

Watching Brief on Reprocessing, Partitioning and Transmutation

Canadians have expressed interest in knowing more about the possibility of recycling or reusing used nuclear fuel. Reprocessing involves the separation of potentially fissile materials, such as plutonium, from used nuclear fuel through the application of chemical and physical processes for recycling in a reactor. This watching brief summarizes recent technical and strategic reviews of reprocessing, partitioning and transmutation (RP&T).



Executive Summary

Work continued in 2011 in several international programs to review and assess the implications of advanced fuel cycles, including reprocessing, partitioning and transmutation (RP&T), on waste management issues. Comprehensive technical reports were published by the International Atomic Energy Agency (IAEA), the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA), the Electric Power Research Institute (EPRI), US Blue Ribbon Commission on America's Nuclear Future (BRC), US Government Accountability Office (GAO) and US Nuclear Waste Technical Review Board (NWTRB) in 2011. Additional strategic reviews were published by the EPRI and the UK Nuclear Decommissioning Authority (NDA). These technical and strategic reviews, which were prepared independently by various teams of international experts, all reached quite similar conclusions:

- » Some form of deep geological repository is required regardless of the fuel cycle in order to be able to deal with long-lived radioactive wastes.
- » While RP&T has the potential to reduce the volume of used nuclear fuel and high-level waste for placement in a deep geological repository (when combined with advanced fuel cycles using fast reactors), it also significantly increases the quantity of long-lived low- and intermediate-level waste (which also requires a deep repository for long-term management) and does not significantly reduce the underground footprint of the repository.
- » Advanced fuel cycles are at least many decades away from being ready for commercialization due to the time required for the technical research, and to develop and demonstrate the reactor technologies. Broad public acceptance issues are also likely to inhibit their demonstration and deployment in the near term.
- » The lifecycle cost of advanced fuel cycles is higher than once-through fuel cycles, due to the high costs of developing and constructing the new generation reactors, reprocessing facilities and fuel fabrication plants. If such fuel cycles could be developed, the cost and project risks for implementing them on a commercial scale would currently make them very unattractive for utilities to deploy.
- » Some countries currently engaged in fuel reprocessing (such as the UK) are considering discontinuing this practice due to the lower cost option of direct placement of used fuel in a deep geological repository.

These conclusions are consistent with those stated in previous NWMO watching brief reports [Jackson 2008, 2009, 2010].

Discussion

The NWMO has kept a watching brief on reprocessing, partitioning and transmutation (RP&T) developments over the past few years. Previous detailed technical reports are available on the NWMO website [Jackson 2008, 2009, 2010]. This present report provides a summary of recent international activities since the 2010 report was published.

In 2010 and 2011, the US Blue Ribbon Commission on America's Nuclear Future (BRC) conducted an extensive review of available options and technologies for management of the back end of the nuclear fuel cycle. The BRC was appointed by the US President in 2010 following his decision not to proceed with the Yucca Mountain repository project. The mandate of the BRC was to "...conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense used nuclear fuel and nuclear waste. This review should include an evaluation of advanced fuel cycle technologies that would optimize energy recovery, resource utilization, and the minimization of materials derived from nuclear activities in a manner consistent with U.S. nonproliferation goals."

In their final report [US BRC 2012a], the BRC stated (among other things):

- » *The conclusion that disposal is needed and that deep geologic disposal is the scientifically preferred approach has been reached by every expert panel that has looked at the issue and by every other country that is pursuing a nuclear waste management program.*
- » *Technologies exist today or are under development that would allow spent fuel to be at least partly re-used; systems have also been proposed that could – in theory and at some point in the future – possibly allow for the continuous recycle of reactor fuel, thereby fully "closing" the fuel cycle. Substantial uncertainties exist, however, about the cost and commercial viability of the more advanced of these technologies; in addition, significant concerns have been raised about their impacts on weapons proliferation risks and other aspects of the fuel cycle (e.g., the production of LLW) even if they could be successfully deployed.*
- » *...no currently available or reasonably foreseeable reactor and fuel cycle technology developments – including advances in reprocessing and recycling technologies – have the potential to fundamentally alter the waste management challenge this nation confronts over at least the next several decades, if not longer.*
- » *In any event, we believe permanent disposal will very likely also be needed to safely manage at least some portion of the commercial spent fuel inventory even if a closed fuel cycle were adopted.*
- » *One of our central recommendations, therefore, is that the United States should undertake an integrated nuclear waste management program that leads to the timely development of one or more permanent deep geological facilities for the safe disposal of spent fuel and high-level nuclear waste.*

Additional detailed reports were also issued by each of the three subcommittees of the BRC (Reactor & Fuel Cycle Technology, Transportation & Storage, and Disposal) [US BRC 2012b, c, d].

The US Nuclear Waste Technical Review Board (NWTRB) was established in 1987 with a mission to evaluate the technical and scientific validity of activities undertaken by the US Department of Energy (DOE) related to implementing disposal of civilian used nuclear fuel and high-level waste, and provides objective expert advice on nuclear waste management to Congress and the Secretary of Energy. Board members are appointed by the US President from a list of candidates submitted by the National Academy of Sciences. In its 2011 review of waste management issues associated with advanced fuel cycles, the NWTRB stated [US NWTRB 2011a, b]:

The results [of this review] reinforce the need for a deep geologic repository for disposal of both SNF and vitrified HLW in the United States and demonstrate that the timing of the availability of such a repository will fundamentally affect the need for additional SNF storage capacity. The results also show that, for the existing LWR fleet and the additional LWRs being considered by the NRC, the reprocessing scenarios considered here would have limited benefit in reducing the demand for natural uranium and limited benefit in reducing the volume of SNF and HLW, while significantly increasing the amount of low-level radioactive waste requiring disposal.

The Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency's (NEA) Working Party on Scientific Issues of the Fuel Cycle has carried out several recent technology evaluations related to advanced fuel cycles involving partitioning and transmutation [e.g. NEA 2010, 2011]. Its most recent report [NEA 2011] provides a review of the current scientific understanding of the impacts of these technologies and fuel cycles on repositories, including such aspects as repository performance, estimated dose rates, decay heat, waste volumes, and retrievability and reversibility. The report provides a detailed technical summary and analysis of previous research conducted in Europe, the US, Japan and elsewhere since the 1990s. Some of the main conclusions of the report are:

- » *The P&T strategy of recycling actinides allows in principle a combined reduction of the amount of radioactive waste to be stored and the associated residual heat, although processing will increase the amount of intermediate and low-level waste. Despite a very large number of studies, both at national and international levels, there is not a general consensus on the impact of such P&T strategies on repository performance.*
- » *[Partitioning and] Transmutation of part of the waste, e.g. the higher actinides, through use of advanced fuel cycles, although perhaps feasible in the coming decades, would not eliminate the need to manage the currently existing waste (i.e. vitrified waste) and remaining high-activity, long-lived radioactive waste, e.g. fission products, and other activated materials from future fuel cycles.*
- » *While P&T will never replace the need for waste repositories, it has the potential to significantly improve public perception regarding the ability to effectively manage radioactive waste by largely reducing the transuranic (TRU) waste masses to be stored and, consequently, to improve public acceptance of the geological repositories.*

Most of the proposed advanced fuel cycles are based on the use of "fast reactors." Compared to most of the reactors in operation today (including all CANDU reactors), which rely on lower energy "thermal neutrons" to maintain the fission process, fast reactors use a higher energy spectrum "fast neutrons." This can utilize a wider range of actinide isotopes, thus extracting more energy from the fuel and

converting (or transmuting) more of the long-lived actinides into shorter-lived fission products. In order to maximize the efficiency of this process, also known as “actinide burning” or “deep burning,” the fuel must be recycled numerous times. However, the technology for fabricating and recycling the fuel is not fully developed, and is complex and costly. In addition, the system requires large-scale deployment of a new generation of fast reactors. There are currently only a few such prototype reactors in operation or under development around the world. Some previously operated fast reactors (e.g., in the UK, France and Japan) have been shut down due to technological difficulties or economic considerations. There are no fast reactors in Canada and currently no plans to construct one, although Canada is a member of the Generation IV International Forum group of countries collaborating on the research of such reactors. Construction of a prototype reactor is a program of tens of billions of dollars. The high temperatures, high pressures, high neutron fluxes and/or corrosive fluids used in fast reactor designs require the development of new materials for the core structure as well as the fuel matrix. This is a potential showstopper issue – without these advanced materials, which have not yet been developed and proven in service, the reactors cannot be built.

A recent International Atomic Energy Agency (IAEA) review of the status of fast reactor fuel cycles [IAEA 2011] looked at a number of technical issues with reprocessing and recycling related to fast reactors. One of the issues that is raised in the report relates to the length of time that the fast reactors need to operate in order to achieve their goal of transmuting the actinides:

The burnup achieved with the FR [fast reactor] fuel is usually limited to about 250 GW-d/t HM. Thus, an effective actinide burner cannot operate in a once-through mode but rather requires a fuel cycle, which allows the fuel to be recycled many times. For the maximum burnup of 250 GW-d/t HM and recycle intervals of six years, it would take 96 years to achieve a hundredfold waste mass reduction. Thus, it can be concluded that an effective transmutation system needs a fully closed fuel cycle in which all actinides are recovered with nearly 100% efficiency and then recycled. To fully exploit the potential of such a system, it must be operated for an extended period of at least 100 years.

Achieving the goal of near 100% actinide recovery efficiency requires a technologically complex (and expensive) system that will produce a wide range of chemically complex wastes. The IAEA report recognizes that the development of suitable treatment and conditioning processes for these wastes is an important issue still requiring substantial research:

Thus, in the case of the FR fuel cycle, there is an incentive for development of waste matrices that can tolerate higher salt content and can also remain stable for extended periods of time in a geological environment. Ceramic matrices for waste immobilization have been under development in many countries for this purpose. However, there is no industrial scale experience on immobilization of waste in ceramic matrices. Identification of matrices with lower melting temperatures, and tolerance for higher loading in terms of salt content as well as radioactivity content are important areas of innovation.

The status of the DOE's advanced fuel cycle research plan in the US was the topic of a US Government Accountability Office (GAO) report in 2011 [US GAO 2011]. The GAO is an independent, non-partisan oversight agency that works for the US Congress. Essentially an auditing agency, the GAO investigates how the US federal government spends taxpayer dollars. The 2011 report examined DOE's research plan relative to its goal of being able to select one or more advanced fuel cycles for further development by 2020 and demonstrating them by 2050. The GAO evaluation recognizes that the research required to reach this goal is substantial, long-range, costly, and ultimately, will fail unless there is substantial collaboration with the commercial nuclear sector, which would need to deploy the technology. As such, the GAO concludes that the DOE research plan needs to be revised such that it provides a clear

methodology to be able to focus on key and promising areas for future research while minimizing efforts in other areas.

The UK Nuclear Decommissioning Authority (NDA) is a government body in the UK charged with managing the legacy assets of the UK nuclear industry, including decommissioning, used fuel reprocessing, site cleanup and restoration, and waste management. It recently published its review of options for oxide fuels (mainly from the UK fleet of advanced gas reactors (AGRs)) [UK NDA 2011]. The previous UK policy was to reprocess the fuel from these reactors to recover the fissile material for eventual reuse in MOX fuel and advanced reactors. The review, which is currently out for public comment, recommends completing existing reprocessing contracts, then discontinuing any further reprocessing after 2018. This is on the basis that the costs for the reprocessing facility have already been sunk, making this option more cost-effective for the time being. If these facilities were not available, or required major refurbishment in the future in order to complete the existing contracts, then the program would be terminated early since it is more cost-effective to directly emplace the used fuel in a deep repository rather than to develop new reprocessing capability. In addition, the UK currently has no plans to use MOX fuel or to operate fast reactors, so the separated fissile material is not being used for any purpose and would be treated as a waste. The NDA study also concluded that the difference in geological repository size for direct emplacement versus reprocessing was less than 10%, which they considered to be insufficient to be a factor in the decision. (The direct emplacement repository was calculated to be less than 10% larger than a repository for long-lived waste from reprocessing for a given quantity of used fuel.)

The Electric Power Research Institute (EPRI) is a utility supported and funded group based in the US. Although its primary focus is US utilities, the EPRI also has a number of international members, including Canadian utilities. It conducts research into many areas of interest to power generation companies, including nuclear topics. Its nuclear program includes waste and fuel cycle related issues. Two recent reports [EPRI 2010a, b] look at advanced fuel cycle issues and costs from an operating utility perspective. The reports highlight the technological complexity of the advanced fuel cycles and the need for complete integration of all aspects of it. Without the complete system of reactors, reprocessing, fuel fabrication and disposal systems for the different waste types, the fuel cycles will not work. One of the main conclusions of the review states:

Many options can be envisioned; however, many of those represent dramatic changes compared to the current situation and are not likely to lend themselves to industrial-scale deployment. An evolutionary and progressive pathway is likely to be more realistic than a revolutionary pathway that attempts to simultaneously solve all real or perceived fuel cycle issues with advanced technologies. The externalities of nuclear energy, such as waste generation and proliferation risks, have to be addressed in a safe, but reasonable, way. Thus, advocating transmutation of all the transuranics and fission products or making nuclear materials so unattractive that they are practically unusable in the fuel cycle itself do not represent realistic options.

The report goes on to state:

The technical and economic conditions for the breakthrough of these advanced technologies are challenging because they encompass not only reactors, but also dedicated reprocessing, fuel fabrication, and waste disposal facilities. These elements are closely interdependent, and their performance will have to be consistent. Their competitiveness may be anticipated on paper, but it will have to be proven by experience.

Figure 1 (extracted from reference [EPRI 2010a]) shows the complexity of a typical advanced fuel cycle, the number of facilities involved, and the integration and interactions required in order to get the fuel cycle to work. Certain key elements of the cycle, such as the fuel fabrication plant and reprocessing plant for fast reactors, have not been designed or demonstrated yet. Each of the facilities also produces a wide range of operational and decommissioning wastes in a variety of forms.

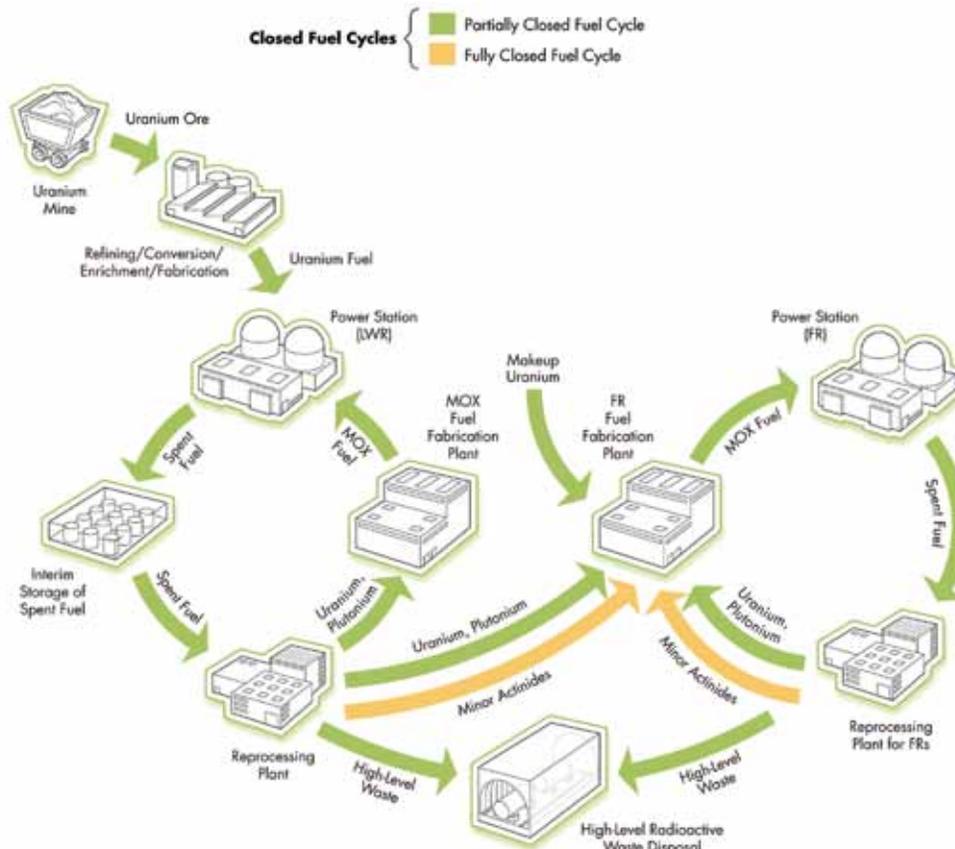


FIGURE 1: Illustration of an advanced nuclear fuel cycle [EPRI 2010a]

Several countries that operate both CANDU type reactors with natural uranium fuel and light-water reactors with enriched uranium fuel (such as China, South Korea and India) are also researching or developing synergistic fuel cycles for managing their used light-water reactor fuels such as DUPIC (“Direct Use of PWR fuel In CANDU”) and NUE (“Natural Uranium Equivalent”). After mechanical, thermal and/or chemical processing to resize the fuel pellets and remove volatile fission products, their used light-water reactor fuel is reconfigured as CANDU fuel bundles and introduced into their CANDU reactors to extract additional energy. Note that these technologies are designed for managing light-water reactor fuels and are not applicable in Canada, since Canadian utilities do not currently operate light-water reactors and the technologies are not applicable to used CANDU fuel.

Basic technical research is also progressing in a number of advanced reactor and fuel cycle areas, including RP&T, and has been reported at a number of conferences, such as ICENES (15th International Conference on Emerging Nuclear Energy Systems) and GLOBAL 2011. Although the research shows the wide variety of work that is being carried out on very specific topics, it also demonstrates that the

technology is still far away from practical implementation since none of the work has progressed from the laboratory environment. There are many basic technical challenges facing these advanced technologies, such as development of suitable materials to contain the very high temperatures, pressures and/or corrosive nature of the process fluids while operating in the high-energy and high-flux neutron fields required in the core for these reactors, as well as the development of suitable fuel matrices. Some of these challenges related to materials and fuels would be “showstopper” issues for the advanced reactors if they cannot be resolved.

Conclusions

A number of comprehensive technical and strategic reviews of reprocessing, partitioning and transmutation (RP&T) programs and issues were carried out in 2010 and 2011. These studies all reached very similar conclusions, which are consistent with previous NWMO watching brief reports.

- » Some form of deep geological repository is required regardless of the fuel cycle in order to be able to deal with long-lived radioactive wastes.
- » The use of advanced fuel cycles does not significantly reduce the underground footprint of the repository.
- » Advanced fuel cycles are at least many decades away from being ready for commercialization due to the time required for the technical research, and to develop and demonstrate the reactor technologies.
- » Broad public acceptance issues are also likely to inhibit the demonstration and deployment of advanced fuel cycles in the near term.
- » The lifecycle cost of advanced fuel cycles is higher than once-through fuel cycles, due to the high costs of developing and constructing the new generation reactors, reprocessing facilities and fuel fabrication plants.

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