ECONOMIC APPRAISAL OF DEPLOYMENT SCHEDULES FOR HIGH LEVEL RADIOACTIVE WASTE REPOSITORY IN FRANCE

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The deep geological repository (DGR) is generally considered as the reference solution for the definitive management of spent nuclear fuel/high-level waste (SNF/HLW). Different countries have different decisions concerning the disposal deployment schedule. In this article, we raise the question of the economic ground of the decision made by the French Parliament, by proposing a utility function which aggregates various costs and benefits procured by the disposal implementation decision.

The simple economic comparison of storage and disposal costs showed that it appears more favorable to extend the interim storage than to dispose of the waste rapidly[1]*. By contrast, France decided a quick disposal. This decision is based rather on political/social than economic criteria to avoid over-burdening future generations. Furthermore, a quick DGR implementation would facilitate the nuclear renewal decision in France. This analysis may help French decision-makers in managing the DGR construction and commissioning schedules.*

I. INTRODUCTION

Nuclear energy has been considered as the major electricity source in France since decades; however, discussions are still going on about what to do with the radioactive waste produced by the nuclear fuel cycle. The least hazardous waste categories (low and intermediate level of short lived radionuclides), occupying about 90% of the radioactive waste volume, are already safely managed in near-surface repositories. Nevertheless, the remaining with most active and dangerous components (high level waste (HLW) and long-lived intermediate level waste (LL-ILW)) lacks of a definitive management option. France has undertaken research to find an optimal solution in terms of safety, environmental impacts and future generation burden minimizing, and the deep geological repository (DGR) is the predominant option, as it is defined as “the reference” by law.

France is one of countries having most important advances in disposal program with the potential of opening a DGR in the next decade; the disposal opening process and schedule was fixed by the 2006 law about the radioactive waste management[2]. This law decided a “quick” disposal implementation. In principle, this choice of the French Parliament has been decided in order to solve a problem of significant importance for the society, and thus to increase the welfare of the French citizens.

From a “purely” economic point of view, the long-term interim storage of HLW appears more favorable than the deep geological repository. The choice of having a quick disposal is therefore based on political and social reasons rather than economic criteria. The government’s priority is not to minimize the cost of long-lived waste management, but to set up a definitive solution rapidly to relieve future generations of the burden of managing the radioactive waste. The rapid demonstration and implementation of the HLW management solution is considered to have higher value (i.e. increasing the global welfare) than the optimization of waste management costs.

Economists often measure such a gain in global welfare by using a utility function which is quantifiable in monetary terms (i.e. in euros). The components of such a function appear very different by nature:

- 1st component: "**national social utility**" of a rapid disposal, as viewed from the majority of the French citizen, who prefer to choose this management solution. This item mainly includes the satisfaction of relieving next generations of the burden of managing the radioactive waste (this is the major result of the large debate which occurred in the year preceding the law). This share of the global utility appears very difficult to measure in monetary terms and we shall consider it as unknown.
- 2nd component: "**overall economically quantifiable impacts**", which are in principle the sum of all the impacts which could be measurable, when using existing methods. In this paper, we will try to integrate at maximum the economically quantifiable impacts:
    - Main technical costs (e.g. storage, disposal, R&D),
    - Main benefits (e.g. technology patent sale),
    - Option of maintaining the nuclear option (due to better social acceptance for nuclear development induced by the disposal implementation),
    - Consequences of a possible accident during the storage or the operation phase of the repository.

In the end, the global welfare procured by the DGR implementation is the sum of the two above-mentioned items. Even if we don't know the sign of each element, we are still able to presume that the global utility of a "rapid" disposal, in France, is higher than the one of extended storage (because a rapid disposal is fixed by law, decided after a long national debate). It seems, in fact, reasonable to suppose that the **national social utility** is positive (in red, in Fig. 1). The second term, **overall economically quantifiable impacts,** (in blue, in Fig. 1) is the sum of negative terms (mainly the disposal costs) and positive ones (e.g. the option value quoted above). Its sign is uncertain; it can be negative if the costs exceed the benefits, but the sum of red and blue zones remains positive.

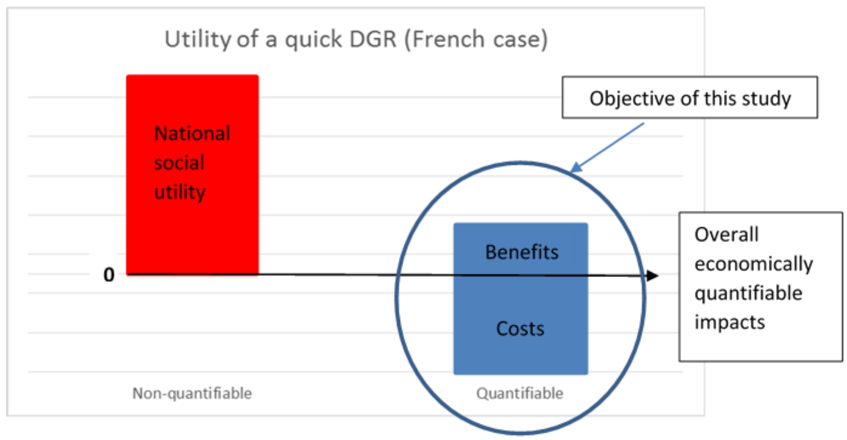

Fig. 1. Value of the "immediate" DGR implementation decision (French case)

While focusing on the French choice, the main objective of this paper is to analyze the global utility of the DGR project through the second item (in blue); in other words, through quantifiable parameters and to observe its sensitivity according to different DGR deployment schedules. Moreover, given a long-timescale project, we always introduce a discount rate in the analysis. According to the uncertainty level on the long-term economic growth (low, medium or high uncertainty), we have proposed three possible evolutions of the discount rate. They all decrease over time but at different speeds.

Obviously, economics is not the only or even the principal factor affecting decisions concerning the DGR schedule. However, economics is not unimportant, particularly in the nuclear industry, which faces an increasingly competitive environment. At a minimum, if the "immediate" DGR implementation decided by the French government is being done to achieve other objectives than economical ones (see above), it is still worthwhile to know how much they are willing to pay for those objectives.

II. UTILITY FUNCTION OF THE RADIOACTIVE WASTE DISPOSAL IN FRANCE

II.A. Analytical Function

Based on the disposal costing data of ANDRA (2014)[3] - French national radioactive waste management agency and the recent ministerial order fixing the long-term management cost of long-live waste,[4] we investigate the question of an "optimal timing" for French DGR. Here, this optimum, if it does exist, refers only to economically quantifiable items. Thus, if the study shows that a late disposal would appear cheaper, it does not mean that the choice made by the French Parliament is wrong. It means that we can suppose a higher (but non observable) social utility in the case of a rapid disposal.

The objective of this section is to set up an analytical utility function integrating different quantifiable costs and benefits procured by the DGR implementation. Because our main concern is the DGR deployment schedule choice, we can directly built the utility function with respect to time (in this study, the disposal start-up date[a]) and search for the "optimum" point.

I.A.1. Interim Storage

The interim storage is an indispensable step in the management process of the long-lived radioactive waste; during this phase, the short lived radionuclides decay until the waste heat power becomes sufficiently low to allow the next stage implementation – waste deep disposal. This storage step requires permanent site monitoring and maintenance until the last package to be disposed of. Therefore, while supposing no operational period change, postponing the DGR implementation schedule (and hence the closure date) would thus prolong the waste cooling period, resulting in increased storage cost. In case of n year delay, we have:

$$S(n) = S(0) + A\sum_{i=1}^{n}\frac{1}{(1+r)^{t_{end}+i-t_0}} \qquad (1)$$

With $S(n)$: the storage cost if disposal opening is delayed for n years, $S(0)$: the storage cost until the planned closure date of the DGR (t_{end}), t_0 discounting year (2016), r discount rate, A annual storage cost.

I.A.2. Research and Development:

In France, due to considerable progress in the preparation of disposal project, neither French nuclear operators nor the government have aimed at delaying the DGR implementation. However, if for some reasons (technical problem or social opposition), the disposal would be delayed, the competences/skills and the relationship with the people living around the repository need to be maintained until the DGR implementation. ANDRA and three main "waste producers" (EDF, CEA, Areva) continue, therefore, their research activities at the underground laboratory (Bure).

$$R(n) = R(0) + A'\sum_{i=0}^{n-1}\frac{1}{(1+r)^{t_p+i-t_0}} \qquad (2)$$

Where $R(n)$ the expenditure on R&D if the DGR implementation is postponed for n years, $R(0)$ the amount spent until the planned DGR opening (t_p) and A' yearly spending for these objectives.

I.A.3. Disposal:

The next cost to be considered is the DGR cost. This cost in levelized value is represented as below:

[a] : Other decisive parameters affecting the DGR utility function are the reversibility degree, the disposal closing date, the safety level, etc.

$$DGR(n) = \frac{DGR(0)}{(1+r)^{(t_p+n-t_0)}} \qquad (3)$$

Where $DGR(n)$ the levelized disposal cost if the DGR opening is delayed for n years and $DGR(0)$ the levelized disposal cost if all goes as planned.

I.A.4. Radiological accident risks:

Our utility function also takes into account the costs of potential accidents during the waste management process. We mean possible accidents in surface storage plants (fire, plane crash, etc.) and those inside disposal installation during operation[b] (fire, package drop, etc.), leading to possible radioactive releases in the environment. Each accident cost item is separately analyzed through two parameters: physical and human costs. In the case of storage malfunctions, the physical cost (represented by M_1) includes all the expenditures required for recovering and resetting of waste packages, for the decontamination and decommissioning of the old storage facility, for the construction of a new one, and the "image cost" (impact on food production, other agricultural products, tourism and exports, etc.). The human cost element (M_2) presents the cost of human lives affected by facility defaults, including health and psychological aspects (e.g. cancer risk increase, psychological disorders). It is represented by a random process supposed to follow a geometric Brownian motion:

$$\frac{dM_2}{M_2} = \alpha dn + \sigma_1 dW_n^1 \qquad (4)$$

Where α represents the positive drift in human life value (here approximately 2%/year) and σ_1 its volatility. The severity of radiation release accident on human life is assumed to increase in the long run (M. Boiteux (2001)).[6] The expected discounted cost of accidental radiation releases of the interim storage facilities if the deep disposal occurs at time $t_p + n$ is expressed as below:

$$AS(n) \approx AS(0) + \sum_{i=1}^{n} \Pr ob_{acc} \frac{\left[M_1 + M_2(t_0).\exp(\alpha(t_{end} + i - t_0)\right]}{(1+r)^{t_{end}+i-t_0}} \qquad (5)$$

With $AS(0)$ the storage accident cost if all goes as planned, M_1 physical cost (supposed to be constant), M_2 human cost depending on n (DGR delaying duration), $\Pr ob_{acc} = 10^{-5} / year$.[7] The longer we postpone the deep disposal, the higher $AS(n)$ will be due to the prolonged storage period.

Similarly, the expected discounted cost of accidental radiation releases during the DGR exploitation if the deep disposal occurs at time $t_p + n$ is calculated as below:

$$ADGR(n) = \sum_{i=t_p+n}^{t_{end}+n} 10^{-5} \frac{M'_1}{(1+r)^{i-t_0}} \qquad (6)$$

The human cost M'_2 is negligible in case of DGR defaults[c], because of the intrinsic properties of waste packages which are precisely designed to retain radioactivity, even in severe crash scenarios and of the operation mode in the repository, relying mostly on remote technologies.

Due to the lack of cost estimates for storage and disposal facility accidents, all accident parameters (mentioned above), are calculated based on the IRSN estimate (2014)[8] for a severe core melt accident in a nuclear reactor.

[b] : After the permanent closure, the risk of an accident inside the DGR that could lead to inacceptable radioactive releases is negligible (F. Sorin(2016)).[5]

[c] : ANDRA expert estimates

However, compared to a nuclear plant accident, due to the cooler source term (waste package), the consequences of a storage accident (or DGR accident) are supposed to be roughly 100 times less serious than in case of a reactor core fusion.

I.A.5. Technology patent sale:

Once the long-lived waste is disposed of into the DGR, as one of first countries developing this waste management solution, we suppose that we could benefit from selling technology patents. In case of DGR implementation delaying, it will decrease and follow a geometric Brownian motion with negative drift $-\beta$ (-2%/year) because of the technological progress in other countries (CEDD (2013)) [9] and a volatility parameter σ_2:

$$\frac{dP}{P} = -\beta dn + \sigma_2 dW_n^2 \qquad (7)$$

I.A.6. Analytical utility function:

The utility function of the DGR implementation is written as follows:

$$F(n) = \sum Benefits - \sum Costs$$
$$= P(n) - [S(n) + AS(n) + R(n) + DGR(n) + ADGR(n)]$$

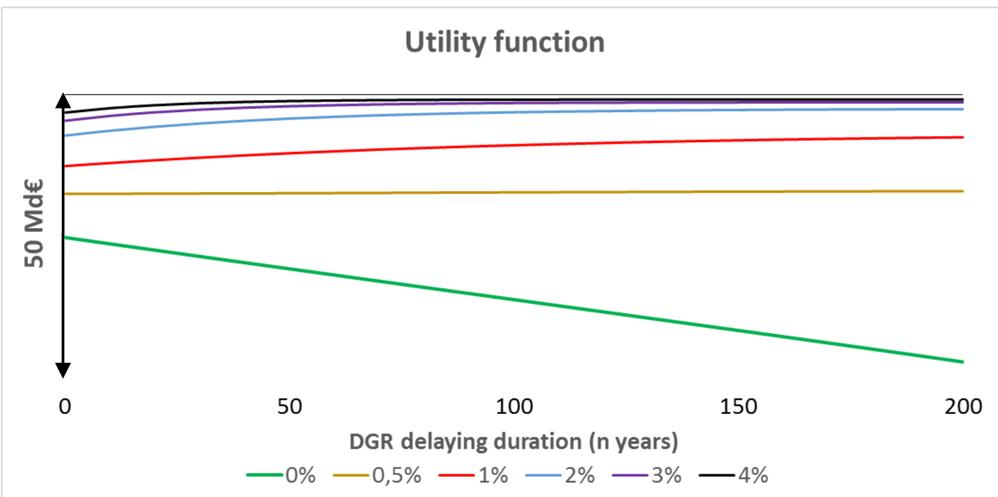

Fig. 2. Evolution of the utility function as function of the project delaying duration, with different discount rates

Taking into account the costs and profits in gross values (in green in Fig. 2), the utility function will decrease if the DGR implementation is postponed. However, since this project covers a long period with impacts in the far future, the time value needs to be integrated in our function by a discount rate. Fig. 2 showed that with "usual" discount rates (≥1%), the utility function is increasing according to the DGR delay duration. Therefore, there will be no economic interest in disposing of the radioactive waste immediately.

However, according to the Eurobarometer survey on radioactive waste in 2008 (Fig. 3), [10]

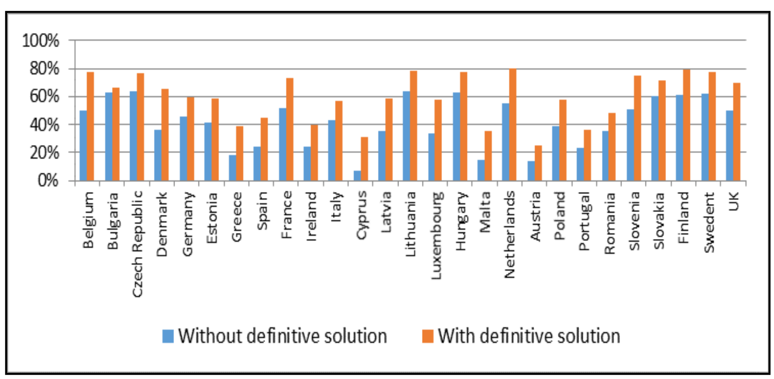

Fig. 3. Opinion modification if there was a permanent and safe solution for the management of radioactive waste

the non-existence of a permanent solution of radioactive waste management is considered by many people as an important reason to oppose the nuclear energy. In France, around 75% of respondents would be in favor to nuclear energy if the radioactive waste was safely managed (instead of 50% without a waste management solution). Therefore, to gain a widespread social acceptance for the renewal of nuclear power stations, the long-lived waste problem needs to be soon resolved or at least a small disposal for testing the feasibility of DGR solution (e.g. industrial pilot phase) needs to be soon implemented. In addition, with ambitious greenhouse gas reduction targets, France decided on the decrease of fossil energy dependence. The levelised cost of electricity produced by the renewable energy varies between countries, and in France, it remains higher than nuclear for at least the next two decades (Fig. 4, NEA (2015)).[11] There is therefore a strong interest in maintaining the nuclear option open. Thus, apart from different cost/benefit elements mentioned above, another aspect that will be influenced by the repository implementation rescheduling is the electricity production cost. Concretely, while waiting for the deep disposal to be set up, because of the nuclear opposition, renewable technologies would be in charge of electricity generation instead of the nuclear power, which could lead to a strong increase in the electricity price.

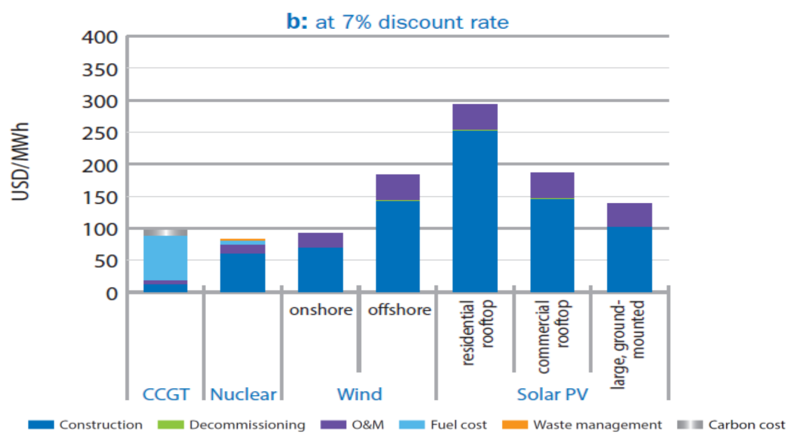

Fig. 4. Levelised cost of electricity (USD/MWh), France

On average, from 2020, in France, about 2 GW nuclear will be annually produced for the nuclear plant renewal. The electricity cost difference between renewable and nuclear sources is represented by l €/MWh. Non-nuclear installations need to be operated during at least 20 years to be profitable. Therefore, the loss resulting from the replacement of nuclear energy through renewable in case of DGR implementation delay (n years) is calculated by the following formula:

$$L(n) = n * \frac{2.018GW}{year} * \frac{7*10^6 MWh}{GW} * \frac{l€}{MWh} * \sum_{i=0}^{19} \frac{1}{(1+r)^i} \quad (8)$$

Each GW produces 7 TWh per year.

Therefore, the utility function of the DGR implementation is rewritten as below:

$$\begin{aligned} F(n) &= \sum Benefits - \sum Costs \\ &= P(n) - [S(n) + AS(n) + R(n) + DGR(n) + ADGR(n) + L(n)] \end{aligned}$$

Our analysis indicates that when $l \geq 1$ €/MWh, with "usual" discount rates, the utility function is decreasing $\left(\frac{dF}{dn} \leq 0\right)$. It would be therefore preferable to maintain, as planned, at least the industrial pilot phase implementation (designed for testing the DGR feasibility) for keeping the nuclear energy option. However, there would always be an economic interest in postponing the normal operational phase of the deep disposal[d].

II.B. Quantitative Function

However, while it may seem simple, an analytical function can be difficult or even impossible to be identified when taking into account a decreasing discount rate for evaluating long-term issues, such as the DGR project. Therefore, we turn away towards a quantitative evaluation. Instead of calculating the derivative $\left(\frac{dF}{dn}\right)$, we compute the variations of each cost/benefit item depending on different DGR deployment schedules. We investigate and compare the utility function in case of the planned and shifted schedules. The 5-year interval is chosen in case of the disposal shifting as it fits the normal delay duration of most industrial projects. We have:

$$\Delta F(n) = \sum \Delta Benefits - \sum \Delta Costs$$
$$\Delta F_{before-IPP}(n) = \Delta P(n) - \left[\Delta S(n) + \Delta AS(n) + \Delta R(n) + \Delta DGR(n) + \Delta ADGR(n) + \Delta L(n)\right]$$
$$\Delta F_{after-IPP}(n) = \Delta P(n) - \left[\Delta S(n) + \Delta AS(n) + \Delta R(n) + \Delta DGR(n) + \Delta ADGR(n)\right]$$

The composition difference between $\Delta F_{before-IPP}(n)$ and $\Delta F_{after-IPP}(n)$ is the term $\Delta L(n)$. As mentioned above, the industrial pilot phase (IPP) is an essential step to maintain the nuclear energy option.

As aforementioned, given a long-term issue, we always introduce a discount rate in our appraisal and compare the levelized costs of various DGR deployment schedules. The fixity of discount rate in the analytical function by supposing that the long-term growth rate is known and constant, appears somehow unrealistic. It seems in fact be more relevant to introduce the precautionary principle in the discount rate formula to deal with the uncertainties on the future growth rate. Assuming that the growth rate of our economy in long-term can take n different values $\mu_1, \mu_2, ..., \mu_n$ with probabilities $p_1, p_2, ..., p_n$ provided that $\sum_i p_i = 1$, the formula developed by Lebègue (2005)[12] is taken as the reference method for determining the discount rate:

$$r_t = -\frac{1}{t}\ln\left[\sum_{i=1}^{n} p_i e^{-(\delta+\gamma\mu_i)t}\right]$$

(δ rate of pure time preference and γ elasticity of marginal utility)

The rate of pure time preference δ represents our attitude towards the future. The higher this rate is, the greater our selfishness level will be: we prefer having the money now rather than investing on future generations. Therefore, for ethical reasons, we propose to fix this rate at 0 (Gollier (2011)) [13]: no priority is given to the present generation and neither to our “grand-children”.

Concerning the term γ representing the elasticity of marginal utility of the consummation, the estimation of this coefficient has provoked numerous discussions. Different values are proposed in the large range of 0 up to 10. However, the objective of this analysis isn’t to justify a particular value of γ; as a results, we utilize the value of $\gamma = 2$, suggested by Gollier (2011).

The Fig. 5 presents the evolution of our economic growth rate over the period 1980-2014.[14]

[d]: According to the French disposal concept, there are two phases: firstly, the industrial pilot phase (10 – 15 years) for testing the disposal feasibility and secondly, the normal operational phase (over 100 years).

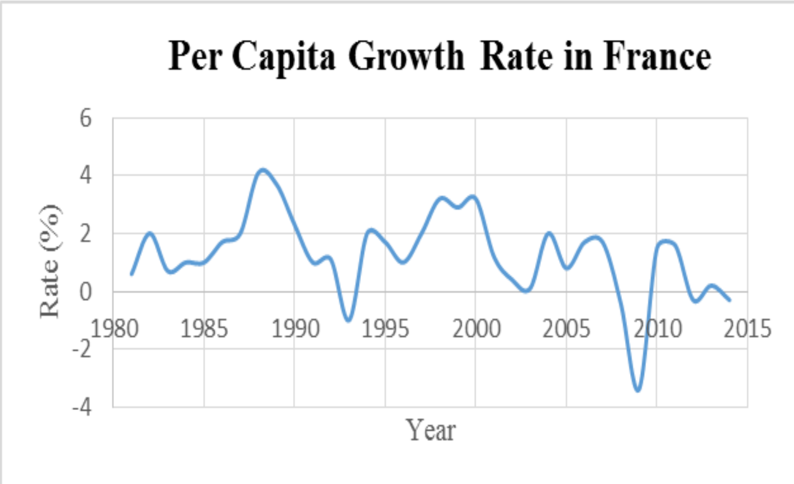

Fig. 5. Evolution of the per capita growth rate in France

We can simulate the discount rate with different values of the per capita growth rate in France; for instance: two extreme values $(\mu_1 = 0\%; \mu_3 = 3.5\%)$ and an average value $(\mu_2 = 1.75\%)$. There are numerous possible combinations with these 3 values; for example S_1 scenario with small risk on the average economic growth rate (1.75%), or in the contrary S_3 scenario with high uncertainty level on the growth rate. In this paper, we consider 3 scenarios (TABLE. I).

When the uncertainty on the growth rate is high, the discount rate will decrease faster in long-term (Fig. 6). In other words, the more efforts must be made in the present if there is little certainty about the future growth. The evaluation of the disposal utility function (presented in this paper) will take into account these 3 discount rate scenarios. That would bring us valuable information on the relation between the DGR timing decision and the economic growth perspectives.

TABLE I. Parameters of different scenarios

Scenario	S_1 Low uncertainty level	S_2 Medium uncertainty level	S_3 High uncertainty level
Minimal rate μ_1	0%	0%	0%
p_1	0.1	0.25	0.33
Average rate μ_2	1.75%	1.75%	1.75%
p_2	0.8	0.5	0.33
Maximal rate μ_3	3.5%	3.5%	3.5%
p_3	0.1	0.25	0.33
Time preference rate δ	0%	0%	0%
Elasticity of marginal utility γ	2	2	2

Fig. 6. Evolution of discount rate in long-term of different scenarios

II.C. Numerical Results

Depending on different scenarios of the discount rate evolution, we will observe how different cost/benefit elements and the DGR utility function vary in case of the disposal delay and then propose three decision fields (Fig. 7):

- (1) There would be an economic interest in delaying the whole disposal project $(\Delta F_{before-IPP}(5) > 0)$ (in red).
- (2) The industrial pilot phase should be started as scheduled to maintain the nuclear energy option $(\Delta F_{before-IPP}(5) < 0)$, but the normal operational phase (NOP) should be postponed $(\Delta F_{after-IPP}(5) > 0)$ (in blue).
- (3) "Immediate" DGR implementation $(\Delta F_{before-IPP}(5) < 0)$ and $(\Delta F_{after-IPP}(5) < 0)$ (in green).

Moreover, given the uncertainties on different cost/benefit items (storage, DGR, R&D, etc.), the variations of the DGR utility function before and after the industrial pilot phase implementation (without counting $(\Delta L(5))$) are illustrated by two Gaussian curves on the left and right sides of each figure. The breakdown of three decision fields (red, blue, green) varies as function of the level of uncertainty on the long-term economic growth (low, medium and high uncertainty levels).

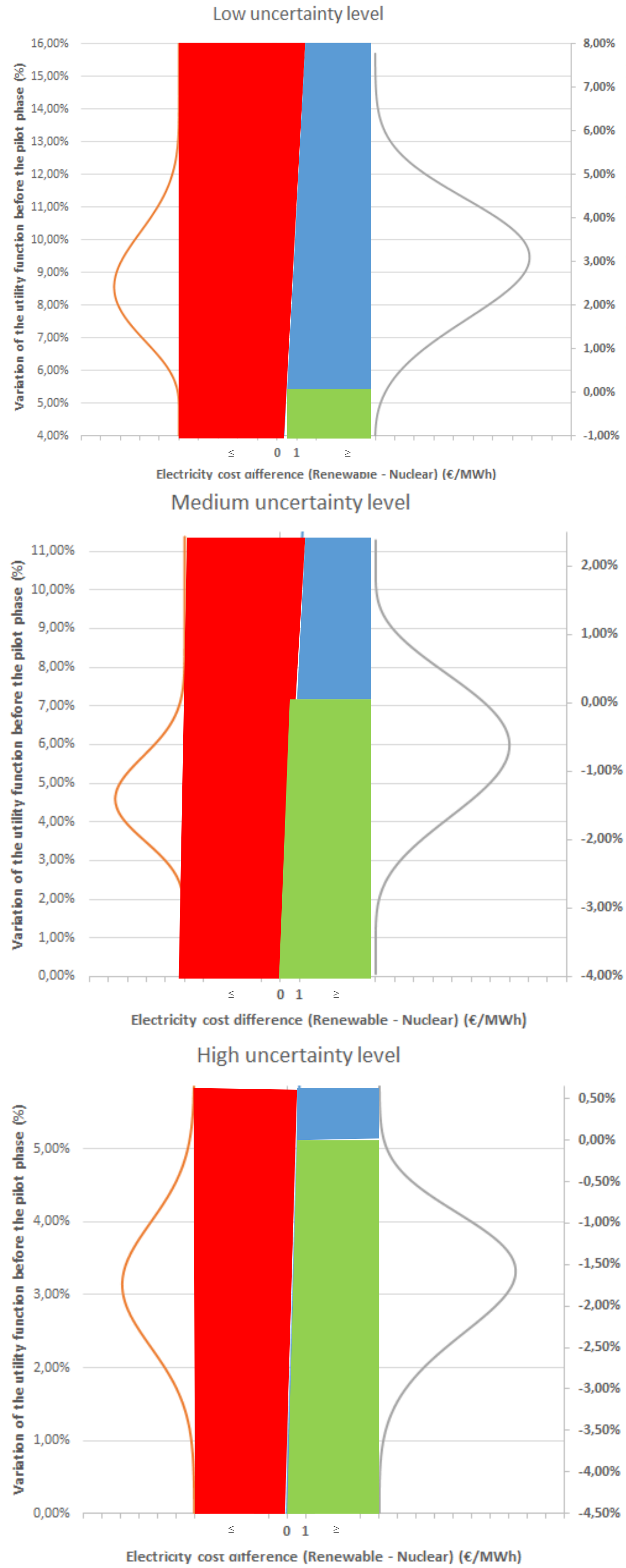

Fig.7. Variation of the utility function in 3 discount rate scenarios (French case)

In all cases, if the economic benefit of the nuclear production compared to the renewable energy is under 1 €/MWh (which is a very low value), there is no need to maintain the nuclear option. Delaying the whole DGR project (red zone) will be the most economical choice, i.e. with low uncertainty level, the 5 year disposal shifting would induce a gain up to 16% of the total disposal cost (the most likely value is 9%). Otherwise, in case the production cost is strongly increased when electricity is produced by renewable sources (at least 1 €/MWh), nuclear power is worth being continuingly supported. For this to happen, given the considerable controversy around the nuclear issues including the waste management problematic, the industrial pilot phase needs to be soon settled (blue or green zone) to gain widespread social acceptance.

The red zone remains constant and does not change excessively under different scenarios. However, after the disposal testing step, depending on the uncertainty level on the long term economy, different decisions concerning the DGR normal operational phase implementation might be taken. For the low uncertainty level case, there is no economic interest to continue immediately the normal operation phase NOP (after IPP) in 90% of cases. By contrast, delaying this phase for 5 years would generate a gain of up to 8% of the NOP cost. However, the more uncertain the future (medium and high uncertainty), the more it would be important to ensure the continuity of the DGR project (green zone). Moreover, it would be difficult to restart the project after a significant delay due to the eventual reduction of the social acceptance.

The long-term management of long-lived radioactive waste is a very complex issue, and this model haven't yet taken into account all of the parameters affected by the DGR implementation rescheduling. Although we have tried our best to reflect all available information on storage/repository costs and accidental costs, there still has a lack of social values which are difficultly quantified. However, this analysis would help the decision-making of the DGR implementation schedule on the economic front; and some work on the social front still has to be done to complete this study.

III. CONCLUSIONS

In France, most of the radioactive waste (including short-lived low- and intermediate-level waste) generally benefits from a well-developed short and long run management process (be disposed of in near-surface repositories). However, the remaining waste (long-lived waste and high level waste) accounting for a very small proportion of the total radioactive waste volume (≤10%), but almost all the radioactivity, is still waiting for a definitive solution implementation: deep geological disposal. Given the long timescales involved, the timing with respect to deciding to deploy a DGR is one of the key nuclear issues and remains one of the main public concerns. France decided an "immediate" disposal, with an opening date that is mainly conditioned by technical and social development steps. With such a strategy, present generations bear all the responsibility of their own radioactive waste and do not impose any undue burdens on future generations. In this paper we address this issue by analyzing different DGR deployment schedules of the French case, from an economic perspective, which should help guide decision-makers when it comes to managing DGR timescales.

In this analysis, we have built a utility function integrating at maximum the economically quantifiable impacts:

- Main technical costs (e.g. storage, disposal, R&D),
- Main benefits (e.g. technology patent sale),
- Value of maintaining the nuclear option (due to better social acceptance for nuclear development induced by the disposal implementation),
- Consequences of a possible accident during the storage or the operation phase of the repository.

This function is clearly not the "global utility function" of the repository, as it does not encompass all the factors, but we think that its identification is still an important new step in the economics of nuclear waste disposal, compared to the little literature available in this domain (e.g. Gollier (2001)[15], Loubergé (2001)[16]). Then, we have computed the function sensitivity according to the disposal start-up date. Because of the long-timescale of these projects, we always introduce a discount rate in the analysis. According to the uncertainty level on the long-term economic growth (low, medium or high uncertainty), we have proposed three possible evolutions of the discount rate. They all decrease over time but at different speeds.

If we consider only storage and disposal costs, it always appears more economically favorable to extend the interim storage than to dispose of the waste immediately. This result remains valid even when taking into account also accident costs and gain from the technology patent sale. However, in France, the quick repository implementation is probably a favorable condition for maintaining the nuclear development. Indeed, supposing that in case of disposal implementation shifting, the lack of trust in the radioactive waste management would lead to a strong nuclear opposition, old French nuclear power plants would be replaced by renewable energy which remains more expensive than the nuclear at least for the next 20 years. In this situation, the electricity cost increase will far exceed the gain due to the disposal shifting. Therefore, at least the “industrial pilot phase”, already defined by l’ANDRA (after the public debate on the waste management subject in 2013) for progressive implementation and for testing the disposal feasibility, needs to be implemented as scheduled to maintain the nuclear option. After this pilot phase, the question of the normal phase schedule can be discussed. Depending on the uncertainty level on long-term growth rate, a shifting of the DGR normal operational phase could be beneficial or not. With low uncertainty level on the long-term economy, we still have a certain economic interest in delaying the disposal normal operational phase. However, the more the distant future is uncertain, the more we should maintain the efforts for completing a non-stop disposal.

Here, our purpose is not to re-analyze the decision of the DGR implementation but to clarify the decision-making of the disposal time management on the economic front. Even if the opening of the repository is fixed by political choices, our appraisal gives for the first time an assessment of the economic consequences of different DGR deployment schedules and opens the way for clarifying the differences in scheduling decisions in different countries. We know that our approach remains a partial one, but we are confident in the future opportunities to further develop the global utility function, including other social values procured by the disposal implementation. Works could be launched to explore this domain, for instance by doing surveys and interviews.

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