Protecting the health and safety of Canadians

a supplementary submission by

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to accompany the original submission

Health Implications of Pelleting Operations at the BWXT-Peterborough plant

that was included as part of the CARN/CELA submission to CNSC

February 18 2020

The Situation at a Glance

Photograph by Robert Del Tredici, November 3, 2019

Foreground: Prince of Wales Elementary School Playground, 1211 Monaghan Road, Peterborough, Ontario.

Background: BWXT Nuclear Energy Canada, Fuel Fabrication Plant with smokestack, 1160 Monaghan Road.

Protecting the health and safety of Canadians

The CNSC was created under the terms of the Nuclear Safety and Control Act. Its primary mission, under Article 9 of the Act, is "to prevent unreasonable risk, to the environment and to the health and safety of Canadians…." In making their licensing decisions, Commissioners are charged to be the champions defending the health and safety of Canadians. This is especially true for the most vulnerable members of our society, such as pregnant women, fetuses, and young children.

Exposure to ionizing radiation can harm the health of persons in various ways, generally classified as stochastic (i.e. probabilistic, or random) and non-stochastic (deterministic) effects. It has been long recognized by scientists that non-stochastic effects (e.g. prompt death, radiation sickness, radiation burns, hair loss, etc.) can be prevented by limiting individual radiation doses to levels well below a certain "threshold level", whereas stochastic effects (e.g. cancers and genetic damage) do not have any such "safe threshold". In fact, the same is true for most other carcinogenic agents. Because the damage is done at the cellular level, involving random alterations to the DNA of one cell (according to the monoclonal nature of cancerous growths), any exposure can trigger a cancer. If there is an increase in the exposure of a given population to a given carcinogen, it is expected to increase the frequency of cancers in the exposed population.

The linear no-threshold (LNT) model of radiation carcinogenesis, which is the basis of radiation protection policy for the CNSC and other regulatory bodies, implies that the number of radiation-induced cancers in an exposed population can be reduced by limiting the total population dose. But the severity of a radiation-induced cancer is unaffected by the dose that caused it. In other words, cancers caused by a low-dose exposure are indistinguishable from cancers caused by a high-dose exposure.

The Need for Justification

For this reason, one of the cardinal principles of radiation protection is that all unnecessary exposures to ionizing radiation should be eliminated or avoided when possible, and no additional exposures to ionizing radiation should be allowed by the regulator without a very clear justification in terms of explicit benefits to the individuals being exposed or to society at large. The profitability or the convenience of the enterprise that gives rise to such radiation exposures should not be a matter of concern. The justification of otherwise preventable exposures to ionizing radiation must be expressed in terms of benefits to the affected individuals and/or benefits to society.

These considerations led the International Commission on Radiological Protection (ICRP) to recommend as follows in ICRP 26 (1976):

> *"For the above reasons, the Commission recommends a system of dose limitation, the main features of which are as follows:*
>
> *"(a) no practice shall be adopted unless its introduction produces a positive net benefit;*
>
> *"(b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account; and*
>
> *"(c) the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission."*
>
> *ICRP 26 (1977) p.3*
>
> https://journals.sagepub.com/doi/pdf/10.1177/ANIB_1_3

The same system of dose limitation was upheld and reinforced in ICRP 60 (1990), where the need for explicit formal justification for new and existing ongoing radiation exposures was spelled out in more detail:

> "The process of justification is required, not only when a new practice is being introduced, but also when existing practices are being reviewed in the light of new information about their efficacy or consequences. If such a review indicates that a practice could no longer be claimed to produce sufficient benefit to offset the total detriment, withdrawal of the practice should be considered. This option should be treated in the same way as the justification of a new practice, but it must be remembered that the disadvantages of withdrawing a well-established practice may be more obvious than the advantages of introducing a comparable new one and withdrawal of the practice may not result in the withdrawal of all the associated sources of exposure. Preventing the further extension of an existing practice that is no longer justified may sometimes be a reasonable compromise…."

https://www.icrp.org/publication.asp?id=ICRP%20Publication%2060

The German government has enshrined into law the need for a formal justification of any new radiation exposure to a previously unexposed population:

> "In order to keep the risk of stochastic damage from ionising radiation as low as possible, three general principles have been set out in radiation protection for dealing with ionising radiation.
>
> "These principles are based on recommendations from the International Commission on Radiological Protection (ICRP).
>
> "The German Radiation Protection Act and the European Directive 2013/59/Euratom make these principles legally binding:
>
> 1. Justification
> 2. Dose limitation
> 3. Optimisation

"Every new application of ionising radiation or each new use of radioactive materials by man must be justified in advance. This legal requirement for justification also applies when, due to new activities, people are occupationally exposed to existing, mostly natural radiation at an increased level….

"The legal requirement for justification means that new activities are permitted only when they are associated with a reasonable benefit for the individual and for society. In this case, 'reasonable' means that the benefit outweighs any health detriment possibly caused by the activity."

Bundesamt für Strahlenschutz, Principles of Radiation Protection
https://www.bfs.de/EN/topics/ion/radiation-protection/introduction/principles/principles.html

Pelleting in Peterborough – Where is the Justification?

In the context of the current licence renewal. BWXT has asked the Commissioners to approve a special provision that would be added to the existing licence to allow the company to commence pelleting at its Peterborough plant if and when management decides to do so.

The pelleting operation in Toronto emits about 3000 times as much airborne uranium as the non-pelleting operations that currently take place in Peterborough. Thus BWXT is, in effect, asking the Commissioners to approve an increase in airborne uranium emissions in Peterborough by three orders of magnitude.

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

As it happens, the Prince of Wales Elementary School is situated adjacent to the BWXT Peterborough plant, right across the street on Monaghan Avenue. The outdoor school playground faces the facility with the BWXT smokestack clearly visible. The school has a student body of about 600 students, aged 4 to 14 years, who will be attending classes and playing in close proximity to the BWXT plant for up to nine or ten years (from kindergarten to grade eight). Over a period of nine years, there will be a total of about 1200 young schoolchildren exposed to airborne emissions from the BWXT plant, as there is a turnover of about 75 children in the student body each year.

These children and their teachers – and to a lesser degree their parents or caregivers as well as neighbours – will undoubtedly be exposed to increased airborne radioactive emissions and consequently increased exposure to ionizing radiation if pelleting begins at the Peterborough plant. The Commissioners are duty-bound to determine whether there is an adequate justification for this new exposure to ionizing radiation on the part of hundreds of young children. Where is the benefit? Evidently there is none for the children, their teachers, or their families. Does society need another pelleting plant, when the demand for CANDU fuel pellets is on the decline? Does BWXT need to put its pelleting operation in such a thoroughly residential area, and so close to an elementary school? Can BWXT not rent or build other facilities that are further removed from downtown Peterborough with a suitable exclusion zone surrounding the plant?

Of course, the existing pelleting operation in Toronto is also located in a densely built-up residential area, which is hardly ideal. However, poor siting decisions in the past should not be used to justify even poorer siting decisions going forward. The only thing worse than siting the plant in a downtown residential area is citing it right beside an elementary school full of young vulnerable children. As was stated in ICRP 60 (see citation above): “Preventing the further extension of an existing practice that is no longer justified may sometimes be a reasonable compromise….”

Is uranium a human carcinogen?

Uranium is an alpha-emitting radionuclide. Alpha-emitters are harmless outside the body but can be especially harmful inside the body, when in contact with radiosensitive tissue. Radon gas, radium, polonium, thorium and plutonium are all examples of alpha-emitters that are well-documented human carcinogens.

All alpha particles are identical in nature, regardless of the alpha-emitting material that is the source of those ionizing projectiles. When an alpha particle comes to rest it is simply a helium nucleus, consisting of two protons and two neutrons bound tightly together. But when it is emitted from the nucleus of a radioactive atom it has enormous energy, measured in units of “millions of electron-volts”, or MeV. An alpha particle given off by a uranium atom has an energy of about 4.2 MeV, and has a range of less than 30 microns in soft tissue.

The International Agency for Cancer Research (IARC), operating under the aegis of the World Health Organization (WHO), says this about alpha-emitting materials:

> "Internalized radionuclides that emit α-particles are *carcinogenic to humans (Group 1).* In making this overall evaluation, the Working Group took into consideration the following:
>
> "• α-Particles emitted by radionuclides, irrespective of their source, produce the same pattern of secondary ionizations, and the same pattern of localized damage to biological molecules, including DNA. These effects, observed *in vitro*, include DNA double-strand breaks, chromosomal aberrations, gene mutations, and cell transformation.
>
> "• All radionuclides that emit α-particles and that have been adequately studied, including radon-222 and its decay products, have been shown to cause cancer in humans and in experimental animals.
>
> "• α-Particles emitted by radionuclides, irrespective of their source, have been shown to cause chromosomal aberrations in circulating lymphocytes and gene mutations in humans *in vivo*.
>
> "• The evidence from studies in humans and experimental animals suggests that similar doses to the same tissues — for example lung cells or bone surfaces — from α-particles emitted during the decay of different radionuclides produce the same types of non-neoplastic effects and cancers."

IARC Monograph 100D-9 (2012) p.275
https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100D-9.pdf

This statement clarifies the basic scientific fact that all alpha-emitters are human carcinogens when they become internalized. This is because all alpha particles are fundamentally the same, no matter what alpha-emitting material they come from, as indicated in the above passage. Moreover, all alpha particles do the same kind of damage to living cells – random damage involving DNA molecules that in some cases results in cancer many years later. Given the very short range of alpha particles in soft tissue, however, the fundamental consideration becomes how close the alpha-emitting material is able to come to radiosensitive tissues. The dangers from some of the more infamous alpha emitters like radon, radium, polonium, plutonium and thorium, have been very well-documented in large part because sizable populations have been exposed internally to these materials – through breathing (radon), ingesting (radium), smoking (polonium), medical injections (thorium), machining of nuclear weapons components (plutonium), or absorption through cuts and wounds (laboratory work). In many cases there have been methodologies to estimate with reasonable accuracy the exposures of the people involved, and good follow-up procedures to match cancers that occur decades after those exposures may have taken place.

Are the children at Prince of Wales Elementary School in any way at risk of developing cancer as a result of airborne emissions from BWXT Peterborough if pelleting begins there? As the CNSC staff has pointed out: "The primary hazard is radiation dose to the lungs from UO_2 [uranium dioxide], which is an insoluble form of uranium." (pp. 32-33, CMD H-22). As long as the Peterborough plant handles only pre-fabricated ceramic uranium dioxide pellets, there is little to no chance that the schoolchildren will have an opportunity to internalize that uranium dioxide into their lungs. Once pelleting begins, however, uranium dioxide emissions will occur routinely in the form of a very fine powder consisting of particulates with diameters of less than 10 microns. The HEPA filters will trap well over 99.9 percent of the coarser particles, and so it is reasonable to presume that those particles that escape will have diameters less than 2.5 microns. Such particles are ideally suited to be inhaled into the deepest parts of the lung, where they can lodge for a very long time because of their high degree of insolubility. Children inhaling such particles will carry with them an internalized body burden

of uranium that will continue to irradiate their lung tissue – even on the weekends, or when they are sleeping, or when they are on summer vacation.
Is such exposure justified?

Evidence of uranium as a lung cancer carcinogen

The epidemiological evidence of lung cancer carcinogenesis in the case of uranium dust is somewhat inconclusive, in part due to the fact that few populations have been exposed to uranium dust in a form that is sufficiently finely subdivided to be inhaled into the deepest parts of the lung and so insoluble that it can lodge in the lung tissue for a long time. The residence time is important because uranium has a very long half-life and so its alpha particles are emitted much more slowly than is the case with other alpha-emitters. It is worth noting however that thorium (Th-232) has an even longer half-life than uranium and yet its carcinogenic characteristics have been convincingly demonstrated.

The 2012 IARC monograph 100D-9 refers to

> "... a pooled study of seven uranium miller cohorts, [in which] a significant excess of lung cancer mortality was observed in analyses using state mortality rates as a comparison (SMR, 1.51; 95%CI: 1.19–1.89). Potential confounding by smoking, silica exposure, or other occupational hazards complicated the interpretation of these results, and these studies lacked a direct measure of cumulative exposure to uranium."

IARC 100D-9 p. 261
https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100D-9.pdf

Uranium millers are involved in the crushing of uranium ore, the chemical separation of uranium from residues (which become the tailings), and the production of yellowcake powder that is shipped in drums to a uranium refinery. It is worth noting that the particulate sizes in the case of yellowcake are often larger, and the chemical form of uranium is often more soluble, than is the case with the uranium dioxide powder used in pelleting. The finer insoluble particulates from pelleting have easier access to the radiosensitive lung tissue and the residence time is likely to be considerably longer, as soluble forms of uranium are more easily cleared from the lungs.

The same IARC monograph also reports that

> "Uranium ore dust containing 44% elemental uranium induced bronchioalveolar carcinomas, bronchial carcinomas and squamous cell carcinomas in rats by inhalation (Mitchel *et al.*, 1999)."
>
> IARC 100D-9 p. 264

and that

> "Overall, two epidemiological cohort studies of uranium enrichment workers reported significant positive associations between the radiation dose quantified by personal dosimeters and lung cancer (McGeoghegan & Binks, 2000b; Richardson & Wing, 2006). Lung cancer risk could be caused either by external exposure to γ-radiation, or by α-particles emitted by uranium particles inhaled into the lung, or both. In addition, an excess of lung cancer mortality was observed in cohorts of mortality among uranium millers. However, these associations are not consistent across all studies, and there is the potential for confounding of these associations by smoking as well as occupational hazards other than uranium." IARC 100D-9 pp. 263-264

Since the IARC monograph was published, there have been newer studies that document a significant increase In human cancers from exposure to uranium.

Here is a passage from a European Study published in ***Epidemiology*** on May 17 2017, entitled “Risk of lung cancer mortality in nuclear workers from internal exposure to alpha particle-emitting radionuclides”, by Grellier J, Atkinson W, Bérard P, et al. The study shows that Internal exposure to alpha particles emitted by radionuclides (particularly plutonium and uranium) is associated with an increased risk of lung cancer mortality. The results are consistent with estimates of risk from other types of radiation and compatible with current Radiation Protection recommendations.

> “Knowledge of the long-term health effects of ionizing radiation (i.e. radiation with enough energy to break chemical bonds such as those in DNA molecules) derives mainly from populations exposed to gamma and X-rays, particularly Japanese atomic bomb survivors, and populations receiving external doses due to occupational, medical and environmental exposures.
>
> “However, very little is known about the long-term effects of low level internal exposure to alpha particles. In contrast with neutrons, gamma or X-rays, alpha particles only travel a few centimetres in air and are unable to penetrate the skin. However, they can cause serious cellular damage if ingested or inhaled.
>
> The goal of the study was to estimate the risk of lung cancer in populations exposed to low doses of alpha particles through inhalation. The authors conducted a case-control study of lung cancer mortality among Belgian, French and UK cohorts of uranium and plutonium workers, for which they determined individual lung doses from alpha-emitters.
>
> Most subjects in the study had low doses from uranium and/or plutonium. However, a dose-related increased risk of lung cancer was still observed. ‘This study is the first in which individual estimates of

dose have been reconstructed to estimate the risk of lung cancer mortality among European nuclear workers exposed to these radionuclides' says Elisabeth Cardis, coordinator of the study."

https://www.isglobal.org/en/-/la-inhalacion-de-particulas-alfa-emitidas-por-uranio-y-plutonio-aumenta-el-riesgo-de-cancer-pulmonar-en-trabajadores-nucleares

This European study associates, for the first time, low to moderate doses of alpha-emitters with lung cancer risk. Elisabeth Cardis**,** coordinator of the study, is Research Professor in Radiation Epidemiology at ISGlobal. Until April 2008, she was the head of the Radiation Group at IARC in Lyon, where she coordinated studies of ionising and non-ionising radiation for over 20 years.

"METHODS:

"We conducted a case-control study, nested within Belgian, French, and UK cohorts of uranium and plutonium workers. Cases were workers who died from lung cancer; one to three controls were matched to each. Lung doses from alpha-emitters were assessed using bioassay data. We estimated excess odds ratio (OR) of lung cancer per gray (Gy) of lung dose.

"RESULTS:

"The study comprised 553 cases and 1,333 controls. Median positive total alpha lung dose was 2.42 mGy (mean: 8.13 mGy; maximum: 316 mGy); for plutonium the median was 1.27 mGy and for uranium 2.17 mGy. Excess OR/Gy (90% confidence interval)-adjusted for external radiation, socioeconomic status, and smoking-was 11 (2.6, 24) for total alpha dose, 50 (17, 106) for plutonium, and 5.3 (-1.9, 18) for uranium.

"CONCLUSIONS:

"We found strong evidence for associations between low doses from alpha-emitters and lung cancer risk. The excess OR/Gy was greater for plutonium than uranium, though confidence intervals overlap. Risk estimates were similar to those estimated previously in plutonium workers, and in uranium miners exposed to radon and its progeny. Expressed as risk/equivalent dose in sieverts (Sv), our estimates are somewhat larger than but consistent with those for atomic bomb survivors. See video abstract at, http://links.lww.com/EDE/B232 ."

The epidemiological evidence for lung cancer carcinogenesis from uranium is growing. There can be little doubt that alpha radiation from uranium can and does trigger lung cancer. Consequently no unnecessary exposure is justified.

Children are not young adults

Researchers in the field of ionizing radiation have long known that children are much more susceptible to radiation damage, including cancer induction, than adults are. The World Health Organization has issued a Training Package for the Health Sector entitled “Children's Health and the Environment” that says in part:

> “Ionizing radiation is a known carcinogen to which children are particularly vulnerable. Relevant exposures include pre- and postnatal irradiation for medical reasons, radon in the home, and accidental radiation releases. In some cases, children may receive higher doses than adults because of higher intake and accumulation. Furthermore, sensitivity to radiation is highest early in life.
>
> “Although the mechanism of greater susceptibility is not well understood, it is likely to be linked to greater cell division in growing and developing tissues. In addition, a longer expected lifetime, with a resultant increased chance of repeated exposure and accumulated damage, also leads to higher cancer risk for children.
>
> The absorbed dose is a measure of the amount of energy actually absorbed in a material, and is used for any type of radiation and any material. Gray (Gy) is the unit of measurement for absorbed dose in the International System of Units (SI).
>
> “One gray is equal to one joule of energy deposited in one kilogram of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations.
>
> “The equivalent dose is the product of the absorbed dose and a ‘radiation weighting factor’ depending on the quality of the particular

> type of radiation (e.g. "1" for X-rays, gamma rays and beta particles, "20" for alpha radiation, between "1-10" for neutrons). This weighting factor relates the absorbed dose in human tissue to the effective biological damage of the radiation.
>
> "Ionizing radiation is a complete carcinogen since it can act to initiate, promote and progress cellular changes that lead to cancer. The dose of radiation received by an individual affects the probability of cancer, but not its aggressiveness. Radiation-induced cancer is indistinguishable from cancer from other causes. The probabilistic nature of this risk means that children have more time to accumulate exposures and damage, and more time after exposure to develop the disease."
>
> WHO Children's Health and the Environment
> https://www.who.int/ceh/capacity/radiation.pdf

If we calculate the absorbed dose delivered to a tiny volume of lung tissue in a child who has inhaled a one-micron diameter particulate of uranium oxide that has lodged in his lung for a year, we arrive at a figure of 22.5 milligrays. If the particulate were two microns in diameter, the absorbed dose during one year would be 142 milligrays. Bearing in mind the "radiation weighting factor" of 20 (mentioned above in the WHO Training Package), we see that these doses of alpha radiation would be equivalent to 450 milligrays of beta or gamma radiation for a one-micron particle, and 2,840 milligrays of beta or gamma radiation for a two-micron particle *[details of the calculation are indicated in the attached report].*

These are very large doses, delivered to a very small volume of tissue. Moreover, any one of the cells in that tiny volume of lung tissue could be damaged in such a way as to yield a full-blown case of lung cancer twenty years (or more) later. We do not have any epidemiological studies of children exposed to the routine inhalation of insoluble particulates of uranium dioxide. Surely it is not justifiable, given that there are no discernible benefits to the children or to society for pelleting to take place at this location, to make these children the potential cohort for a future lung cancer epidemiological study!

The ALARA principle is invoked by CNSC staff to keep all radiation exposures "As Low As Reasonably Achievable". In this case, ZERO is the number that fits the ALARA principle the best. If the Commissioners do not give permission for BWXT to commence pelleting in Peterborough, then all these calculated exposures can very easily be reduced to zero.

Summary and Conclusion

The purpose of the CNSC as stated in the Nuclear Safety and Control Act is to "prevent unreasonable risk ... to the health and safety of persons" [Article 9].

Playground with BWXT in background *Photo by Robert Del Tredici*

The Peterborough plant is right next to an elementary school with about 600 young children, aged 4 to 14, in close proximity to the plant for years – from kindergarten to grade 8. The smokestack is quite close to the playground.

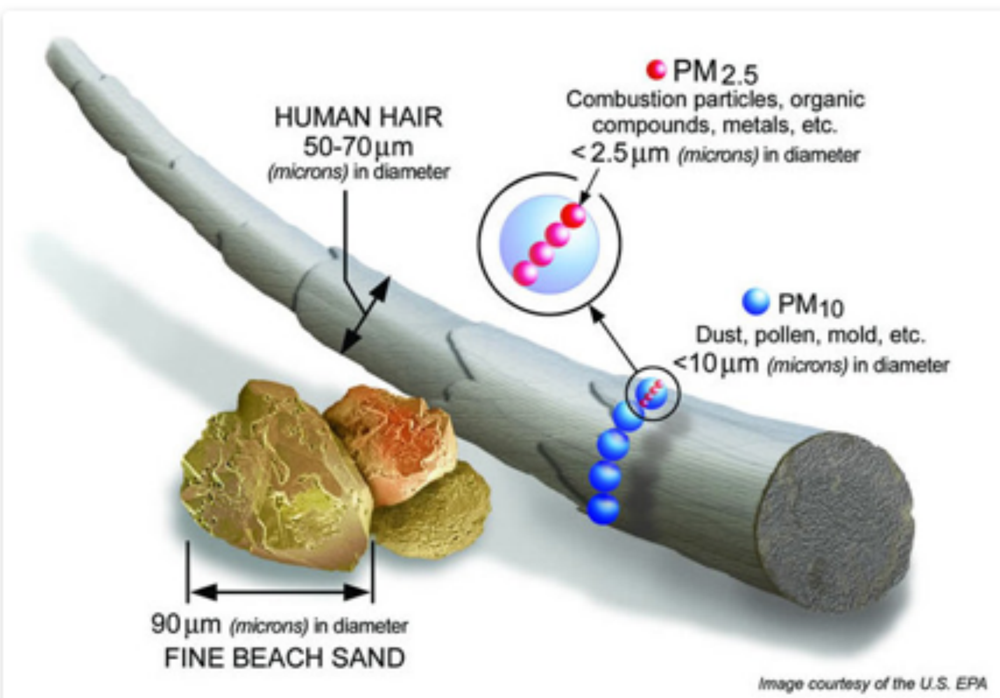
Over a nine-year period about 1200 children will be exposed to airborne emissions of uranium dioxide particulates on a daily basis at school if pelleting occurs.

It is a fundamental principle of radiation protection that no unnecessary exposure should be allowed if it can be prevented or avoided. Unjustified exposures are unreasonable.

If these children are protected from unnecessary risk, then others will be protected also.

Pelleting in Peterborough will increase airborne emissions of uranium by a factor of about 3000.

This is an image of the tiny particulates of size $PM_{2.5}$ (less than 2 1/2 microns in diameter) that will be emitted by the hundreds of billions every year from BWXT Peterborough if it begins pelleting *[174 billion one-micron particles per gram of UO_2.]*



The size of the uranium dioxide particulates is indicated in red.

These particulates of uranium dioxide (shown in red) are much smaller than the finest human hair and can only be seen by using an electron microscope.

Such particles are uniquely suited to be inhaled into the deepest parts of the lung and lodge there for a very long time.

This will give hundreds of schoolchildren an unnecessary radiation exposure with no benefit to them and no justification offered by BWXT.

Uranium gives off alpha particles that travel a very short distance in living tissue (less than 30 microns).

The next photograph shows the tracks made by alpha particles emitted from an alpha-emitting particulate lodged in the lung tissue of an experimental animal, irradiating a very tiny region of the lung.

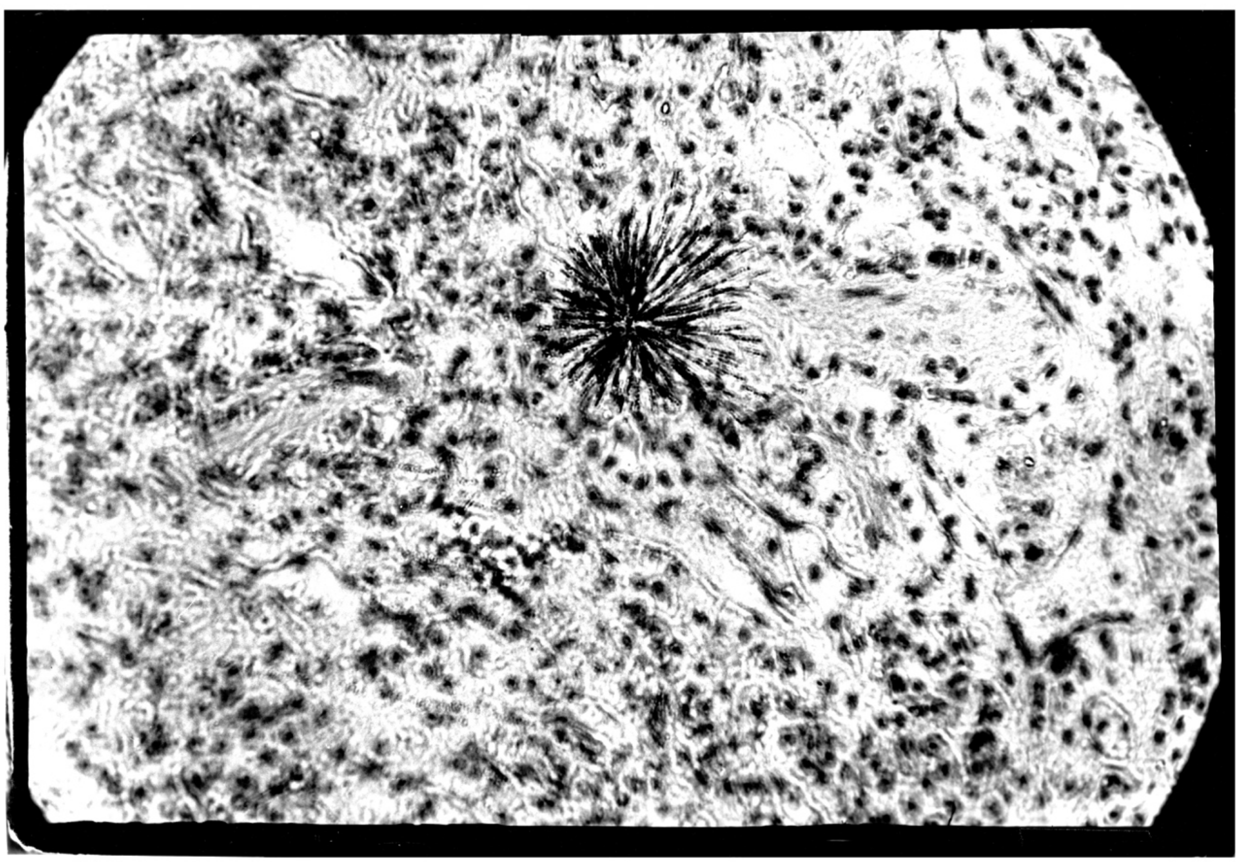


photo by Robert Del Tredici

A single one-micron diameter particle of uranium dioxide dust will give a very large absorbed dose in one year to a very small volume of lung tissue (more than 22 Grays of absorbed dose – see the calculation in the attached report).

WHO's IARC asserts that all alpha-emitting materials are carcinogenic in contact with radiosensitive tissues like lung tissue (IARC 100D-9, previously cited).

A single alpha radiation-damaged cell can develop into a cancer years or decades later, based on the monoclonal nature of cancerous growths.

Young children are known to be far more susceptible to radiation-induced cancers than adults.

Conclusion

** CNSC has a duty "to prevent unreasonable risk to … the health and safety of Canadians" (NSCA Article 9).*

• A basic principle of radiation protection is: "All unnecessary exposures should be eliminated or prevented".

• There is no justification of any kind offered for the commencement of pelleting in Peterborough.

• BWXT should not be given permission to expose hundreds of schoolchildren to needless risk.

• All unjustified radiation exposures, with no specified benefits, are unreasonable.

***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.*

Health Implications of Pelleting Operations at the BWXT-Peterborough Plant

By Gordon Edwards, Ph.D.

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)

February 3 2020

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 and a half centimeters high, with a diameter just less than one centimetre. 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 led several scientists from the Peterborough community (see Annex A) to conclude that airborne beryllium emissions from the plant 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). It seems unreasonable that these children will begin routinely inhaling several thousand times more uranium dust from the plant.

It is bizarre 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 that the airborne beryllium travelled [Annex A].

Because of pelleting, 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, insoluble uranium dioxide particulate matter that has settled in the soil can easily be 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 pelleting operation in Toronto 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. These emissions result from the handling of fine uranium dioxide powder.

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

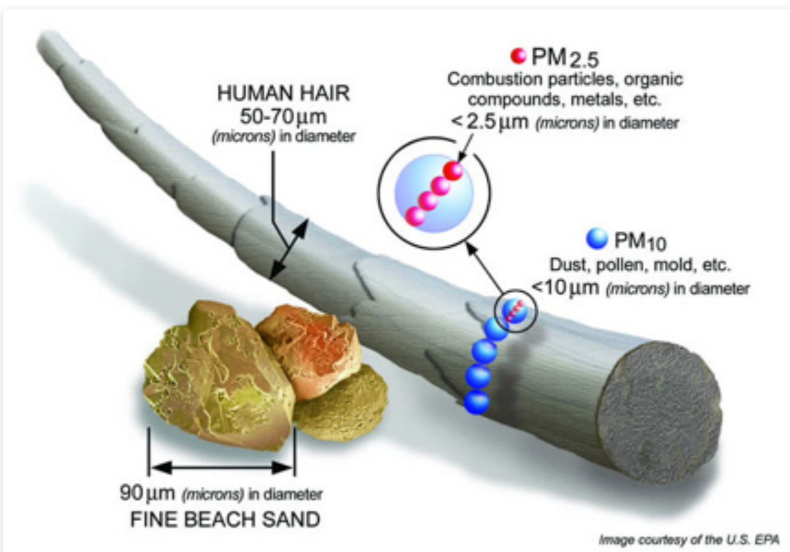


Figure 5. Particulates with diameter 2.5 microns compared to a human hair. https://blissair.com/what-is-pm-2-5.htm

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."
>
> See complete email in Annex B

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."

MacQuarrie's assertion not only implies that there is no danger associated with radioactive materials from natural sources, but also that this opinion is a well-established and unchallenged scientific fact.

The assertion is simply wrong. It is a very misleading public statement from the president of a company seeking a ten-year licence from the CNSC, and as such it is irresponsible. Unfortunately, CNSC staff did not see fit to offer a correction or commentary on MacQuarrie's statement, despite CNSC's statutory obligation to "disseminate objective scientific … information". Surely such high-profile and incorrect statements about radiation dangers should not go uncorrected.

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

Radium has been described by the British Columbia Medical Association as "a superb carcinogen" [The Health Hazards of Uranium Mining, BCMA, 1980, www.ccnr.org/bcma.html]. 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. Both Marie Curie, the discoverer of radium, and her daughter Irene 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. [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 harmless 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.

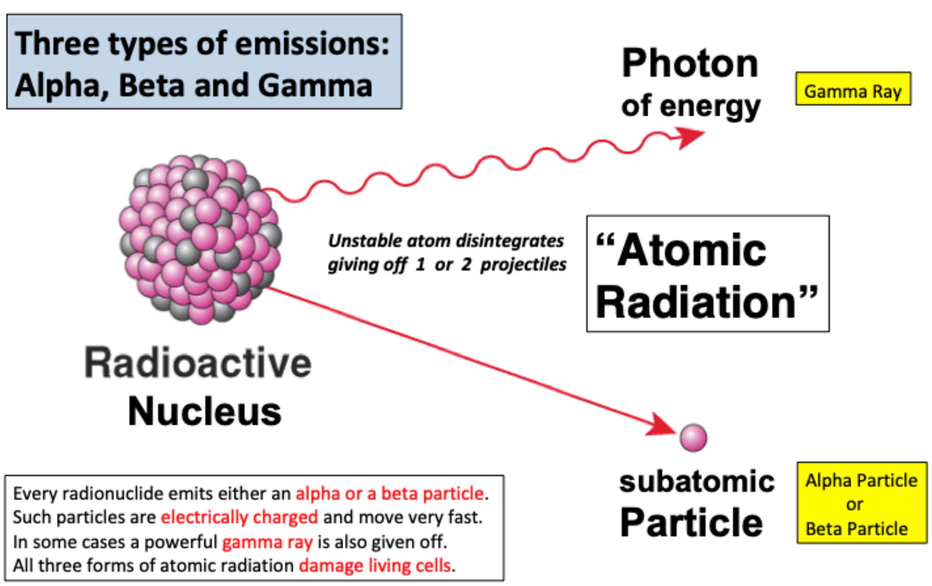


Figure 6. Three types of radioactive emissions: Alpha, Beta and Gamma.

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.

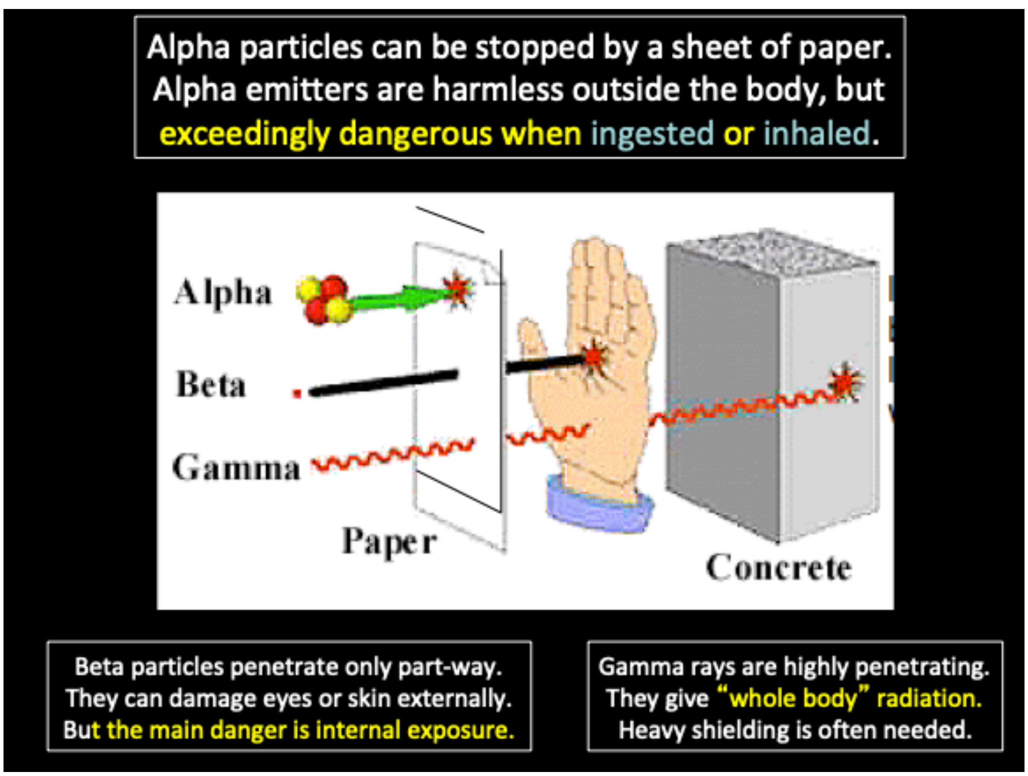


Figure 7. Alpha particles have very little penetrating power

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 (equivalent 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 ~