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September 2014

CNSC Staff Submission to the Joint Review Panel
Regarding PMD 14-P1.64

Request from the Joint Review Panel

CNSC staff has been requested to provide information regarding to the submission from Dr. Charles Rhodes (Xylene Power Ltd), PMD 14-P1.64.

In particular, the Panel requested analysis and comment from CNSC staff on the observations in the submission related to the reduction of waste inventory and recycling. CNSC staff response will consider what is technically possible for low and intermediate level waste (L&ILW) and what may be foreseeable for these wastes. This response will make a clear distinction between L&ILW and high-level waste.

Introduction

CNSC staff's review of PMD 14-P1.64 determined that it is connected to discussions that took place during JRP hearings in 2013. In particular, the PMD refers to the Ottensmeyer Plan. The Ottensmeyer Plan was part of the oral statement submitted to the Panel from Dr. Ottensmeyer (PMD 13-P1.139). While Dr. Ottensmeyer's statement focused on high-level (used fuel) waste and transmutation processes for reducing the volume of this waste, discussions on October 9, 2013 included the possible application of such processes to L&ILW from power reactors. Comments made by CNSC staff during these discussions remain valid following the review of PMD 14-P1.64.

CNSC Staff's Assessment

The text identified within the boxes that follow are extracts from PMD 14-P1.64 relevant to the discussion provided by CNSC staff. The underlining has been added by CNSC staff for emphasis.

1. CNSC Staff Comment #1 – Fast Neutron Reactors

PMD 14-P1.64 makes reference to the different kinds of waste associated with the nuclear fuel cycle. That is, low-level waste (LLW), intermediate-level (ILW) and high-level waste (HLW). It also speaks to the transmutation of long-lived actinides within all waste types and the mechanism to transmute them to shorter-lived nuclear decay products.

PMD Statement – 1

> *<u>PAGE 2</u>*
> *Nuclear waste in ground water tends to be concentrated by certain fish and plant species. To avoid this problem <u>long lived radio isotopes must be modified via transmutation</u>. Short lived isotopes should be isolated and stored in engineered containers until they almost completely decay. <u>Hence, in addition to proper DGR siting, proper: radio chemistry, nuclear transmutation, container engineering, container monitoring and container access are all essential aspects of a viable nuclear waste disposal plan.</u>*

CNSC Staff Analysis – 1

The statement speaks to a vision of recycling spent nuclear fuel, ILW, metallic reactor components and tritium/helium-3. It also speaks to a nuclear regime where different reactor designs (fast neutron reactors) are being used for nuclear power production, and the unique ability of such reactors to convert long-lived actinides to short-lived fission products. The submission provides an estimate of the value of the materials that could be recovered from recycling. However, costs and timelines for development, construction and licensing of all accessory facilities required to achieve this vision have not been provided, nor have impacts from resulting secondary waste streams. Besides requiring a different style of DGR for the secondary waste streams, this vision requires an associated suite of new nuclear facilities to be designed, constructed, and licensed.

The statement also speaks to radionuclides being concentrated in certain fish and plant species. Empirical studies done at Perch Lake, in Chalk River, have shown that there is a progressive decline in the concentration of certain long-lived radionuclides as they are transferred to higher trophic levels. Therefore, most radionuclides are not subject to biomagnification up the food chain, in contrast to organic pollutants such as DDT. In addition to this, excretion and other metabolic mechanisms have been shown to result in reducing uptake in fish of radiocaesium.

PMD Statement – 2

> *<u>PAGE 7</u>*
> *Today I do not have time to criticize the minutia of the OPG plan. What I can do is paint in broad strokes a much more viable alternate plan. This plan is the work product of over one hundred scientists and engineers and has been in the making for more than 50 years. <u>The plan involves sophisticated radio chemical material processing, fast neutron nuclear transmutation, engineered porcelain ceramic storage containers, robotic hard rock mining equipment, container monitoring and gamma ray spectroscopy</u>, none of which are currently contemplated by either OPG or the NWMO. As compared to the OPG / NWMO plan, in the alternate plan most of the waste is either recycled or rendered harmless within a few centuries, not a million years.*

CNSC Staff Analysis – 2

This plan would include fast neutron reactors, nuclear fuel reprocessing facilities, ILW disassembly and chemical separation facilities, large component disassembly and chopping facilities and metal melting and milling facilities. All of these would have to be designed, constructed and licensed for highly activated radioactive materials. All of these would also have secondary and hazardous waste streams that must also be managed, and all would at some future time be subject to decommissioning.

All of these types of facilities would be required in order to transmute long lived actinides and to conduct recycling of activated materials and metals as envisioned and described in this submission. Currently, OPG does process LLW at their Western Waste Management Facility. The kind of processing is limited to volume reduction through incineration and compaction, and does not include the kinds of chemical and isotopic separation being considered by PMD 14-P1.64.

A key aspect of the submission is the use of fast neutron reactors to ‘transmute’ long-lived actinides that are found in high-level waste and to some extent ILW in order to convert them to shorter-lived decay products. Fast neutron reactors (FNR) were designed to operate more efficiently and to remove the world’s reliance on U-235 as the world’s primary reactor fuel. The fast neutron reactor is not a new design. It can ‘burn’ uranium more efficiently than typical commercial nuclear power reactors, and it also has the ability to convert long-lived actinides that are produced in high level waste to shorter lived radioactive byproducts.

About twenty fast neutron reactors have been constructed world-wide, but they have not gained widespread interest for use in commercial power production due to their high cost of construction and operation. The countries that are developing FNR technologies are typically seeking to close their fuel cycle in part to increase energy independence by recycling used fuel which is seen to be a national resource. The used fuel for reprocessing may be from the country’s own plants or from other countries as part of fuel repatriation agreements. Some of the wastes associated with reprocessing are liquid and some are classed as high-level wastes.

A variant of the fast neutron reactor is the ‘fast breeder reactor’ and this was developed to produce more plutonium than it ‘burns’, thus creating new nuclear fuel as a by-product of its operation. Because of this reactor’s ability to produce greater amounts of plutonium, they have been of interest to countries with nuclear weapons programs and countries that have developed nuclear fuel reprocessing and enrichment facilities. All of the countries with FNR’s have proceeded with L&ILW repositories in parallel with their fuel cycle activities as a matter of public policy recognizing that not all radioactive waste can be reprocessed. The radioactive waste is acknowledged as requiring disposal in a safe manner.

The PMD also makes reference to the transmutation of actinides in intermediate level waste as a waste management process to be considered. The author refers to plans for a machine called an intense neutron generator, but in the absence of such a machine, an FNR would otherwise be required. To CNSC staff’s knowledge, none of the countries involved with FNRs are looking into ways to process L&ILW. To date, no FNR or the required associated facilities have been designed, constructed or licensed for operation in Canada, and no such project has been proposed for deployment.

2. CNSC Staff Comment – Deposition of waste, recycling

PMD 14-P1.64 speaks to the deposition of LLW, ILW, material recycling and also to tritium/helium-3.

2.1 Low-Level Radioactive Waste (LLW)

PMD Statement – 3

> *Appendix 6, page 65*
> *Low level waste (LLW), consisting of isotopes with half-lives of less than 30 years, is from an engineering perspective simple to deal with. The LLW can be safely isolated in engineered containers that are stored for 300 years in a gravity drained depleted hard rock mine that is high above the local water table. Thus stored the LLW will spontaneously decay into stable isotopes.*

CNSC Staff Analysis – 3

Low-level radioactive waste comprising of short-lived radioisotopes are not described in detail by this submission, as they are expected to decay to negligible quantities within 300 years. Consequently, the authors concerns are related to recycling of intermediate level waste (ILW). It should be noted that LLW arising from various sources within power reactor operations are not devoid of longer-lived radionuclides. The definition of LLW used in Canada and by OPG is material with radionuclide content above established clearance levels and exemption quantities and which contains primarily short-lived radionuclides (shorter than or equal to 30-years). And while LLW generally has limited amounts of long-lived activity, for long lived beta and/or gamma emitting radionuclides such as 14C, 36Cl, 63Ni, 93Zr, 94Nb, 99Tc and 129I, the allowable average activity concentrations can be considerably higher (up to tens of kBq/g) and can be specific to the site and disposal facility. Higher concentrations of these longer lived nuclides in different waste streams can influence the suitability of the waste for relatively short term storage for decay disposal options.

2.2 Intermediate Level Radioactive Waste

PMD Statement – 4

> *Appendix 6, page 65*
> *All nuclear power technologies produce some intermediate level waste (ILW). The main source of this ILW is exposure of reactor component materials to the intense particle and radiation fluxes present inside a nuclear reactor. This ILW is the most difficult nuclear waste to deal with in the long term and deserves attention on an element by element basis. The ILW problem isotopes are Ni-59, Ni-63, Cl-36, Ca-41, Zr-93/Nb-93m, Nb-94, and C-14.*
>
> *(Appendix 6) (page 66)*
> ***CALCIUM:*** *Calcium is a substantial component of concrete and mortar..... New reactors should be designed to avoid production of Ca-41. That means that new nuclear reactor*

designs should not rely on concrete for peripheral neutron absorption. Adding more non-concrete neutron shielding will likely increase the initial cost of new nuclear reactors, but so be it. The Joint Review Panel should recommend that the CNSC ensure that Ca-41 formation is negligible in new Canadian nuclear reactor designs.

(Appendix 6) (page 66)
***CHLORINE:** In a CANDU reactor chlorine occurs as a component of chlorinated hydrocarbons used to in sealing and insulating materials. Neutron absorption by the stable isotope Cl-35 results in Cl-36, which has a half life of 308,000 years. Fortunately, as compared to the masses of nickel and calcium, the chlorine content of a CANDU reactor is relatively small..... In the future the Cl-36 formation problem can be minimized by changing from CANDU reactors to liquid metal cooled fast neutron reactors that do not use chlorinated materials anywhere near the neutron flux.*

(PAGE 2) (Point 7)
Development of a safe, economic and reliable methodology for concentration, isolation and storage of long lived low atomic weight isotopes such as Ca-41 and Cl-36 that have no present or foreseeable future value for recycling.

CNSC Staff Analysis – 4

PMD 14-P1.64 identifies the following elemental components to be of concern in ILWs; nickel, chlorine calcium, zirconium, niobium and carbon. It suggests that calcium and chlorine have no potential recycle value and that their creation can be minimized through new reactor designs (i.e., not using concrete and, develop a liquid metal cooled fast neutron reactor. This leaves nickel, zirconium, niobium and carbon as having potential recycling opportunities. The PMD later introduces H-3/He-3, a component of ion exchange resins as a potential recycling opportunity as well. Discussion of the recycling of nickel, zirconium and niobium follows.

PMD Statement – 5

Page 2, point 4
Recycling of irradiated nuclear reactor materials such as nickel, zirconium and carbon to both reduce the cost of new nuclear reactors and to minimize the mass and volume of radio toxic material in storage;

Page 10
Hence there should be careful waste material sorting on reactor sites and there should be a radio chemistry facility near the DGR site.

Page 10
Material recycling requires that the DGR remain structurally safe, dry and accessible for thousands of years into the future. Waste categories of immediate interest for recycling are tritium/helium-3, zirconium, nickel, uranium and concentrated actinides including plutonium. After about 300 years in storage numerous fission products become enormously valuable.

> *Page 15*
> *The current OPG/NWMO plan for the Bruce DGR does not address material recycling. Of particular concern is inattention to recycling of nickel, zirconium and neutron reflector carbon.*

CNSC Staff Analysis – 5

Nickel, zirconium and niobium are components of steel and pressure and calandria tubes. Their recycling approach (metal melting) would be similar for all three types and is discussed in more detail below.

PMD Statement – 6

Nickel

> *Appendix 6, page 66*
> Nickel: Future displacement of fossil fuels with nuclear power will require much more nickel. From a nickel conservation perspective it makes little sense to irradiate fresh nickel and then 60 years later to permanently bury that irradiated nickel. It makes much more sense to recycle irradiated nickel into future nuclear reactors. Such recycling may require a dedicated steel mill facility. However, the major point is that metal alloys with significant radioactive nickel content should be interim stored in a safe, accessible, high and dry location, such as Jersey Emerald or another comparable naturally dry mine, until the inventory of these irradiated alloys is sufficient to justify the dedicated steel mill facility required to process these alloys into new nuclear reactor components.

Zirconium/Niobium

> *Appendix 6, page 67*
> The real issue with zirconium is that it is an essential alloy component of fuel for liquid sodium cooled fast neutron reactors. The zirconium prevents formation of a low melting temperature plutonium-iron eutectic. In a fast neutron flux Zr-93 becomes Zr-94 which is a stable isotope.
>
> For this reason neutron irradiated zirconium should not be buried. It should be stored in a safe accessible high and dry location, such as Jersey Emerald, until it is required as a fuel alloy component for fast neutron reactors. That date may be only a few years hence. Under no circumstances should irradiated zirconium be stored or buried where it is not easily accessible.
>
> NIOBIUM: In CANDU reactors a small fraction of the fuel tube weight is niobium. Neutron absorption by the stable isotope Nb-93 results in Nb-94 which has a half life of about 20,000 years. The simplest way to deal with Nb-94 is to leave it alloyed with its host zirconium and to use it as a component of fast neutron reactor fuel. In a fast neutron flux Nb-94 becomes Nb-95, which has a half life of 35 days and decays into stable Mo-95.

CNSC Staff Analysis – 6

To accommodate radioactive recycling of these metals, highly activated metals would have to be characterized, chopped, sorted, melted, purified, milled and remanufactured in a specialty waste and metal recycling facility for use as cladding or other purposes in future nuclear reactors. Radioactive slag would result from the refining process as would hazardous and radioactive gaseous emissions.

Metal refining and processing are industries with significant amounts of environmental emissions and CNSC staff is not aware of any country where this is an acceptable practice for highly contaminated metals. As a comparison, the processing of steam generators in Sweden simply extracts the non-radioactive components of steel for reprocessing, leaving for disposal a smaller amount of contaminated inner radioactive tubing.

PMD Statement – 7

Carbon

> *Appendix 6, page 67*
> *For the foreseeable future the C-14 problem can be mitigated by storing carbon containing ILW in containers in a dry, dark and low temperature environment, such as Jersey Emerald, so that the carbon remains chemically bound to other elements and does not react with air or ground water. In the long term mankind will likely have to rely on careful containment to keep the local C-14 concentration at an acceptable level.*
>
> *A challenging problem in nuclear reactors is the use of graphite (C) or boron carbide (B4C) as a neutron reflector. The carbon in the neutron reflector is exposed to an intense neutron flux which will gradually produce C-14. The alternative is to make the reactor physically twice as large and rely upon a uranium blanket for peripheral neutron absorption.*
>
> *This issue of C-14 formation might in the long term become a public health issue. In my view the best interim solution is to recycle the irradiated carbon so that the total amount of irradiated carbon is minimized and the C-14 remains chemically bound in a stable compound such as B4C from which oxygen and water are carefully excluded. If C-14 is placed in the Bruce DGR it will eventually dilute into the environment. To minimize the environmental load carbon used in neutron reflector applications should be recycled.*

CNSC Staff Analysis – 7

In relation to minimizing the formation of carbon-14, PMD 14-P1.64 suggests that nuclear reactors be made physically twice as large and rely upon a uranium blanket for neutron absorption. In relation to managing the current carbon-14 inventory, the submission suggests that radioactive carbon-14 can be recycled into neutron reflectors for new nuclear reactors or, to a stable compound for long-term storage and containment.

To accommodate these suggestions, nuclear reactors would need to be redesigned, and existing inventories of waste would need to be characterized, sorted and the radioactive carbon chemically extracted and reprocessed into a new compound, requiring specialty waste separation, chemical extraction and chemical reprocessing facilities, with all the associated wastes and emissions from these additional processes.

PMD Statement – 8

Tritium / Helium-3

> *Page 2, point 5*
> *Recovery of tritium/helium-3 for sale to third parties to prevent illicit nuclear weapon proliferation, to earn income and to reduce the mass and volume of radio toxic material in storage;*
>
> *(Appendix 7) (page 69)*
> *A significant fraction of the low level waste from CANDU reactors is tritium which in storage decays with a half life of 12.6 years into into helium-3 (He-3). Helium-3 is a valuable commodity which is absolutely essential for detection and prevention of illicit nuclear weapon transport. After 126 years in storage over 99.9% of the tritium has converted into He-3. If this waste is stored for 252 years, 99.9999% has converted to stable He-3. After 300 years in storage the conversion exceeds 99.99999%.*
>
> *Much of the existing tritium is trapped in bulky ion exchange cartridges. On decay it releases inert He-3 gas which is valuable (~ $5000 gm) but must be trapped in a gas tight container. He-3 is readily separated from all other gases by cryogenic refrigeration. It is essential that this waste be future accessible for several reasons:*
>
> *1) He-3 is economically very valuable;*
> *2) He-3 is uniquely suitable for detecting neutrons emitted by illicit shipments of fissile materials. Detection of such shipments is essential for preventing illicit proliferation of nuclear weapons in a future world which will likely involve two orders of magnitude more nuclear power reactors;*
>
> *He-3 has unique fluid properties at less that 4 degrees K which make it essential for a wide range of physical property research;*
> *He-3 has unique properties for imaging certain human lung conditions;*
> *He-3 has potential application as a second stage fusion fuel with relatively low neutron emission. Hence the DGR should be accessible to allow recovery of He-3.*

CNSC Staff Analysis – 8

To accommodate recovery of He-3 as proposed, ion exchange resins would need to be located in recoverable gas tight containers for hundreds of years followed by separation of helium in a cryogenic refrigeration extraction facility. However, it is not clear that there would be a large demand for helium-3 given the few potential uses provided.

CNSC Staff Analysis Summary

CNSC staff does not disagree with PMD 14-P1.64 that recycling of some nuclear materials from L&ILW as presented is theoretically possible. What has not been discussed is how effective and efficient the recycling process would be, what kind of secondary waste streams would be generated, and the number and cost of all of the various kinds of facilities that would be required to be designed, licenced and operated.

To implement this complete vision, existing reactors would have to be shut down or be totally re-designed, new fast neutron reactors would have to be developed, fuel reprocessing facilities would be required, as well as the development of a suite of new waste processing facilities. These might include, a redesigned DGR, facilities to open existing waste container packages and materially separate wastes, facilities to chemically extract waste components, chemical and isotopic separation and reprocessing facilities, large metal component disassembly and chopping facilities and metal melting, refining and milling facilities, all designed, operated and licenced to allow the safe handling of highly activated nuclear substances.

These facilities would need to be funded, designed and licenced. While they would need to be designed to meet strict environmental and health protection requirements, they would also result in doses to workers, exposures to chemical hazards, and emissions to the environment. Societal concern with these kinds of facilities is also likely to be considerable.

The key point is that the PMD does not contain sufficient information to suggest that this is a practicable or viable alternative option to the proposed DGR approach. Based on CNSC staff's knowledge and experience, staff is of the opinion that the reduction of nuclear materials in L&ILW through transmutation is not doable at this time. It should be noted that the CNSC requires OPG to have provisions in place to minimize, reuse, and recycle materials and reduce the volume of waste produced. OPG discussed their approach for reduction at source, during the hearings in 2013.