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Dr. Diane Cameron
Director
Nuclear Energy
Natural Resources Canada
580 Booth Street
Ottawa ON K1A 0E4

Re: Review of Radioactive Waste Policy: Recycling of Used CANDU Fuel
A new approach under 2002 Nuclear Fuel Waste Act, §20(2)

Dear Dr. Cameron,

First of all thank you for the decision to review Canada's radioactive waste policy and the changing role of the Nuclear Waste Management Organization (NWMO).

There are several aspects of that role and of its underlying assumptions that must be changed in view of Canada's examination and introduction of small modular reactors (SMRs). Here I will only address used fuel and its recycling rather than also intermediate and low level waste. While the proposed changes affect the work of the NWMO they also have major implications on the future survival of the nuclear industry itself [1].

I consider the changes and my recommendations below to be all positive for the country, with almost immediate savings of perhaps $ 8 billion of the nuclear fuel management funds in trust that can revert back to the contributing utilities and AECL in Ontario, New Brunswick and Quebec towards suitable SMR programs, plus a potential benefit of some $ 60 trillion in non-carbon electricity down the road.

I am pleased to be able to say that on their review of the recommendations I have received the support of the Ontario Society of Professional Engineers for this request (see statement on page 6).

Prime among the necessary changes is the existing view that CANDU fuel consumed to a mere 0.74% is "<u>waste</u>". By that analogy a birch log of which only the bark has been partially burned off in a dying fire would also no longer be considered fuel. The remaining 99%, in both instances, is of course still almost entirely fuel in a better furnace.

<u>SMRs with special characteristics and needs</u>

That better "furnace" for the used uranium from a CANDU reactor is in the form of SMRs, particularly fast-spectrum SMRs, that are now being examined for possible introduction into the Canadian nuclear energy sector.

Those fast-spectrum SMRs, with fuel recycling, can <u>consume ALL</u> of the remaining heavy atom isotopes in the used CANDU fuel stockpiles. At the same time they maintain the fissile fuel complement required for a chain reaction in subsequent cycles of fuel use. It is in such reactors that used CANDU fuel, including its plentiful U238 isotope, becomes over 99% useful fuel and is therefore definitely not "waste".

No thermal reactors, SMRs or full size, have that characteristic. Physics does not permit it.

Furthermore, our used fuel stockpiles contain a crucial component, fissile transuranic isotopes, that are required as starting fuel for all SMR reactors. Without extracting and recycling this material there is no Canadian source to operate such reactors. Without this, we would become completely dependents on foreign enriched uranium fuel for any nuclear energy from SMRs. Therefore recycling, as opposed to disposition of our used nuclear fuel is fundamental for Canadian fuel independence and energy sovereignty.

Let me enlarge briefly.

<u>Uncertain foreign sources of enriched U235</u>

All SMRs require enriched fissile fuel to operate. Only CANDU-like reactors operate on non-enriched natural uranium. Most often that enrichment is in the form of U235. However, Canada has no U235 enrichment facilities due to a deliberate political decision made early in our nuclear energy history. Thus if enriched U235 is to be used, Canada is immediately dependent on foreign countries, likely on nuclear weapons nations such as the USA, France, the UK, Russia or China. Even CAMECO's recent purchase in the USA into Global Laser Enrichment, an experimental enrichment approach, does nothing to lift our dependence on foreign supplies of such uranium and at worst hastens the depletion of Canada's uranium reserves to less than 30 years [1].

Being at the mercy of foreign powers for Canada's own energy supply is not particularly satisfactory in light of recent international difficulties between Canada and such countries regarding embargos on commodities such as "strategically important" aluminum and steel, and Canadian citizens being arbitrarily incarcerated. The recent Europe-first kerfuffle with COVID-9 vaccine delivery from the European Union is another case in point. Certainly enriched U235 would be considered "strategically important" by any nation.

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However, enriched starting fuel can be obtained from Canada's used CANDU fuel via its content of fissile transuranic isotopes that were created naturally during irradiation of fresh uranium fuel in the CANDU reactors. The currently stored used CANDU fuel contains enough transuranic isotopes to provide Canadian enriched fissile starting fuel for fast-spectrum reactors with a total power equal to 24,000 MWe.

That is not "waste". .

Canada's used CANDU fuel: a $ 60 trillion non-carbon energy resource via fast-spectrum SMRs

By means of such fast-spectrum SMRs coupled with fuel recycling to extract fission products, our current and increasing 60,000 tonnes of CANDU fuel "waste" become at minimum a $ 60 trillion electricity resource. That resource can provide an additional 130 times more non-carbon energy from the used CANDU fuel than the total energy that has already been extracted in our CANDU reactors.

At the same time the complete use of this energy resource would avoid the emission of about 560 billion tonnes of CO_2, an amount equal to about 16% of the CO_2 in the entire atmosphere.

It is unconscionable to maintain the delusion that this $60 trillion non-carbon energy resource is "waste" and to continue to plan to dispose and sequester it permanently from the biosphere to the detriment of the World's population that in light of climate change effects requires huge amounts of non-carbon energy to survive.

Reuse, recycle to eliminate million-year radiotoxicity: no DGR

Moreover, in choosing to reuse that fuel in fast-spectrum SMRs, and to split all of its heavy atom isotopes, including the transuranic isotopes, one effectively also removes and eliminates the long-term, million-year radiotoxicity of those atoms in the used CANDU fuel that is the prime reason for the plans for a still generally unwelcome and politically sensitive Deep Geological Repository.

Indeed such "detoxification" of the stored stockpiles of used CANDU fuel can occur relatively quickly. As an example one can calculate that the 15,000 tons currently stored near the Pickering reactors could have all of their transuranics removed and used in about 20 years of operation of fast-spectrum reactors equivalent in power to the current Pickering fleet.

The residues left on recycling, the fission products, are less than 1% of the current 60,000 tons, or only about 475 tons, with an estimated volume less than a 6 m cube. They consist of useful medium sized atoms 70% of which are non-radioactive immediately, while the radioactive remainder in large part decays in a much shorter period than a million years. Even now the oldest Pickering used fuel contains only two major radioactive fission product isotopes, Sr-90 and Cs-137, each with a 30-year half-life. A further handful of fission products left are so long-lived (e.g. iodine-129 at 16 million years) that

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their radioactivity is well below that of natural uranium. And even iodine-129 can be removed during recycling and transmuted to short-lived iodine-130, changing the half-life from 16 million years to only 12.4 hours.

A superfluous DGR

These considerations remove the need for a long-term DGR, and suggest a need instead for accessible short-term shielded storage for fission products. The fission products are medium-sized useful atoms with a total value that can be estimated to be $ 3 million per tonne. As an example, some immediately non-radioactive isotopes are platinum-group metals, such as ruthenium and rhodium, at concentrations higher than in the best ores in Africa.

The large amounts of recovered uranium from recycling used CANDU fuel do not require special shielded storage, since due to an exceptionally low content of U232 created in the CANDU reactors this uranium is no more radioactive than fresh natural uranium fuel.

Available technology

The fast-spectrum reactor technology has been available since the 1950s when the EBR-1 in the USA produced the first electricity ever by nuclear power on December 20, 1951. Commercial fast-spectrum reactors have been operating in Russia since the 1970s, with the largest, the 800 MWe BN-800, coming on line in 2016. In total there are over 450 reactor-years of experience with such reactors.

Several fast-spectrum designs with nuclear-waste-consuming capabilities are already being considered in Canada by Canadian Nuclear Laboratories (CNL) and the Canadian Nuclear Safety Commission (CNSC), and apparently favoured by New Brunswick Power for those capabilities. Some of these include the ARC-100 of Advanced Reactor Concepts (USA), the SSR-W (fast) of Moltex Energy (UK), the Sealer of Leadcold (Sweden), and the PRISM of GE-Hitachi (USA).

Fuel recycling was developed for such fast-spectrum reactors in the 1980s in the form of proliferation-resistant electrorefining in a molten salt (pyroprocessing), and is still operating at the Argonne National Laboratories (ANL) and the Idaho National Laboratories (INL) in the USA. This seems to be the method of choice more generally, with a Russian statement indicating that "it was decided that MOX fuel production using recycled materials from both light water and fast reactors should be based on electrometallurgical (pyrochemical) reprocessing". A variation of the technology is being promulgated by Moltex Energy (Canada) in New Brunswick, and is being developed jointly with Canada's CNL.

The creation of enriched fissile fuel based on transuranic isotopes in uranium involves the partial extraction and recovery of unconsumed pure uranium from used CANDU fuel as well as the partial removal of fission products. In this way the recycled fuel is enriched without having to extract and purify any fissile transuranic components such as plutonium or americium, avoiding proliferation concerns.

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Such procedures are similar to those employed by CAMECO in its purification of uranium, though the proposed used fuel recycling process for used nuclear fuel is on a smaller scale, and with additional shielding.

Costs, Rewards and Failure

Estimates of costs indicate that commercial scale recycling by pyroprocessing will be about one fifth (20%) of the cost for the current PUREX reprocessing used in France and Russia. Recycling processes using fluoride volatility methods will be about 15% of the cost of the PUREX process [1].

In comparison, the monies accumulated for a DGR, at $ 3600 per used CANDU fuel bundle (2019 values), are almost three (3) times the cost of recycling by pyroprocessing [1].

Moreover, disposal in a DGR produces no value from the used CANDU fuel in terms of non-carbon energy. The DGR, once sealed, will deny current and future generations access to the huge non-carbon energy content of that used fuel. It results in no diminution of the radioactive decay time of the material, and does not guarantee that the radiotoxicity will not adversely affect future generations. Indeed, three international efforts at a safe DGR in Germany and the USA have already failed.

Thus even the international "best practices" in DGR deployment promulgated by the NWMO appear certain to require future expensive above and below ground clean-up efforts, and possibly abandonment.

Recommendations: A new Approach

The government of Canada should redirect the NWMO, to end its efforts of developing a long-term used nuclear fuel DGR, which will no longer be needed in the future, and instead develop commercial scale technologies to recycle used CANDU fuel in order to profitably:

1) furnish enriched fissile starting fuel for fast spectrum SMRs, and to

2) recycle used fuel from future SMRs.

Indeed, the approach is estimated to be substantially less expensive than the funds of over $10 billion already accumulated in trusts such as the Ontario Nuclear Fund Agreement Trust for used nuclear fuel management towards a DGR, and could with continued recycling for increasing numbers of SMRs even become a profit-making venture.

A substantial fraction of the over $10 billion in trust would not be required. This portion of the funds could revert back to the utilities and AECL in Ontario, New Brunswick and Quebec to be used for the

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acquisition of fast-spectrum SMRs that can consume effectively all of the current and future used nuclear fuel.

The Nuclear Fuel Waste Act of 2002 permits such a change towards the actual elimination of nuclear radiotoxicity under paragraph 20 (2) as a new approach to nuclear waste management.

I would be happy to answer any questions about further details regarding these recommendations.

Yours sincerely,

[redacted]

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Professor Emeritus
University of Toronto

Currently:
Councillor - Canadian Nuclear Society (CNS)
Co-chair - CNS Education and Communication Committee

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Statement of Support by the Ontario Society of Professional Engineers (OSPE)

The Ontario Society of Professional Engineers has reviewed Dr. Ottensmeyer's letter, and supports his recommendations.

Sincerely,

[redacted]

Ontario Society of Professional Engineers

cc.: NRCan

Hon. Seamus O'Regan	Minister
Paul Lefebre	Parliamentary Secretary
Jean-Francois Tremblay	Deputy Minister
Shawn Tupper	Assoc. Dep. Minister
Environment and Climate Change	
Hon. Johathan Wilkinson	Minister
Terry Duguid	Parliamentary Secretary
T. Christine Hogan	Deputy Minister
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Utilities

[redacted] [redacted]

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References

[1] Ottensmeyer FP. "Sovereign Nuclear Canada at a Crossroads: Recycle or Die", 40th Ann. Conf. Nucl. Soc., Saint John, NB, May 31-June 3, 2020.

Abstract

For over 60 years Canada has relied on its mined natural uranium to power its CANDU reactors. At current rates of mining and exporting, Canada's 500,000 tons of economical uranium reserves will be exhausted by 2050. The addition of small modular reactors (SMRs) will only quicken the reduction of this resource, particularly since the SMR requirement for enriched fuel calls for manifold the volume of natural uranium. However, recycling of Canada's current stockpiles of used CANDU fuel can furnish starting fuel enriched with fissile transuranics for SMRs with a total power of 24,000 MWe. Moreover, for SMRs that can maintain and augment their fissile components, the fuel can be replenished for centuries solely with U238 or depleted uranium, while such SMRs provide fissile fuel for our CANDU reactors at equivalent power. We are at a crossroads. We can either do nuclear right, or it dies.

[2] Ottensmeyer P. "The SMR Challenge in Canada: Enriched Fuel; A Solution: Recycling of Used CANDU Fuel." 4th Canadian Conference on Nuclear Waste Management, Decommissioning and Environmental Restoration, Ottawa, ON, September 8-11, 2019.

Abstract

The recently released Canadian Small Modular Reactor Roadmap (SMR Roadmap) expresses a concern about the availability and security of fuel for SMRs in Canada. This paper outlines an extraction/recycling approach that eliminates that concern. The small cores of SMRs engender a greater loss of neutrons than larger Canadian CANDU reactors that can operate on natural uranium fuel. That

loss has to be compensated by an enriched fissile isotope concentration in the SMR fuel to permit neutron balance for operation of such small reactors. Canada has no enrichment facilities, with an imminent consequence that this country would henceforth have to rely on the good will of other nations, nuclear weapons states such as the USA, Russia, China, France or the UK to furnish SMRs in Canada reliably with such enriched, relatively expensive fuel. Alternatively Canada can maintain its fuel independence by recycling its stored used CANDU fuel to extract enough fissile transuranics (TRUs) from the current existing 60,000 tonnes of stored used fuel "waste" to furnish starting fuel for the equivalent of 24,000 MWe fast-spectrum SMRs. Business plans for such extraction/recycling facilities show that fuel enriched to 19.9% TRUs would be about half the cost, or less, of 19.9% low-enriched U235 purchased in the USA. Moreover, since the TRUs from used CANDU fuel are a mixture of isotopes that prevents weapons production without much further very costly isotope separation, concerns with weapons proliferation are effectively negligible. The extraction/recycling approach of used CANDU fuel would keep Canada independent and sovereign in nuclear fuel. Moreover, with a suitable choice of types of SMRs that can maintain or augment their fissile fuel components, this technology would provide fuel security for the Canadian nuclear industry for many centuries.

[3] Ottensmeyer P. "Repurposing the Pickering Nuclear Generating Station as an Advanced Recycling Centre: A Key to the Future of Cleaner Nuclear Power". 38th Ann. Conf. Can. Nucl. Soc., Saskatoon, SK, June 9, 2018.

Abstract

With the shut-down of Pickering's CANDU reactors in 2024 some 5000 highly skilled jobs will be lost directly as well as about $1 billion in annual revenue to the region. Eight silent venerable CANDU reactor hulls will remain for about 40 years. So will 15,000 tonnes of used CANDU fuel stored on site, with very little prospect politically and societally to move such highly radiotoxic material elsewhere through the roads and towns of Ontario. The alternative examined here is to detoxify the material locally via economical recycling through proven-safe waste-consuming fast-neutron reactors (FNRs). At power equal to current levels, 3000 MWe, this detoxification can be done in about two decades without producing further long-lived nuclear fuel waste. The remnants consist of less than 1% stable and fast-decaying valuable fission products plus benign depleted uranium that serves as FNR fuel replenishment for centuries. Jobs are maintained and so is the local economy.

Further relevant manuscripts at: https://www.cns-snc.ca/search_cns_papers/?q=ottensmeyer