrial difficulties may arise in view of the dismantling of numerous LWR units simultaneously. Indeed more than 300 LWR units are currently operated worldwide, which have been commissioned these last 50 years. So in some countries, many units may be permanently shut down over a period of few years in the next decades. Such a situation addresses the issue of the overall management of large quantities of spent nuclear fuel (SNF) and decommissioning waste for the concerned units. For example, in France, the legislative and regulatory framework for the nuclear facilities favors their dismantling "as soon as possible" after their permanent shutdown which implies as well to limit the duration of the transition period from operation to decommissioning. Furthermore 58 LWR units have been commissioned between 1977 and 1999 in France – on average more than 2 units per year. In this context, the operator (Electricité de France – EDF) plans to remove quickly the SNF then to perform dismantling actions immediately after the permanent shutdown of the LWR units. One issue is to remove the SNF from all the relevant units, even if this removal is simultaneous in many units (permanently shut down or still under operation). Similar issue has to be taken into account regarding the management of the radioactive waste (RW) produced by the dismantling and clean-up actions, notably the RW that cannot be disposed of in a near surface repository. One method followed by the French technical support organization (Institut de Radioprotection et de Sûreté Nucléaire – IRSN) to analyze these issues is the use of estimates of flows of SNF and RW. These estimates are based notably on a phasing-scenario and a planning template defined for the decommissioning of the units of one nuclear power plant (NPP) and coupled to an overall schedule for phase out all the units of the fleet. The estimates relative to the next decades can be compared to the current experience feedback of flows of SNF and RW for units under operation, in order to identify risks when facing decommissioning. The risks highlighted are driven by key parameters (as duration of the main dismantling actions) of the estimates which can be adapted to minimize their impact. On this basis, it is possible to identify the key-factors to dismantle each unit of NPPs and phase out the fleet regarding SNF and RW management. It is noteworthy that this work needs to be done in any case upstream the studies and the implementation of dismantling actions. Finally it can be underlined that another issue is the human resources (staff, skills and knowledge) necessary to perform all the decommissioning actions, but this aspect is not addressed in the present paper.

INTRODUCTION

About 270 Pressurized Water Reactors (PWR) and 100 Boiled Water Reactors (BWR) have been commissioned in the dozen countries[1] with the largest number of Nuclear Power Plants (NPP) worldwide (references [1] to [5]). Among these 370 LWR units, more than 70% of them have been commissioned in the 70's, 80's and 90's. So, a large part of these units are already in operation for 30 to 40 years. Extension of the operating life of the units or their permanent shutdown is an issue that falls first to the operators, but also to the state authorities and the governments, which also interests people. In view of a permanent shutdown of these LWR units at a similar rate to that of their commissioning, some specific industrial difficulties may arise if dismantling of numerous LWR units has to be done simultaneously. Indeed, such a situation addresses the issue of the overall management of large quantities of SNF and decommissioning waste for the concerned units.

For example, in France, the legislative and regulatory framework for the nuclear facilities favors their dismantling "as soon as possible" after their permanent shutdown which implies as well to limit the duration of the transition period from operation to decommissioning. Furthermore 58 PWR units have been commissioned between 1977 and 1999 in France – on average more than 2 units per year. In this context, the operator (EDF) plans to remove quickly the SNF then to perform dismantling actions immediately after the permanent shutdown of the PWR units. One issue is to remove the SNF from all the relevant units, even if this removal is simultaneous in many units (permanently shut down or still under operation). Similar issue has to be taken into account regarding the management of the RW produced by the dismantling and clean-up actions, notably the RW that cannot be disposed of in a near surface repository.

One method followed by the French technical support organization (IRSN) to analyze these issues is the use of estimates of flows of SNF and RW allowing comparisons. These estimates are based notably on a phasing-scenario and a planning template defined for the dismantling of the units of one NPP and coupled to an overall schedule for phase out all the units of the fleet. This method is described later in the paper and, to be more comprehensive, a dedicated illustration has been built. In this illustration (case study), a situation of a "dummy" country is considered, where a fleet of 32 LWR units are under operation and located over 10 sites named A to J (2 or 4 units per site). To simplify the estimates of SNF and RW flows, only one kind of reactors has been hold: twinned pairs of 900 eMW PWR units (3 loops Westinghouse's / Framatome's design, described in the documents [6] and [7]). For the same reason, it is supposed that all the 32 units have been commissioned within 10 years, between the late 70's and late 80's. Additional information about the fleet of PWR units is given in TABLE I.

[1] : Canada, China, France, Germany, India, Japan, Russia, South-Korea, Spain, Sweden, Ukraine, United-Kingdom and United-States of America.

TABLE I. Information concerning the fleet of twinned pairs of 900 eMW PWR units

Type[a]	Commissioning years	Number in operation	Sites of units	Units designation[b]
0	Late 70's / Early 80's	5	A, B & C	[A-1, A-2], [B-1, B-2], [B-3, B-4], [C-1, C-2] & [C-3, C-4]
1	Early / Mid 80's	6	D, E, F & G	[D-1, D-2], [D-3, D-4], [E-1, E-2], [F-1, F-2], [F-3, F-4], & [G-1, G-2]
2	Mid / Late 80's	5	H, I & J	[H-1, H-2] [I-1, I-2], [I-3, I-4], [J-1, J-2] & [J-3, J-4]

a: design evolution to improve operation and safety.
b: [X-i, X-i_{+1}], twinned pair of 900 eMW PWR units No. i and i_{+1}, located on site X.

EXPERIENCE FEEDBACK FROM ENTIRE DISMANTLING OF ONE PWR UNIT

Currently, worldwide, 6 PWR units[2] with a power exceeding 100 eMW have been completely decommissioned until the termination of their authorization, all operated in United States of America (USA). The experience feedback from the SNF removal, primary circuit loops (PCL) rinsing, dismantling and clean-up actions and RW management of these PWR units is consigned, for example, in the EPRI's reports [8] to [13]. General lessons may be learned or observed from this experience feedback, these are notably:

- the dismantling actions started immediately or a few years later after the permanent shutdown of the units;
- among the first operations performed, there is often the PCL rinsing;
- the dismantling actions of the PCL equipment, reactor vessel and its internals were implemented over a period less than or equal to 5 years;
- the reactor vessel internals mostly were cut under water;
- the reactor vessel and its closure head mostly were removed whole;
- all the dismantling and clean-up actions were implemented over a period less than 15 years, site remediation and buildings demolition included;
- the SNF and intermediate level-long lived (IL-LL) RW transfer from the storage pool of the PWR unit to the dry storage facility built and commissioned on the same site, may sometime last almost as long than the decommissioning stage;
- at the end of decommissioning, no further building of the PWR unit (or other superstructure) remains on the site.

These items are taken into account in the present paper to define a "generic" phasing-scenario and its planning template for the decommissioning of the LWR units of one NPP. These phasing-scenario and planning template are used to

[2] : Connecticut Yankee (560 eMW), Maine Yankee (860 eMW), Rancho Seco (873 eMW), San Onofre 1 (436 eMW), Trojan (1 095 eMW) and Yankee Rowe (167 eMW).

estimate the annual flows of SNF and RW during the transition, dismantling and clean-up actions of several LWR units of different NPPs.

GENERIC PHASING-SCENARIO AND PLANNING TEMPLATE FOR NPP DECOMMISSIONING

The generic phasing-scenario and planning template for the decommissioning of the LWR units of one NPP are based on assumptions which are defined to be consistent with the national context (LWR units operated, legislative and regulatory framework…). So, some assumptions of the present paper take into account the peculiarities of the French context, as the national strategy of a dismantling as soon as possible after the permanent shutdown of a facility and also some EDF's considerations, but can be modified as needs. These assumptions are the following:

- the permanent shutdowns of the NPP's units are shifted against each other and for each LWR unit, the unloading of the last SNF core from the reactor vessel to the storage pool is performed immediately upon the permanent shutdown of the concerned unit;
- during the transition period and for each LWR unit, the SNF removal from the storage pool of the fuel storage building (FSB) is performed in a few years, the removal of the operational IL-LL RW and the PCL rinsing too;
- the turbine hall (TH) of the first LWR unit permanently shut down on a site is refurbished to manage RW from decommissioning actions of all the NPP's units and the other THs are decommissioned in the same time than the nuclear buildings;
- the dismantling actions of the main systems are performed successively in each LWR unit;
- in the reactor building (RB), the dismantling actions phasing distinguishes the reactor vessel with its head and its internals, the PCL equipment and the other equipment located in the RB;
- the dismantling actions of the reactor vessel and its internals are based on their cutting under water;
- the dismantling actions in the other nuclear buildings are performed in the same time than those in the RB;
- the clean-up actions are performed in the working areas of a nuclear building after completion of the dismantling actions (removal of all equipment) in this building;
- the superstructure of each building is demolish after completion of the dismantling and clean-up actions.

As indicated above, to illustrate the method, a case study has been built based on a fleet of 16 twinned pairs of 900 eMW PWR units in 10 NPPs, each NPP having 1 or 2 twinned pairs. Compared to the previous assumptions, the gap between the permanent shutdowns of the NPP's PWR units is fixed identical and equal to 2 years (smoothing of the SNF and operational IL-LL RW removal), the duration of the SNF and operational IL-LL RW removal, identical and equal to 3 years for each PWR unit. The durations of the dismantling actions are fixed identical for each PWR unit. They are equal to 3 years for the reactor vessel and its internals, and to 2 years for the

PCL equipment. The durations of the other dismantling, clean-up and conventional demolition actions, as well as their phasing, are shown on the Figure 1 (NPP with 2 PWR units type 0, 1 or 2) and on the Figure 2 (NPP with 4 PWR units type 0, 1 or 2). Concerning the phasing between the dismantling actions of the vessel and its internal, those of the PCL equipment and those of the other equipment located in the RB, "basic phasing" and "alternative phasing" are considered, as defined on Figure 3. Compared to the previous items, it must be underlined the main assumption which consists for one NPP (with 2 or 4 PWR units), to limit to approximately 20 years the duration of the dismantling, the clean-up and the conventional demolition actions performed in all its PWR units.

However, to estimate the annual flows of SNF and RW at the scale of an entire fleet of LWR units, it may be difficult to use the phasing-scenario and planning template defined for a NPP. For a large fleet (dozens of LWR units), "simplified" phasing-scenario and planning template are considered, built on the basis of the entire phasing-scenario and planning template relative to one NPP and where each LWR unit is treated as a single entity and not as a set of several buildings. The simplified phasing-scenario and planning template may be used depending on the accuracy of the estimates of RW flows (for example, main categories of RW, without consideration on their nature and detailed pre-disposal management solution). For the case study, simplified phasing-scenario and planning template have been used to estimate the RW flows (excepted for the IL-LL RW); these are shown on the Figure 1 (NPP with 2 PWR units) and on the Figure 2 (NPP with 4 PWR units). The average annual flows are calculated for one LWR unit, by dividing the total amount of SNF and those of different categories of RW by the duration of their phase of removal or production. Then, all units flows are added at the scale of the fleet and the contribution of the decommissioned LWR units to the total flow may be analyzed. To do that, it is necessary, if it does not exist, to define before an overall schedule concerning the phase out of all the LWR units of the fleet.

OVERALL SCHEDULE FOR PHASE OUT ALL THE LWR UNITS OF THE FLEET

The permanent shutdown of one LWR unit may be a decision taken by the operator, for technical and/or economic reasons, but also a decision imposed by the local or national political authorities. The phase out of all the NPPs units operated in a country is a decision that seems more political, although economic and technical factors are taken into account. So, an overall schedule for phase out all the LWR units of the fleet is something which in practice never exists. Nevertheless, it seems necessary to perform such analysis of the SNF and RW flows in the next decades.

In this context, alternative assumptions may be used to build a theoretical and realistic overall schedule to phase out all the LWR units of the fleet. Meanwhile, a continuity of the nuclear power generation, by the commissioning of new reactors, also has to be taken into account. For that, alternative assumptions may be used too. Finally, the use of a set of alternative assumptions allows assessing the influence of the alternatives on the total flows of SNF and RW (sensitivity study).

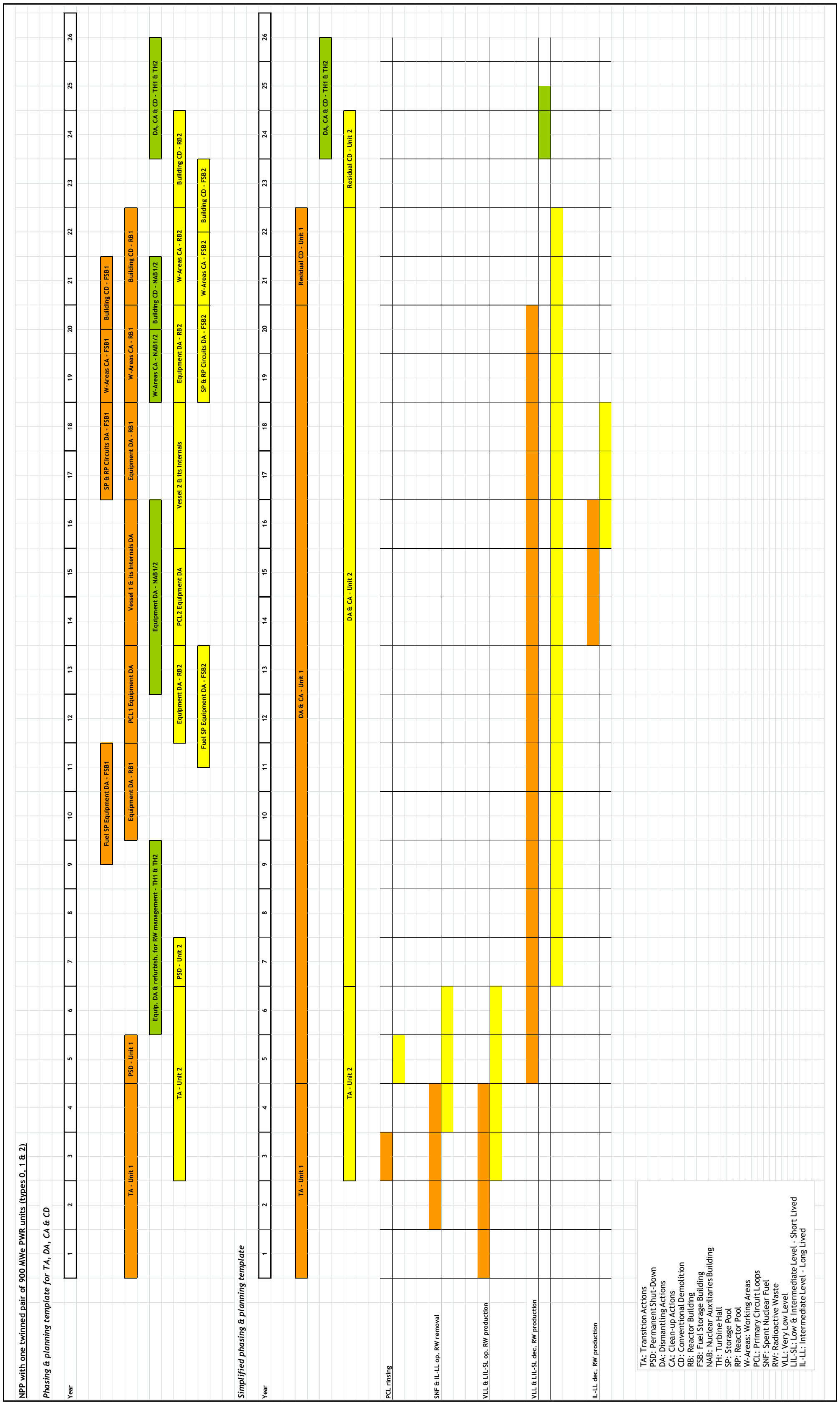

Figure 1. Decommissioning of a NPP with 1 twinned pair of 900 eMW PWR units (all types)

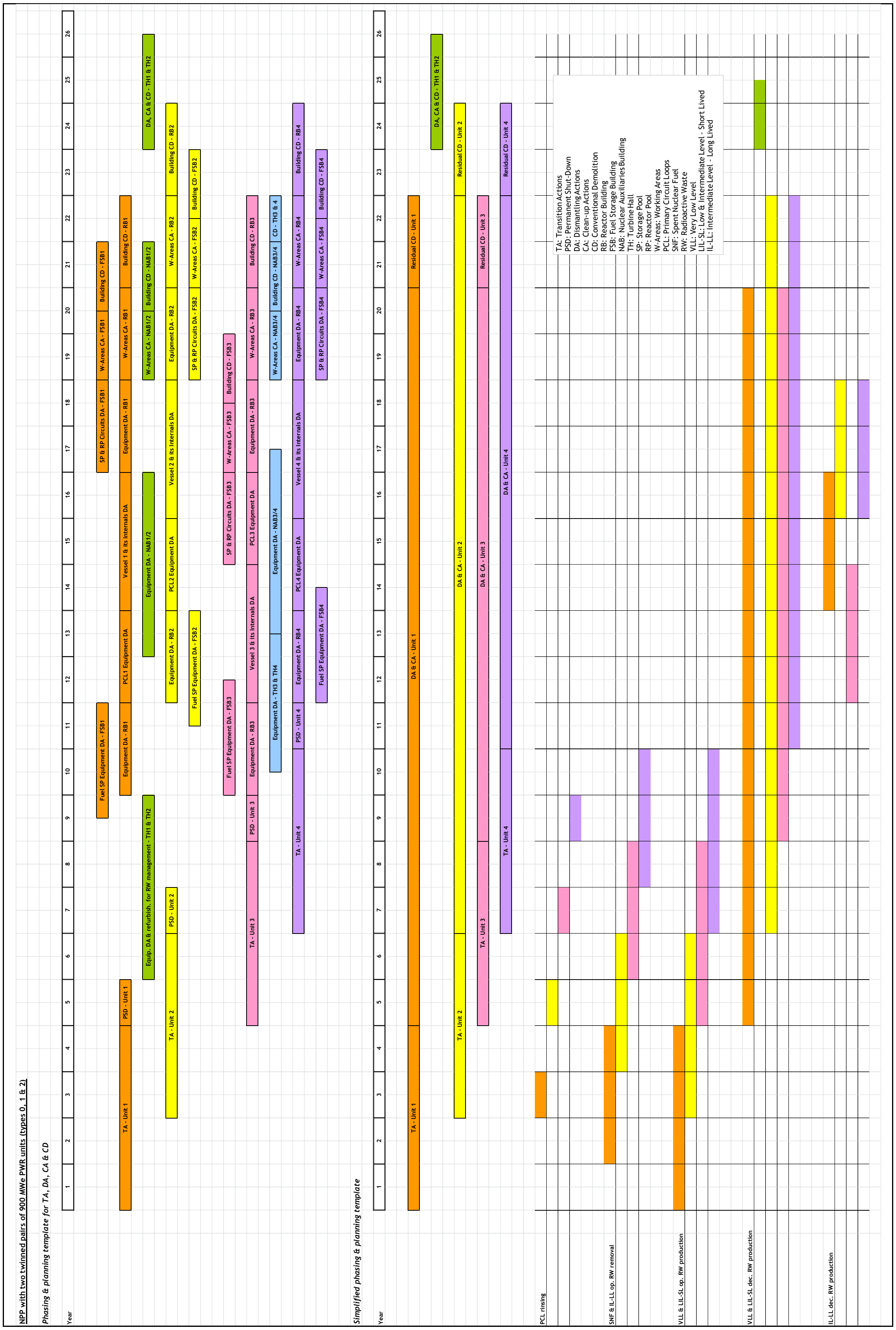

Figure 2. Decommissioning of a NPP with 2 twinned pairs of 900 eMW PWR units (all types)

Figure 3. Phasing of dismantling actions in the RB and FSB (all NPP's units)

For the case study, the alternatives assumptions use to define the phase out of all the PWR units of the fleet are the following:

- the operating life of each of the 32 PWR units is similar and is approximately equal to 50 years;

OR

- the operating life of each of the 32 PWR units depends on its type and is approximately equal to 40, 50 and 60 years respectively for the types 0, 1 and 2.

The previous values, assumed for the operating life of each 900 eMW PWR unit, are considered realistic. In the second assumption, the link between the operating life of a PWR unit and its type is supposed reflect a possible extension of this operating life upon technical and economic considerations, according to the upgrading of the initial design from one type to the following.

Then, the alternative assumptions are coupled with the simplified phasing-scenario and planning template for the decommissioning of the PWR units of one NPP. On this basis, the assumptions relative to the operating live of the PWR units govern the year of the permanent shutdown of the first unit of the NPP and for the over NPP's units, their years of permanent shutdown are given by the simplified phasing-scenario and planning template (gap of 2 years from one unit to the following). The assumption of a similar operating life, approximately equal to 50 years for each PWR unit, leads to the overall schedule to phase out all units of the fleet shown on the Figure 4, called "homogeneous overall schedule". The alternative assumption, operating life of the PWR unit approximately equal to 40, 50 or 60 years depending on its type, leads to another overall schedule to phase out all units of the fleet, shown on the Figure 5 and called "heterogeneous overall schedule".

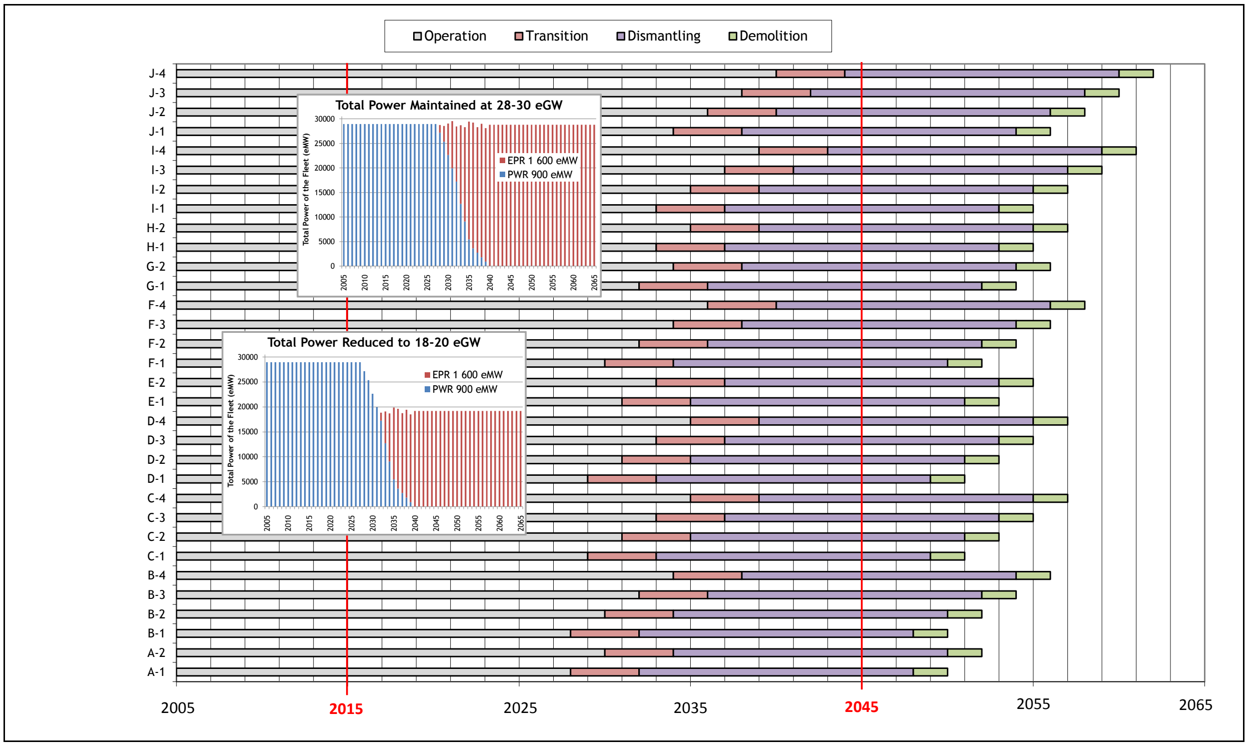

Figure 4. Homogeneous schedule to phase out the fleet of 900 eMW PWR units
(& corresponding commissioning of EPR units to maintain or reduce the total nuclear power)

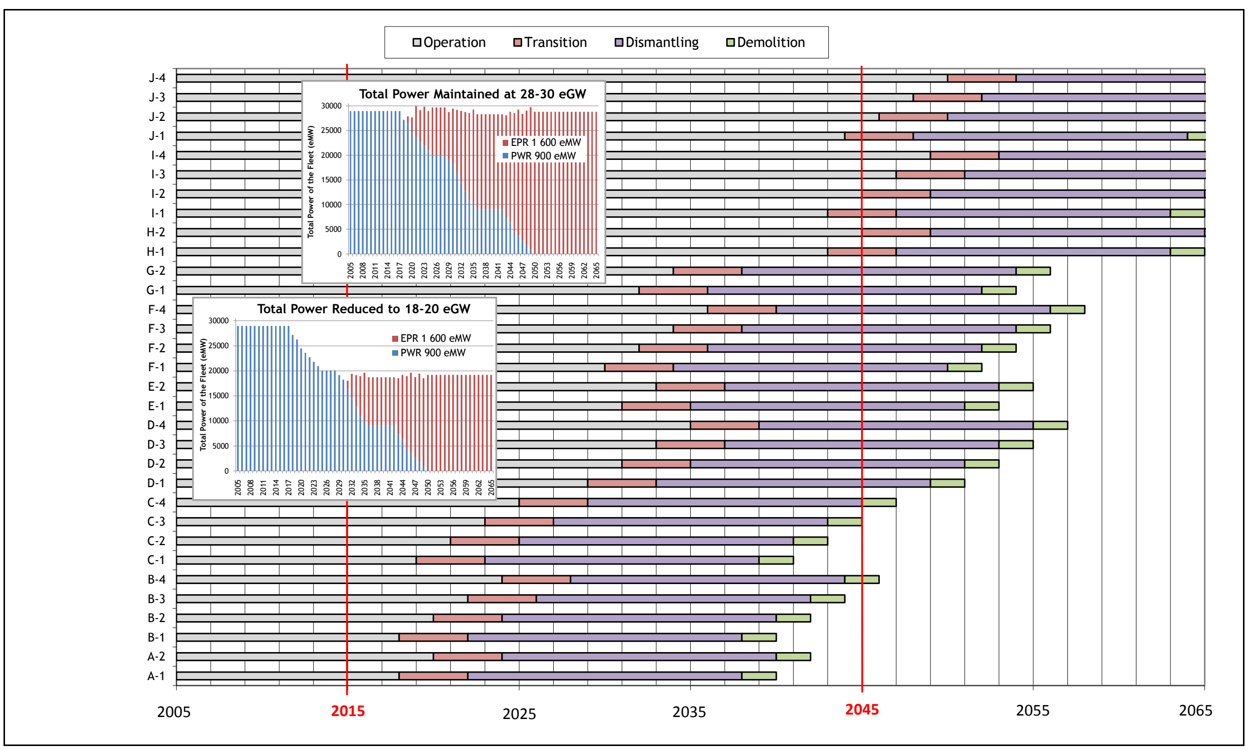

Figure 5. Heterogeneous schedule to phase out the fleet of 900 eMW PWR units
(& corresponding commissioning of EPR units to maintain or reduce the total nuclear power)

In each alternative schedule to phase out all the PWR units of the fleet, an equal period of 5 decades (2015 – 2065) is taken into account. Such a long period is used for calculation, but to look at the results and analyze main lessons, it may be more relevant to consider a shorter period (first 2 or 3 decades).

As indicated above, to assess the total flows of SNF and RW, the continuity of the nuclear power generation has also to be considered (by the increase, the maintaining or the reduction of the total installed nuclear power). Such continuity supposes that a sufficient number of new reactors have to be commissioned in parallel that reactors of the current fleet are permanently shut down. For the case study, two alternative assumptions are used to quantify the continuity of the nuclear power generation and all the new reactors commissioned are 1 600 eMW PWR units (EPR type, AREVA's design, described in the document [14]). So, the alternative assumptions are the following:

- the total installed nuclear power of the country is maintained at 28-30 eGW (by the gradual commissioning of 18 new EPR units, not before 2019);

OR

- the total installed nuclear power of the country is progressively reduced at 18-20 eGW then maintained at this level (by the gradual commissioning of 12 new EPR units, not before 2031).

Finally, the total flows of SNF and RW have three main contributors: the PWR units of the current fleet still in operation, the PWR units of the current fleet permanently shut down then dismantled and the new EPR units commissioned (Figure 4 and Figure 5). For the EPR units, their operating life is supposed equal to 60 years. So, the permanent shutdown and the dismantling of the EPR units (later than 2065) have not to be taken into account.

ANNUAL FLOW OF REMOVED SNF

Method and additional assumptions

The total annual flow of SNF depends on the SNF quantities removed each year from each LWR unit in operation (current fleet and new LWR units) and from each LWR unit permanently shut down (during the transition period). To estimate this flow, additional information and assumptions are needed, relative to the operation of the LWR units, the irradiation of their nuclear fuel (core management) and the SNF quantity stored in the pool when the LWR units are permanently shut down. More accurately, for each LWR unit, the additional assumptions concern:

- the coefficient of productivity;
- the SNF quantity definitively unloaded each year from the core and those annually removed from the storage pool;
- the core management evolutions and the facility modifications during the operating period;
- the total quantity of SNF to remove during the transition period (sum of the SNF amounts of the last core and still in the pool at the permanent shutdown).

For the case study, the additional assumptions used to estimate the total annual flow of SNF are simplified, but considered realistic; they are the following:

- the coefficient of productivity is the same for each PWR unit and equal to 80%;
- the SNF quantity removed each year from the storage pool is equal to those definitively unloaded each year from the core;
- the SNF removal from the storage pools begins the 9th year of operation for the new EPR units;
- the nuclear fuel type and its irradiation cycles, defined for the PWR units of the current fleet and for the new EPR units, are those shown in the TABLE II;
- the core management and the facilities (equipment and buildings) are identical until the permanent shutdown;
- the total quantity of SNF to remove during the transition period of a permanently shut down PWR unit is those shown in the TABLE III.

TABLE II. Core management of the PWR units

Kind of reactor	**Nuclear fuel type and irradiation cycle characteristics**	**Quantity of SNF removed (t_{ihm}/y)**
900 eMW PWR unit (types 0, 1 and 2)	natural U oxide enriched in U-235 at 4,00% 0,460 t_{ihm} per fuel assembly 52 new fuel assemblies per irradiation cycle (1/3 core) 394 equivalent days of irradiation at full power per cycle average burn-up of 45 GWd/t_{ihm} at the definitive unloading	17,7
1 600 eMW PWR unit (EPR type)	natural U oxide enriched in U-235 at 4,50% 0,529 t_{ihm} per fuel assembly 61 new fuel assemblies per irradiation cycle (1/4 core) 392 equivalent days of irradiation at full power per cycle average burn-up of 55 GWd/t_{ihm} at the definitive unloading	24,0
t_{ihm}/y: tone of initial heavy metal per year *GWd/t_{ihm}: gigawatt day per t_{ihm}*		

TABLE III. SNF amount to remove after the permanent shutdown of a PWR unit

Type of 900 eMW PWR unit	**SNF of the last core (t_{ihm})**	**SNF stored in the FSB's pool at the permanent shutdown of the unit (t_{ihm})**	**Total SNF in the unit at its permanent shutdown (t_{ihm})**
Type 0	72,2	48,1	120,3
Type 1 and 2	72,2	72,2	144,4

Results of the estimate

After completion of the estimate of the total annual SNF flow over the next decades, the possible impact of the permanently shut down LWR units can be analyzed. Notably, the total annual SNF flow when all the LWR units of the fleet are operated can be compared to that when a part of the LWR units are permanently shut down (SNF removal during the transition period). In the situation where the total annual SNF flow increases, it may be necessary to anticipate. Various solutions are then possible. For example, the duration of the transition period may be extended or the removal of all the SNF stored in the FSB's pool may be performed before the permanent shutdown of the considered LWR units. Another way may be adapting the SNF management strategy to take into account the increase of the total annual flow of SNF. In consequence, it could be necessary to design, build and commission in timely manner needed independent SNF storage facilities and also, if required, casks to transport the SNF from NPPs to these storage facilities.

For the case study, the total annual SNF flows calculated are shown on Figure 6. Regardless of the overall schedule considered to phase out the fleet of 900 eMW PWR units and the total nuclear power considered for the country, the SNF flow increases for several consecutive years comparatively to that when no unit of the fleet is permanently shut down (566 t_{ihm}/y). For the heterogeneous overall schedule to phase out the fleet, the SNF flow increases up to +15% for a few years firstly around 2020 and secondly around 2030. For the homogeneous overall schedule, this increase reaches up to +23% for a few years around 2030 only. Whatever is the considered case, such variations of the SNF flows have to be analyzed to set out the SNF management strategy for the next decades so that the transition actions of PWR units permanently shut down are not unduly disrupted.

ANNUAL FLOWS OF PRODUCED RW

Method and additional assumptions

The total annual flows of RW depend on the RW quantities produced each year by each LWR unit in operation (current fleet and new LWR units) and from each LWR units permanently shut down (during the decommissioning period). To estimate these flows, additional information and assumptions are needed, relative to the RW produced by the LWR units in operation, the physical inventory of the facilities, the activation and contamination of the equipment and in the working areas. More accurately, for each LWR unit, the additional assumptions concern:

- the flows of operating RW, which may be defined on the basis of information taken from the operating experience feedback;
- the amounts of the activated dismantling RW, which may be estimated on the basis of neutron transport and materials activation calculations;
- the amount of the contaminated equipment and those of corresponding dismantling RW, which may be defined on the basis of the physical inventory and information taken from the operating and decommissioning experience feedback;
- the contaminated working areas and the amounts of corresponding dismantling and clean-up RW, which may be defined on the basis of the physical inventory and information taken from the operating and decommissioning experience feedback.

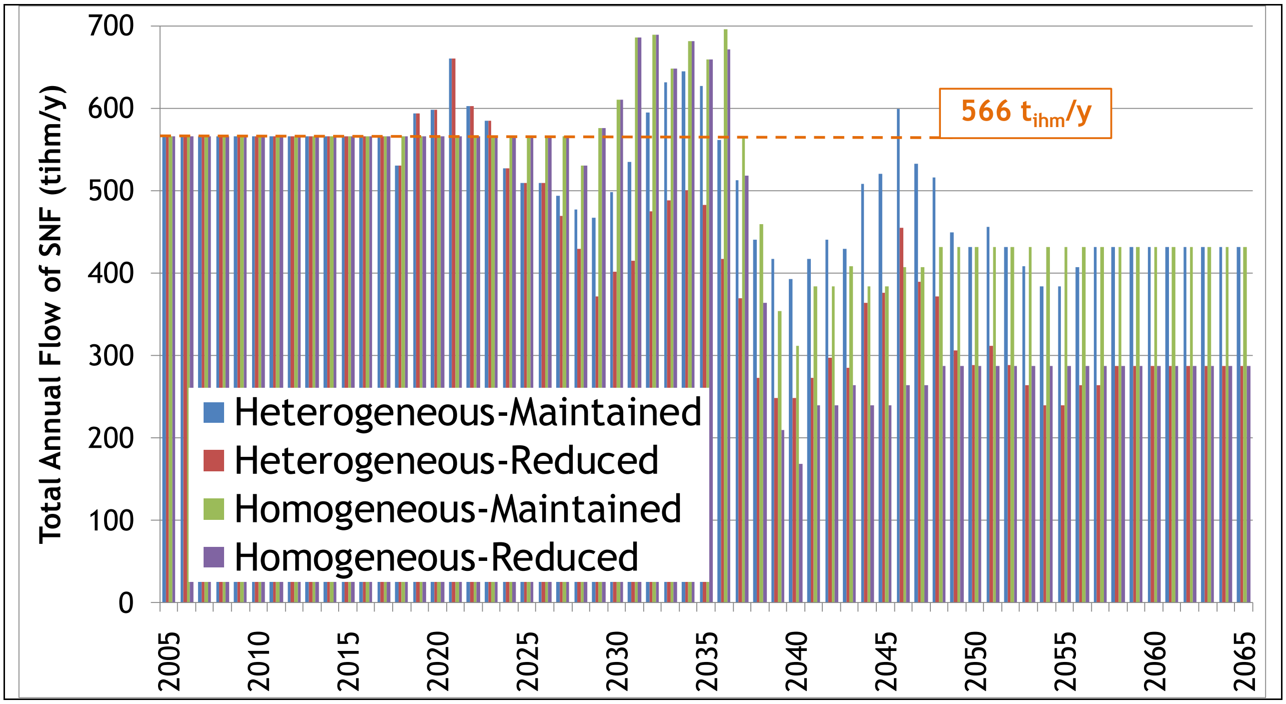

Figure 6. Total annual flows of SNF for the alternative assumptions

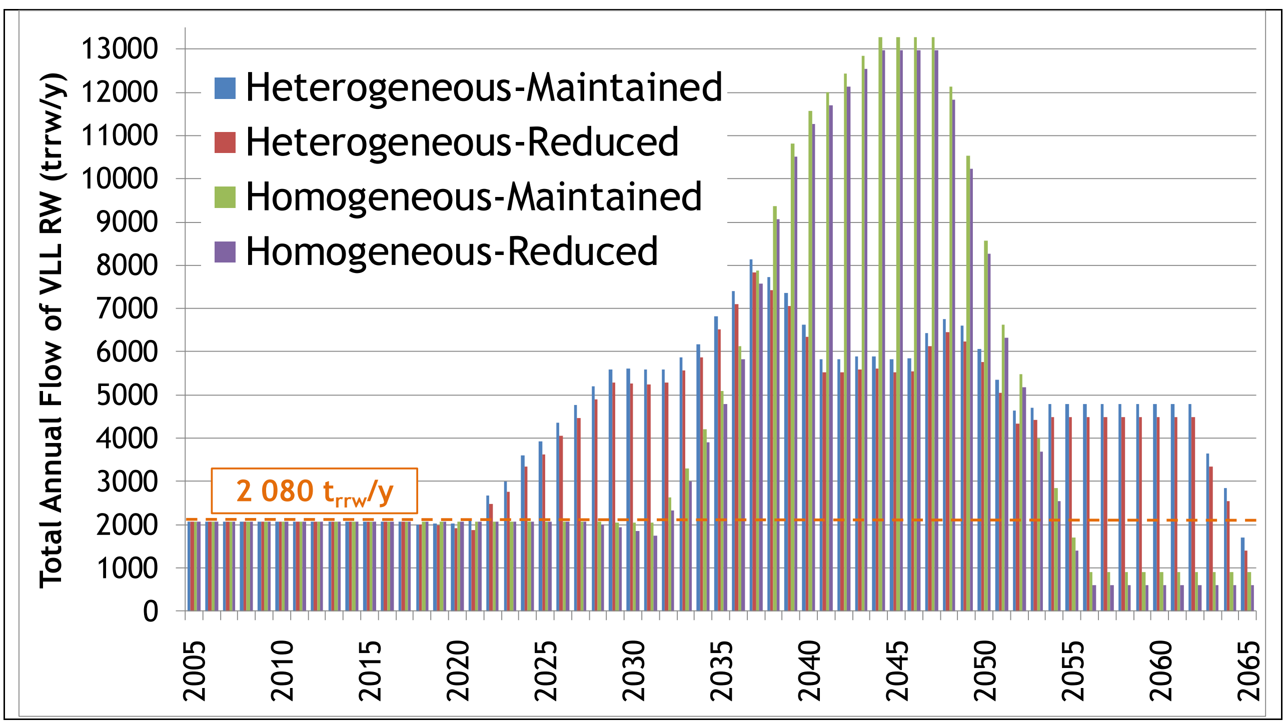

Figure 7. Total annual flows of VLL RW for the alternative assumptions

As indicated previously, for the decommissioning RW, the average annual flows are calculated for one LWR unit, by dividing the total RW amounts by the duration of their phases of production. For the case study, only the different RW categories are taken into account (using of simplified phasing-scenario and planning template relative to the decommissioning of one NPP). Nevertheless, some additional assumptions are required to estimate the total annual flow of RW; they are the following:

- the flows of operating RW are identic for each PWR unit and based on operating experience feedback notably detailed in reference [16];
- the operating IL-LL RW (control rods, absorbent bundles…) are stored in the FSB's pool until the PWR unit is permanently shut down;
- the flows of operating LIL-SL and VLL RW during the transition period are supposed the half of those when the PWR unit is operated;
- the amounts of the activated RW are identic for each decommissioned PWR unit and estimated on the basis of neutron transport and materials activation calculations detailed in EPRI's report [15];
- the amounts of contaminated equipment are identic for each decommissioned PWR unit and match to the vessel, its head and its internals, also the PCL equipment, the auxiliary and emergency circuits and the ventilation equipment; their spread in the categories of dismantling RW are defined accordingly to information taken from the operating and decommissioning experience feedback notably detailed in reference [16];
- the working areas are supposed all contaminated in each decommissioned PWR unit; the corresponding amounts of dismantling and clean-up RW are defined and spread in each RW category accordingly to information taken from the operating and decommissioning experience feedback notably detailed in reference [16].

Finally, on the basis of the previous items coupled with the physical inventory of one 900 eMW PWR unit extract from documents [6], [7], [17] and [18], the amounts of RW generated during operating and decommissioning are those shown in TABLE IV, estimated for each category.

TABLE IV. Amounts of operating and decommissioning RW

RW category	**RW amount produced annually by a 900 eMW PWR unit in operation (t_{rrw}/y)**	**Total amount of RW produced by the dismantling of a 900 eMW PWR unit (t_{rrw})**	**RW amount produced annually by an EPR unit in operation (t_{rrw}/y)**
IL-LL	0,4 to 0,5 (stored in the FSB)	50	(not considered)
LIL-SL	130 (65 during TA)	2 500	100
VLL	65 (32,5 during TA)	5 500	50

IL-LL RW: 10^6 Bq/g < specific radioactivity < 10^9 Bq/g
LIL-SL RW: 10^2 Bq/g < specific radioactivity < 10^6 bq/g
VLL RW: specific activity < 10^2 Bq/g
t_{rrw}: tone of raw radioactive waste
TA: transition actions

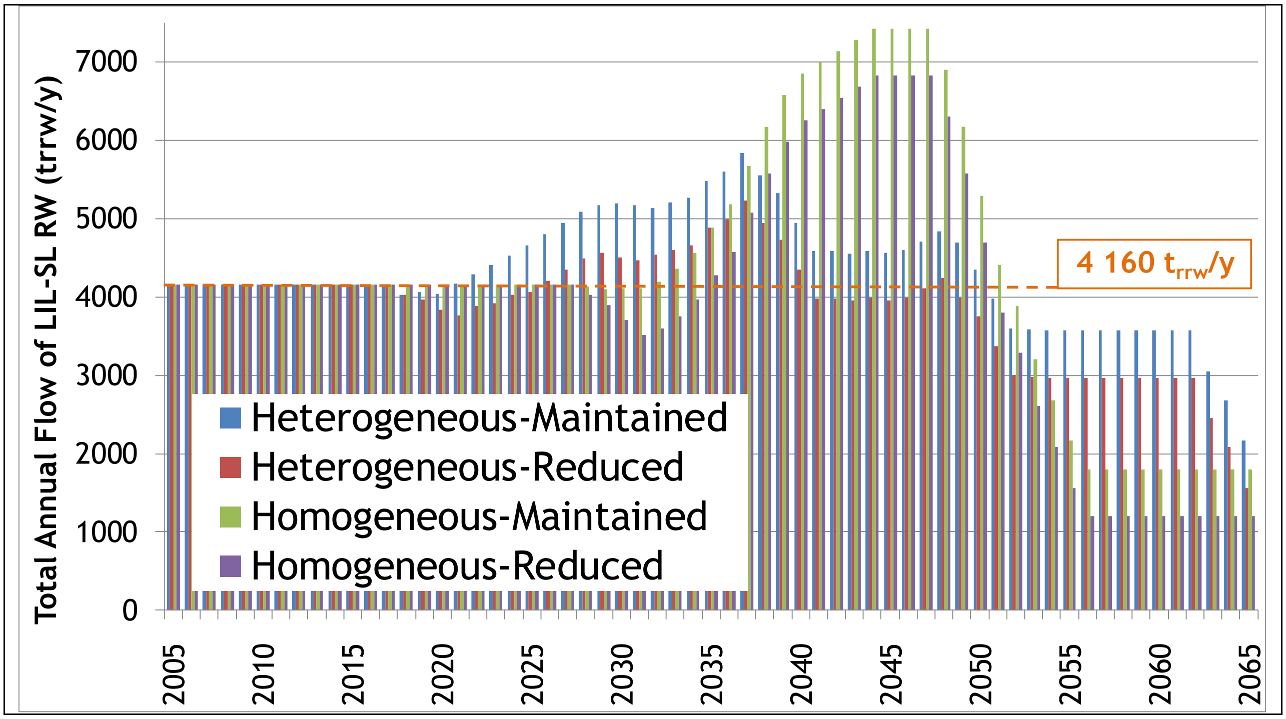

Figure 8. Total annual flows of ILL-SL RW for the alternative assumptions

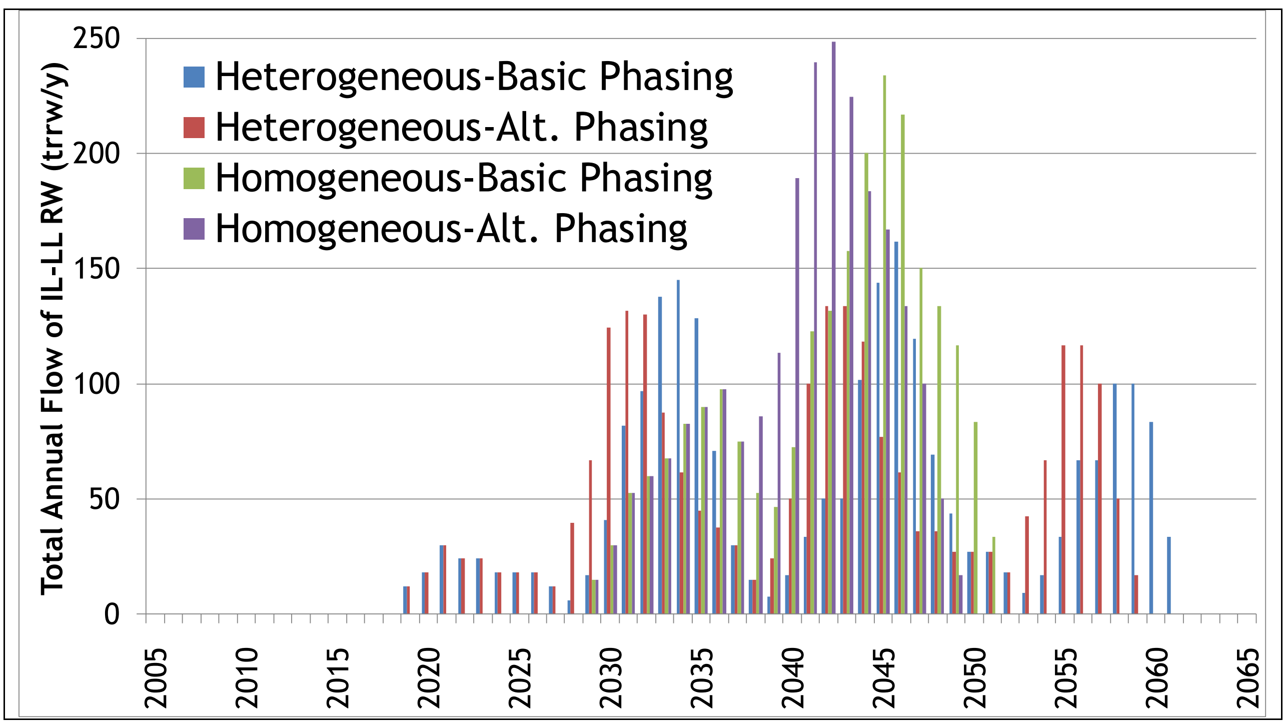

Figure 9. Total annual flows of IL-LL RW for the alternative assumptions

Results of the estimate

After completion of the estimate of the total annual RW flows over the next decades, the possible impact of the permanently shut down LWR units can be analyzed. Notably, the total annual RW flows when all the LWR units of the fleet are operated can be compared to those when a part of the LWR units are permanently shut down (RW production during the decommissioning period). If the total annual flow increases for some kinds (metal, concrete…) or categories of RW, it could be necessary to anticipate this notably to avoid any accumulation of RW within the buildings of the decommissioned LWR units. Various solutions are then possible. For example, the duration of the dismantling and clean-up actions may be extended for some LWR or these actions may be further shifted from one LWR unit to another. Another way may be adapting the RW management strategy to take into account the increase of some total annual RW flows. As a matter of fact, it could be necessary to design, build and commission in a timely manner needed RW storage facilities on the NPPs sites and, if required, adapt the means to transport from NPPs, to process, to store elsewhere then to dispose of these RW.

For the case study, the total annual flows calculated are shown on Figure 7 (VVL RW), Figure 8 (ILL-SL RW) and Figure 9 (IL-LL RW). For the VLL RW, their flow, in comparison with the situation where all 900 eMW PWR units were under operation (2 080 t_{rrw}/y), increases by a factor 2 to 6 over 2 to 3 decades after 2025 or 2035, essentially according to the overall schedule considered to phase out the fleet. For the ILL-SL RW, their flow, comparatively to that when no 900 eMW PWR unit is permanently shut down (4 160 t_{rrw}/y), increases between +10% and +60% over 2 to 3 decades after 2025 or 2035, according to, first, the overall schedule considered to phase out the fleet, second, the total nuclear power considered for the country. Concerning the IL-LL RW, their flow rises up to 150 t_{rrw}/y over 4 decades and after 2018 for the heterogeneous overall schedule, up to 250 t_{rrw}/y over 2 decades and after 2028 for the homogeneous overall schedule. Whatever is the considered case, such RW flows have to be analyzed to set out the RW management strategy for the next decades so that the decommissioning actions of PWR units permanently shut down are not unduly disrupted.

CONCLUSION

The management of numerous LWR units permanently shut down in parallel with those which may be still under operation needs to address some key issues. The simultaneously removal of the SNF and management of all the RW generated by the related decommissioning actions can be analyzed by considering the estimates of SNF and RW flows, in particular for the radioactive waste that cannot be disposed of in a near surface repository. These estimates are notably based on a phasing-scenario and a planning template defined for the decommissioning of the LWR units of one NPP and coupled to an overall schedule for phase out all the LWR units of the fleet. They are relative to the next decades and can be compared to the current experience feedback of flows of SNF and RW for units under operation, in order to identify risks when facing decommissioning. The risks highlighting are driven by key parameters (as duration of the main dismantling actions) of the estimates which can be adapted to minimize their impact. On this basis, it is possible to identify the key-factors to dismantle each unit of NPPs and phase out the fleet regarding SNF and RW management. It is noteworthy that this work needs to be done in any case upstream the studies and the implementation of dismantling actions. Nevertheless, the question of "who should do that?" arises, especially in countries having many operators. In addition, it can be underlined that another issue is the human resources (staff, skills and knowledge) necessary to perform all the decommissioning actions, but this aspect is not addressed in the present paper.

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