SCENARIO DEVELOPMENT AND EVALUATION FOR THE NPP KRŠKO REVISED DECOMMISSIONING PROGRAM

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ABSTRACT

In this first revision, several integrated scenarios of the NPP Krško dismantling and waste management were developed and analyzed in order to estimate the decommissioning program (DP) costs and to propose an appropriate funding plan. Most dismantling technologies and cost estimates were derived from the original decommissioning plan adopted in 1996. The LILW disposal cost estimates, however, rely on the tunnel type facility design which was developed in Slovenia a few years ago, whereas the SF repository design for this DP was adapted from the Swedish deep disposal concept.

The starting assumptions for this DP were that the LILW repository would be licensed by 2013, the NPP would be permanently shut down in 2023, and the SF repository would become available in 2030. The boundary conditions also specified that DP should first re-evaluate the SID strategy from the original plan ("Strategy Immediate Dismantling" with immediate SF disposal, but also with a long period of on-site decay storage for the activated components, so that it actually terminates only after 96 years), and then modify it to achieve truly prompt decommissioning in which all planned activities should be completed within about 15 years after the NPP shut-down. In addition, the option of SF export to a third country should be introduced in all DP scenarios, as a realistic alternative to SF disposal into the local repository (in Slovenia or in Croatia). And finally, dry storage of SF for some 30 years before disposal or export, in an independent installation on unspecified location, should be evaluated within the DP sensitivity analysis.

After a thorough analysis of the original SID strategy, it became clear that substantial modifications would be necessary in order to meet the boundary conditions while complying with the specified design and technologies of the assumed LILW and SF disposal facilities. Therefore, a systematic procedure for development and financial evaluation of feasible scenarios was adopted. The procedure relies on an integrated scenario timetable, in which decisive DP activities are charted side by side, together with the schedule of their annual expenses which will be used as input for the subsequent discounting and cash flow calculations. This finally led to three groups of scenarios consistent with the boundary conditions: (1) SID-96 scenarios (the required re-evaluation of the original SID strategy); (2) SID-15 scenarios in which all DP activities would be completed in 15 years or less; and (3) SID scenarios with dry storage of SF.

The cash flow calculations demonstrated that the SF dry storage scenarios have the lowest discounted costs. Also, they provide the greatest confidence in timely realization of the SF disposal or export plans. In addition to a pair of 30-year dry storage scenarios (with the SF disposal or export), an option of 45-year SF storage was also introduced. Actually, the SID-30 and SID-45 scenarios can be viewed only as limiting cases of an entire range of the intermediate SF dry storage options. Therefore, the decision on the DP funding can reasonably be based upon the SID-45 cost estimates, possibly rounded upwards to an amount which would encompass some of the shorter variants too.

1 INRODUCTION

Among the initial steps in implementation of the recently adopted Slovenian-Croatian agreement on the jointly owned nuclear power plant in Krško, Slovenia, the first revision of the NPP decommissioning plan was undertaken by a joint project team in the summer of 2003 and completed in February 2004. The requirements on this revision were:

(a) to develop and analyze feasible scenarios of decommissioning program (DP) which should integrate both dismantling of the NPP and management of all its RW and SF, including disposal; and

(b) to estimate DP costs and propose a conservative funding plan based on the most favorable integral decommissioning scenario.

After analysis of the previous preparations for the NPP Krško decommissioning plan revision [1,2] and of the other project specifications, the following general approach was adopted:

1. Due to time constraints in this DP preparation, the schedules, technologies and cost estimates for the NPP dismantling were to rely, as far as practicable, on the original plan from the year 1996.
2. However, more elaborate and site specific projects should be developed or adopted for RW and SF disposal, and incorporated into the integral DP scenarios.

2 THE FORMER DECOMMISSIONING PLAN AND THE NEW CIRCUMSTANCES

The first NPP Krško decommissioning plan was based on a study prepared during 1995-96 by a German company with considerable experience in the field, NIS Ingenieurgesellschaft mbH [3]. The NIS study introduced a special scenario named SID (Strategy Immediate Dismantling), in which dismantling activities would generally be completed within 14 years after the NPP shut-down in 2023, but the reactor pressure vessel and its internals, together with the main components of the primary circuit, would remain on-site in a decay storage for some 80 years more, in order to reach free release levels. One of the reasons the NIS study gave for selecting SID strategy (over the options of deferred dismantling and entombment) was its inherent flexibility to reduce or entirely eliminate the decay storage period.

Whereas it had analyzed dismantling activities in full detail, the NIS study made only lump sum estimates of RW and SF disposal costs, assuming that a near surface repository for LILW and a deep geological repository for SF would both be available at the beginning of the NPP post-operational period in 2023.

In the present revision, however, DP is based on much more specific disposal projects. Both in Slovenia and in Croatia, two types of near surface LILW repository concepts, the surface vault and the subsurface tunnel, have been explored for more than a decade. The LILW disposal cost estimates for this DP rely on the tunnel type facility design which was developed in Slovenia a few years ago [4], and was selected for this program as a more conservative option than surface vault.

No specific disposal concepts for the NPP Krško spent fuel had been previously considered, so the first SF repository conceptual design was developed within this DP project. It was adapted from the Swedish deep disposal concept, which was selected as best suited to the Slovenian/Croatian geological environment. The repository design and disposal technology were found to have a significant impact on DP scenarios.

The starting assumptions for this DP, specified in the form of boundary conditions, were that the LILW repository (one facility for all NPP waste, either in Slovenia or in Croatia) would be licensed by 2013, the NPP would be permanently shut down in 2023, and the SF repository would become available in 2030 (again, a single facility at as yet undecided location). The boundary conditions also specified that DP should first re-evaluate the original SID strategy, and then modify it to achieve truly prompt decommissioning in which all planned activities should be completed within about 15 years after the NPP shut-down. In addition, the option of SF export to a third country should be introduced in all DP scenarios, as a realistic alternative to SF disposal into the local repository (in Slovenia or in Croatia). And finally, dry storage of SF for some 30 years before disposal or export, in an independent installation (ISFSI) on unspecified location, should be evaluated within the DP sensitivity analysis.

3 DEVELOPMENT OF INTEGRAL DECOMMISSIONING PROGRAM SCENARIOS

After a thorough analysis of the NIS study concepts and calculations, it became clear that substantial modifications of the original SID strategy would be necessary in order to meet the boundary conditions while complying with the specified design and technologies of the assumed LILW and SF disposal facilities. Therefore, a systematic procedure for development and financial evaluation of feasible scenarios was adopted. The procedure relies on an integrated scenario timetable (Fig. 1), in which all DP components (the NPP dismantling, and the RW and SF management) are charted side by side, together with the schedule of annual expenses (nominal 2002 costs) that will be used as input for the subsequent discounting and cash flow calculations.

As the starting point for all scenarios, the NIS study program was first broken down to several tasks that will be modified or rearranged in the new timetables. Then the new assumptions about SF management were projected into these timetables, indicating (a) the availability of SF disposal and the needs for interim storage or (b) the possibilities for SF export, with or without the interim storage. Based on this analysis it was decided that, as far as possible, parallel scenarios of equal duration would be developed to illustrate the alternative of SF disposal or export, because such approach would be most suitable for costs comparison and would clearly indicate the future date when the choice between the respective options should be made. This finally led to three groups of scenarios consistent with the boundary conditions: (1) SID-96 scenarios (the required re-evaluation of the original SID strategy); (2) SID-15 scenarios in which all DP activities would be completed in 15 years or less; and (3) SID scenarios with dry storage of SF.

3.1 SID-96 scenarios

The original SID scenario starts with an expensive post-operational period in which, for five years after the NPP shut-down in 2023, most systems are maintained operational while the SF is transported from the NPP storage pool directly to the SF repository (loaded in 16 German CASTOR casks which travel back and forth during 39 months). At the beginning of this post-operational period, the last cycle fuel elements were transferred from the reactor to the pool. At its end, the reactor core internals will be cut under water in the empty pool and packed for disposal (in 16 Mosaik containers).

The actual dismantling, which is still under licensing during these operations, will begin only in 2028 and will be completed nine years later. Five years will be spent on removal of the reactor pressure vessel with its internals (RPV) and of the main components of the primary circuit (MC) into the on-site decay storage building, and on dismantling of all other facilities. In the next four years, all buildings will be demolished and site restoration carried out.

MC and RPV remain in the storage building until 2116. Then in the next two years, in the original SID, they are treated for free release or re-use in nuclear industry, and the storage is decommissioned. Total duration of all activities in this scenario thus accumulates to 96 years, so the scenario is referred to as SID-96.

During the NIS study review, many objections were raised to various aspects of the activities proposed, as well as to the transparency of the entire presentation [5]. However, the project specifications and time limitations for this DP did not allow thorough modifications or detailed re-evaluation of the original SID-96 concept. Only one minor modification was immediately accepted for the revised SID-96 scenarios. It was decided that the RPV should be declared as LILW even after the storage period, and disposed into the repository which would anyhow have to be operational at that time in order to accommodate the waste arising from the RPV melting proposed by the original SID. Otherwise, the revised SID-96 scenarios were derived from the original SID with as few modifications as possible. Their costs re-evaluation will be described in the next section, together with the expenses of other scenarios.

3.1.1 SID-96 with export

The assumption of the original SID, that the SF disposal into a local repository will begin in 2023, is incompatible with the Swedish repository concept adopted for this DP. Development of this repository is expected to take 20 years, so it cannot become available in time. More importantly, fuel elements from last

NPP cycles require some time to cool down, so the year 2031 is the earliest date to begin SF disposal in a safe and affordable manner, while still later dates are preferable.[1]

SF repository			SF storage				where is SF?						LILW repository			year	NPP dismantling: main components and reactor vessel							where is HLW?					nominal costs			
development	operation	closure	wet store construction	wet store dismantling	dry store construction	dry store dismantling	removal of last cycle elements	NPP SF pit	wet store	dry store	disposal	export	development	operation	closure		removal	decontamination	cutting	storage	transport	all other facilities	buildings demolit. & site restoration	NPP SF pit	wet store	dry store	disposal	export	NPP dismantling	SF transport and storage	LILW disposal	SF disposal or export
																2002															1,1	
																2003															0,9	
																2004															0,9	
																2005															0,9	
																2006															0,9	
																2007															1,3	
																2008															1,4	
																2009															1,9	
																2010															2,9	150,0
																2011															24,2	
																2012															26,1	
																2013															20,4	
																2014															3,7	
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																2025																
																2026																
																2027													23,7	8,3	3,7	
																2028													16,0		3,7	
																2029													14,7		3,7	
																2030													16,1		3,7	
																2031													15,8		3,7	
																2032													8,2		3,7	
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																2036													3,6		3,7	
																2037													0,2		3,7	
																2038													0,2		3,7	
																2039													0,2		3,7	

SID-96 with export

Figure 1. Timetable for the scenario *SID-96 with export* (incomplete)

[1] In order to meet the boundary conditions, two variants of the repository project were developed. In the more expensive one (more disposal casks, with fewer fuel elements in each one, requiring longer disposal tunnels), disposal begins in 2031 and lasts for six years. In the other variant, disposal begins in 2051 and ends in four years, with the nominal cost 20% lower.

Therefore, the original SID timetable can be preserved only if the SF is exported during the time period of its previously assumed disposal (years 2023-26).[2] The resulting scenario *SID-96 with export*, which otherwise fully resembles the original SID (except for disposal of the RPV), is shown in Fig. 1.

Figure 1 is an example of the timetable form used for all scenarios. For most columns the meaning is obvious. In the SF repository, SF storage and LILW repository columns, decisive phases in the lifetime of these facilities are charted. The section "where is SF?" follows the fate of spent fuel, from the year when the last cycle elements are removed into the pool until disposal or export is completed, because each phase has significant cost consequences. The equivalent section for LILW is not included, because it will be disposed over a number of years into the repository operated at a uniform annual cost which is practically independent of the disposal rate (with an annual compensation to the local community as the most prominent fixed expense). The similar section on HLW (arising mainly from the management of core internals and RPV) is included here for completeness, but the actual cost estimates are left for later DP revisions.[3]

The section on the NPP dismantling is structured so as to underline differences between the scenarios considered in this DP. Therefore, most of its columns describe management of MC and RPV. The first decontamination entry in this section (and the only one in Fig. 1, the red field at the year 2027) covers also the management of the core internals which in the original SID as well as in this export scenario occurs at the end of post-operational period (and produces waste denoted by a green field in the HLW section). Two parallel five-year fields, which follow decontamination in this section of Fig. 1, represent dismantling of all facilities and removal of MC and RPV into the storage building in the *SID-96 with export* scenario. Finally, only the beginning of the storage period is shown in the Fig. 1, as it extends uneventfully over the next 80 years. However, it should be noted that the LILW repository is kept operational throughout that period, both in this SID-96 scenario and in the other one described below, in order to accommodate the waste arising from the RPV after storage.

The last section in the scenario timetables is devoted to cost estimates. The numbers in these columns are the nominal costs in million € 2002 (as if the respective activities were carried out and paid for in the year 2002).[4] Decommissioning planning and licensing annual costs, as well as the costs of site management during post-operational period, shown at the beginning of the dismantling costs column, do not have parallel graphical entries in the dismantling chart columns, because they are similarly included in all scenarios. SF transport and storage costs include transfer of the fuel elements from the NPP pool to the CASTOR casks, and the pool dismantling, but their major portion comes from purchasing the casks, which is done annually so as to meet the needs in the following year.[5] The LILW disposal expenses refer only to the repository funding (which has already started, with the initial development costs) and to disposal of all LILW; operational waste storage, treatment and conditioning expenses are a part of the NPP operational cost, whereas the decommissioning pre-disposal waste management is included among the expenses of the NPP dismantling. The SF export expenses are evenly spread over the four-year export period, after deduction of a reasonable advance payment made at the time of an assumed export agreement negotiation (set at the year when the local repository development should start in the parallel SF disposal scenario).[6]

3.1.2 SID-96 with disposal

While the previous adaptation of the original SID to the SF export option looked reasonable, there was no way to combine the SF disposal, scheduled for the years 2031-36, with the NIS dismantling concept into a

[2] Such a four-year SF export period is adopted for all export-oriented scenarios in this DP. It provides an ample time for the transfer of all fuel elements from the NPP pool to CASTOR casks (even if some of them should be repeatedly used). Also, it is comparable with the SF disposal period, which is appropriate for the costs comparison, because any presumed differences in their duration would be hard to justify at this time.

[3] These costs are not significant when compared to the contingency amounts added to various components of DP.

[4] Most cost estimates were based on the 2002 prices, or corrected for inflation if estimated more than a couple years earlier

[5] The fate of the CASTOR casks after SF transport is not considered in this DP, as it is not likely to incur significant additional expenses.

[6] The expenses were estimated based on the SF export cost per kg of metal uranium. The amount was deduced from the range of potential prices indicated in preliminary contacts of the interested parties.

viable scenario. Nevertheless, in order to meet the boundary conditions requirement, a formal solution was proposed: to extend the post-operational period and postpone all dismantling activities (without any other modifications of the original strategy) until the end of SF disposal. Thus, the resulting scenario *SID-96 with disposal* does not quite parallel its export alternative; it keeps the NPP personnel employed for unreasonably long time after the plant shut-down, significantly increasing the costs of dismantling.

3.2 SID-15 scenarios

The requirement that all DP activities be completed within 15 years after the NPP shut-down leads to elimination of the MC and RPV decay storage, and to their disposal during the NPP dismantling. With the exception of the previous SID-96 options, this modification will be applied in all other DP scenarios.[7]

3.2.1 SID-15 with export

As was the case with the SID-96 scenarios, the option of the immediate SF export during the years 2023-26 allows for the most straightforward adaptation of the original strategy to the scenario requirements. The removal of MC and RPV generally occupies the same period in the time schedule as in the Fig. 1, but additional activities and costs are introduced.

After a thorough decontamination, these components have to be cut and packaged in order to fit into the tunnel-type LILW repository (and another 16 Mosaik containers will probably be needed for the unacceptable waste exceeding the LILW limits). The costs for these activities were deduced from the recent decommissioning experiences at similar facilities [6], with an appropriate estimate of additional expenses compared to the one-piece reactor disposal [7].

These modifications transformed the former *SID-96 with export* into a truly prompt decommissioning scenario *SID-15 with export* (partly shown in Fig. 2), with full release of the NPP site and with very brief operational period of the LILW repository.

3.2.2 SID-15 WS scenarios

In order to achieve a comparably prompt decommissioning scenario with SF disposal into the local repository, further modifications of the original SID approach were introduced. In SID-15 concept only a few years, at most, can be spent on any DP activities after 2036 which is the earliest date for completion of SF disposal allowed by the repository technology. Therefore, the NPP dismantling should be carried out in the meantime, with no prolongation of the post-operational period such as in *SID-96 with disposal*.

Removal of all SF into some dry store facility immediately after the NPP shut-down would make that possible, but dry storage is generally not planned for such brief periods because of its high initial expenses; the option of dry storage will be included in other scenarios with later SF disposal. More reasonable option for this case was to plan modification of the NPP spent fuel pool, so that it would serve as an independent SF wet storage (WS) facility during the NPP dismantling.

In the resulting scenario *SID-15 WS with disposal* (Fig. 2), the SF pool is adapted for that purpose within about a year[8] after the NPP shut-down, most dismantling activities (except for buildings demolition and site restoration) are completed before the beginning of SF disposal, and even the LILW repository operations end in 2038.

A far less reasonable option, *SID-15 WS with export*, is included in this group of scenarios in order to maintain the parallelism between SF disposal and export where possible. Whereas there are some merits to postponing the start of SF export until 2031 (easier financing[9]), as compared with 2023 in the previous

[7] Although such modification may be interpreted as a decisive departure from the original NIS strategy, all DP scenarios will retain the attribute “SID” for two reasons. The first one is that most other elements from the original SID will be retained; and the second reason is that, regardless of other DP components duration, dismantling preparations and activities will immediately follow the NPP shut-down.

[8] The NPP Krško SF pool is not within the containment building.

[9] Only the effect of the funds compounding due to interest rates is calculated in this DP, while the possibility that export prices may decline with time is but noted.

export scenarios, the need to finally purchase transport casks (which could have been used for dry storage as well) seriously offsets these merits. Also, both WS scenarios are very sensitive to timing assumptions, as extended wet storage would soon become more expensive than dry storage.

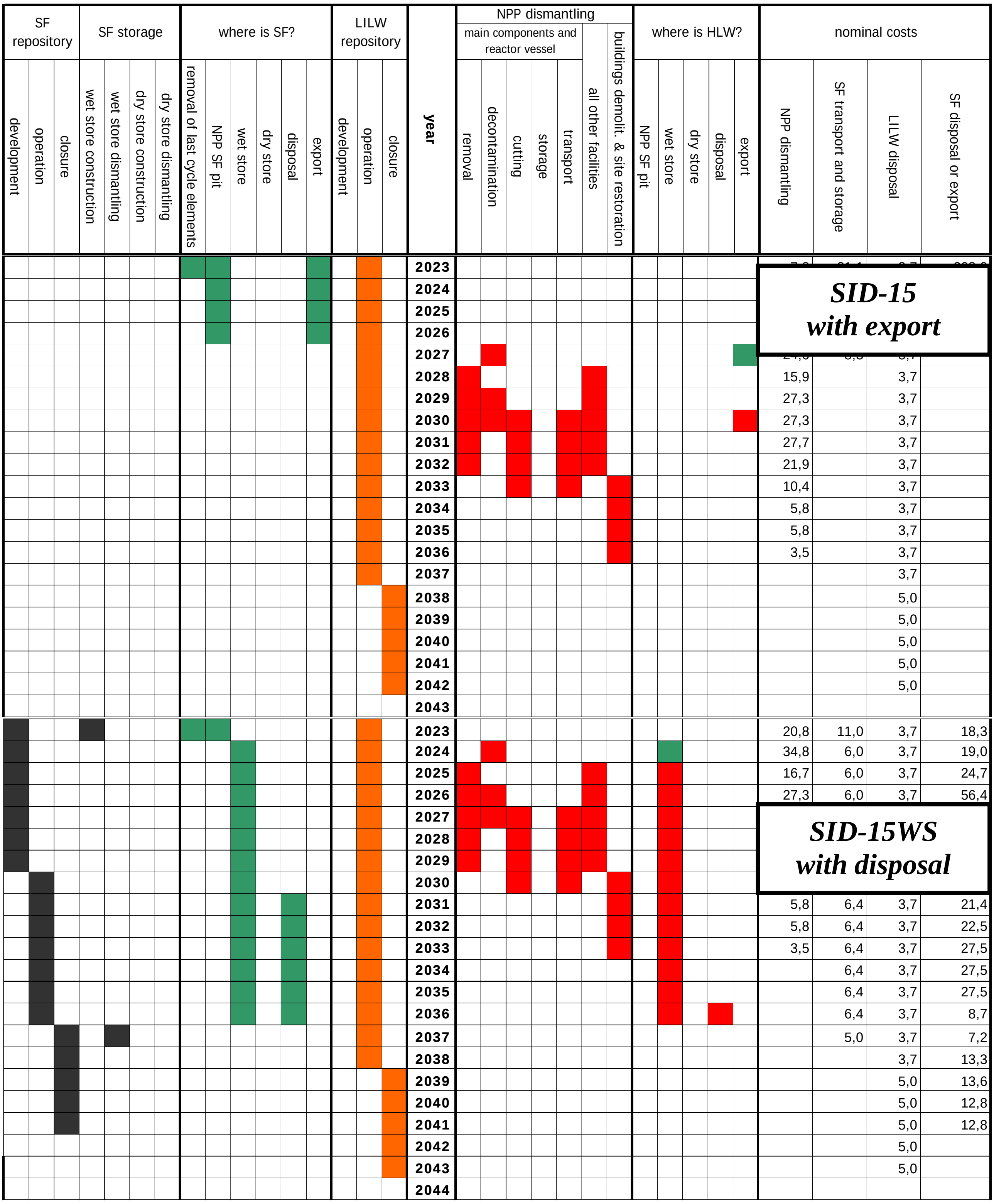

Figure 2. Comparison of the *SID-15 with export* and *SID-15 WS with disposal* timetables

3.3 SID scenarios with SF dry storage

Boundary conditions had originally specified that SF dry storage be examined only as an item within the DP sensitivity analysis, but later review of the SID strategy and, more importantly, SF disposal concept adopted in the meantime, indicated that dry storage should be incorporated into fully developed DP scenarios.

In all dry storage scenarios it is assumed that an ISFSI on unspecified location is constructed in 2023, and all SF is transferred from the NPP pool to the ISFSI by 2026 (where it is stored in CASROR casks). All the NPP dismantling activities are scheduled as in the scenario *SID-15 with export*, so that the site restoration ends in 2036.

3.3.1 SID-30 scenarios

The *SID-30* scenarios follow the boundary conditions requirement that SF dry storage should last for about 30 years. Then during 2051-54 the SF is disposed into the local repository[10] or, alternatively, exported within the same period. The LILW repository remains operational for another two years to accept any remaining waste (as in all previous scenarios).

3.3.2 SID-45 scenarios

The choice of the thirty-year dry storage period was rather arbitrary, at least regarding any technical limitations. It may reasonably be assumed that dry storage in the same CASTOR casks can be licensed for a period of up to 50 years. Therefore, it was decided that yet another pair of scenarios, with later SF disposal or export, would be worth considering.

It had already been calculated that total discounted costs for the *SID-30* scenarios were lower than for the other analyzed scenarios, so it was clear that prolonged SF dry storage would additionally relax DP funding requirements. In order to maintain conservative approach, the new scenarios did not fully exploit the potential cost reduction, but were equally concerned with enhancing the robustness of dry storage option. First, the SF dry storage was extended to 45 years rather than to 50, so that the scenarios would retain some flexibility regarding the SF disposal or export timing. Second and more important element of this conservative approach was an extension of the SF repository development period (supported by additional financing[11]), which should considerably increase confidence in timely realization of disposal schedule. Also, the LILW repository timetable is optimized in the *SID-45* scenarios.

Thus, the LILW repository development period is extended for several years, and its operations begin in 2018, which still provides ample time for disposal of all operational waste before the main NPP dismantling activities start.[12] The SF repository development begins in 2023 (which is a very reasonable date for conclusion of the negotiations about its potential location), with good chances for continuing engagement of the former repository development team; and the spent fuel will be disposed from 2066 till 2069. The LILW repository stopped operations in 2037 (one year after the NPP site restoration was completed), with the assumption that any remaining waste will be disposed elsewhere (i.e. during the closure of the SF repository), rather than to maintain the expensive and mainly useless activity for another thirty years.

[10] The less expensive variant of the facility design, since all fuel elements have cooled down sufficiently: disposal casks are filled to their full capacity, and disposal tunnels are shorter.

[11] In all other SF disposal scenarios, the repository development is financed for twenty years before the operational license. While there is no doubt that this is quite sufficient from the technical point of view, it is a common experience that problems with public acceptance or other socio-political circumstances can considerably delay the repository licensing.

[12] Further (and comparable) savings could be achieved if the surface vault repository is introduced instead of the tunnel type. But it would be a serious departure from the conservative approach to exploit both opportunities for cost reduction (the later repository construction and the cheaper design). However, the final and a more defensible choice regarding these options should actually be made by the stakeholders.

4 COSTS DISCOUNTING AND DP FUNDING PLAN CALCULATION

The proposed funding plan is based on detailed analysis of all considered DP scenarios. Conservative estimates of the nominal costs for all scenario activities were used, whereas the assumed interest and inflation rates reflect the actual recent values.

The nominal costs for most NPP dismantling activities, as well as the SF transport and storage, are based on the NIS study estimates, but with a correction for inflation and with all labor expenses doubled.[13] The annual inflation rate of 0.73% was applied, based on the growth of the industrial prices in Germany in the 1995-2002 period. Other cost estimates, in particular the expenses for the repositories, did not need such adjustments because they were based on new projects.

All estimated costs were then increased by an appropriate contingency amount, which reflected the level of confidence in the respective estimate. Total SF disposal costs were raised for 30%, the LILW disposal costs for 10%, and the NPP dismantling and SF transport and storage costs for about 15%.[14] Costs comparison with similar facilities confirmed that resulting estimates were well within the range of typical values [8].

SID-45 with disposal			
k factor =	**1,0429**	No of anuities	**19**
i factor =	**1,0073**	Fund 2003	**0,0**
d factor =	**1,0353**	Sum 2003	**S**
all expenses in millions €			
Expenses of LILW disposal			
nominal	inflated	fixed	discounted
		0,0	
Expenses of SF disposal or export			
nominal	inflated	fixed	discounted
		0,0	
Dismantling expenses			
nominal	inflated	fixed	discounted
		0,0	
Expenses of SF transport and storage			
nominal	inflated	fixed	discounted
		0,0	
Total expenses			
nominal	inflated	fixed	discounted
$\sum_n c_{0n}$	$\sum_n (c_{0n}\, i^n)$	**0,0**	$\sum_n (c_{0n}\, i^n/k^n)$
ANUITY			**a**

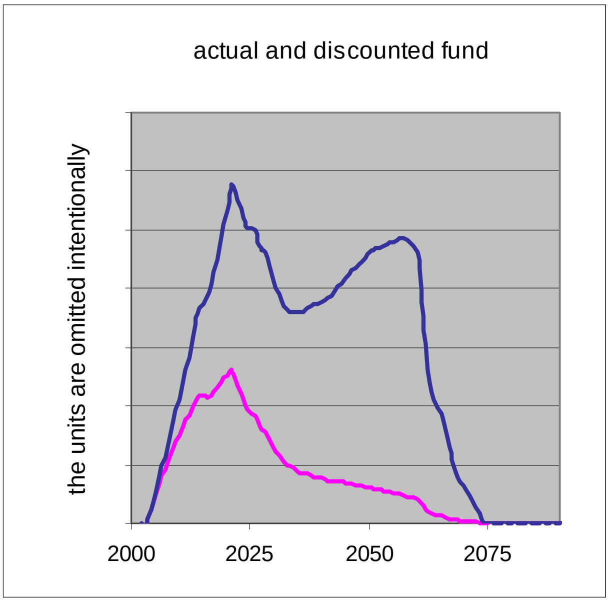

Figure 3. Presentation of results and the cash flow in the fund

[13] The NIS study labor costs reflect the 1995 wages in Slovenia, which have in the meantime been growing far above any relevant inflation rates.

[14] They were mostly based on the adjusted NIS study costs. Since the labor costs (accounting for 60% of dismantling expenses) had already been doubled, they were not further increased, but the remaining expenses were now raised for 50% (to account for the uncertainties noted in the original strategy, as well as for those induced by its modification), with the exception of CASTOR casks expenses which were raised only for 20%.

The first step towards cash flow calculations is already included in the scenario timetables (partly shown in Figs 1 and 2), where the 2002 nominal costs for all DP activities are broken down to annual expenses.[15] In the next step, all these annual amounts are increased for the assumed inflation in the period from 2002 until the respective year of their commitment, and the results are denoted as "the inflated costs".[16]

As the bilateral funding of the NPP Krško DP is expected to begin immediately after the approval of these cost estimates, it is assumed that it will be based on 19 consecutive annual installments of equal face value during the remaining period of the NPP operation, deposited into a dedicated fund at the end of the year, the first one in 2004 and the 19th installment in 2022. For this revision of DP, it is also assumed that such joint fund (starting from zero in 2003)[17] will compound the investments at the annual interest rate of 4.29%.[18]

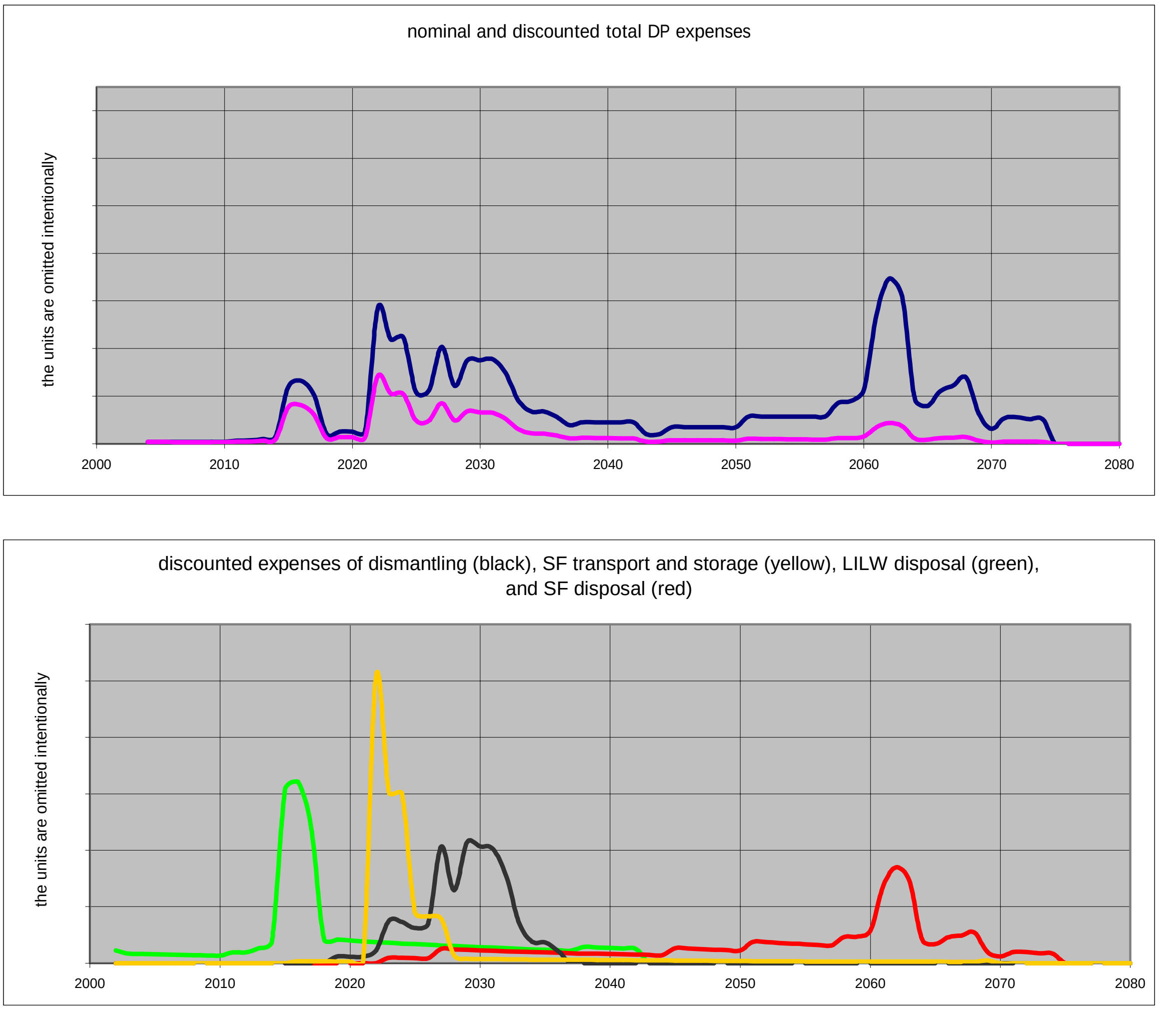

Figure 4. Scenario *SID-45 with disposal* annual expenses

[15] These are still 2002 prices. As mentioned earlier, the term "nominal costs" refers to the expenses estimated as if they should be paid at the end of 2002 for the job done during that year.
[16] The same inflation rate is applied as in the previous correction of the original NIS study prices. It is expected that the overall costs of DP will not grow faster than the prices of other industrial products, because at least a comparable progress in DP-related technologies can be assumed.
[17] The actual circumstances differ from this model. A decommissioning fund in Slovenia has already accumulated about 83 million € (at the end of 2003), but two symmetrical funds should eventually be achieved, one in each country.
[18] This is the long-term interest rate on state bonds (paid in €) in Slovenia at the end of 2003.

Based on the above assumptions, discounted expenses for each DP scenario and the associated annual payments to the hypothetical joint fund were calculated in MS Excel (throughout this text, “discounted” means “discounted to the year 2002”). An expense “discounted to the year 2002” refers to the amount of money which would suffice to finance the respective activity if that money was deposited into the fund at the end of 2002 (compounding the interest until the payment of the inflated cost). This means that for each nominal cost $\mathbf{c_0}$ its discounted cost $\mathbf{m_0}$ is given by the relation

$$\mathbf{m_0\, k^n = c_0\, i^n} \quad \text{or} \quad \mathbf{m_0 = c_0 / d^n}\,, \qquad (1)$$

where **i**, **k** and **d** are the inflation, interest and discount factors, respectively. Each of these factors is raised to the **n**-th power, where **n** is the number of years elapsed from 2002 until the year for which the expense is scheduled in the scenario timetable. The inflation and the interest factor are calculated from the assumed respective rates, whereas the discount factor is deduced from their values, i.e.

$$\mathbf{i} = 1{+}0.73\% = 1.0073; \quad \mathbf{k} = 1{+}4.29\% = 1.0429; \quad \mathbf{d} = \mathbf{k/i} = 1.035342; \qquad (2)$$

which means that the resulting discount rate is about 3.5%.

The annual payments to the fund for any scenario are easily calculated from its discounted total cost. However, the actual calculation algorithm for this DP was designed so that it can accommodate an arbitrary initial amount which may be introduced into the fund at the end of 2003. Therefore, an intermediate step has been devised, in which the discounted scenario cost is multiplied by the interest factor (so that it becomes discounted to the year 2003), and then the initial investment (called “fund 2003”) is deduced from it in order to get the remaining sum **S**, for which the 19 annual installments will be calculated (rather than for the total scenario cost discounted to the year 2002). The calculation is a simple exercise in the geometrical series partial summing, and gives the required annuity **a** as

$$\mathbf{a = S(k-1) / (1 - k^{-19})}\,. \qquad (3)$$

In the present version of DP, though, no initial investment is assumed (the “fund 2003” is zero), so the annual installments **a** are the same as if they were calculated for the total costs discounted to 2002.

The results of calculations are not presented here, because an independent peer review has been planned (and has not yet been completed by the time of submission of this report). Only the general form of the results presentation is illustrated, and the scenario *SID-45 with disposal* is selected as an example. The table in Fig. 3 illustrates a typical overview of total expenses and of their main components[19]. The fields for the calculation results are left blank (except for the last row, in which the respective calculation formulas are displayed[20]). The graph in Fig. 3 shows the overall cash flow in the fund, whereas Fig. 4 graphically describes annual expenses of the scenario *SID-45 with disposal*. In all charts the Y-axis units are suppressed in order to avoid communication of the absolute values.

5 CONCLUSION

The calculations have shown that all analyzed scenarios with an early SF export (SID-96, SID-15 and SID-15 WS) are far too expensive for this DP, each with the total discounted costs about twice as high as in the least expensive SF dry storage scenario. However, they may be reconsidered in later revisions, if the export prices substantially decrease.

Although the two early SF disposal scenarios (SID-96 and SID-15 WS) are more affordable (discounted costs about midway between the most and the least expensive options), they have a few weak points (when compared to the SF dry storage scenarios). Both require that the SF repository development begins soon and finishes within 20 years, which is not a high confidence assumption. In addition, *SID-96 with disposal* has too many internal inconsistencies to deserve any further consideration. If the need for prompt completion of all DP activities becomes a dominant criterion in scenario evaluation, *SID-15WS with disposal* has much more potential for further optimization.

[19] The table column “fixed expenses” (here with zero values) is used only for the SF export costs in the alternative scenarios, because no inflation is applied to these costs.
[20] All symbols correspond to those used in relations (1)-(3).

The results of calculations show that the SF dry storage scenarios are the most affordable group. Discounted costs for the options ending with the SF disposal do not differ much (SID-45 is about 15% less expensive than SID-30). With the present export price estimates, only SID-45 has comparable discounted costs for disposal and export, whereas the earlier export in SID-30 is considerably more expensive, but the difference is not so great that it could not disappear in the near future. Therefore, both pairs of scenarios have not only great flexibility regarding their actual future timing, but are additionally flexible due to the interchangeability of the export and disposal option. Furthermore, they also provide much more time for the SF repository development or the SF export arrangements than any other scenario.

It is important to note that the SID-30 and SID-45 scenarios can be viewed as the limits of an entire range of the intermediate SF dry storage options, in which the optimizations from the SID-45 case can also be introduced into shorter dry storage variants. Therefore, the decision on the DP funding can reasonably be based upon the SID-45 cost estimates, possibly rounded upwards to an amount which would encompass some of the shorter variants too.

However, all the funding estimates are strongly dependent on the assumed interest and inflation rates. Although the values used in this DP are reasonably based on the data from the past years, the trends may change in the future. The only way to deal with this uncertainty is to regularly revise the DP estimates, in relatively short intervals, so that any significant rate changes between the revisions can be compensated for through the remaining payments to the fund. These revisions are also expected to be used for improvement of the nominal costs estimates and for modifications of DP scenarios. For the next revision of the Krško NPP decommissioning program, a particular effort should be aimed at improvement of the power plant dismantling plan.

The present revision has revealed, beside a number of minor inconsistencies, two serious inherent problems of the NIS plan. The first one is that the original SID was developed without any consideration of specific SF repository concepts, whereas a rational NPP dismantling procedure should be adjusted to the adopted SF disposal technology. The second problem is that the SID strategy was based on the extensive use of cheap labor, but the wages have already doubled and are expected to rise further, so that straightforward adjustments within the same strategy would increase dismantling expenses unacceptably. Therefore, more appropriate NPP Krško dismantling procedures, with reasonable labor engagement and better suited to the particular SF disposal concept, should be developed independently of the NIS study before the next revision of DP is undertaken.

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