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Risk and Responsibility Sharing in Nuclear Spent Fuel Management

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Abstract

With the Nuclear Waste Policy Act of 1982, the responsibility of American utilities in the long-term management of spent nuclear fuel was limited to the payment of a fee. This narrow involvement did not result in faster or safer development of a solution for commercial nuclear waste. In most other countries, the financial liability and practical involvement of utilities appear more extensive. This paper highlights how such differences in institutional frameworks affect risk sharing and economic incentives. It argues that a greater allocation of risk and responsibility to the utilities should reenter the debate over nuclear waste in the US.

INTRODUCTION

Like many human activities, nuclear electricity generation produces a variety of waste streams. Some waste streams can be detrimental to our health and activities if introduced to our environment, while others are benign. In the case of nuclear energy, the industrial process includes several critical steps such as the release of radon gas during uranium ore mining, the decommissioning of nuclear sites at the end of their life, and the management of spent nuclear fuel and other radioactive products induced through fission. The waste handled during these steps has unique characteristics, notably in terms of

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longevity, which require the development of specific technologies.[1] The complexity of this nuclear waste management problem, already raised by military programs, took on a new dimension when the generation of electricity from commercial nuclear power plants started: new plants in the US raised the spent fuel discharge rate from 0.6 MTHM in 1968 to 1,082 in 1978 and 2,407 in 2002.[2] Unfortunately, more than 50 years after the start-up of the first commercial reactor and more than a decade after the anticipated opening of a final repository, no operating waste management solution for this commercial spent fuel exists in the US.

A new light has been cast on the spent fuel management situation, as recent global climate change concerns opened the way to a revival of the nuclear industry. Despite the advantages of nuclear power as a source of low CO_2 emitting energy generation, the current handling of spent fuel from the existing US reactor fleet does not meet the very sustainability principles that are advancing the renewed interest in nuclear electricity. As a consequence, even some academics and industrials who favor nuclear power condition the desirability and acceptability of a nuclear "renaissance" to the successful development of waste management solutions.[3]

Solving the problem begins with understanding what allowed the paralysis observable in the current American situation. Historically, the US demonstrated a strong

1 For instance, it takes in the order of 10 million years for non-treated fuel discharged from current reactors to reach the radiotoxicity level of the natural uranium it was fabricated from, a time scale far greater than all human institutions (Westlén, 2007). Chemical industries dealing with toxic products such as lead or mercury have similar problems.

2 EIA. *Annual Spent Fuel Discharges (1968-2002)*.
http://www.eia.doe.gov/cneaf/nuclear/spent_fuel/ussnftab3.html

3 Richard K. Lester (2008)
John Rowe, Chairman and CEO of Exelon Corp: "I think the waste disposal issue is the single biggest hang-up to a nuclear renaissance" (PBS, October 2007)
MIT (2003). "The perceived lack of progress towards successful waste disposal clearly stands as one of the primary obstacles to the expansion of nuclear around the world."

technical capacity through its numerous nuclear and civil engineering projects. Therefore, this paper chooses to examine the institutional framework as a potential source of the observed inefficiencies.

Section 2 of this paper summarizes briefly the history and current situation in the US. We then argue that the American system is characterized by a limited involvement of utilities, which translates into an inappropriate transfer of financial risks to the federal government (Section 3) and the cancellation of natural incentives in waste management solutions development (Section 4). In the paper, we provide a theoretical perspective on the American system and contrast it with examples from other countries.[4]

THE AMERICAN PATH

Current stage

In the United States, the modalities of waste disposal were framed by the 1982 Nuclear Waste Policy Act (NWPA), which was triggered by the operation of commercial power plants and the need to dispose of defense waste. The Act notably established:

- Federal responsibility for the development of repositories for commercial spent nuclear fuel or high-level waste therefrom (HLW);[5]

[4] For the latter methodology, there are obviously many varying parameters and fundamental differences across nations, such as nuclear development strategy and size, or legislative organization, which this study does not pretend to overcome but merely benchmarks.

[5] There are different ways in which nuclear fuel can be burnt. In the once-through cycle currently used, the spent uranium oxide (UOX) fuel coming out of thermal reactors is entirely treated as waste and disposed of. In other "closed" cycles, this spent fuel is recycled: separated into several streams, some of them (like Plutonium) can be used further in thermal or fast reactors to extract more energy, while others have to be disposed of (HLW).

- the transfer of all long-term waste disposal costs from the utilities, initial owners of the fuel, to the Department of Energy (DOE) in exchange for the payment of a fee, accrued in a Nuclear Waste Fund

The implementation started with a broad siting program to locate sites for repositories as required by the Act.[6] Political reactions to the siting process, as well as the escalating cost of evaluating potential repository sites, led to the 1987 amendment to the NWPA, which required the DOE to focus its efforts on evaluating the suitability of Yucca Mountain in Nevada as the sole candidate for the nation's permanent repository. Although the repository was initially scheduled to open in 1998, the latest estimations relied on a start of operation in 2017 and gave no insight into the need for a second repository.[7] Increasing delays in the project, on which $14 billion had already been spent by 2007, resulted in expensive lawsuits brought against the DOE by utilities.[8] Finally, and while most sites now have to supplement pool storage with dry cask storage, President Obama's administration placed the Yucca Mountain project on hold.[9]

Perspectives beyond siting

The results of some international programs stand in stark contrast to the US plight. In the 1970's, Swedish utilities built their first commercial reactor and gathered into Svensk Kärnbränslehantering (SKB) to develop a waste management solution. SKB

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[6] For more details, see Cotton (2006).

7 In the absence of a second repository, there exists a statutory limit of 70,000 MTHM for Yucca Mountain. This falls short of the anticipated amount of waste: in the absence of recycling, spent fuel should reach 109,300 MTHM by 2045 with current reactors (fuel from past and present reactors, licensed by the Nuclear Regulatory Commission (NRC) as of January 2007 as in OCRWM (2008b)).

[8] Utilities prompted 67 lawsuits, leading until 2007 to $290 million paid damages, $420 million more being appealed, and total damages projected to reach $9 billion if no spent fuel is moved before 2017 (Committee on Environment and Public Works (2008). *Ten Years Overdue*).

[9] World Nuclear News (2009). *Obama dumps Yucca Mountain* http://www.world-nuclear-news.org/newsarticle.aspx?id=24743

built CLAB - a central interim repository able to store the fuel from all present reactors - as well as a low- and intermediate-level waste disposal facility. Recently, the site for a final repository expected to operate by 2023 was chosen.

A well-identified factor that partly explains the diversity of results between waste management programs worldwide is the ease of siting facilities. Siting is very specific to each country's legal and political practices regarding the sub-national level in the national decision process. In the US, the investigations of many sites as potential storage facility locations led by the Nuclear Waste Negotiator as well as groups of utilities have been blocked at the State level, and are examples of such siting problems.[10]

Nevertheless, criticism of the Yucca Mountain project, actually pursued despite opposition from the State of Nevada, does not solely stem from a lack of public acceptance. Other institutional aspects related to economic incentives and efficiency should also be considered when analyzing the US waste policy. These aspects may even enter the siting debate, as building an organization with economic and industrial credibility could help build public acceptance and protect projects from deferment.

RISK SHARING

Uncertainty in spent fuel management costs

Whether the cycle considered involves direct disposal of spent fuel or its recycling, waste management requires capital-intensive industrial projects with overnight costs in the tens of billions of dollars. Unfortunately, uncertainties in construction costs are inherent to large civil engineering and industrial projects, especially to those first-of-

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[10] In 1997, eight utilities created Private Fuel Storage LLC (PFS) to store used fuel temporarily on a site in Utah (Skull Valley).

a-kind. In the debate on recycling, some authors like Bunn et al. (2003) adequately draw attention to the fact that building another La Hague (the French reprocessing plant) is not exempt from mishaps, citing the tripling of Rokkasho-Mura's anticipated cost. However, there is also limited experience in building geologic repositories for nuclear waste, and the potential for cost escalation is real.[11]

In such RD&D intensive projects, it is common for degree of completion to remain the same while incurred cost increases (e.g. cost of characterizing a candidate repository site). Figure 1 represents the evolution of the estimated time before the start of operations of a geologic repository in the US, and the difficulty for the project to get within 10 years of operations.

***Figure 1**. Evolution of the expected time before operations*[12]

[11] Today the only operating repository for long-lived radioactive waste is the Waste Isolation Pilot Plant in New Mexico.

[12] Update from Callen (1995)

The expected cost is also prone to major revisions after the start of construction reveals necessary modifications in the project, which can be costly once the foundations have been led. Even projects which have not yet started to be implemented at full-scale already exhibit significant volatility. This fact is illustrated in Figure 2 for Sweden and the US.[13] For the latter country, the graph exhibits a near doubling of expected repository cost between 1989 and 2007.[14]

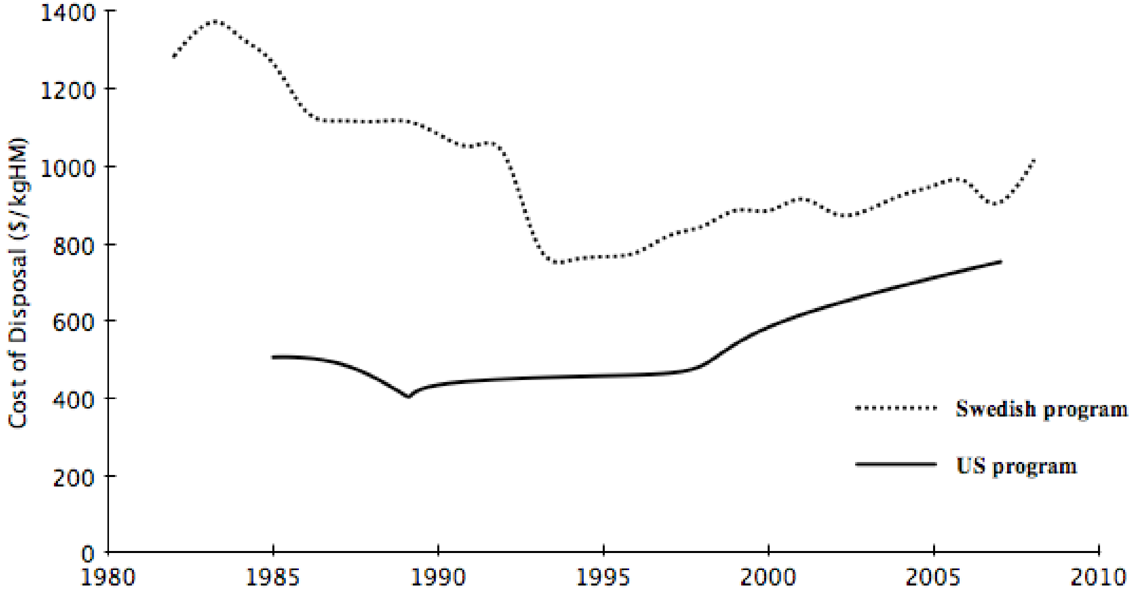

***Figure 2**. Evolution of the commercial waste disposal cost for the Swedish and US programs*[15,]

[13] For another study of the Swedish program, see (Segelod, 2005)

[14] Cost measured in overnight cost of disposal per kgHM.

[15] Costs reported by SKB and OCRWM respectively, and expressed in 2008 dollars using Power Purchasing Parity (PPP)

Typology of risk and its allocation

Financing projects with such a long time frame, and variable costs, requires an adequate management of risks. The identification of this issue has led to explicit regulation in countries like Sweden, where reactor owners must provide upfront payments, or "guarantees", to cover the risks associated with waste management. One guarantee covers the event of premature shutdown, while another covers the possibility of funds shortage after all of the reactors have been shut down.[16]

By extending this designation, we dissociate two kinds of risk:

- **Risk I, funding risks**: the risk that the waste generating firm does not reach the funding target, i.e. the amount anticipated to cover all future costs. It covers events such as early reactor shutdown, bankruptcy or ill-planned fund growth rates.
- **Risk II, project risks**: the risk of unexpected costs. This includes biased cost estimations, cost escalation, or even unexpected events such as natural disaster, which happen mostly during construction or after sealing of the repository.

These risks are taken by the entity which bears the financial liability for the waste. This liability initially lies with the waste producers, but can be transferred over time. The operators can trade the responsibility of future implementation and monitoring against a present payment sufficient to cover future costs. Such liability transfer is natural: the firm may not live long enough to see the closure of a repository, let alone the long-term consequences of disposal. As a result, in every country, financial liability has to be

[16] Kärnavfallsfonden, Annual Report 2007.

transferred to a more perennial structure, i.e. the state, which will be paying for potential future costs from this point onward.

The types of risks are illustrated without too much loss of generality in Figure 3.

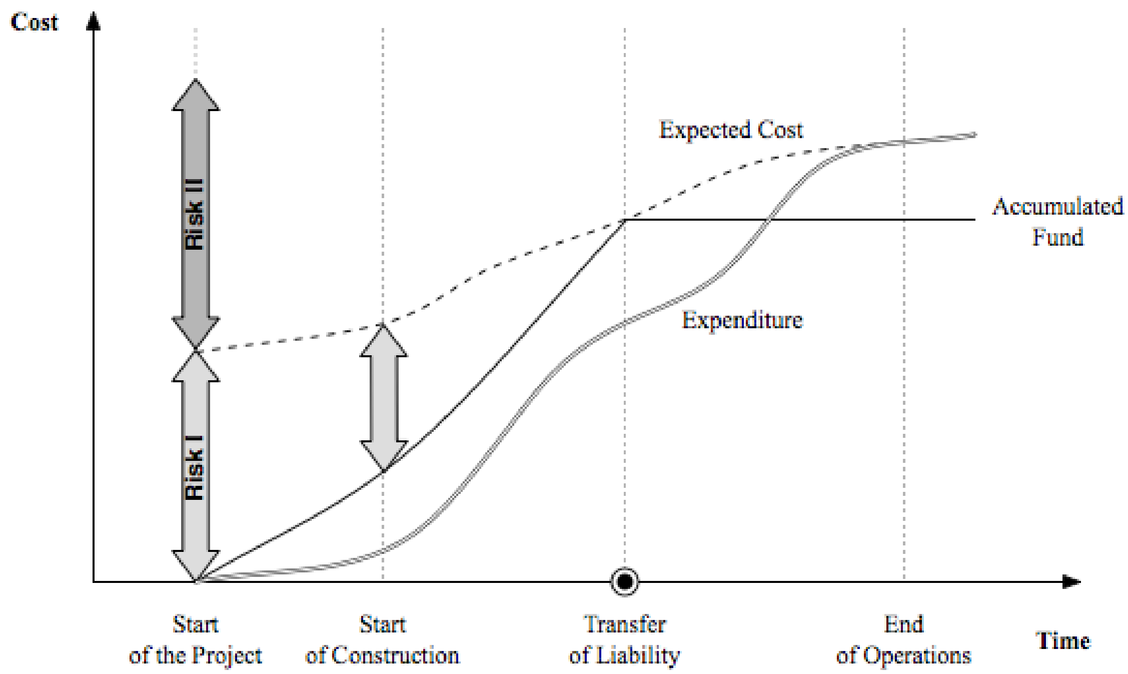

Figure 3. *Evolution of costs, funding level and risks for a spent fuel management project*

As can be seen in the figure, the earlier the transfer, the greater the potential unanticipated costs which will fall to the state. Consequently, the time of transfer is central to the allocation of risks between the industry and the state. It can primarily happen at times such as:

- waste production or before the construction of a repository
- acceptance at the repository, or during its “stable” operation
- closure of the repository

In countries like Finland, the government only takes ownership of and financial responsibility for the fuel at the closure of the repository. However, transfers are generally more complex and gradual: for instance, Belgium takes the financial liability at acceptance of the fuel but waste producers are liable until 50 years after acceptance of the waste in the repository for hidden defects.

Identifying risk and limiting state exposure

In the United States, the 1982 Act established the transfer of all long-term waste management costs from the utilities to the federal government in exchange for the payment of a fee at the time the electricity is generated.[17] As in many countries, this transfer of financial liability only included long term costs: utilities, which hold title to the fuel until acceptance by the Department of Energy, remained responsible for the costs of continued storage of the waste until removed from their sites. However, the transfer of liability has been furthered by the outcome of recent lawsuits which found the Department of Energy to be in partial breach of the contract with utilities and allows the latter to recover the costs of storage of their spent fuel beyond the time at which the Department of Energy was required to pick it up for disposal.

The Act required the Secretary of Energy to review annually this disposal fee, originally set to 1 mill/kWh, to ensure that the full costs of disposal are borne by the utilities.[18] Despite inflation, changes in anticipated costs, evolution in the number of

[17] "In paying such a fee, the person delivering spent fuel, or solidified high-level radioactive wastes derived therefrom, to the Federal Government shall have no further financial obligation to the Federal Government for the long-term storage and permanent disposal of such spent fuel, or the solidified high-level radioactive waste derived therefrom". Nuclear Waste Policy Act (1982)

[18] "The Secretary shall annually review the amount of the fees […]. In the event the Secretary determines that either insufficient or excess revenues are being collected […], the Secretary shall propose an adjustment to the fee to ensure full cost recovery." Nuclear Waste Policy Act (1982)

repositories or building schedules, the fee has remained unchanged for 27 years. A relative stability in regulation is necessary for industries to develop. However, for comparison, the fee set by the Swedish government on electricity produced by nuclear plants changed every year since 2002, except in 2004.[19]

This fee freeze highlights two potential pitfalls in the US risk identification and management process:

- Use of delays in implementation to cover increasing costs by economic discounting. Unfortunately, delays not only entail direct side costs.[20] Delays also put off the implementation closer to the shutdown of nuclear reactors, which diminishes the ability of DOE to recover unexpected expenses by posterior fee increases levied on future nuclear electricity production.[21] The consequence is an increase in risks of type I.
- Underestimation of uncertainty in project cost. The last public reports on the adequacy of the fee focus solely on the sensitivity to the financial discount rate and to the defense share (sometimes assessed optimistically).[22] Sensitivity to the cost of the project, which we showed to be volatile, was not assessed. The consequence is the lack of visibility over risks of type II.

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[19] http://www.karnavfallsfonden.se/informationinenglish/

[20] Beyond lawsuits in the current US system, the introduction of hesitations is likely to weaken the image of nuclear in the public and suggest inadequateness of the present system in its totality.

[21] Indeed, among the nuclear reactors still running by the time a fee increase is decided, a significant increase may prompt some reactor shutdown. This issue is partially addressed by recent license extensions for some nuclear reactors to 60 years. However, if not, a levy would have to be put on all kWh, as in Italy where 4 reactors were prematurely shutdown.

[22] OCRWM (2001, 2008). For instance, OCRWM seems to give great importance to the number of “positive scenarios” (ie. with positive balance in 2133). The fact that a scenario is positive depends greatly on the defense share. In 2008, although this share was 19.6% and decreasing from 2001, OCRWM considered cases with a defense share of 15%, 20%, 25%, 30%. Considering only the first 3 cases as realistic, the number of positive scenarios would be brought back to 12 out of 21 (instead of 18 out of 28).

In other words, the US system seems to lack proper accounting for risks borne by the state. By contrast, not only does the Swedish system identify these risks but it also reflects them onto the utilities, on top of the fee levied to carry the project.

If risks I and II are not reflected, delaying implementation and transferring liability have similar consequences: they potentially shift unexpected costs to others, either future generations instead of present ones, or the government instead of industry. By contrast, it seems sound that the beneficiaries of present nuclear energy should pay its full cost of production. If nuclear energy is conceived as a strategic option for the whole community, the liability can be extended accordingly and not be limited to nuclear energy consumers. Ideally, however, this decision should enter the public debate and one should limit the shift of this liability to the state and future generations. As expressed in a more general article from the Harvard Law Review (1981),

> "A waste generator's liability for costs stemming from its activities should be coextensive with the hazardous life of the wastes plus the time reasonably necessary to discover the injuries caused by the waste. Any other approach places a limitation on liability that is inconsistent with the principle that waste-creating activities should bear the full costs of those wastes."

This rigorous principle is practically impossible for long-lived waste of any kind, hence the necessary transfer of liability. However, the current legislation only allows an insufficient level of funding to be covered on future electricity produced by reactors still operating. In this sense, the transfer of liability in the US happens at reactor shutdown, which for a growing number of reactors will actually be earlier than acceptance of the waste into a repository, and hence earlier than in most countries.

For illustration, Zion 1 and 2, two reactors operated by Exelon, were permanently shut down in 1998. Because construction of the repository was delayed, it was already too late to fully expose Exelon to the variability of waste management costs for the waste produced during the 25 years of operation.[23] Using an adaptive fee, which need not be unique for all reactors, guarantees and a later transfer of liability would directly make utilities more exposed to the full cost of nuclear energy production.[24]

RESPONSIBILITY ALLOCATION

Mishaps from a State-only management in the US

The intersection between market risks faced by utilities and the need for public safeguards possibly influenced the US regulators' decision for a simple, centrally-planned solution by the Federal Government. Then and even now, the process could seem appealing to promote nuclear among a great diversity of utilities.

Nevertheless, the implementation of industrial projects by government did not prove to be a guarantee of safer development, as shown by the uncertainty about the future geologic repository and the resulting interim storage situation at decentralized reactor pools. Moreover, there are actually examples of implementation between multiple

[23] Early reactor shutdown provides a partial hedge by bringing down the amount of spent fuel. However, the $14 billion already spent for Yucca Mountain seem to advertise for high fixed costs and hence little reduction of the funding target, while risks of fund growth rate and project escalation are at best proportionally unchanged.

[24] In the Exelon case, extra cost for this waste could be covered by future fee increases which will affect all still-operating reactors (some of which, but not all, belonging to Exelon). The principle of a fee levied on nuclear electricity, without consideration of utility, creates solidarity between remaining nuclear reactor operators.

private and public operators under governmental supervision. Japan, Sweden and Switzerland respectively gathered their 10, 3 and 4 actors into single autonomous entities in charge of spent fuel management.

Notably, the management of the Fund dedicated to Yucca Mountain by the government did not result in a greater availability than if held by utilities. Originally, the US Nuclear Waste Fund was a separate account in the federal treasury.[25] Indeed, the program of the Office of Civilian Radioactive Waste Management (OCRWM, the office within DOE responsible for the repository program) was "self-financed", i.e. in contrast to research programs or purely regulatory offices the OCRWM had a direct funding source for a specific project. However, the Balanced Budget and Emergency Deficit Control Act of 1985 made the Nuclear Waste Fund subject to the government budget sequestration process. Despite its autonomous nature, the OCRWM now had to compete with other DOE programs and other departments for its budget. The competition led to a dynamic of increasing gaps between cautious budget requests and uncertain appropriations illustrated in Figure 4. The resulting funding instabilities were deemed detrimental by the OCRWM.[26] The phenomenon could provide an illustration to the Government Accountability Office's view that unstable funding leads to "increased costs and schedule, and reduced quality due to stop and start; loss of project momentum" (GAO 2009).

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[25] "There hereby is established in the Treasury of the United States a separate fund, to be known as the Nuclear Waste Fund". Nuclear Waste Policy Act (1982)

[26] "Absent a change in the funding mechanism, the contractual user fee revenues collected in the NWF are not available to meet their intended purposes." OCRWM (2001)
"While this assessment does not warrant a change in the fee, without a change to the current budgetary process to allow consistent and sufficient annual funding, the assumption that adequate funding is provided cannot be maintained.." OCRWM (2008).

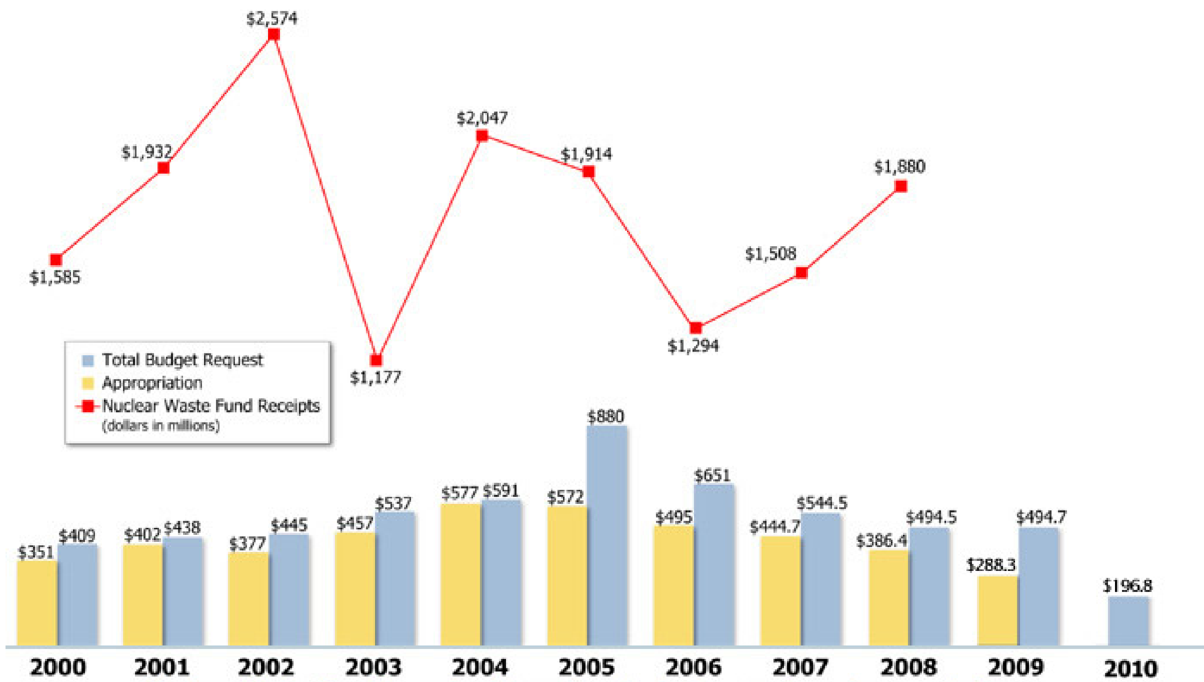

Figure 4. *Nuclear Waste Fund receipts (fees plus interest), OCRWM budget requests and appropriations*[27]

On the other hand, there are reasons to involve waste producers. Most notably because, as long as they are exposed to the total cost of spent fuel management, waste producers have incentives to make the spending process more efficient and optimize the fuel cycle. Such natural incentives disappear in the US system, for both government and utilities. Indeed, the fee is theoretically adjusted to cover all governmental costs with little incentive for efficient spending by DOE, since there is currently no independent financial and management oversight body that reviews the prudence of expenditures. As for utilities, they have limited capacity to capture the benefits of new fuel cycles or other initiatives which would decrease the total nuclear fuel cycle cost.

27 Source: OCRWM, http://www.ocrwm.doe.gov/about/budget_and_funding.shtml.

This loss of incentives has been increased further by the outcome of recent lawsuits on costs to the utilities prompted by delays in the Yucca Mountain project. Indeed, the resulting damages are paid for out of the federal Judgment Fund, not the Nuclear Waste Fund or allocations to the OCRWM. Even if the fee were adequate to cover expenses of the Nuclear Waste Fund, the costs would hence be borne by all federal taxpayers and not only utility ratepayers. Therefore, increasing storage costs resulting from delays in the federal disposal program do not provide a direct incentive to utilities nor to the federal actors.

Seeking greater balance of powers

These failings do not mean that a utility-only program should be advocated, but more generally that the self-adaptive features necessary to policies dealing with uncertainties and long time frames should be restored.[28] For this purpose, a different sharing of responsibilities could be considered. A gradation of organizations mixing public and private exists in various sectors, and in all countries: governmental program offices (e.g. office within ministry), independent authorities (e.g. safety authority), government-owned corporations (e.g. independent corporation fully owned by government, like postal services in many countries), or private corporations (with mixed ownership) are a few examples.

Such possibilities were already studied by a 1984 advisory panel to the Secretary of Energy (AMFM, 1984), but its conclusions were rejected by DOE in 1985 due to concern that a FedCorp could not "balance the dichotomy between a tight performance

[28] "Because changes in knowledge, relevant technologies, exposure patterns, and public priorities are often pervasive and typically cannot be known in advance, the capacity of regulatory systems to adapt and self correct is perhaps the key to effective long term performance." McCray and Oye (2007)

schedule and the need for extensive public consultation and intergovernmental relations".[29] It is possible that part of these concerns could be lifted by the creation of a fully governmental entity specifically and solely in charge of siting, for instance.

This complex issue, which the 2001 update of the AMFM report recommended for further investigation, can perhaps be touched upon through the balance of powers created by two key aspects of a spent fuel management program: funding and implementation. But for the US and the current system in the UK, these roles are shared between the industry and the state in most countries (see Table 1). We use the Finnish system to provide an illustration of how these two aspects could be used to create incentives for utilities:

- utilities are responsible for disposal implementation, and gathered in Posiva to carry out the schedule drawn up by the government
- the money for all anticipated remaining costs, estimated on a yearly basis by Posiva and reviewed by Ministry of Trade and Industry, must be set aside, undiscounted, in a Fund. Only 75% of this Fund can be borrowed back by utilities, while the remaining 25% can be borrowed back by the government at industry rates.[30]
- utilities can only be reimbursed as they complete the work. For instance, the cost of the disposal site for ILW and LLW (in Olkiluoto and Loviisa) were included in the Fund target until their completion by Posiva.
- fuel ownership and financial liability transfer occur at closure of the repository validated by the safety authority.

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[29] AMFM (2001)

[30] Under split management agreements, the participants can borrow the monies back (usually at standard rates like Euribor 5 years), which allows different actors to actually manage the Fund. This is also the case in Belgium (operator can borrow 75% back).

CONCLUSION

The limited involvement of utilities in the US has transferred significant financial and industrial risks to the federal government and eliminated natural incentives for utilities to develop new or more efficient waste management solutions. By placing the entire responsibility of a spent fuel management solution on the Federal government, the current system has neutralized the commercial players in the system while relying on a federal agency, which is not exposed to the costs and benefits of its own choices. The Federal government must find ways to harness the commercial skills of the private sector, and at least fully reflect the risks, which it accepts to bear. The nuclear renaissance provides the opportunity to challenge the 1982 principles for the institutional management of the radioactive waste program.

Table 1. Overview of spent fuel management characteristics in selected countries

	Vision on Nuclear	Disposal Implementation	Fund Management	Reprocessing		Transfer of Financial Liability	Current Hurdles
				View	Investment		
Belgium	Phase Out (until 2009)	State	Operator	Voluntary ->Forbidden	Operator	acceptance into repository	Delays in repository siting
Finland	Resume	Operators	Operators and State	Export Forbidden	/	closure of repository	
France	Generation IV	State	Operators	Compulsory	Operators and Foreign	(?)	
Germany	Phase Out	Operators and State	Operators	Compulsory ->Moratorium	Operators	acceptance into repository	Delays in repository siting
Japan	Generation IV	Operators	State	Compulsory	Operators	(?)	Tax on all kWh to finance Rokkasho-Mura escalation
Sweden	Phase Out (until 2009)	Operators	State	Forbidden	/	(?)	
Switzerland	Resume	Operators (and State)	State	Voluntary ->Moratorium	Operators	closure of repository	Delays in repository siting
UK	Resume	State	State	Voluntary	State and Foreign	(?)	Difficult cleanup of BE and BNFL legacy
USA	Resume	State	State	Voluntary	/	acceptance or reactor shutdown	Delay in repository licensing + law suits

This table is a simplification based on a more extensive review of IAEA's Country Nuclear Power Profiles, World Nuclear Association's Country Briefings, country legislations, and when available information from company statements, summarized briefly below.
For a more detailed comparison EDRAM (2005) provides a good reference despite recent changes in legislations (e.g. French 2006 law). For a thorough EU cross-country comparison on the subject of reactor decommissioning, see Wuppertal Institute (2007)

Belgium. Nuclear electricity is produced by Electrabel (GDF-Suez). ONDRAF is a public authority responsible for the strategy of disposal and its implementation. After 2003, funding was made separate into Synatom (owned by Electrabel with a "golden share" for the state) already managing enrichment, recycling and storage. The management of this fund is approved by a surveillance committee, which relies on ONDRAF for the level evaluation. 75% of the total provisions can be lent back to Electrabel. The ownership and cost of waste management remains with Electrabel until acceptance by ONDRAF, with operators responsible for hidden defects for 50 years.

Finland. Two utilities Fortum (51% state owned), and TVO (42% state owned) operate commercial nuclear reactors, and new private consortiums are also interested. In 1983, the government set guidelines and a schedule for long-term nuclear waste management, and established an absolute local veto on siting. Although individually responsible for their waste, the companies created Posiva Oy in 1995 as a joint−venture (60% TVO and 40% Fortum). Utilities make payments into a fund managed by the state but separated from its budget. Provisions reflect the total undiscounted cost of the remaining decommissioning and waste management work. The nuclear utilities are entitled to borrow up to 75% of the fund, against securities, and the government 25%. Legal and financial responsibilities remain with the producers until the nuclear safety authority (STUK) has confirmed it to be permanently disposed of.

France. EDF (85% state owned) is the sole operator of commercial reactors. Under the 1991 Act updated in 2006, a national agency, ANDRA, is responsible for the development of a retrievable disposal facility to be licensed by 2015. The Act also reaffirms the need for reduction of the quantity and radiotoxicity of waste (hence reprocessing). Under a national surveillance committee, the waste producer (EDF or Areva) is required to evaluate waste management costs cautiously and to provision the discounted expenses in internally segregated assets. So far, the producer has kept responsibility and ownership of waste even when disposed of at ANDRA (monitoring of Manche facility for LLW and ILW funded by EDF).

Germany. Nuclear reactors are primarily owned by E.ON, RWE, EnBW (45% EDF, 45% municipalities), and Vattenfall. Reprocessing was mandatory until 1994 but subsequently banned. Other decisions also led to the creation of a cap on the lifetime of operating reactors in 2000. Under the Atomic Energy Act amended in 1976, federal government is responsible for construction and operation of disposal. The BfS (federal office) commissioned DBE (owned at 75% by GNS, a consortium of utilities) to design and construct the repositories. Costs of waste disposal are estimated by BfS with DBE, and provisioned in the accounts of operators but with no restrictions over the investment of the funds. Ownership of the fuel and liability are transferred at delivery to the repository.

Japan. The nine regional electric companies (e.g. TEPCO), as well as JAPC (held in majority by the regional companies), operate nuclear reactors. The policy of compulsory reprocessing led to the construction of the Rokkasho□Mura reprocessing plant by JNFL (joint venture of the utilities). In 2000, the Diet mandated deep geological disposal of high−level waste from reprocessed fuel. As a result, the utilities created NUMO, responsible for site selection, licensing, construction, operation and monitoring. A 2005 legislation led to the creation of funds for reprocessing and disposal, external to the utilities and managed by an independent body supervised by the government. Utilities are reimbursed by the fund for their reprocessing expenses.

Sweden. Reactors are owned through cross participations of E.ON, Fortum and Vattenfall (state owned). Utilities gathered in SKB (34% directly held by Vattenfall) to implement disposal following the waste legislation of 1977. SKB already built an LLW and ILW disposal facility as well as an interim storage facility for spent fuel. The financial needs, i.e. the tax on kWh and the guarantees for each reactor are set annually by the Ministry after proposal of SKB reviewed by SKI, the safety authority. Since 1996 the funds are held and invested in bonds by the Nuclear Waste Fund, a government authority, while expenditures need to be approved by SKI.

Switzerland. Nuclear electricity is produced by 4 utilities, with majority held by cantons. In 1972 a cooperative (NAGRA) of waste producers was set up, involving plant operators and the federal government (for medicine, industry and research waste). Utilities also gathered in ZWILAG to build an interim storage facility. The waste disposal expenses occurring during the operation of the plants are provided for directly by the operators. The Radioactive Waste Management Fund, set in 2000 and managed by the Confederation, accrues a levy on nuclear power production for future costs, which are estimated by NAGRA and reviewed by the fund committee.

UK. Nuclear reactors are operated by British Energy (80% EDF) and Magnox Electric (state owned). Reprocessing is technically necessary for Magnox fuel, but is otherwise a matter for commercial judgment. In 2004, the government set up the NDA as an executive non−departmental public body, which took the assets and liabilities of BNFL (state owned), including the Sellafield reprocessing plant and Magnox reactors operated by contractors. A number of financial arrangements have been made to establish Nuclear Liabilities Fund (NLF) managed by the NDA; and new policy efforts (e.g. creation of NFLAB) seek to make future reactors internalize waste and decommissioning costs. In 2007, the NDA established the Radioactive Waste Management Directorate (RWMD) to devise and later implement a disposal solution.

REFERENCES

AMFM, 1984, "Managing Nuclear Waste – A Better Idea", D. F. O'Scannlain, E. L. Draper, M. E. Gates, R. D. Grimm, B. W.Johnson, B. Keating-Edh, T. R. Lash, M. Sampson, S. F. Singer, D. W. Stevens, S. M. Stoller, L. J. Wallace, A. Wight.

AMFM, 2001, "Alternative Means of Financing and Managing the Civilian Radioactive Waste Management Program", DOE/RW-0546.

Bunn, M., S. Fetter, J. P. Holdren and B. van der Zwaan, 2003, "The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel", Harvard Kennedy School, Project on Managing the Atom.

Callen, Ronald C., 1995, "Congress's Nuclear Waste 'Contract with America' - Where Do We Go From Here?", The Electricity Journal.

Cotton, Thomas A., 2006, "Nuclear Waste Story: Setting the Stage", Uncertainty Underground, MIT Press

EDRAM, 2005, "Radioactive waste ownership and management of long-term liabilities in EDRAM member countries"

GAO, 2009, "GAO Cost Estimating and Assessment Guide, Best Practices for Developing and Managing Capital Program Costs".

Harvard Law Review, 1981, "Allocating the Cost of Hazardous Waste Disposal", Vol. 94, No. 3, pp. 584-604.

Lester, Richard K., 2008, "Clearing the path toward a nuclear renaissance", The Boston Globe.

McCray, Lawrence and Oye, Kenneth A., 2007, "Adaptation and Anticipation: Learning from Policy Experience".

MIT, 2003, "The Future of Nuclear Power", S. Ansolabehere, E. S. Beckjord, J. Deutch, M. Driscoll, P. E. Gray, J. P. Holdren, P. L. Joskow, R. K. Lester, E. J. Moniz and N. E. Todreas.

OCRWM, 2001, "Civilian Radioactive Waste Management Fee Adequacy Assessment Report".

OCRWM, 2008, "Civilian Radioactive Waste Management Fee Adequacy Assessment Report, Fiscal Year 2007", DOE/RW-0593.

OCRWM, 2008b, “Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007”, DOE/RW-0591.

Segelod, Esbjörn, 2005, “The cost of the Swedish nuclear waste program”.

Westlén, D., 2007, “Reducing radiotoxicity in the long run”.

Wuppertal Institute, 2007, “Comparison among different decommissioning funds methodologies for nuclear installations”.