Health Implications of Pelleting Operations at the BWXT-Peterborough Plant

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a report commissioned by

The Canadian Environmental Law Association (CELA)

And

Citizens Against Radioactive Neighbourhoods (CARN)

to be submitted to the Canadian Nuclear Safety Commission (CNSC)

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Background : The BWXT Licence Application

The present report was prepared for the Canadian Environmental Law Association (CELA) and the Peterborough-based community group, Citizens Against Radioactive Neighbourhoods (CARN). The report addresses potential health impacts of pelleting at the BWXT-Peterborough plant.

BWXT Nuclear Energy Canada Inc. operates two Class 1 nuclear facilities, one in Toronto and the other in Peterborough, under the terms of a ten-year licence from the Canadian Nuclear Safety Commission (CNSC) governing both plants. These facilities have been authorized for many years to work in tandem to produce CANDU fuel bundles for Ontario's nuclear reactors, and to pursue other licenced activities as well.

The BWXT-Peterborough plant receives finished ceramic uranium pellets from the Toronto plant and assembles those ceramic pellets into CANDU fuel bundles. Workers at the Peterborough plant stack the solid ceramic pellets into 30-centimeter long zirconium alloy rods, which are then sealed. More than two dozen of these parallel fuel rods are bound together into a cylindrically shaped CANDU fuel bundle, welded together into a solid unit with zirconium alloy spacers.

Small zirconium alloy appendages are brazed to the surfaces of the outer fuel rods using beryllium, a metal that is lighter than aluminum, tougher than steel, and transparent to neutrons. It is also one of the most toxic metals known. The appendages make it easier to slide the fuel bundles through the long horizontal fuel channels inside a CANDU reactor while maintaining some separation between the inner wall of the channel and the fuel rods themselves, and allowing coolant flow with less resistance. Bundles produced by BWXT are used at the Pickering and Darlington reactors.

Figure 1. CANDU fuel bundle showing brazed appendages

The pelleting operation that currently takes place at BWXT-Toronto involves an entire suite of materials and processes having almost nothing in common with the fuel bundle assembly that takes place at the BWXT- Peterborough plant. Very fine uranium dioxide powder from the Cameco conversion facility in Port Hope is shipped to BWXT-Toronto. There the uranium oxide powder is formed into a cylindrical shape under a pressure of 12 to 15 tons per square inch. The resulting “green pellets” are then sintered at a temperature of about 1650 to 1700 degrees C in a pure hydrogen atmosphere to prevent oxidation and to vaporize and remove the zinc stearate lubricant used in the pressing operation. The finished pellets are cylindrically shaped, approximately one centimeter high, with a diameter of comparable size. The ceramic pellets are then shipped to BWXT-Peterborough for fuel bundle assembly.

Figure 2. Uranium dioxide powder.

Figure 3. Sintered uranium dioxide fuel pellets

At present, pelleting is carried out at the BWXT-Toronto plant but not at the BWXT-Peterborough plant. BWXT Nuclear Energy Canada Incorporated (BWXT NEC) is currently asking the Canadian Nuclear Safety Commission (CNSC) to renew the licences for these two facilities, enabling BWXT to continue performing the same functions at the same two plants for the next ten years, but with an extra provision that would allow BWXT to begin pellet-making operations at the Peterborough plant at any time during the licence period if management so decides, for reasons that are not specified in the licence application or in any of the supporting documentation.

According to article 9 of the Nuclear Safety and Control Act, one of the four principle objects of the CNSC is to regulate the nuclear industry "in order to prevent unreasonable risk, to the environment and to the health and safety of persons…." The other three objects of the CNSC are "to prevent unreasonable risk to national security…", to "achieve conformity with measures of control and international obligations…", and "to disseminate objective scientific, technical and regulatory information…."

CNSC has no mandate to approve a project, no matter how convenient it may be for the licensee, if that project entails risk to the health and safety of persons or the environment that is judged to be "unreasonable". It follows that a fundamentally important consideration for any licencing hearing must be for the Commissioners to deliberate on whether the facility under consideration poses a reasonable risk, or an unreasonable risk, to the people most likely to be exposed to the emissions from the plant, and whether that risk is justified. The documentation in this case contains no detailed examination of health matters as it may affect those most likely to be impacted by a pelleting operation at BWXT-Peterborough, nor does it provide justification.

Recommendation 1: *CNSC Commissioners are urged not to approve the additional pelleting provision requested by BWXT NEC unless and until a detailed safety case is presented and subjected to public scrutiny regarding the potential health consequences of initiating a pelleting operation at BWXT-Peterborough, as well as the possible implications for emergency preparedness in the event of severe accidents.*

Canada. Nuclear Safety and Control Act.

9. The objects of the Commission are

(a) to regulate the development, production and use of nuclear energy and the production, possession and use of nuclear substances, prescribed equipment and prescribed information in order to

(i) prevent unreasonable risk, to the environment and to the health and safety of persons, associated with that development, production, possession or use,

(ii) prevent unreasonable risk to national security associated with that development, production, possession or use, and

(iii) achieve conformity with measures of control and international obligations to which Canada has agreed; and

(b) to disseminate objective scientific, technical and regulatory information to the public concerning the activities of the Commission and the effects, on the environment and on the health and safety of persons, of the development, production, possession and use referred to in paragraph (a).

Exhibit 1: Nuclear Safety and Control Act, article 9, the objects of the Commission

Those most at risk at BWXT-Peterborough

Those most likely to be exposed to airborne emissions from the BWXT plant are elementary school children attending the Prince of Wales school just across the street from the plant. Commissioners must consider whether these children may be exposed to an unreasonable risk simply by going to school and playing in the playground.

Evidence recently made available from the Independent Environmental Monitoring Program (IEMP) – posted on the CNSC web site on January 22, 2020 – has indicated to several scientists from the Peterborough community (see Annex A) that airborne beryllium emissions from the plant may have been slowly accumulating in the soil, even in the school's playground area, since 2014, when soil sampling began. The playground in question is one where children frequently play sports and engage in other outdoor activities, and it extends to a point that is within 50 metres of the plant across the street (Figure 4).

Figure 4. Prince of Wales elementary school playground with BWXT plant and stack in background. Photo by Robert Del Tredici, December 3, 2019.

If pelleting is to commence at BWXT- Peterborough there will be an anticipated increase in uranium emissions into both air and water – likely by a factor of three to five orders of magnitude (see tables 1 & 2 below). Is it reasonable or unreasonable that these children will begin routinely inhaling several thousand times more uranium dust from the plant?

It is unusual to see a Class 1 nuclear facility sited so close to an elementary school, where about 600 children attend classes from Kindergarten to Grade 8. Many of those kids will likely be spending nine years at the same school, entering Kindergarten at age 5 and progressing to grade 8 before graduating to high school. The student body will turn over (on average) by about 67 children per year, so in the course of a decade there could be a total of about 1200 young kids exposed to airborne BWXT emissions, each one for a period of time ranging from one to nine years. These exposures would occur simply as a result of attending school and playing in the playground.

It is reasonable to infer that, as uranium oxide particulate emissions inevitably increase due to pelleting, uranium depositions will also begin to accumulate in the soil of the playground, following the same pathway as the airborne beryllium may have travelled.

Under such circumstances, children at play will be more likely to inhale, not only minute amounts of beryllium, but also minute amounts of uranium dioxide particulate matter. Moreover, such insoluble particulate matter that has settled in the soil can easily become resuspended due to running, jumping, kicking, skipping or simply walking.

Let's examine the increases in uranium dioxide emissions to the air and the water to be expected. Comparing reported uranium emissions from the two plants from 2014 to 2018 we see that the Toronto pelleting operation released from 5000 to 94,000 times more uranium into the water each year, and from 2700 to 3700 times more uranium into the air each year, than has been the case from the fuel bundle assembly operation in Peterborough.

grams of uranium into the air	2014	2015	2016	2017	2018
BWXT-Toronto	10.9	10.8	10.8	7.4	6.3
BWXT- Peterborough	0.003	0.003	0.004	0.002	0.002
Ratio : T/P	3633	3600	2700	3700	3150

Table 1. Source: BWXT 2018 Compliance Report, Figures 10 and 11

grams of uranium into the water	2014	2015	2016	2017	2018
BWXT-Toronto	720	300	650	940	940
BWXT- Peterborough	0.14	0.06	0.13	0.03	0.01
Ratio : T/P	5143	5000	5000	31,333	94,000

Table 2. Source: BWXT 2018 Compliance Report, Figures 13 and 14.

The atmospheric uranium emissions in question are in the form of a very fine particulate matter – tiny specks of uranium dioxide powder that are easily inhaled into the deepest parts of the lung. Uranium dioxide powder is much finer than refined flour. The diameter of a uranium dioxide particulate is typically less than 10 microns (micrometres) in diameter, with a median value of about 6 microns. This is much smaller than the width of even the finest human hair. The size of uranium dioxide particulates that escape into the atmosphere through a HEPA filter are even smaller in size, generally less than two microns in diameter, and often smaller than one micron in diameter. Particles in this category are so small that they can only be detected with an electron microscope.

Relative sizes	
Diameter of Flour particulate	110 to 570 microns
Diameter of Human Hair	17 to 181 microns
Diameter of Uranium Oxide particulate	1 to 10 microns
Diameter of Particulate escaping HEPA filter	0.5 to 2 microns

Table 3. Relative sizes in microns

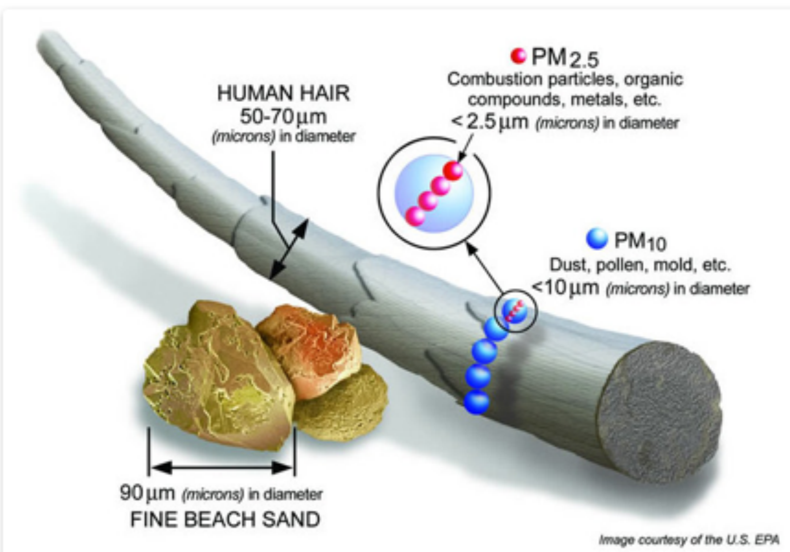

Figure 5. Particulates with diameter 2.5 microns compared to a human hair.
https://blissair.com/what-is-pm-2-5.htm

A single gram of uranium oxide is equivalent to almost 175 billions of such one-micron particulates (density = 10.9 g per cm^3). Since the mind has difficulty grasping such large numbers, suffice it to say that the number of uranium oxide particulates emitted into the air from BWXT-Toronto – each year – is comparable to or greater than the number of stars in the Milky Way galaxy. If BWXT-Peterborough follows suit and begins pelleting, the schoolchildren at Prince of Wales Elementary School will have ample opportunity to inhale a few of these myriad tiny uranium oxide particulates into their lungs.

Elimination versus Control of Risk

CNSC's Jenna Hartviksen wrote to Jane Scott of CARN on August 6, 2019, saying that technical staff at CNSC had provided the following information for public dissemination:

> "About a few micrometers in diameter, these dust particulates may be inhaled if they become airborne. Inhalation of uranium dust may result in internal dose to lung tissue from the alpha particles, as well as chemical toxicity if it is absorbed in the bloodstream and transported to sensitive tissues, notably the kidneys.
>
> "It is precisely for this reason that the CNSC mandates stringent worker health and safety programs at BWXT to eliminate or limit exposure to uranium particulates inside the facility. This includes, but is not limited to, the use of engineering controls, work processes, and personal protective equipment."

Ms. Hartviksen reports that CNSC safety programs are designed to "eliminate" the exposure of workers to uranium particulates if possible, or, if elimination is impossible, to "limit" the exposure. The same philosophy presumably applies to the public. If public exposure to uranium dioxide particulates can be eliminated altogether, that is the ideal outcome. If such exposure cannot be eliminated, then it must be limited. Given the unusual circumstance of a Class 1 nuclear facility sitting on the doorstep of an elementary school, and the mandate of CNSC to protect health, Commissioners may choose to go beyond the advice of CNSC staff, which is to approve the licence as is.

Much attention has been devoted in recent years to the health dangers of particulate matter, especially $PM_{2.5}$ – particulate matter smaller than 2.5 microns in diameter. Such particulates are especially dangerous because they can be inhaled into the deepest and most sensitive parts of the lung, where they may lodge for an extended period of time. On a Government of Canada web site, for example, we read the following:

> "Outdoor $PM_{2.5}$, as measured at area monitoring stations, has been shown in a large number of studies to be strongly associated with cardiovascular and respiratory mortality and morbidity endpoints (Health Canada and Environment Canada 1999; WHO 2005; US EPA 2009). There is no recognized threshold of health effects for outdoor $PM_{2.5}$ regardless of where exposure occurs (i.e., indoors or outdoors), and there is evidence that adverse health effects occur at current levels of exposure."

Health Canada. Guidance for fine particulate matter (PM2.5) in residential indoor air.
https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-fine-particulate-matter-pm2-5-residential-indoor-air.html

Children are particularly sensitive to the health effects of breathing such fine particulate matter for a variety of reasons. A recent article (2017) published in Particle and Fibre Toxicology points out that:

> "Exposure to airborne particles has a major impact on global health. The probability of these particles to deposit in the respiratory tract during breathing is essential for their toxic effects…. Exposure to airborne particles may pose different risks to different sub-populations, and children have been identified as one of the most sensitive groups…. The study included in total 67 non-smoking participants, aged 7–67 years…. Seven of the participants were 7–12 years old.… The real difference in deposition rate, and thus in deposited dose, is expected to be higher due to the generally higher activity level, and thus breathing volume, of children…."

Deposition efficiency of inhaled particles related to breathing patterns and lung function: an experimental study in healthy children and adults
https://particleandfibretoxicology.biomedcentral.com/articles/10.1186/s12989-017-0190-8#auth-3

Recommendation 2. *The Commissioners are urged not to approve the special pelleting provision in the BWXT licencing application, thereby preventing and eliminating all future routine exposures of hundreds of schoolchildren at Prince of Wales elementary school to elevated levels of respirable particulates of uranium dioxide dust in the* $PM_{2.5}$ *category as a result of pelleting at BWXT-Peterborough.*

Radiological risks and public information

In a guest editorial that appeared in the Peterborough Examiner on December 13 2019 John MacQuarrie, President of BWXT NEC, wrote:

> "Naturally occurring radiation is all around us and inside us all of the time. It comes from cosmic and earth-based sources, like radon gas in the air we breathe, and small amounts of uranium and other radioactive elements in the water we drink, and from radioactive elements in the ground, and in our food. Credible studies have consistently shown that low levels of radiation, such as from these natural sources, do not negatively impact health or the environment."
>
> *John MacQuarrie, guest columnist, Peterborough Examiner, Dec 13 2019*
> https://www.thepeterboroughexaminer.com/opinion-story/9774832-guest-column-bwxt-has-a-track-record-of-safe-operations/

MacQuarrie's statement is incorrect. Naturally-occurring radon gas in homes has been identified by many countries, including Canada, as a major public health concern. Radon has been identified as the leading cause of lung cancer among non-smokers, and the US EPA has estimated that about 20,000 American citizens die annually from breathing radon in their homes.

> "**Radon** is the number one cause of lung cancer among non-smokers, according to EPA estimates. Overall, radon is the second leading cause of lung cancer. Radon is responsible for about 21,000 lung cancer deaths every year. About 2,900 of these deaths occur among people who have never smoked."
>
> *Exposure to Radon Causes Lung Cancer in Non-smokers and Smokers Alike*
> *US Environmental protection Agency, https://www.epa.gov/radon/health-risk-radon*

MacQuarrie suggests that he bases his remarks on a thorough scientific knowledge of the subject by saying "Credible studies have consistently shown that low levels of radiation, such as from these natural sources, do not negatively impact health or the environment."

Many people would likely interpret MacQuarrie's statement to mean that there is no danger at all associated with radioactive materials from natural sources, and that this opinion is a well-established and unchallenged scientific fact.

Reading such one-sided and misleading public statements like this from the President of a company seeking a ten-year licence from the CNSC does not inspire confidence. Regrettably, CNSC staff did not see fit to offer any public correction or commentary on MacQuarrie's article, despite the statutory obligation of CNSC to "disseminate objective scientific … information".

In fact, it is well documented that radon, radium and polonium are three naturally-occurring radioactive materials that are all exceptionally dangerous. They are elementary substances found in nature, formed as a result of the radioactive disintegration of uranium atoms. They are called "uranium progeny".

Radium has been described by the British Columbia Medical Association as "a superb carcinogen" (The Health Hazards of Uranium Mining, BCMA, 1980). In the 20th century scores of people died from radium-induced bone cancer, fatal blood diseases, and head cancers, many of them young women. Some radium-induced deaths were quite sensational such as the 1927 demise of Eben Myers, a prominent steel tycoon who regularly drank "radium water" as a tonic. Marie Curie and her daughter Irene both died from fatal anemias caused by prolonged contact with radium.

Polonium – another disintegration byproduct of uranium – is 250 billion times more toxic than hydrogen cyanide according to the Los Alamos National Laboratory. (See https://periodic.lanl.gov/84.shtml .) A small amount of polonium-210 dissolved in tea was used to murder ex-Russian agent Alexander Litvinenko in London, England, in 2006. The American Health Physics Society, whose members include industry experts in radiation health monitoring, estimates that a large fraction of the deaths attributed to cigarette smoking are due to minute traces of radioactive lead-210 and radioactive polonium-210 in the tobacco.

These three materials – radon, radium and polonium – are not only “radioactive progeny” of uranium, but they share with uranium the fact that they are “alpha emitters”. Alpha emitters are harnless outside the body but are far more biologically damaging than other forms of atomic radiation once in close contact with living cells.

In order to understand the nature of the potential radiological hazard associated with the inhalation of uranium dioxide particulates from the BWXT pelleting operation, it is important to understand what an alpha-emitter is.

Physical Facts about Alpha Radiation

Some elementary background is necessary. Every atom has an extremely tiny compact core called a nucleus. The nucleus contains most of the mass of the atom. An atomic nucleus is surrounded by a number of orbiting electrons.

The forces that hold the nucleus together are millions of times more powerful than those holding the electrons in orbit. Because of this, nuclear energy – energy that is released directly from the nucleus of an atom – is millions of times greater than any form of chemical energy. Most chemical reactions involve re-arranging the orbital electrons of different atoms in order to combine those atoms into molecules, without altering the nucleus of any one of the constituent atoms.

Most atoms normally encountered in the natural world have a nucleus that is stable, eternal, never-changing. A radioactive atom (radionuclide) is one whose nucleus is unstable. Such a nucleus will suddenly and violently disintegrate, usually giving off an energetic charged particle – an alpha particle or a beta particle – in some cases accompanied with or followed by the emission of a gamma ray. Most radioactive elements are either alpha-emitters or beta-emitters; radon, radium, polonium, uranium, and plutonium are alpha emitters.

A beta particle is a very high-speed electron that originates from within the nucleus, not from the ranks of orbiting electrons outside the nucleus. An alpha particle is a much heavier projectile that is also thrown out from inside the nucleus with great force. It is identical to the nucleus of an ordinary helium atom, with two protons and two neutrons bound together, but it travels extremely fast and thereby acts as kind of subatomic cannonball. An alpha particle is 8000 times more massive than a beta particle and has twice the electrical charge. Accordingly, in living tissue, alpha particles are far more damaging than beta particles, breaking thousands of chemical bonds before coming to rest.

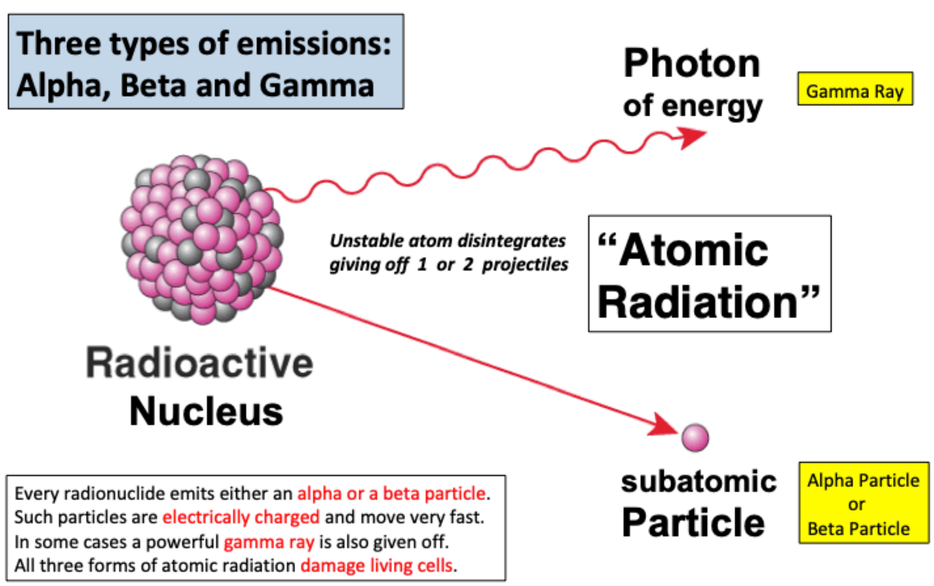

Figure 6. Three types of radioactive emissions: Alpha, Beta and Gamma.

A gamma ray is a photon of pure energy (with zero rest-mass) travelling at the speed of light. It is similar to an x-ray but more penetrating and more powerful. There are two important facts to bear in mind. 1. Gamma rays are much easier to detect with instruments than either beta particles or alpha particles. 2. Beta-emitters and alpha-emitters are primarily internal hazards, whereas gamma-emitters are both internal and external hazards.

An alpha particle in living tissue has little penetrating power, despite its exceptionally high energy and speed; it comes to rest within a very short distance: 20 to 70 microns. That range represents a thickness of one, two or three cells. The precise range of an alpha particle depends on its energy, measured in millions of electron-volts (MeV). An alpha particle with an energy of 5 MeV has a range of about 30 microns in soft tissue; alphas from uranium are about 4.2 MeV. All alpha particles can be stopped by an ordinary sheet of paper.

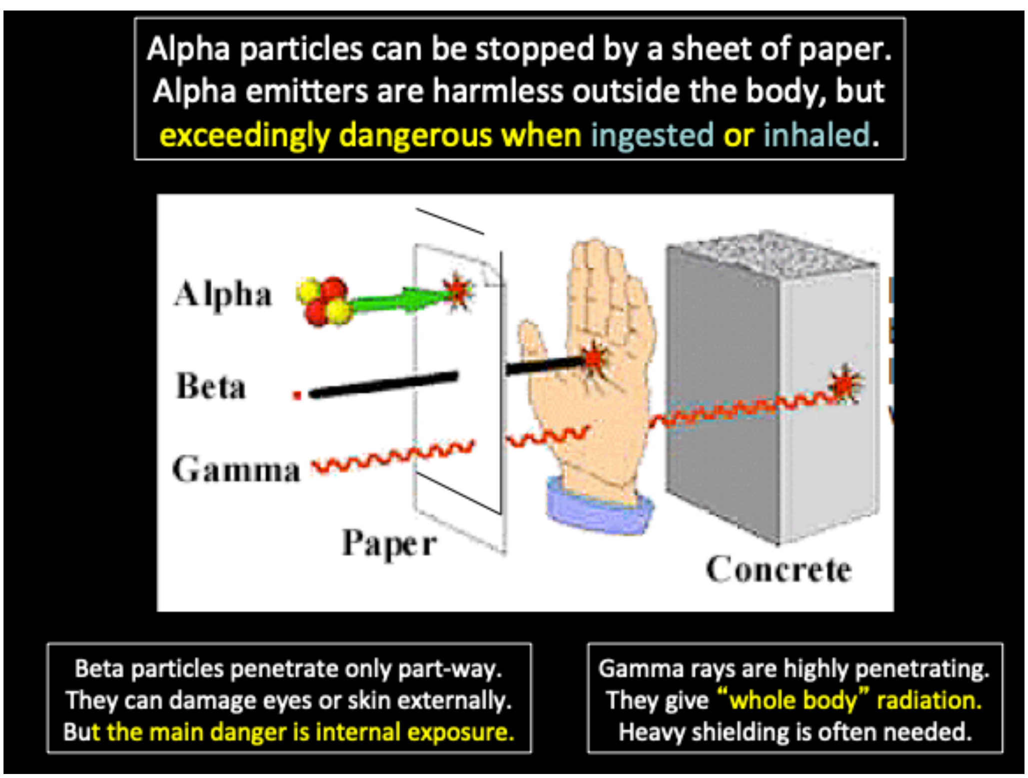

Figure 7. Alpha particles have very little penetrating power

For a given radioactive material, one becquerel indicates one radioactive disintegration per second. The half-life of a radioactive material is the time required for half of the atoms to disintegrate. For an alpha-emitter, the number of becquerels indicates the number of alpha particles that are emitted each second.

Access to Radiosensitive Tissues

Alpha emitters are extremely effective cancer-causing agents when they are in close contact with living cells. Indeed, per unit of energy deposited in tissue, alpha particles are regarded by the CNSC and other regulatory bodies to be twenty times more damaging than beta particles or gamma rays delivering the same amount of energy. The reason for this is only partly understood, but it is related to the fact that an alpha particle leaves behind an extremely dense track of broken and damaged molecules, far greater than is the case for a beta particle or a photon of gamma energy.

Nevertheless, alpha-emitting materials are generally harmless outside the body because the alpha particles they give off cannot penetrate through the dead layer of cells on the skin. This harmlessness disappears when there is a mechanism by which a particular alpha emitter can enter the body and come into contact with radiosensitive cells inside.

For radium, the most effective pathway into the body is ingestion. Drinking radium water or licking the tips of paint brushes with tiny amounts of radium-based paint on them, or contaminating hands and fingernails with minute amounts of radium, some portion of which ends up dissolved by saliva and incorporated into the body – these mechanisms contribute enough radium to the skeletal frame of its hundreds of victims to promote extreme osteoporosis and bone cancer, while damaging the blood-forming organs in the bone marrow so as to cause acute life-threatening cases of anemia.

For radon gas, the obvious mechanism is inhalation, especially after the radioactive gas has time to accumulate a number of its pernicious radioactive byproducts called “radon progeny” – notably the alpha-emitting elements polonium-218 and polonium-214. When the toxic mix of radon gas and its progeny is inhaled, a massive dose of alpha radiation is delivered to the delicate lung tissue, causing many radiogenic lung cancers

Adding polonium-210 to a cup of tea provides an ingestion pathway that turns the tea into a murder weapon. Inhaling polonium-210 along with the smoke from a burning cigarette guarantees that the alpha-emitting material is deposited in the deepest parts of the lung. Some polonium-210 even crosses the blood-air barrier to introduce the alpha-emitting material into the bloodstream. Some researchers hypothesize that minute amounts of polonium-210 found in the arterial plaque of smokers during autopsies may play an important role in causing the otherwise unexplained elevated incidence of cardiovascular diseases among smokers.

In the case of uranium, it is less obvious how a large dose of alpha radiation can be delivered to radiosensitive tissues inside the body. Because of the extremely long half-life of uranium, alpha particles are emitted at a very slow drawn-out rate, compared with other alpha emitters having shorter half-lives. Uranium is less likely to be absorbed through the gut and is often in a chemical or physical form that prevents entry into the deepest parts of the lung or facilitates fairly rapid clearance from the body – soluble compounds, for example.

However, the minute highly insoluble uranium dioxide particulates that are continuously emitted into the air from the BWXT pelleting operation enables inhalation to act as an extraordinarily effective means for pulling one particular alpha emitter – uranium – into the most radiosensitive pulmonary regions.

Due to the extremely small diameters of the almost perfectly spherical BWXT particulates, specks of uranium oxide dust are able to lodge in the lung tissue. And, because of their insoluble nature, the particulates, once lodged, can remain in place for a very long time – many years or even a lifetime – providing a "body burden" to the individual who inhaled the dust. The internal bombardment of the lung tissues with alpha particles will continue as long as the particulate is lodged.

> "The distribution and retention of uranium in the body after inhalation of an aerosol depends critically on the aerodynamic size of the particulates and on their solubility in biological fluids. Inhalation of insoluble compounds is associated with uranium retention in lung tissue…"
>
> *US National Academy of Sciences, BEIR-IV,*
> *Health Risks of Radon and Other Internally-deposited Alpha-emitters, p.14*

There are hundreds of children currently attending Prince of Wales Elementary School. They have no choice but to be there day after day, possibly for years, right across the street from the plant that will be emitting enormous numbers of these invisible specks of insoluble radioactive dust into the air, if the CNSC approves the requested licence condition that would allow BWXT management to implement the pelleting operation in Peterborough at will.

Due to an unfortunate incident in 2009 during the Bruce Power refurbishment, over 500 local tradesmen inhaled alpha-emitting dust over a period of several weeks, but at least they were paid for the job. These hundreds of children enjoy no benefits whatsoever from their unnecessary exposure to alpha-emitting dust.

Ionizing Radiation and Calculation of Absorbed Dose

The biological damage done by alpha particles is caused by random breaking or damaging of thousands of chemical bonds that hold molecules together as the alpha particle blazes its way through the surrounding medium before coming to rest. When a molecular bond is broken or damaged, the fragments left behind are electrically charged objects called “ions”.

Scientific measurements have demonstrated that a single alpha particle travelling through air will create over 10,000 different “ion pairs”. Similarly, when an alpha particle traverses through soft bodily tissues, thousands of ion pairs are created and many organic molecules are damaged, including DNA molecules.

Damage to a DNA molecule can result in a cell with altered genetic instructions that is nevertheless still able to reproduce. Such a crippled cell may become the precursor of a cancer many years or decades later, giving rise to a growing colony of clones that constitutes a malignant growth, a cancer that threatens to destroy the host.

Cancer induction happens only rarely, as most radiation-damaged cells are killed or unable to reproduce; thus not every exposed individual will develop cancer. Radiogenic cancer induction is a stochastic or random event, affecting only a probabilistically-determined fraction of those individuals exposed. Larger doses result in greater probability, lesser doses correspond to reduced probability. However, no exposed individual is immune from suffering such a fate: cancer is always a possible end-point from exposure to internally emitted alpha particles.

All types of atomic radiation – including alpha particles, beta particles and gamma rays – are forms of "ionizing radiation" because they all create ion pairs and break molecular bonds. X-rays are included in this category also, for it too is an ionizing agent.

Extensive scientific evidence has shown that exposure of a sizable population to a sufficient amount of ionizing radiation will produce an excess of cancers as a result of DNA damage. These extra cancers are said to be "radiogenic".

However there is a delay of several years before radiogenic cancers begin to be seen. This delay is called the "latency period"; it depends on the type of cancer as well as other factors.

In the case of lung cancer, the "latency period" following exposure to ionizing radiation, before radiogenic cancers begin to be seen, is about twenty years. Once that minimum latency period has expired, new radiogenic cancers continue to appear year after year even if all the individuals were exposed to the same degree of ionizing radiation at more or less the same time. The British Columbia Medical Association describes the situation for atomic workers:

> "Risk of lung cancer from radiation, although beginning after several years of employment, continues many years past termination of employment; thus a gradually flowering crop of cancers grows larger each year."
>
> *Health Dangers of Uranium Mining, BCMA, 1980*

To get a handle on the likelihood of cancer induction, we use a scientifically defined unit called the "gray". It provides a measure of how much ionization is taking place in given amount of living tissue. Specifically, it corresponds to the total amount of ionizing energy (measured in joules) divided by the mass of living tissue that absorbs all of that ionizing energy (measured in kilograms).

In the context of the proposed BWXT-Peterborough pelleting operation, any affected individual will have to have inhaled one or more specks of uranium dioxide particulate into his or her lungs. Being insoluble, such a particulate will lodge in place for months or years.

For purposes of discussion we calculate the absorbed dose due to a uranium dioxide particulate residing in lung tissue for one year for two separate cases
(1) for a one-micron diameter particulate
(2) for a two-micron diameter particulate.

Some of the details of the calculation are indicated in Table 5 below. To obtain a conservative result (one which tends to underestimate rather than overestimate the true value) we assume that the range of an alpha particle emitted by the particulate is 30 microns (it is somewhat less than that because the energy of an alpha particle given off by uranium is less than 5 MeV).

For a one-micron particulate residing in place for one year, the absorbed dose to the surrounding small volume of tissue (radius 30 microns) is 22.5 milligrays (mGy), and for a two-micron particulate it is 142 milligrays (mGy).

Alpha exposures normally are considered to be 20 times as biologically effective as the equivalent exposures from beta or gamma radiation, so the quantities calculated here and cited above correspond to 450 mGy of beta/gamma exposure for a one-micron speck and 2,840 mGy of beta/gamma exposure for a two-micron speck.

These are very large doses of absorbed radiation, albeit confined to extremely small regions of the lung. If they were whole-body doses they would be unacceptable, way beyond the regulatory limits even for atomic workers. The comparison however is not helpful – for interpreting the biological consequences of internal irradiation is still a very arcane and controversial subject.

The maximum annual exposure to whole-body radiation for an atomic worker in Canada is 50 millisieverts (equivalent to 50 milligrays of gamma radiation), and for a member of the public it is 1 millisievert (equivalet to 1 milligray of gamma radiation).

Nevertheless, it is undeniable that some portions of the lung are heavily irradiated. There is no reason to doubt that such alpha exposures are capable of triggering the creation of one or more precancerous cell, leading to a full-blown lung cancer decades later. This statement is consistent with the prevailing view of the monoclonal origin of cancer, that a single cell can be and usually is progenitor of such a malignancy. But even so, many that are exposed will never contract cancer as a result of that exposure; it depends on the DNA damage.

Particulate Diameter	Particulate Volume	Mass of Uranium	Ionizing Energy	Mass of Tissue	Absorbed dose	Beta dose equivalent
	cm cubed	grams	ergs	grams	milligrays	milligrays
1 micron	5.2 E-13	4.7 E-12	2.54 E-5	1.13 E-7	22.5 mGy	450 mGy
2 microns	4.2 E12	2.98 E-11	1.61 E-4	1.13 E-7	142 mGy	2,840 mGy

Table 4. Calculation of absorbed dose assuming an alpha range of 30 microns in soft tissue

Because of the extremely long half-life of uranium and the fact that the alpha particles given off by uranium are not as energetic as those from other well-known alpha-emitters, it is clear that the number of ionizations will be correspondingly less and so the number of cancers caused will also be less.

Statistics may be too coarse an instrument to reveal the truth. There are relatively few people exposed to breathing insoluble uranium dioxide particles.

It would be a fallacy to conclude that people are not being killed simply because the number of extra deaths are not statistically significant. For example, even a mass murderer is unlikely to alter the mortality statistics for a population – even while people are being murdered. Similarly, it may be that people are suffering from radiogenic lung cancer caused by uranium exposure, but not in large enough numbers to register as a statistically significant increment.

The situation is complicated by many additional factors – the long latency period for lung cancer, requiring decades of follow-up time; the almost impossible job of estimating exposures accurately; and the extra radio-sensitivity as well as the unusual breathing patterns of children. Science and ethics both suggest that there is no room for complacency on these matters.

The Need for Justification

The fundamental principle underlying radiation protection is that all unnecessary exposures to ionizing radiation should be eliminated or prevented, and where that is not possible, exposures should be limited and kept as low as reasonably achievable (ALARA). Meeting regulatory standards is no substitute for the option of eliminating exposures altogether.

> “For practical reasons, the ICRP adopted in the 1950s a linear no threshold (LNT) dose-response relationship, a model indicating that there will be some risk even at low doses, that has served as a base for radiation protection regulations. While the debate over the effects of low level radiation is still contentious and unsettled, the sole application of

> permissible limits to the inferred risks is, until presently, considered not enough, and a system based on the general principles of justification, optimization and dose limits is required to protect individuals, society as a whole and the environment."
>
> *ICRP, General Principles of Radiation Protection*
> *https://link.springer.com/chapter/10.1007/978-3-319-42671-6_11*

The potential exposure of young children attending Prince of Wales Elementary School to significant increases in the amounts of respirable uranium dioxide dust can be prevented simply by not granting prior approval to the commencement of pelleting across the street at the BWXT-Peterborough plant.

The precautionary principle indicates that we should not presume to take chances when there is the possibility of an unacceptable outcome for some individuals and no justification for approving the project that spawns that outcome.

Indeed, no justification of any kind has been offered for commencing pelleting at BWXT-Peterborough. The only mainstream customer for unenriched uranium fuel pellets produced by BWXT appears to be, at present, Ontario Power Generation, to provide fuel for use in OPG's Pickering and Darlington reactors.

The six operating Pickering reactors will be shut down permanently in the foreseeable future, perhaps by 2024 or 2025, leaving only the four Darlington reactors in operation. That drops the number of CANDU reactors in question from ten down to four. During refurbishment of the four reactors at the Darlington nuclear plant, that power station will also have a temporarily reduced demand for new fuel bundles. The CANDU market will be sharply reduced.

Since all Small Modular Nuclear Reactors (SMRs) use enriched fuel, there are no prospects for new business for BWXT on that score. In short there is no perceptible need for a second pelleting operation.

CNSC is being asked to approve a licence condition simply to suit the convenience of BWXT management, while possibly subjecting Peterborough schoolchildren to unnecessary and preventable radioactive exposures that may produce a lifetime body burden of alpha-emitting materials in their lungs.

One of the principles of radiation protection is that all unnecessary exposures to ionizing radiation should be prevented. It is not sufficient to meet arbitrarily imposed standards of radiation exposure. Any exposure to additional levels of ionizing radiation requires a detailed justification designed to demonstrate that the advantages to those being exposed, or to society at large, clearly outweigh any risks that may be involved. Failing such justification the additional exposure should not be allowed to take place.

It is entirely within the competence of BWXT to rent or build additional structures to house a second pelleting operation, removed from built-up residential areas and far away from playgrounds and schools that are used by small children.

Accordingly we reiterate the main recommendation of this report:

Recommendation. *The Commissioners are urged not to approve the special pelleting provision in the BWXT licencing application, thereby preventing and eliminating all future routine exposures of hundreds of schoolchildren at Prince of Wales elementary school to elevated levels of respirable particulates of uranium dioxide dust in the* $PM_{2.5}$ *category as a result of pelleting at BWXT-Peterborough.*

Siting a Nuclear Facility on the Doorstep of an Elementary School

It is not clear whether existing CNSC regulations would preclude the siting of a brand new Class 1 Nuclear Facility right on the doorstep of an elementary school, given that hundreds of schoolchildren might be subjected routinely to small but unnecessary and entirely preventable exposures to radioactive contaminants and other toxic effluents from such a facility.

In fact, the Commissioners are not legally bound to grant a licence, even if staff unanimously recommends it, when the Commissioners themselves remain unconvinced that granting such a licence may be inconsistent with the primary legal obligation to prevent unreasonable risk to persons and to the environment.

This question is not merely academic, but apropos to the case at hand. BWXT is, in a very offhand way, proposing to locate a brand new Class 1 nuclear facility right across the street from the Prince of Wales Elementary School. It will of course be co-located with the existing facility, but entirely different in the details of its operation – requiring a large tank of liquified hydrogen gas, drums of fine uranium dioxide powder delivered and stored on site, sharply increased emissions of uranium oxide dust into the air and water, powerful pellet-forming presses, and ovens for baking ceramics in a hydrogen gas atmosphere. None of these characteristics is evident at BWXT currently. There is virtually no overlap between the materials and processes presently utilized at BWXT- Peterborough for the assembly of fuel bundles, and the entire suite of other materials and processes needed for pelleting.

The pelleting operation will significantly increase the potential for onsite emergencies to occur at the BWXT-Peterborough because of fire and explosion possibilities associated with materials that do not now exist at this site.

Hydrogen is a highly flammable gas, much more combustible than gasoline. Under adverse circumstance it is capable of producing violent explosions when mixed with air in a wide variety of concentrations. Uranium dioxide powder is also combustible and can spontaneously catch fire in certain instances. As the US Nuclear Regulatory Commission warned:

> "The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice to alert addressees to the potential for fires involving uranium dioxide (UO2) powder at various stages of transfer and conversion….
>
> "It has been common experience that unstable uranium oxide feed material (comprised mostly of UO2, with a few other oxide forms present) in granulated form and in contact with oxygen undergoes exothermic oxidation reactions. In some cases, the heat generated by the reactions ignites combustible elements of the transfer passages or other powder handling equipment …."

Information Notice No. 92-14: Uranium Oxide Fires at Fuel Cycle Facilities
https://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1992/in92014.html

And, referring to one particular incident of a uranium dioxide powder fire:

> "All of the combustible elements in the containment between the hammermill and the slugger press (e.g., the Viton hose and the Neoprene boot, as well as the Lexan parts of the containment housing) were consumed by the fire. The primary HEPA filters were extensively damaged. The secondary filters, however, were intact…."

Information Notice No. 92-14: Uranium Oxide Fires at Fuel Cycle Facilities
https://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1992/in92014.html

Due to the presence of an elementary school across the street, emergency planning may be seriously compromised. The students no doubt know how to vacate the school premises in the event of a fire drill, but is this the best thing for them to do if the air if filled with fine uranium dioxide dust resulting from burst drums of uranium powder or inoperative HEPA filters?

The school authorities may not have the necessary equipment nor the training needed to escort some 600 children away from the vicinity of the plant in a rapid and orderly fashion. Mothers, fathers, and other relatives and friends are likely to converge on the school property to locate and rescue their children, thereby heading directly towards the site of the accident instead of away from it as prudence would normally dictate.

Indeed, since many of the mothers of these young children will still be of child-bearing age, there may be several cases of pregnant women visiting the school on a nearly daily basis and becoming exposed to the fine respirable uranium oxide particulates from the pelleting operation, not only at the school grounds but in laundering the clothes of their school-age children that may contain such particulates trapped in the fibres of the cloth. Uranium oxide powder will be readily resuspended in the air at home by simply shaking out the children's clothes prior to laundering.

Conclusion

According to the Nuclear Safety and Control Act, the CNSC was formed for the purpose of serving Canadians and the Government of Canada, and not for the purpose of acting for the convenience of the industry. We urge the CNSC not to approve the licence condition that would allow pelleting at Peterborough. Any other decision would be, in effect, granting BWXT a licence to pollute.

~ fin ~

Annex A: Letter to the editor of the Peterborough Examiner, Jan 28 2020

28 January 2020

Dear Editor,

We are a group of scientists who reside in the neighborhoods around BWXT, and we would like to draw your attention to the results of the Independent Environmental Monitoring Program conducted by the Canadian Nuclear Safety Commission and published on their website on January 22, 2020.

We are concerned because concentrations of the heavy metal beryllium (Be), which is used in the BWXT production process, have steadily and significantly increased in soil samples taken in the vicinity of BWXT since recording began in 2014. The clear increase of Be in soil samples is likely being driven by significant increases in air concentrations, which is particularly worrying because beryllium can be toxic if inhaled. More worryingly, the highest values of beryllium in 2019 were found in the samples in the Prince of Wales school playground. Although none of these samples have reached the threshold at which intervention is mandated, the increase alone mandates intervention and further evaluation to ascertain the source.

BWXT responsibly monitors the outputs of the production process to detect pollutants such as beryllium and has indicated that their outputs are at or near zero. This statement is inconsistent with the publicly available results of CNSC's environmental monitoring program that shows, clearly and unambiguously, that beryllium concentrations are increasing.

Given the accumulation of Be in soils, it seems inappropriate to discuss an unrestricted licence renewal (or extension) before establishing the source of this contaminant. The only reasonable course of action is to request that, prior to any licensing agreement, the cause of this increase in Be be identified so that it can be stopped.

Yours sincerely,

Julian Aherne, PhD
James Conolly, PhD
Gary Burness, PhD
Peter Lafleur, PhD
Erica Nol, PhD
Mark Parnis, PhD