

RADIOACTIVE OPERATIONAL WASTE FROM CANDU REACTORS: A BILLION DOLLAR OPPORTUNITY

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Abstract

The intent of Ontario Power Generation (OPG) is to bury the low-level and intermediate-level nuclear waste from the operation of its CANDU reactors in a \$1 billion deep geological repository (DGR). The Canadian Nuclear Safety Commission (CNSC) Joint Review Panel has examined the OPG proposal, but what has not been discussed is the full effect of the CNSC's own Regulation of "Reduce, Reuse, and Recycle" on such actions. Here we examine the raw material value of some of the components intended currently for burial. Among others they include steam generator steel shells and Inconel tube bundles, reactor pressure tube zirconium, as well as radioisotopes such as carbon-14 and tritium. Even a cursory assessment suggests that materials worth from a minimum of \$120 million to several billion could be recouped for reuse, recycle and, when markets and economical separation methods permit, today or in the future, for profit. To effect such a recovery would require the expansion of the "raison-d'être" of OPG from the efficient production of electricity to an even more responsible corporate citizen of today's world. The effort could yield substantial profits and at the same time reduce the capacity requirements of longer-term storage facilities such as the DGR.

1. Introduction

Since its beginnings in the 1950s, or the 1960's in Canada, the nuclear industry has done well in providing the world with many gigawatt-years of non-carbon electricity. As the fleet of reactors ages the challenge is not only its renewal, but also the legacy left behind of accumulated highly radioactive used fuel and of radioactive operational and structural material as the reactor facilities are decommissioned at the end of their lives.

In light of the current topical exhortation to "Reduce, Reuse and Recycle", even made part of Regulation P-290 by the Canadian Nuclear Safety Commission [1], it seems that there are numerous opportunities to reuse and recycle before safe disposal becomes a final pursuit. Since much of the material is radioactive, either through activation or through surface contamination or both, it presents specific challenges to clean and/or extract. However, much has been learned over the years about radiation and appropriate shielding, so that much non-radioactive material can be recovered and much radioactive material can be repurposed rather than being jettisoned.

In previous presentations [2,3] it was advocated that highly radiotoxic used CANDU fuel, officially designated as nuclear fuel "waste", be reused and continuously recycled through commercially available fast-neutron reactors (FNRs). In such an approach the worrisome long-term radiotoxicity of the transuranic actinide component (Fig. 1) would actually be eliminated by producing non-carbon energy from those atoms by fission. The fissioned heavy atoms would leave only a residue of medium-sized atoms fission products (FPs) generally with much, much shorter life-times.

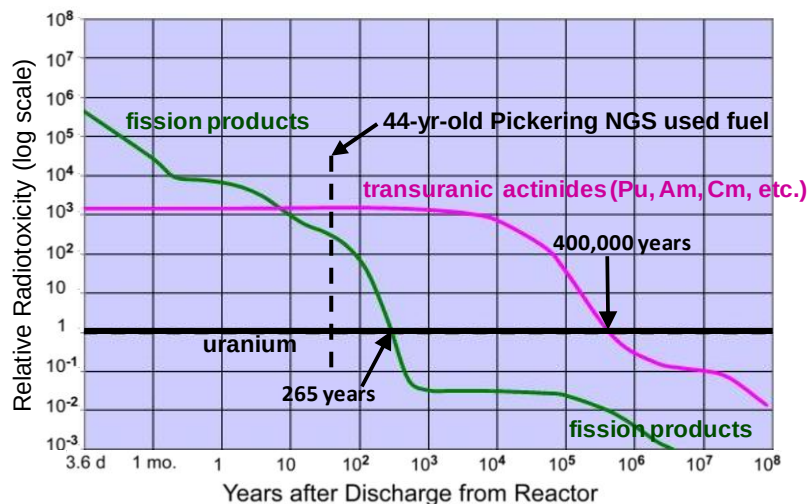


Figure 1. Evolution of Radiotoxicity from Used CANDU Fuel Components Relative to Natural Uranium.

Elimination of the transuranic actinides in fast-neutron reactors and extraction of uranium from the used fuel waste would shorten the time of decay of radiotoxicity to background levels of natural uranium from 400,000 years to 265 years. After 265 years the radiotoxicity of the fission products is lower than that of the natural uranium from which they are created in the reactor. The broken line indicates current radiotoxic state of the oldest used fuel (44 years) at the Pickering nuclear generating station (NGS). Note the log scales of both axes.

In terms of energy, today's 50,000 metric tons of stored used CANDU fuel when passed through fast-neutron- reactor/fuel-cycle-facilities (FNR/FCFs) could produce non-carbon electricity worth \$1.5 billion/ton, enough in total to replace all of Ontario's current greenhouse-gas-emitting fossil energy needs in transportation, industry and homes for over 800 years.

Even the fission products created from the split heavy atoms are valuable, as shown in Fig.2. About 70% of them are non-radioactive immediately [4], while virtually all the others become non-radioactive

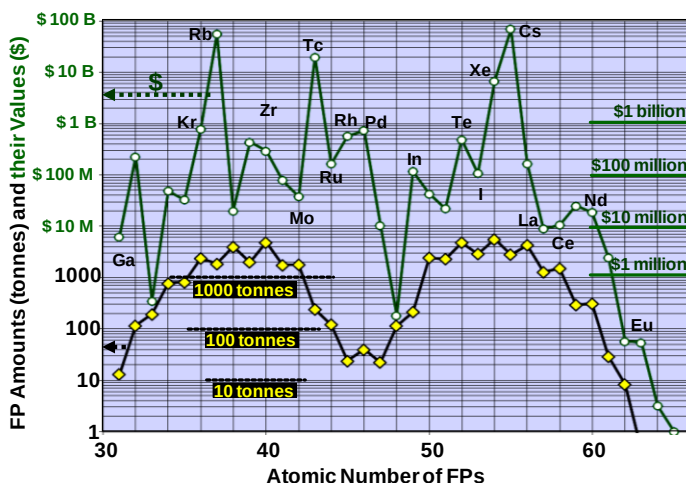


Figure 2. Amounts and Values of Fission Products from the conversion of 50,000 tons used CANDU fuel to energy. (Amounts: Brookhaven Nat'l Labs; values: internet suppliers)

in days, months or years rather than in the thousands of millennia for the TRUs. The global value from converting the current 50,000 tons of used fuel to FPs would be \$157 billion today, or \$3.1 million/ton. Indeed, non-radioactive isotopes of Russian fission products are already being offered [5], while even radioactive Russian isotopes are entering the market [6].

Can an analogous approach be used for non-fuel components of refurbished or decommissioned CANDU reactors? All such components are currently slated for burial in a planned low- and intermediate-level waste deep geological repository (DGR).

Intriguingly, that same process of cycling used CANDU fuel also provides options to manage intermediate-level and low-level “waste” from the refurbishment and decommissioning of nuclear plants. Zirconium tubing is a case in point, since it can be reused even in radioactive form in the metal fuel of FNRs which ideally is constituted with about 10 wt% Zr as a useful alloying element that raises the fuel melting point [7]. Reusing the nuclear-grade zirconium from refurbished pressure and calandria tubes would provide great savings in such FNR fuel, and reduce space needed in any DGR.

That example will lead off an examination of items that are currently intended for DGR disposal as low and intermediate level waste. For other examples it will become obvious that much preliminary investigation has already been carried out by Ontario Hydro (now Ontario Power Generation (OPG)). Why more steps, and further steps, were not taken is not obvious from the available written accounts. Was it solely economics, or was it also the reluctance of an industrial concern charged with the efficient production of electricity to branch out into secondary industries to profit from use of materials that for the pure production of electricity is considered waste of the current technology ?

But OPG has taken at least one such step, in the mounting of the radioactive-tritium recovery program [8,9]. While purposed to protect OPG workers, the program now also supplies that isotope worldwide.

Such secondary industries also exist elsewhere, implying profitability of such endeavours [5,6,14]. With suitable encouragement by government, by the primary industries such as OPG, Bruce Power and Cameco, and by a societal consciousness towards reusing and recycling, appropriate industries with their associated high skill-level employment might proliferate locally more fully as well.

While used CANDU fuel is discussed elsewhere [2,3], we here examine three specific non-fuel items that are currently part of the inventory of materials intended for disposal [10]. First we will consider 600 tons of nuclear grade zirconium metal in radioactive CANDU core tubing, worth \$265 million if bought anew [13]. This metal, though activated, can be reused in a shielded fast-neutron reactor/fuel-cycling facility (FNR/FCF) as a needed 10 % alloying element in recasting the metal fuel rods of FNRs [7]. Second we discuss almost 10,000 tons of carbon steel and 3300 tons of high alloy Inconel 600 in 210 heat exchangers and steam generators [10], worth \$ 8 million and \$ 37 million respectively. Third, we will consider a carbon-14 recovery facility to recoup almost 90,000 Ci of that isotope by 2018, increasing to close to 145,000 Ci altogether by 2062 [10]. This isotope in a basic industrial chemical, barium carbonate, would currently fetch \$54 million for each 1000Ci. If added value is considered in the form of other simple or more complex radiochemicals for biochemical research and medicine, then this value increases for instance about 500-fold for carbon-14-labelled caffeine, with lesser or greater values for other compounds.

As a fourth key item for recovery, tritium will be highlighted. As an example of a path already chosen, the current tritium recovery facility [8,9] will be considered, with a pointer to the potential of another available 13,000 Ci of tritium already concentrated on existing and future ion exchange resins [10].

As an important secondary consideration, these items are intended to take up a volume of ~22,000 m³ of the planned volume of 170,000 m³ [10]. If diverted from the deep geological repository (DGR), this represents not only a space saving of close to 13% of the total volume, but more importantly equivalent savings in transport, labour, stainless steel containers, etc., and therefore size and cost of the total DGR operation. At a planned total cost of \$1 billion, that would result in a further saving of \$130 million on top of the recouped value of only the four items mentioned above.

While the current low- and intermediate- level DGR is integral to discarding operational and refurbishment materials between now and 2062, decommissioning of the reactors around that latter time will result in an entire new equivalent set of structural materials from steam generators to pressure tubes for recovery and reuse, with an equivalent salvage value of many millions of dollars.

What is not discussed is the cost of mounting the means to extract the value of the materials. The suppliers and the clients of the goods and services, even for decade-old existing facilities, have uniformly indicated the existence of real or imagined legal barriers as well as business confidentialities.

2. Zirconium recovery

The Reference Low and Intermediate Level Waste Inventory for the Deep Geological Repository (“Inventory” hereafter) compiled by OPG indicates that the main quantities of zirconium (Zr) are in the decommissioned pressure tubes at 430 tonnes zirconium alloyed with 12 tonnes or 2.7% niobium (Nb), as well as in the calandria tubes at 170 tonnes zirconium alloyed with 0.17 tonnes or 0.1% antimony (Sb) (in [10], Table 3.4).

The 612 tonnes pressure and calandria tube metals will include neutron activated isotopes:

	Radiation Bq	Particle energy β (electrons)	gamma ray energy
0.25% activated Zr-93	2.1×10^{14}	60 keV	< 90 keV
activated Nb-94	4.6×10^{15}	600 keV	< 0.87 MeV
activated Sb-125	7.5×10^{14}	0.1-0.6 MeV	0.036-0.67 MeV

In addition to these intrinsic elements the internal and external surfaces of the tubes are covered with a variety of adsorbed stable and radioactive elements of lesser importance (in [10], Tables 3.2, 3.3).

Such “contamination” suggests that the otherwise pure nuclear grade zirconium would serve no further purpose, especially since Zr-93 has a half-life of 1.5 million years and Nb-94 of 20,000 years ($T_{1/2}$ for Sb-125 is relatively short at only 2.7 years). Safe sequestering would appear to be a logical choice.

Yet zirconium is required as a 10 wt% alloying element in the metal fuel of future fast-neutron reactors (FNRs) [7, p.124-134], a milieu in which the radioactivity of the zirconium is of no consequence. Moreover, since FNR used fuel recycling already occurs in a shielded environment, the additional costs of handling and reuse of radioactive zirconium within such a facility would be minimal.

Such fuel cycling FNR technology which provides about 130 times more non-carbon energy from the same fuel already used in our CANDU reactors must be adopted if nuclear power is to have an impact on supplanting greenhouse gas emitting fossil energy in a meaningful way [11].

Fuel in FNRs can be consumed theoretically to ~35wt % in one fuel cycle [2], and has been tested experimentally up to 25 wt% [12]. Thus by permitting 25 wt% non-fuel elements (fission products) plus 10 wt% zirconium, the FNR fuel is rather forgiving. Nevertheless it is useful to remove as much as possible of the residual adsorbed surface elements from the inside and outside of the pressure and calandria tubes. This reduces neutron absorption losses in the FNRs and also recovers in total about 140 kg U238 plus other heavy atoms [10] that are FNR fuel replenishment. A process perhaps simpler than that proposed below for steam generator tubes might be suitable for such open straight pipes. This should be done before the tubes are crushed flat and guillotined into square sections as is currently contemplated for efficient storage.

Because the cost of nuclear grade zirconium currently is \$440 per kg [13], such foresight, with relatively little additional labour, would result in \$ 265 million saved or earned as the 600 tons of recovered zirconium metal are used in FNR fuel in the future.

3. Heat exchangers/steam-generators

The carbon steel in the shell of heat exchangers and steam generators from nuclear reactors is already being recovered in European nations [14]. An attempt to recover value from steam generators (SGs) was made in Ontario around 2010-11 [15], with a proposal to ship 16 such decommissioned structures to Studsvik of Nyköping in Sweden. In spite of authorization by the Canadian Nuclear Safety Commission the attempt was blocked among others by Great Lakes municipal politicians fearful of the potential of any radiation dispersing in the waters of the lakes in the water-born transit of sealed SGs from Kincardine to the Atlantic Ocean.

Nevertheless, the then sitting chair of the Great Lakes Mayors Association, Mayor McMullan of St. Catharines, suggested that with the objections to water transport of our SGs, we should investigate mounting a clean-up and dismemberment service of present and future SG assemblies in Ontario.

Enquiries made to Studsvik, as well as to Canadian utilities, regarding decontamination costs fell on deaf ears. Nevertheless, the fact that such service is being carried out by Studsvik in Sweden (SG operations now merged/sold to EDF in France) indicates that it is a profitable venture.

The OPG Inventory indicates that there will be a total of 210 steam generators (Fig. 3) and heat exchangers of different sizes and constructions [in [10] pp. 102, 124, 126, 128, 130]. The casing of all of them is carbon steel, while the tubing on the inside is primarily Inconel 600, with some Incoloy 800 [10]. Extrapolating from Table 3.5 of the Inventory [10] to include the heat exchangers the total carbon steel from all 210 assemblies weighs 9870 tonnes, while the Inconel 600 of the inner tube bundles weighs 3290 tons.

The current price for carbon steel is CDN \$ 832 per tonne [16], and for Inconel 600 it is \$ 11,180 per tonne [17]. This puts the value of the total weights of those materials at \$ 8.2 million for potentially

recovered carbon steel and at \$ 36.8 million for Inconel 600.

Clean-up of steam generators (SGs) occurs even during the operating life of such devices in order to improve heat transfer between the primary side (the inside of the tubing) and the secondary side (inside the casing, but outside the Inconel tubing). Magnetite build-up occurs on the primary side creating a

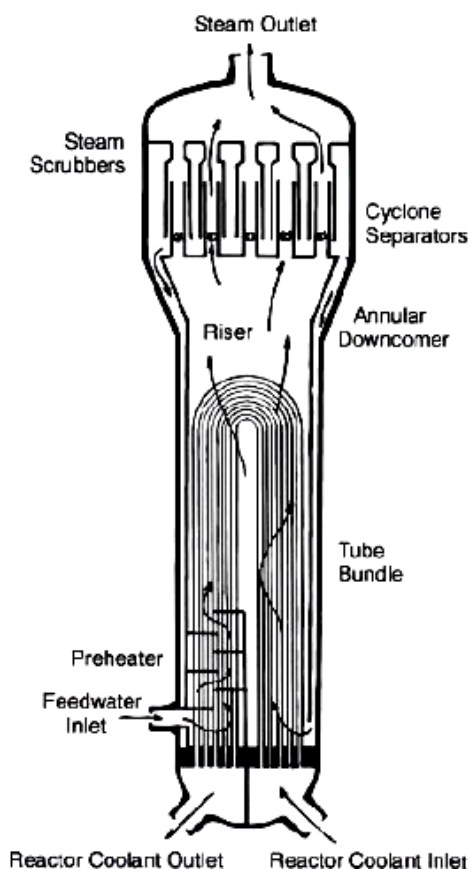


Figure 3. CANDU Steam Generator. Height 12-21 m. Individual tube diameter ~16-22 mm [19,29].

thicker wall more resistant to heat transfer. In addition radioactive elements deposit along with the magnetite. These are caused in part by neutron-activated elements in the steel and zirconium within or near the core, such as Co-60 or Nb-95, that are dissolved in and carried by the heated heavy water to the SGs where some of it deposits. Moreover, if a fuel bundle fails, then some radioactivity from that bundle circulates with the hot heavy water and deposits in the circuit before the bundle is removed and the water suitably filtered. This would include fission products such as Ru-106 and Ce-144 [18].

During scheduled downtimes of the reactor a mild solution treatment has been undertaken to remove some of these elements. A mixture of organic acids, such as oxalic and citric acid, along with a chelator such as EDTA (ethylene-diamine-tetraacetic acid) in CANDECON and CANDEREM, then dissolved radioactive residues particularly in pipes at the face of the CANDU reactor to reduce occupational exposure. However, unless the cooling circuit was re-routed, the solution also dissolved and cleared part of the deposits in the primary side of the SG [18].

For longer outages the SG can be opened on the secondary, non-radioactive side to descale deposits and sludge on tube sheets and on the outside of the tubes using techniques such as water lancing [20]. At times the primary side is opened and accessible, particularly if a leak occurs in one of ~4000 primary tubes of the SG, necessitating sealing of that particular tube.

During decommissioning less gentle techniques could be used on an SG to clean the primary side of its radioactive scale. Studsvik in Sweden uses blasting with beads of various sizes made of various materials from glass to steel [14]. The beads are recycled to minimize processing waste. AREVA uses a similar process called Sivablast. As an indicator of progress achieved, a single 3 minute blast per tube

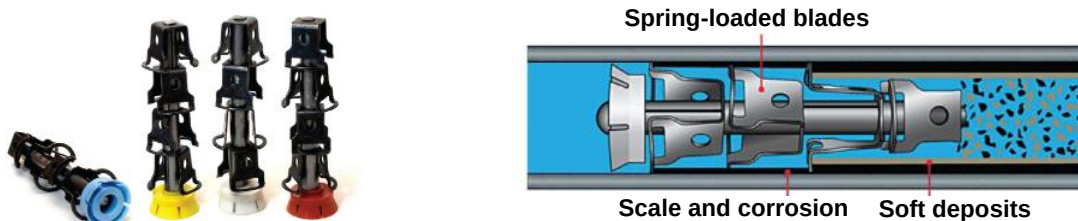


Figure 4. Vaned projectiles (left) pushed by water pressure through tubes to remove deposits (right) [22].



Figure 5. Tube cleaning rotating heads activated by attached flexible shaft [20].

leaves behind only about 10% of the magnetite build-up in the tube, while a second similar blast removes 90% of the remainder [21].

Other procedures shoot vaned shuttles through the tubes (Fig. 4) with water pressure to scour the sides [22], while still others use rotating augers [23] scouring the sides with brushes of varying hardness up to actually using cutters to ream the inside of the tubes (Fig. 5).

Blasting is preferred by Studvik in Sweden [14]. However, whether that technique to remove the radioactivity has to be augmented with others in the Canadian context, such as dissolution with CANDECON or stronger acids, or with mechanical cleaning heads pushed through or rotated inside the tubes would of course need to be determined. In all cases, the residue left after cleaning or volatilization of solvents is reduced in volume about 100-fold compared to the volume of the SGs.

The material and funds that could be recuperated from the structural SG components in such clean-up and decontamination process could go beyond the close to \$ 50 million gross for the 210 units associated with the current Canadian CANDU fleet. Such a facility could service the decommissioning of that Canadian fleet in later years and also open up to the competitive North American market, particularly if located such that inbound traffic of SGs would not endanger the Great Lakes watershed.

As a final consideration, the Inventory indicates that the deposits inside the SG tubes contain about 140 kg of uranium, mostly U238. While this does not seem to be a substantial amount, used as fuel replenishment in FNRs it would produce ~150 MW-years of electricity, about \$170 million of non-carbon energy at current Ontario rates. Therefore even the residue from the SGs has to be examined for foreseeable future value before it is considered “waste”.

4. Carbon-14 recovery

Almost simultaneously with the investigation of a tritium removal process in the 1990s to reduce exposure of its personnel, OPG also investigated the potential of recovering ^{14}C primarily from the heavy water moderator which had been captured and was accumulating on ion exchange resins [24]. While tritium removal was important for occupational safety reasons, a profit motive may have driven the thrust to isolate ^{14}C . The inducement apparently was not strong enough at the time for OPG to diversify away from its prime object of producing reliable and affordable electricity for the province.

In light of the intent to dispose of the accumulated carbon-14 isotopes, it may be time to reexamine that focus. By now the stored ion exchange resins have accumulated over 85,000 Ci carbon-14, with the amount expected to rise to 146,000 Ci by 2062 [in [10], Tables 2.6, 2.7].

That material could be extracted and converted to barium carbonate, the current industry starting material for synthesis of other ^{14}C -labelled compounds. Barium carbonate in bulk currently sells at 25 milliCi for CDN \$ 1356. While 85,000 Ci would flood the market, 1000 Ci per year at this point would not, and would fetch \$54 million each year. Indeed, now may be the time to enter that market.

At the moment Russia is the only supplier of carbon-14, with an uncertain supply from a single reactor [25]. One of the producers of radiopharmaceuticals is currently building its own facility, not to produce the isotope, but to recover it from its own processing fluids as a hedge against Russian shortfalls [26].

Chang et al. [24] in 1991 indicated after one pilot plant produced 400 Ci per year from OPG's existing ion exchange resins, that the process could be scaled up to produce 2000 Ci per annum or more.

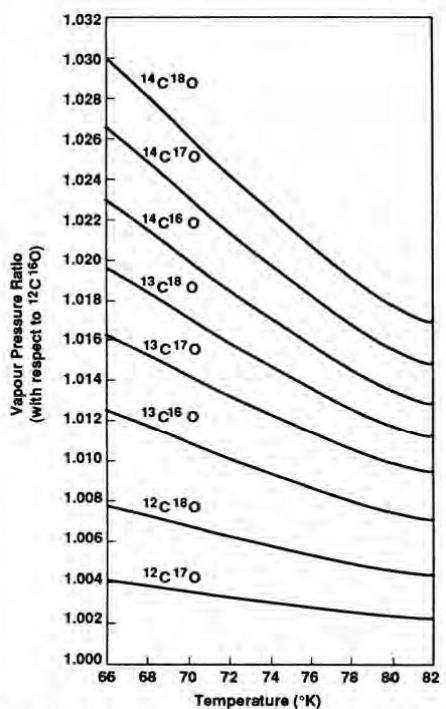


Figure 6. Vapour pressure ratios indicative of the potential of separation of carbon monoxide molecules constituted with different isotopes of carbon and oxygen (from [24]).

In brief, the process involves stirring the resin with 6 N HCl in an aerated reactor to release virtually 100% of the carbon-14 as carbon dioxide in a helium carrier gas. The CO_2 is then trapped cryogenically, with the helium recovered and recycled. The HCl also releases other radioisotopes. However, they can be recovered as a solid residue if the HCl as an azeotrope of 20% in water is evaporated.

The CO_2 from the cryogenic trap is converted to CO (carbon monoxide, a smaller molecule that makes isotopic separation of ^{14}CO from ^{12}CO by differential cry-distillation easier since it increases the vapour pressure differential (Fig. 6)). As an alternative, Quotient Ltd. [26] use an approach that converts CO_2 to methane, a still smaller molecule, to achieve an even greater difference in mass and vapour pressure for ease of separation between $^{14}\text{CH}_4$ and $^{12}\text{CH}_4$. Nevertheless, Chang et al. [24] indicate that their approach already achieves a purity of 99% ^{14}CO . Which process wins would depend on economics.

^{14}C -carbon dioxide is then regenerated from the monoxide by oxidation over a platinum catalyst, with Chang et al. recommending that the resulting $^{14}\text{CO}_2$ be stabilized into barium carbonate by barium hydroxide precipitation from a ^{14}C -bicarbonate of sodium form.

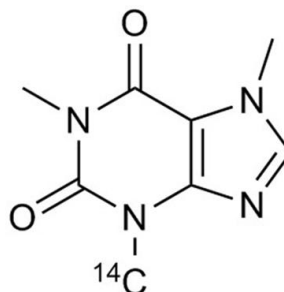
This approach could be the minimal involvement of OPG in such a ^{14}C secondary industry, perhaps less than the involvement in the safety-motivated tritium removal facility it runs currently. It would offer a steady multimillion dollar income stream, at somewhere around \$ 54 million per annum, though it would not very likely approach the gross total of \$ 7.6 billion from the eventual 140,000 Ci of ^{14}C in barium carbonate form.

Should there be interest in added value by synthesizing specific radiochemicals, the benefit could be huge. Compared to ^{14}C -barium carbonate at \$ 54 for 1 mCi, a simple compound such as ^{14}C -methyl iodine would double the yield at \$ 120 per milliCi [27], while a more complex ^{14}C -caffeine (Fig. 7)

would increase it about 500-fold to \$ 26,000 per milliCi [27]. Obviously a good knowledge of organic synthesis would be required.

This potential multimillion dollar revenue opportunity would be thrown out if the ^{14}C -laden resins would be considered waste of no value, and discarded in a DGR.

Figure 7. Structure of ^{14}C -methyl-labelled caffeine



5. Tritium removal – an on-going procedure

At the same time as the studies of Chang et al. on ^{14}C above [24], Busigin and Sood [8] investigated the optimization of extracting tritium from the heavy water moderator of the CANDU reactors at Darlington. Removing tritium would reduce the occupational exposure to this rather volatile radioisotope and also reduce environmental emissions.

Busigin and Sood indicate the objective of the analysis as follows:

- 1) minimize operating costs;
- 2) maximize the rate at which heavy water is detritiated;
- 3) maximize the detritiation factor for processed heavy water;
- 4) maximize the overall tritium production rate;
- 5) maximize tritium product purity.

While it seems curious that safety (detritiation) is secondary to minimizing costs, the end result was a successful tritium removal facility that is still performing its function and supplying the isotope to the world as well. The Darlington facility handles about 1000 tons of moderator heavy water per year and in that time produces between 1 and 2 kilograms of tritium gas [9]. A portion of it is transferred to AECL in Chalk River for resale to customers of OPG for a multitude of uses. These range from gaseous tritium light sources, through luminous signs, dials and instruments, to many tritiated radiopharmaceuticals used in biomedical research.

Certainly the small size of this hydrogen isotope brings with it special challenges: under pressure and at elevated temperatures it can diffuse even through steel containers. In spite of this volatility ingenious means have been devised to capture and transport it over small distances and over continents: it is captured via “getters”, either with thin foil titanium to form a solid titanium-tritide (a hydride) as the preferred medium for long term storage, or on uranium powder to form a more easily reversible uranium tritide.

When tritium is required for use the titanium-tritide or uranium-tritide is heated to above 600°C or 400°C respectively to release the gas. Both metals can be recycled, but the lower temperature process is clearly easier for an end-user.

In comparison to the two kilograms of tritium extracted annually at the Darlington facility, the amount of tritium on the ion exchange resins in the Inventory seems small. There are 4.8×10^{14} Bq on all resins in storage, amounting to only 1.33 grams. Nevertheless, this is 13,000 Ci of radioactivity even if disintegration results in the release of electrons with a maximum energy of only 19 keV each.

Still, captured and converted into simple radiochemicals, tritium becomes quite valuable. For instance, a chemical as simple as tritiated methyl alcohol (methanol), or T_3COH , costs a researcher \$1,275 for 1mCi [27]. A more complex molecule, [4-3H]-naphthol, tritiated on the 4-position of this double ring compound, costs \$800 for 50 microCi. Thus, if one looks beyond the tritium as a raw material, or worse a detriment, but considers the added value of tritiated radiopharmaceuticals, such a secondary industry might become a valuable addition to the economy.

5.1 Return on investment for tritium

The Tritium Removal Facility (TRF) of OPG at Darlington was conceived as a safety measure for personnel. As such the capital costs are not budgeted into the sales of isotopes. Total details are not available (business confidentiality). Nevertheless, if such a facility around 1991 [8] would have a cost of \$ 100 million with a carrying charge of 5% an approximate accounting might be as follows.

TRF capital cost	\$ 100 M	assumed
Carrying charge at 5%	\$ 5.0 M	
OM&A	\$ 1.2 M	[30] (Table 6.3)
Annual cost	<u>\$ 6.2 M</u>	
Isotope sales (H-3+Co-60)	\$ 11.8 M	[31] (Table 1)
H-3 portion assumed 25%	\$ 2.9 M	
Helium-3 (via H-3 decay)	\$ 4.0 M	[31] (Table 1) projected for 2015
Annual revenue	<u>\$ 6.9 M</u>	

This suggests that under steady-state operation with sales from both tritium and helium-3 the facility would recover its operating costs plus interest on capital. However, if added value were considered in spawning an associated radiochemical laboratory for the synthesis and sale of radiopharmaceuticals, it is likely that a major profit could be realized from the recovery of the tritium isotope.

6. Partial value of the inventory

In the discussion above only four items were examined that are slated by OPG to be disposed of in a planned deep geological repository (DGR) for low- and intermediate-level radioactive waste. Recovery and reuse of the metals in pressure and calandria tubes and in steam generators in the OPG Inventory would have a commercial purchase value of \$ 310 million. The work of Studsvik in Sweden suggests that even such steam generator recycling can turn a profit.

Moreover, two commonly used radioisotopes, carbon-14 and tritium, if recovered in quantity from ion exchange resins between now and 2062 and converted to the simplest of radiochemicals would gross conservatively about \$ 54 million and \$ 7 million per year respectively, with much greater amounts possible if value is added via the creation of radiochemicals and radiopharmaceuticals. The market currently seems to have very few suppliers.

At the hearings of the Joint Review Panel of the Canadian Nuclear Safety Commission (CNSC) in 2013 OPG and the NWMO (Nuclear Waste Management Organization) were challenged by the Panel to consider their intended disposal of the content of the Inventory in the planned DGR in light of the CNSC Regulation P-290 of “Reduce, Reuse, and Recycle”. The repeated answer by OPG personnel was that the items listed in the Inventory for disposal were “waste of no value” [28]. While perhaps true for a focus on the production of electricity, it is certainly not true in a more global sense.

The simple and direct examination of the potential of the selected four items above suggests that not all items on the Inventory list are “waste of no value”. Not only did the items have substantial value, ranging solidly up to \$ 350 million, but in addition the mere removal of the above four items from DGR emplacement reduces the required volume of the DGR by about 13%. Considering the total cost of the currently planned DGR to be an estimated \$1 billion, this 13% lesser volume along with equivalent foregone construction and labour costs for the reduced DGR, foregone transportation of inventory, and other items such as stainless steel container material and construction, cement grouting, etc., could amount to a saving of about \$130 million.

7. Conclusion

One of the challenges in the operation, the refurbishment, and the decommissioning of existing nuclear facilities is to recognize the opportunities that arise from the material no longer needed as part of the direct operating continuum. For some parts a clean up or even partial decontamination recovers major values. For others it is the actual “contamination”, the radioactive substance itself, that is the useful product as starting material elsewhere. In general, however, the operational material from Ontario’s CANDU reactors currently stored for disposal is not “waste of no value”. It is instead an opportunity for a revenue stream worth many billion dollars.

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