Managing Used Nuclear Fuel in Canada – Challenges Ahead as a Repository Site is Sought

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In 2007 June, the Government of Canada endorsed the recommendations of the Nuclear Waste Management Organisation (NWMO) and decreed that the concept of Adaptive Phased Management (APM) for used nuclear fuel should proceed. APM involves continuing temporary storage at reactor sites while a central site is chosen, then transportation to the central site where the option of temporary shallow burial may be exercised as a deep, geological repository is developed and constructed. The process is flexible and throughout can be adapted to changing ideas and technologies. Future generations will have the means to dispose safely of the nuclear wastes along with options such as the possibility of reprocessing.

In the next (siting) phase, engagement with Canadians will continue to be important as technical matters are addressed. The issues addressed by the Advisory Council are expected to change in this phase. The outlook for the nuclear industry in Canada is now much different from that during the NWMO's first (i.e., study) phase, when the basis for the recommendation of APM was a limited fleet of reactors producing one type of used fuel; new build is now a virtual certainty and the type of reactor to be installed is likely to be different from that of the current fleet of CANDUs using natural uranium fuel. Thus, Advanced CANDU Reactors (ACRs) and PWRs are being considered – both of which use enriched fuel with the concomitant implications for waste management. Because of the initial enrichment level and the higher burnup achieved in these reactors, their used fuel will contain a much higher concentration of fissile uranium and plutonium than does the current inventory of CANDU used fuel in Canada. This increases the potential for future reprocessing and recycling.

The paper discusses the implications of these issues for the NWMO and the Advisory Council.

Keywords: *used nuclear fuel, waste management, NWMO, Advisory Council, reprocessing, citizen engagement, geological repository, on-site storage, transportation*

1. Introduction

In 2005 November, the Nuclear Waste Management Organisation (NWMO) submitted to the government of Canada the final report [1] on the first phase of its study into the management of Canada's used nuclear fuel. The report was the culmination of three years of intensive study into the social, economic and technical issues that will be involved in the managing of the approximately 3.6 million CANDU fuel bundles that the existing fleet of reactors in Canada will have produced at the end of their estimated 40-year operating lifetime. A major focus of the study was the engagement of Canadians – individuals, communities, Aboriginals, interest groups, etc. – by a range of communication techniques. This was to address one of the findings of a previous Canadian study [2] by the Seaborn Panel, namely, that broad public support is necessary to ensure the acceptability of a concept for managing nuclear fuel waste. A wide range of technical and economic expertise was also tapped in the study in order to ensure a sound basis for the recommendation. In 2007 June, the government accepted NWMO's concept of "Adaptive Phased Management" (APM) and decreed that the next phase of the exercise should proceed. Adaptive Phased Management involves finding a central site for an ultimate repository while temporary storage at reactor sites continues, then developing the site with an intermediate storage facility while the deep geological repository is researched and constructed. Planning for the next phase of “siting” has already begun; again, this phase will involve extensive engagement with Canadians.

Throughout the study phase, the NWMO sought and relied upon advice from its Advisory Council. As already reported [3], the Council is composed of individuals with a range of expertise in the social and physical sciences and in engineering. Nevertheless, despite diverging opinions on the rôle of nuclear energy for the generation of electricity, the Council was unanimous in its endorsement of NWMO’s recommendation of APM, stating in its Final Report (which was appended to Reference 1) that “APM should be implemented with the appropriate leadership, resources and time to undertake the process as described in NWMO’s *Final Study Report*”. In other words, the Council recognized that there must be no relaxing of the commitment of resources, effort and time if APM is to succeed, and emphasis must continue on public engagement with full consideration of all social, ethical and technical factors during the siting phase.

The Council was particularly concerned that energy policy in Canada was not well defined, so that the rôle of nuclear energy in the future was uncertain. It pointed out that the NWMO study was limited to the current fleet of reactors, which consists of traditional CANDUs fuelled with natural uranium. Even with major refurbishments to provide lifetimes of 50 years, they would produce only about 4.4 million used fuel bundles in total, a quantity within the scope of the NWMO study. Any increase in installed nuclear capacity in Canada would lead to a significant increase in that quantity, the Council went on to say. Moreover, a nuclear expansion would likely entail new technologies employing enriched uranium fuel, which would have different characteristics from those of natural uranium fuel when used. The Council therefore concluded that any significant change in the amount or type of used fuel to be managed (whether due to phase-out or expansion of the Canadian nuclear program) should trigger a review of the NWMO’s work to date.

Since the Final Report was put together, the energy scenario in Canada has changed. Existing reactors are being or are planning to be refurbished and new build is contemplated in the provinces of Ontario, New Brunswick and Alberta. In fact, Ontario is virtually certain to commit a fleet of new reactors by the end of 2008. Those reactors will be Advanced CANDU Reactors (ACR-1000s) or light-water-cooled reactors (LWRs), each requiring enriched uranium fuel. With its higher burnup and higher fissile content, the used fuel from these reactors poses different problems of management but also provides greater possibilities for recycling. The future scenarios that the NWMO will have to consider must now include the possibility of reprocessing.

2. Next phase of NWMO’s activities

The NWMO is now expanding its organization as it moves from the previous study phase that led to the recommendation for APM to an implementation phase for finding a repository site. While it will keep abreast of developments in nuclear fuel cycles in the context of long-term energy strategies for Canada, the more immediate issues over the 2008-2012 period are to be addressed via seven strategic planning objectives. These objectives flow from the NWMO’s Vision, Mission and Values, and the objectives and expectations that Canadians said were important for APM. The Strategic Objectives are:

- Seek to build long-term relationships with interested Canadians and Aboriginal people.
- Advance technical and social research.
- Develop and refine a long-term funding formula involving schedules for trust-fund deposits by waste producers.
- Continually review and validate plans in light of new information and changes in nuclear energy policy, such as the introduction of new technologies and different fuel types.

- Continue to develop and maintain a governance structure.
- Build NWMO as an implementing organization.
- Design a process for site selection in collaboration with interested Canadians..

The goal of the engagement program is to build awareness, understanding and support for APM among interested Canadians – particularly in the four nuclear provinces of Saskatchewan, Ontario, Québec and New Brunswick. The intensive public engagement undertaken during the study phase has now set an expectation for the decision-making during the implementation phase. The achievement of NWMO's plans will hinge upon its relationships with interested Canadians and Aboriginal people, who will have a strong influence on all of NWMO's work. A social research program will build NWMO's understanding of best practices for community capacity-building and collaborative processes, and for understanding the impacts of a community's becoming a potential site host.

A strong technical research and development program will ensure that the NWMO will benefit from technological innovation in radioactive waste management developed in Canada and abroad, and will ensure that it maintains adequate human resources to manage the various phases of implementation. Developments in fuel cycle technology and their impact on waste management will be followed closely. Over the next five years, the NWMO will focus on building human capacity, developing the means to evaluate sites from a technical perspective, strengthening its understanding of the safety case for a geologic repository and developing conceptual designs. Specific milestones have been established in each of the four areas of geoscience, safety assessment and licensing, engineering and emerging technologies. At the end of the five years, the NWMO expects that it will be ready to start the technical and socio-economic assessment of a site in an informed, willing host community.

The NWMO will work to ensure that both the development of the site selection process and the process itself are judged to be inclusive, fair and transparent. The NWMO committed in the Final Study Report [1] to develop the siting process and the associated engagement program via public collaboration. The design of the siting process will build on NWMO's principles for seeking an informed and willing community to host the long-term management facility. Technical, social, environmental and economic issues will be considered along with the lessons learned from the engagement programs to date. The site selection process that emerges must meet the expectations of Canadians and address their key issues, such as the transportation of used fuel, and continue to build trust and confidence in NWMO and its operations. Important preliminary work will involve developing institutional policies, practices, structures and arrangements to support the siting process.

3. Future fuel cycles

In a discussion paper [4] presented to the Advisory Council during the NWMO study phase, technical aspects of the disposal of spent CANDU fuel were addressed from the perspective of isotopic composition. It was noted that the economic incentive for reprocessing spent fuel from CANDUs is far less than for reprocessing spent LWR fuel because of its very low fissile content. In fact, the U-235 concentration in the uranium in the spent CANDU fuel (approx. 0.23% by weight) is comparable to the tails assay at the enrichment plants (note that, since fresh CANDU fuel is natural uranium and the CANDU reactor is very neutron efficient, the CANDU reactor uses the least amount of mined uranium per kWh of generated electricity of all existing power reactors). Thus, it would be uneconomic to reprocess CANDU fuel if the sole objective were to recover the uranium, since there are vast amounts of non-radioactive and chemically pure depleted uranium available from past enrichment operations all over the world (probably well over one million tonnes). The only economic incentive to reprocess spent CANDU fuel would then be to recover the plutonium.

The concentration of plutonium in discharged CANDU fuel is small, about 0.4%, compared with 1% in fuel discharged from modern LWRs; however, over the lifetime of existing facilities, the total amount of plutonium accumulated in the inventory of spent fuel in Canada may well exceed 300 te. With current commercial reprocessing technology, high costs and proliferation issues arising from the handling of isolated plutonium all but ensure that the current inventory of spent CANDU fuel will never be reprocessed; it should thus be managed as a waste – at least, for the time being. In the long-term, reprocessing could be required for special applications such as the production of fissile feed to start a fleet of fast breeder reactors, or for the introduction of thorium cycles in advanced CANDU or ACR reactors. This will require only a small fraction of the existing plutonium stock in Canadian spent fuel.

This approach is consistent with NWMO's strategy of APM, leading to the direct disposal of the spent fuel bundles in a deep geologic formation. Appendix 9 of Reference 1 contains a detailed discussion of reprocessing, including the above considerations, and it is indeed concluded that reprocessing as a management approach for used nuclear fuel is considered to be highly unlikely as a viable scenario for Canada at this time. But, it is recognized that reprocessing may be feasible in the future when economic conditions could be much different. APM provides sufficient flexibility to deal with this eventuality by ensuring accessibility to the used fuel for a sufficiently long time so that future generations can make decisions on the final disposition.

Two major factors may lead to an early revision of this perspective in Canada:

- The refurbishment of current reactors and the likelihood of new build. The new reactors will likely be third-generation, designed to increase safety and improve the economics of electricity generation by reducing capital and maintenance costs and increasing operating life. They will be either ACR-1000s or advanced PWRs, each requiring enriched uranium fuel.
- The price of uranium, which has increased significantly since 2002 and is unlikely to go back to its historical level. Utilities are now facing the impact of rising fuelling costs and are supporting the development of advanced fuel cycles aimed at improving uranium utilization. For the longer term, leading nations are collaborating in the development of fourth-generation reactors, aimed principally at closing the fuel cycle and increasing thermodynamic efficiency. To this end, Canada is a member of the Generation-IV International Forum (GIF), and actively participates in two of the six programs (the SCWR and the VHTR) [5].

3.1 Tandem fuel cycles

A direct consequence of rising uranium prices is the increase in value of the large inventories of uranium and plutonium recovered from the commercial reprocessing of LWR fuel around the world. Although some of the plutonium is currently recycled as MOX fuel, this form of recycling only reduces the accumulation rate of plutonium; the stocks will keep increasing. Eventually, fourth generation fast reactors could operate as burners or as breeders of plutonium so that the plutonium stock can be managed optimally, but these reactors are not expected to be deployed for up to 50 years. In the meantime, a strategy for the mid-term is necessary. A number of innovative options for recycle in LWRs have been reviewed [6] and one alternative is of particular interest for CANDU reactors; namely, the introduction of PWR/CANDU tandem fuel cycles.

Slightly-enriched Low Void Reactivity Fuel (LVRF) will soon be used in the four CANDUs at Bruce-B in Canada. The basic fuel design, called CANFLEX, has already been demonstrated at enrichment levels of 2%, and the ACR-1000 reference fuel is a modified version of CANFLEX with a slightly higher enrichment. Development of the ACR fuel is expected to continue in the future in order to increase the discharge burnup beyond 20 MWd/kg and to reduce uranium requirements. Because the enrichment level in the recovered uranium (RU) from commercial reprocessing of LWR fuel falls within this range, an immediate opportunity exists for CANDU utilities to recycle the RU directly with no need for further enrichment.

Over the past 15 years, Korea and Canada have collaborated in the development of the DUPIC fuel cycle. In this tandem cycle, a dry process first reduces spent PWR fuel to a powder. After removal of gaseous fission products, the powder is refabricated into CANDU bundles and used directly in existing CANDUs. DUPIC is therefore a single recycle strategy, in which the residual U-235 and plutonium content can be reused in CANDU. This cycle provides on average an additional 18 MWd/kg of burnup to the discharged PWR fuel, thereby extending the resource by approximately one third [7]. A number of DUPIC fuel elements have been fabricated from spent PWR fuel at Chalk River and have actually been irradiated to a burnup of 22 MWd/t in the NRU reactor.

A recent proposal was for an alternative route to DUPIC using the Fluoride Volatility (FV) process to extract most of the uranium from spent LWR fuel, thereby creating two streams [8]. The first stream, containing over 95% of the uranium, can be readily recycled in CANDU – as envisaged for the RU from commercial reprocessing. The second stream, representing only 5% of the original volume, contains the rest of the uranium, most of the fission products, and all of the actinides including plutonium. Experience with DUPIC suggests that CANDU fuel could be refabricated from this ‘plutonium ash’, and calculations have shown that a burnup as high as 60 MWd/kg could be achieved. Also, although operational experience with MOX fuel in CANDUs is limited, theoretical work has been carried out, supported by small-scale experiments. It confirms that CANDU reactors can efficiently burn MOX fuel, supporting the idea that plutonium ash could also be effective in CANDUs.

These tandem cycles are only possible because of the versatility of the CANDU reactor and are made more attractive by the possibility of using dry processing techniques to convert the used LWR fuel. Those techniques are simpler than the conventional chemical extractions and are inherently safe against proliferation, since the plutonium is never separated from the highly radioactive fission products and other actinides. The total amount of plutonium is significantly reduced with a single recycle, and the spent DUPIC fuel would provide a reduced burden (per kWh of electricity) to any waste repository when compared with the original spent PWR fuel. Tandem fuel cycles obviously hold promise for utilities operating both PWRs and CANDUs, as in Korea or in China. For Canada, which has only CANDU reactors so far, an alternative route to recycling must be found.

3.2 Closing the fuel cycle in Canada

As described above, the new-build reactors in Canada will produce spent fuel with significantly different properties from those of the current inventory of spent CANDU fuel on which the NWMO study was based. For one thing, the burnup of the spent fuel will be 3 to 6 times higher than natural uranium spent fuel, producing significantly higher radioactivity and heat loads. Continuing with the current concept of direct disposal would thus require a redesign of the fuel handling procedures, including equipment for storage and transportation.

If PWRs are chosen for new build, Canadian utilities could benefit from the advantages of tandem fuel cycles, starting with a small inventory of new PWR spent fuel for dry reprocessing. Since it may prove to be difficult to reprocess the Canadian spent PWR fuel offshore, the only alternative would be a successful demonstration and commercialization of an entirely new reprocessing industry in Canada – possibly based on a dry technology such as FV. Future governments would therefore need to consider the impact of this alternative in their long-term strategic planning.

The other possible choice for new build in Canada, the ACR-1000, is very similar to existing CANDU reactors, with pressure tubes and heavy water moderator. The major differences lie in the use of light water as a coolant and a more compact core with fuel enriched to around 2.4% in U-235. At discharge, the ACR fuel will reach 20 MWd/kg, a burnup three times that of the current CANDU fuel. The fissile content of the discharged ACR fuel will be of the order of 1%. This corresponds roughly to the initial enrichment of the LVRF fuel used in the Bruce-B reactors.. Since the inner diameter of the pressure tubes in ACR-1000 and in CANDU are identical, there is the prospect for recycling spent ACR fuel bundles *directly* into CANDU with no reprocessing. Direct recycle of ACR fuel in CANDU would therefore be a simple first step towards closing the fuel cycle in Canada.

Recycling spent CANDU fuel in Canada has not been seriously considered so far because of the low fissile content, the low cost of storage and disposal, the prevailing low uranium prices and the high cost of reprocessing with conventional techniques. With increasing uranium prices, however, there is the possibility of developing advanced recycle technology in Canada that is particularly suited to the low burnup fuel. In particular, the Fluoride Volatility (FV) process [8] mentioned earlier could be applied to the existing spent CANDU fuel to convert most of the inventory into a low-level waste, i.e., depleted UF_6 that can be easily stored and converted for future use in fast reactors as fertile material. The fissile content of the 'plutonium ash' stream could then be adjusted via the residual uranium component to produce new CANDU fuel appropriate for recycle in existing CANDUs or ACRs.

ACR-1000 reactors retain much of the fuel-cycle flexibility of the CANDUs [9]. They are particularly well suited to the thorium cycle, which can offer a sustainable perspective to nuclear power in Canada. A long-term strategy would be to mix thorium with the concentrated plutonium ash extracted with FV from existing spent CANDU fuel to initiate thorium fuel cycles. There are several possibilities, ranging from once-through cycles to closed cycles with recycling of the U-233. The latter results in a dramatic improvement in resource utilization, constituting an effective way of closing the fuel cycle in Canada.

A new vision ensuring energy security for Canada may therefore include recycling spent CANDU fuel using advanced technology. The development of new reprocessing methods will take a long time and require considerable resources, but in the interim significant improvements in resource utilization will be possible with PWR/CANDU or ACR/CANDU tandem cycles – the latter requiring no reprocessing and enabling direct bundle recycle with minor modification. Great potential also exists in Canada for utilizing thorium supplies, which can be introduced early as fuel in heterogeneous ACR reactors in a once-through scheme, providing a significant reduction in primary uranium requirements. The resulting fissile U-233 that accumulates in the spent fuel can be left there to be "mined" via reprocessing techniques as future needs dictate.

Such developments are totally compatible with NWMO's scheme of APM, which was devised very much as a response to public concerns – concerns that include considerations of future re-use of spent fuel. However, until such time as decisions are made on appropriate fuel cycles for Canada, the Advisory Council would recommend no deviation from the current strategy based on deep geologic disposal of unreprocessed fuel. At the same time, public confidence must be maintained as NWMO keeps abreast of the advances in fuel cycle technology and adapts as necessary.

4. Social consequences – Advisory Council perspective

The Advisory Council has discussed at some length changes in energy policy in Canada – particularly the possibility of new nuclear build. Since APM was proposed in 2005, reactor refurbishment has been undertaken and new nuclear generation has become a virtual certainty. Also, as discussed earlier, advanced fuel cycles and reprocessing spent fuel will be considered in the long term. Since NWMO has a legislated requirement to manage all of Canada's used nuclear fuel, Council has emphasized that the organization must prepare for such eventualities and include their social and technical impacts in the management plan. While decisions about Canada's nuclear energy choices will not be made by NWMO, the potential for decisions that may impact the amount and characteristics of spent nuclear fuel to be managed must be recognized. The Council therefore supports NWMO's plans for ongoing monitoring, review and broad discussion of new developments so that the strategy can be adjusted as required. It is encouraged by NWMO's commitment to consider the implications of new nuclear build in its engagement program, its technical and social research programs, its financing formula, its consideration of the size, structure and governance of the organization, and in its design of a process for site selection. This is an issue often raised in NWMO's engagement process. In a recent round of public dialogues completed in Spring 2008, Canadians urged NWMO to address the impact of changing energy policies on the implementation of APM.

This recent round of public engagement confirmed that Canadians continue to have a key interest in the primary issues of safety, security and environmental stewardship. Accountability and governance, independent review and transparency in NWMO's operations are strongly supported. Many identify transportation as a key issue to be addressed in implementing APM, since the used fuel must be moved from seven different sites in Canada to a new central location.

Looking ahead, the Advisory Council will play an important role in providing guidance and counsel to NWMO on the challenges of implementation and on processes which continue to invite open, transparent engagement with Canadians on this important issue.

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