Radioactive Wastes: and Nuclear Demolition

A Slide Show

prepared for
Decommissioning Symposium
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The Age of Nuclear Power is Winding Down
but the Age of Nuclear Waste is Just Beginning
1. In the core, uranium atoms are split, releasing heat.
2. The heat boils water in vessels called steam generators.
3. The steam is used to spin a turbine to generate electricity.
4. Meanwhile **hundreds of unwanted radioactive byproducts are created.**
Nuclear Energy
~ two types ~

1. Nuclear Fission
2. Radioactivity

1896: Discovery of radioactivity.
1938-39: Discovery of nuclear fission.
What is Nuclear Energy?

Every atom has a tiny core called the **NUCLEUS**. It is surrounded by one or more orbiting electrons.

*Photo: Robert Del Tredici*
Chemical energy involves only the electrons . . .

. . . but nuclear energy comes from the nucleus – and it is millions of times more powerful.

NUCLEAR FISSION: ONLY 78 YEARS OF SCIENTIFIC EXPERIENCE!
Destruction of the City of Hiroshima caused by Little Boy, August 6, 1945
**Nuclear Fission**

A subatomic projectile called a neutron starts a nuclear chain reaction by splitting a nucleus of “fissile uranium” (U-235).

Energy is released when a neutron strikes a fissile uranium atom and the results are fission products and more neutrons.
Nuclear Fission

A subatomic projectile called a neutron starts a nuclear chain reaction by splitting a nucleus of “fissile uranium” (U-235).

The nucleus splits into two large fragments and energy is released – along with 2 or 3 extra neutrons.

The 2 broken pieces are new radioactive nuclei called “fission products”.

ENERGY IS RELEASED

U-235

STRIKES A FISSILE URANIUM ATOM

AND THE RESULTS ARE FISSION PRODUCTS

FP

FP
A subatomic projectile called a neutron starts a nuclear chain reaction by splitting a nucleus of “fissile uranium” (U-235).

The nucleus splits into two large fragments and energy is released – along with 2 or 3 extra neutrons.

The 2 broken pieces are new radioactive nuclei called “fission products”.

More neutrons trigger more fissions and so the energy release is multiplied enormously.
Radioactivity

Radioactive Nucleus

- unstable – unlike most atoms it cannot last
- it will suddenly and violently disintegrate
But in a “cloud chamber” you can see the tracks of all 3 types of emissions from uranium ore.
Radioactivity is a form of nuclear energy that cannot be shut off. That’s why we have a nuclear waste problem.
Fission Products are chemical substances which are also radioactive.
Chronic exposure to radioactive materials increases the incidence of cancer, leukemia, genetic damage, anemia, damaged immune systems, strokes, heart attacks, & low intelligence.

BUT there is a “latency period” for exposure at low levels –

– the onset of disease may occur years or decades after exposure.
All radioactive materials are damaging to nearby living cells. That’s why nuclear waste is a public health problem.
POLLUTION FROM THE NUCLEAR FUEL CHAIN

Radioactive and chemical particles and gases contaminate the land, water, plants, animals and people of Northern Canada.

- Radon 222, heavy metals, lead 210, radium 226, thorium 230
- Volatile organic compounds: heavy metals, sulfur dioxide, radon 223, lead 210, uranium 226
- Polonium 210, 214 & 218, protactinium 234m, bismuth 210 & 214, lead 210 & 214, uranium 234 & 238, thorium 230 & 234, radium 226
- Hexachlorobenzene: heavy metals, ammonia, uranium, radium 226, thorium, dioxins, furans
- Iodine 131, carbon 14, tritium oxide, carbon 14, noble gases (argon, krypton, xenon), hydrazine, ammonia

Arrows show generalized exposure pathways through air & water.

Resources:
- Nuclear Power in Canada: Questions & Answers, Canadian Nuclear Association & Nuclear Power in Canada: An Examination of Risks, Pembina Institute

Graphic: Coalition for a Clean Saskatchewan design group, cleangreenia@gmail.com
Irradiated Fuel
~ high level waste ~

Fission Products
Transurnics
Canadian Nuclear Association ad: ‘Small Wonder’
Nuclear fuel rods and pellets can be handled safely before use. Once used, the fission products will deliver a lethal dose of radiation in seconds.

“Small Wonder” : Canadian Nuclear Association Ad
Irradiated fuel must be cooled for years by circulating water in a spent fuel pool.

Photo: Robert Del Tredici
This series of graphics is from AECL’s EIS on the DGR Concept.

The horizontal lines represent underground rock layers.

The colors indicate temperatures (in degrees Celsius).

Heat from the buried irradiated nuclear fuel warms up the rocks.

_from AECL’s EIS on the Geologic Disposal Concept, 1994._
Heat continues to be generated by radioactive disintegration. This heat goes into the rock, raising the temperature. After 50,000 years the temperature returns to near normal.

This 50,000 year period is the “thermal pulse” – a small blip in time compared with the multi-million-year persistence of radiotoxicity.

from AECL’s EIS on the Geologic Disposal Concept, 1994.

70 years

4,400 years

8,800 years

from AECL’s EIS on the Geologic Disposal Concept, 1994.
The minimum amount of water needed to dilute (to drinking water legal limits) one year of “fresh” spent fuel just out of a CANDU reactor is about equal to the volume of Lake Superior.

Royal Commission Report, 1978
For the first 500 – 1000 years, fission products are the deadliest components of nuclear fuel waste.

After 1000 years, actinides are the deadliest components of nuclear fuel waste.
What is an Actinide?

Actinides are heavy elements. They include uranium, thorium, and transuranic elements.

Most actinides are “alpha-emitters”. Alpha radiation is harmless outside the body, but extraordinarily damaging when inhaled, absorbed, or ingested.

Unlike most fission products, the heavier actinides typically have half-lives measured in tens of thousands of years, or even millions of years.
Creation of plutonium inside a nuclear reactor ...

... when an atom of uranium-238 absorbs a neutron
it is transformed into an atom of plutonium-239

two beta particles are emitted

Other transuranic actinides are produced in a similar way.
Alpha particles can be stopped by a sheet of paper. Alpha emitters are *harmless outside the body, but much more damaging than beta or gamma when ingested or inhaled.*

Most actinides are alpha-emitting radioactive materials.

---

Beta particles penetrate only part-way. *They can damage eyes or skin externally but the main danger is internal exposure.*

Gamma rays are highly penetrating. *They give “whole body” radiation. Heavy shielding is often needed.*
This photo shows a tiny speck of plutonium lodged in lung tissue.

The “spikes” are the tracks of alpha particles emitted over 48 hours.

Photo: Robert Del Tredici
The lung tissue of an experimental animal seen through a microscope over a period of 48 hours. At the centre of the "star" is a tiny radioactive particle of plutonium.

Each "spike" is the track of an alpha particle given off during that 48 hour period. These radioactive emissions do not travel very far.

But some of the cells that are damaged may be able to reproduce with defective genes – these cells could be the beginning of cancer.

radium, radon, polonium, thorium, plutonium, uranium – all alpha emitters.
Neutron Activation
~ the bystander effect~

Air and Water
Structural Materials
What is an Activation Product?

When a stray neutron is absorbed by a non-radioactive atom, the result is very often a radioactive atom – an “activation product”.

Example: tritium is an activation product

\[
\text{neutron} + \text{deuterium} \rightarrow \text{tritium}
\]

The diagram shows how a non-radioactive atom of deuterium becomes a radioactive atom of tritium when it absorbs a stray neutron.
There are three different isotopes of hydrogen – different masses, chemically identical.

- **Hydrogen** (stable)
- **Deuterium** (stable)
- **Tritium** (unstable, radioactive)

Each atom has one proton in the nucleus (colored red) and one solitary electron in orbit (colored gold) but different numbers of neutrons (colored white).
What gets activated?

**Water is activated** and produces radioactive tritium (T) (chemically identical to ordinary hydrogen, but radioactive)

**Air is activated** and produces radioactive carbon-14 (C-14).

All organic molecules have carbon and tritium in them, so these radioactive varieties become incorporated into our DNA.

Tritium levels in Lake Onario

Carbon-14 contamination of Pickering workers
What gets activated?

Even the **structural materials** in the core area of the reactor become radioactive waste, dangerous for 1000s of years.

Steel, concrete, zirconium, and other materials are activated – so **cannot be recycled** – but must be stored as radioactive waste.

*Impurities in the fuel and in the cladding are also activated.*

- Cobalt-60 – half-life of 5 ¼ years
  - Iron-55 – half-life of 2 ¾ years

- Nickel-63 – half life of 100 years
  - Nickel-59 – half-life of 76,000 years
Here is the face of a CANDU reactor loaded with fresh (unused) fuel bundles. If the shutdown reactor had ever operated this man would be dead from gamma exposure.
Decommissioning
~ the reverse midas touch ~

Low and medium-level
Repository failures
All radioactive wastes are created in the core, but they are spread by the primary coolant.

Steel vessels, concrete shields, pipes, boilers, heat exchangers, filters... all these things become “intermediate level” radioactive waste
128 steam generators (100-tonne each) from Bruce reactors. Loaded on a 40-wheel truck; destined to be stored as radioactive waste.
Nuclear Intestines

Inside each of the old steam generators from Bruce reactors are 4200 radioactively contaminated tubes, similar to those shown here.

The picture on the right shows the thousands of long narrow tubes inside a steam generator. The tubes become corroded and radioactively contaminated over time; eventually the entire steam generator has to be replaced.

Radioactive materials are deposited on the insides of these tubes by the primary coolant which comes directly from the core of the reactor. When these tubes leak the contamination escapes to the "secondary side" (outside those tubes).
They are contaminated with many radionuclides –

8 materials with a half-life of over a million years,
13 with a half-life of over 100,000 years,
19 with a half-life of over 1000 years,
21 with a half-life of over 100 years.
Here is a partial list of radioactive contaminants inside a used steam generator from one of the Bruce reactors. The amount of radioactivity is expressed in becquerels per cubic metre; one becquerel corresponds to one radioactive disintegration every second. (Source: OPG)

http://www.nwmo.ca/uploads_managed/MediaFiles/539_ReferenceLowandIntermediateWastefortheDGR.pdf (p. 50)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Half-Life (y)</th>
<th>Amount (Bq/m³)</th>
<th>Name</th>
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**TOTALS**

<table>
<thead>
<tr>
<th>Long half-lives only (&gt; 1 y)</th>
<th>8.7E+09</th>
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<tbody>
<tr>
<td>Including short half-lives</td>
<td>1.6E+10</td>
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**Long-lived only (> 1 y half-life)** 8 700 000 000

**Including all radionuclides** 16 000 000 000
**Plutonium in the Bruce “A” nuclear steam generators**

Here is a partial list of radioactive contaminants inside a single used steam generator from each one of the two reactors (Units 1 and 2 of Bruce A), according to CNSC (document CMD-10-H19B). The mass (in grams) of each of the radioactive materials listed is estimated by CNSC staff.

<table>
<thead>
<tr>
<th>RADIONUCLIDE</th>
<th>MASS</th>
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<td><strong>Name of Isotope (with Atomic Mass)</strong></td>
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<td><strong>(years)</strong></td>
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<td>Cobalt-60</td>
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<td>Technetium-99</td>
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<td><strong>TOTALS</strong></td>
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<td>Long-lived (&gt; one year half-life)</td>
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<td>(Source: CNSC)</td>
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There are 5 plutonium isotopes present in the steam generators. In addition there are 18 other long-lived isotopes listed.
The Midas Touch

Everything touched turns to gold
The Reverse Midas Touch

Everything touched turns to nuclear waste

Contaminated materials contaminate other materials on contact
Low and Intermediate level waste “mound” proposed for Chalk River, Ontario.
A surface dump, 7 stories tall, with a base = 70 hockey rinks, 1 mile from Ottawa River.

The waste layers are over 13 humans tall while the base layer is less than one human deep.

The total height = 95 feet = 29 metres
total height is almost 16 humans, each six feet tall.
Canada

*Port Hope Cleanup: $1.2 billion*

*AECL Nuclear Legacy Liabilities Program: $10 bill (est.)*

*NWMO Nuclear Waste Management Org: $26 bill (est.)*

United Kingdom

*Nuclear Decommissioning Authority: $80 bill (est.)*

Japan

*Fukushima Dai-ichi Cleanup: $250 bill. (est.)*
Rolling Stewardship
~ an alternative to abandonment ~

amnesia versus
persistance of memory
Management (n): the process of dealing with or caring for something.

Can we store nuclear waste safely for decades at a time?

YES

Disposal (n): the process of throwing away or getting rid of something.

Do we know how to “get rid” of nuclear waste forever?

NO

Abandon (n): to cease to support or look after; to desert.

Is abandonment of nuclear waste ethical? Is it scientific?

NO
Abandonment leads to amnesia; no one will know what it is or what to do with it...
after abandonment ... amnesia sets in!

Into Eternity...

INFINITY

NO TRANSPARENCY
NO EDUCATION
NO CONSULTATION
NO ALTERNATIVES
NO REMEDIATION

... nobody home
Is there an alternative to “Geological Disposal”?

An alternative is needed because . . .

Moving the waste: adds another waste site to those existing.

Transportation: poses new risks and complicates the picture.

Centralized storage: lays the groundwork for reprocessing.
Rolling Stewardship

Our alternative to abandonment is Rolling Stewardship. It is a new nuclear waste policy based on **frankness**.

*We begin by admitting we have at present no proven solution.*

Wastes are **monitored and retrievable** for the foreseeable future. Wastes are **packaged safely** for extended periods & **repackaged later**. *This is not a solution – but it is an ethical waste management scheme.*

Rolling Stewardship is needed **until a “genuine solution” is found.**

*The production of additional wastes can & should be stopped.*
Rolling Stewardship is continuous; it is based on ensuring Persistence of Memory.
Rolling Stewardship is an intergenerational management strategy.

With a “changing of the guard” every 20 years the necessary knowledge and resources can be communicated to the next generation.

Those in charge must be independent of the nuclear industry.

graphic by Robert Del Tredici
ROLLING STEWARDSHIP

20-year cyclic reviews

RECHARACTERIZE

REpackage REINSTRUCT

incremental improvements

MULTI-GENERATIONAL STORAGE

not forever but until a real solution is found

LONG TERM PLANNING

STAGING PLATFORM for FUTURE GENERATIONS

a bridge
The End

ccnr@web.ca