Main Presentation: Questions and Challenges
What is Nuclear Energy?
What is Nuclear Fission?
What is Radioactivity?
How Toxic is Nuclear Fuel Waste?
Is Geologic Disposal a Solution?
What is Reprocessing?
What is Rolling Stewardship?

Appendix A: Lessons About Radioactivity
What is it?
Why is it Harmful?

Appendix B: Characteristics of Nuclear Fuel Waste
Heat Generation
Chemical Reactions
What is Nuclear Energy?

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

**NOTE:** “nuclei” is the plural of “nucleus”
Chemical energy involves only the outer electrons.

Nuclear energy comes directly from the nucleus — it is millions of times more powerful than chemical energy.
TWO VERY DIFFERENT types of nuclear energy:

**NUCLEAR FISSION** –
nuclei are “split” by neutrons
*(think of A-Bombs & nuclear reactors)*
**DISCOVERED:** Dec 1938 – Jan 1939

**RADIOACTIVITY** –
nuclei spontaneously “disintegrate”
*(think of “clicks” on a Geiger counter)*
**DISCOVERED:** 1896 by Henri Becquerel

Nuclear Fission can be speeded up, slowed down, stopped and restarted by controlling the number of neutrons.

Radioactivity is unstoppable. Nobody knows how to shut it off. We can’t speed it up, or slow it down. It just happens.
Nuclear fission creates hundreds of new materials that are intensely radioactive.

*that’s why we have a nuclear waste problem.*

Radioactive contamination at West Valley NY from nuclear fuel waste:

. . . and nobody knows how to shut off radioactivity.

*if we could only turn it off there would be no problem.*

Detecting radioactivity requires special equipment & protection.
uranium is special
it is the key element
behind all nuclear
fission technology
and
it gives rise to all the
nuclear fuel waste

"A Model of the
Uranium Atom"

Photo: Robert Del Tredici
What is 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”.

More neutrons trigger more fissions and so the energy release is multiplied enormously.
When the nucleus is “split” enormous energy is released (shown by the semicircles) “Fission Products” – broken pieces of split atoms – remain (shown by 2 hemispheres)
A CANDU fuel bundle can be handled safely before it is used, but after it is used it delivers a lethal radiation dose in seconds. This is caused by the intense radioactivity of the fission products.
The main attraction of nuclear energy: one small pellet of uranium fuel, utilizing nuclear fission, gives as much energy as a tonne of coal – with no greenhouse gas.

The main disadvantage of nuclear energy: after it is used you cannot throw that pellet away – you have to keep an eye on it for the next ten million years.
“High-level wastes [nuclear fuel wastes] . . . produce fatal radiation doses during short periods of direct exposure. Ten years after removal from a reactor, the surface dose rate for a typical spent fuel assembly [is still] far greater than the fatal whole-body dose for humans.”

“If . . . these high-level wastes get into groundwater or rivers, they may enter food chains. The dose produced would be much smaller than a direct-exposure dose, but a much larger population could be exposed.”

“Backgrounder on Transportation of Spent Fuel”
US NRC (Nuclear Regulatory Commission)
http://tinyurl.com/oz2p3bb
A radioactive atom has an unstable nucleus. It will **suddenly disintegrate**, giving off a highly energetic particle and/or a photon of energy. These emissions are **damaging to living cells**.
Three types of emissions: Alpha, Beta and Gamma

A radionuclide emits either an alpha or a beta particle. Such particles are electrically charged and move very fast. In some cases a powerful gamma ray is also given off. All three forms of atomic radiation damage living cells.
A gamma ray is like an x-ray, but more powerful.
highly penetrating ~ easily detected

A beta particle is like a sub-atomic bullet.
moderately penetrating ~ harder to detect

An alpha particle is like a subatomic cannon ball.
least penetrating, but most damaging ~ often undetected

Alpha and Beta particles are INTERNAL hazards.
Gamma rays are both INTERNAL & EXTERNAL hazards.
Alpha particles can be stopped by a sheet of paper. **Alpha emitters are harmless outside the body, but exceedingly dangerous when ingested or inhaled.**

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.*
a photo of “alpha rays” from a tiny radioactive speck lodged in lung tissue

Under a microscope, with a 48-hour camera exposure, the tracks of alpha particles are here recorded. Cells close to the source may be damaged, yet able to reproduce, causing lung cancer many years later.
Irradiated Fuel: The first 30 years

1945-62 – research reactors produce irradiated fuel
   stored at Chalk River ~ no public awareness

1962-78 – power reactors produce irradiated fuel
   stored on site in pools ~ no public debate

1975 – Canadian Coalition for Nuclear Responsibility (CCNR)
   pointed out no plan for long-term waste management

   perhaps burial in a “deep geologic repository” (DGR)

   nuclear moratorium is advisable if waste problem not solved
The Shock of Recognition

For 30 years nuclear power was portrayed as “clean” energy.

The multibillion dollar burden of managing nuclear fuel waste in perpetuity came as a shock!

In the mid-1970s, reports in the UK, the USA and Ontario dramatized this problem.
“. . . it would be irresponsible and morally wrong to commit future generations to the consequences of fission power . . . unless it has been demonstrated beyond reasonable doubt that at least one method exists for the safe isolation of these wastes . . .”

Nuclear Power and the Environment
UK Royal Commission on Environmental Pollution
London September 1976
“Growth of nuclear power in the US is threatened by the problem of how to safely dispose of radioactive waste potentially dangerous to human life. Nuclear power critics, the public, business leaders, and government officials all concur that a solution to the disposal problem is critical to the continued growth of nuclear energy.”

Nuclear Energy’s Dilemma: Disposing of Hazardous Radioactive Waste Safely
Washington DC September 9 1977
“Continuous monitoring of waste disposal research should be undertaken by an independent panel of experts. If adequate progress is not being made, say, by 1985, then nuclear power should be reassessed and a moratorium on additional nuclear stations should be considered.”

The front cover of the Royal Commission report shows the “nuclear fuel chain”, from mine, to mill, to fuel fabrication, to nuclear power plant, to . . .
the back cover – posing the unanswered question: where will all that nuclear fuel waste go?
What is the Nuclear Ultimatum?

Simply put it is this:

find a safe way to “get rid” of nuclear fuel waste

or

the nuclear industry will come to an end

So the nuclear industry has a “conflict of interest”—it cannot afford to fail!
The nuclear power industry in Canada has produced **3 million bundles** of nuclear fuel waste to date, weighing over 50,000 tonnes.

Each CANDU fuel bundle **weighs about 20 kilograms**, and is **about the size of a fireplace log**.
Irradiated CANDU fuel is intensely radioactive, and so hot that it has to be cooled by circulating water for 10 years.
After 10 years the irradiated fuel can be robotically transferred to air-cooled "dry storage" containers.
nuclear fuel waste

As the reactors continue to operate, more and more irradiated fuel accumulates inside and outside the reactor.

CANDU Fuel Bundle

Wet Storage (10 yrs)

Dry Storage (decades)

More waste is produced every day
3 million bundles of nuclear fuel waste to date, weighing over 50,000 tonnes.

OPG expects to double this volume over the next 30 years.
Irradiated Fuel: Another 25 years

1978 – Canada/Ontario Agreement involving AECL and Ontario Hydro
   $750 million 15-year research effort to “verify” geologic disposal;
   Underground Research Laboratory is built in Manitoba.

1988-98 – 10 year Environmental Assessment Begins (Seaborn Panel)
   panel is forbidden to consider stopping nuclear waste production;
   public hearings are held in five provinces on DGR Concept

   DGR = Deep Geological Repository

   “DGR Concept is not ready to be adopted as Canada’s approach;
   waste agency is needed that is independent of industry and gov’t”

   despite Seaborn Panel, nuclear waste producers are put in charge –
   Nuclear Waste Management Organization NWMO is not independent
Is burial of nuclear waste proven safe?

- We can’t get HLW into an undisturbed site without disturbing it.
- HLW remains incredibly toxic for many millions of years.
- Science cannot predict events over such long time periods.

- The USA tried 8 times to find a DGR for HLW – and failed 8 times.
- Germany already has had two failed DGRs for Low-Level Waste.
- The only nuclear DGR in America had a serious accident in 2014.

HLW = High Level Nuclear Waste
DGR = Deep Geological Repository
If radioactive materials are ingested (through eating or drinking) internal exposure to alpha, beta and gamma radiation occurs.

Such chronic low-level exposure to radioactivity can cause many types of illnesses years later including cancer & genetic damage.

Regulations have been set specifying the maximum amount of radioactive contamination that is allowed in drinking water.

Ontario’s Porter Commission asked: how much water is needed to dilute nuclear fuel waste to the maximum level of radioactive contamination allowed by current regulations?
The minimum amount of water needed to dilute 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
How toxic is nuclear fuel waste?

No one is saying that nuclear fuel waste is going to be dissolved in the waters of Lake Superior or any other Great Lake.

The Ontario Royal Commission did this calculation to show how important it is to ensure that these wastes do not escape.

If one percent, or 0.1 percent, or 0.01 percent of the nuclear fuel waste gets out into the environment, you have a serious failure.

After ten million years, when the radioactivity is much reduced, the amount of water needed to dilute the waste is still enormous.
Why is nuclear waste dangerous?

The FISSION PROCESS creates hundreds of kinds of radioactive materials as unwanted byproducts.

Most of these did not exist in nature before 1940.

The incredibly complex mixture of radionuclides found in nuclear fuel waste is called “High Level Nuclear Waste”

High Level Nuclear Waste (HLW) could refer to

- solid irradiated fuel [“spent fuel” or “nuclear fuel waste”]
- liquid from dissolving spent fuel in acid [“reprocessing”]
- resolidification of post-reprocessing liquid [“vitrification”]
Three categories of nuclear waste materials:

1. Fission Products (e.g. cesium-137, iodine-131)
   ~ the broken bits of uranium atoms
   (beta and gamma emitters)

2. Activation Products (e.g. cobalt-60, carbon-14)
   ~ transmuted versions of non-radioactive atoms
   “activated” by absorbing stray neutrons
   (beta and gamma emitters)

3. Transuranics (Actinides) (e.g. plutonium, americium)
   ~ heavier-than-uranium elements that are
   created when U-238 absorbs neutrons
   (mainly alpha emitters, very long-lived)

*These three categories are differentiated in the following table of radionuclides.*
# A List of Selected Radionuclides in Irradiated Nuclear Fuel

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**F.I.A.P.** = fuel impurity activation product  **Z.A.P.** = zirconium cladding activation product  [source: AECL]
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This list of 211 radionuclides contained in irradiated nuclear fuel is by no means complete. (AECL)

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F.I.A.P. = fuel impurity activation product; Z.A.P. = zirconium cladding activation product; source = AECL

¥ indicates that the radionuclide is present in the designated category
¥¥¥¥ indicates an activity level of more than a million becquerels per kilogram
Can we not get rid of this waste safely by *burying it all deep underground*?

*Let’s assume that nuclear fuel waste is moved to a distant location as rapidly as possible, and buried as quickly as it can be.*

*Will this solve the nuclear waste problem?*

The following series of graphics explores the possibility in very simple diagrams.
IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

ONE REACTOR

After 2 years

The “X” represents a single nuclear reactor. Each dot represents one year’s production of irradiated nuclear fuel
IRRADIATED NUCLEAR FUEL ACCUMULATION
WITHOUT GEOLOGIC DISPOSAL

AFTER 4 YEARS
IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

AFTER 8 YEARS
As the years go by, more and more nuclear waste accumulates beside the reactor.
IRRADIATED NUCLEAR FUEL ACCUMULATION 
WITHOUT GEOLOGIC DISPOSAL 

AFTER 32 YEARS
IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

AFTER 40 YEARS

Look at all that nuclear waste right beside the reactor! Shouldn’t we get rid of it? Shouldn’t we at least get it off the surface? The nuclear industry offers to solve the problem by burying the waste.
IS GEOLOGIC DISPOSAL INTENDED TO MAKE THE WORLD SAFER?

Why does the industry want to bury its nuclear waste?

- Is it unsafe where it is? [the industry says “no”]
- Will we stop making it? [the industry says “no”]

Can we get rid of all the nuclear waste beside the reactors?

*Common sense says “no” – not if we keep on producing it!*
HERE’S HOW THE PICTURE LOOKS. . .

WITH GEOLOGIC DISPOSAL?

AFTER 2 YEARS

No change at all. Irradiated fuel has to be stored in the spent fuel pool.
WITH GEOLOGIC DISPOSAL

AFTER 4 YEARS

Still no change. All irradiated fuel is being stored in the pool.
WITH GEOLOGIC DISPOSAL

AFTER 10 YEARS

For the first ten years the nuclear waste is so radioactive it cannot be moved. It has to be cooled in water-filled pools to prevent spontaneous over-heating.
AFTER 16 YEARS WITH GEOLOGIC DISPOSAL

After ten years the nuclear fuel waste can be put into dry storage. It could be transported, but it is still too “hot” to be buried underground.
After 10 years the fuel might be moved, but NWMO plans to wait for 30 years. So: 10 to 30 years worth of unburied nuclear waste stays right beside the reactor!
WITH GEOLOGIC DISPOSAL

AFTER 32 YEARS

ONLY THIS PORTION MAY BE TRANSPORTED!
NOTE – The Catastrophe Potential at the Surface Still Remains. The hottest, most radioactive fuel waste, is still sitting beside the reactor.
WHAT DOES THE INDUSTRY HOPE TO ACHIEVE?

To convince Canadians that the waste problem is solved
• so the lifetime of old reactors can be prolonged;
• so new reactors can be built at home and abroad;
• so the industry can continue to expand. . . .

Once the nuclear waste problem is “solved”
the nuclear industry says it is
TIME FOR A “NUCLEAR RENAISSANCE” –
MORE REACTORS, PLEASE!
But building more reactors just adds to the problem of UNBURIED waste,

**EVEN WITH** GEOLOGIC DISPOSAL

With 2 reactors, after 40 years there is **TWICE AS MUCH** UNBURIED NUCLEAR WASTE.
WITH 4 REACTORS

ONLY THIS MAY BE TRANSPORTED!
WITH GEOLOGIC DISPOSAL

WITH 6 REACTORS

ONLY THIS MAY BE TRANSPORTED!
WITH GEOLoGIC DISPOSAL

WITH 8 REACTORS

ONLY THIS MAY BE TRANSPORTED!
**SO EVEN WITH GEOLOGIC DISPOSAL . . .**

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. . . THERE IS AN **EVER-GROWING INVENTORY OF UNBURIED WASTE!!**
The industry does not intend to stop making nuclear waste. And nuclear waste can’t be shipped for at least 10 to 30 years. So if reactors keep running unburied nuclear waste will build up.

As more reactors are built the stock of unburied waste grows faster, – even if older nuclear waste is buried as quickly as possible!

Unless all reactors are stopped, how can burial be a solution?
Could there be another reason for moving the waste?

- Irradiated nuclear fuel contains a dangerous, but valuable, man-made material called plutonium. Extracting plutonium requires moving the irradiated fuel to a remote location.

- In England, France, Russia, India, Japan, and other countries, nuclear waste is REPROCESSED by dissolving the solid fuel in boiling nitric acid to allow for chemical separation of plutonium.

- Plutonium is regarded as the nuclear fuel of the future – it is also the primary nuclear explosive in most nuclear weapons.

- The result of reprocessing is millions of litres of high level liquid radioactive waste, and a great deal of radioactive pollution.
Atomic Energy of Canada Ltd. plans for reprocessing

“The separation and use of plutonium is a long-range job requiring careful planning and research. We are already late in starting. . . . AECL believes that our major long term program should be development and demonstration of fuel recycle and disposal of radioactive wastes.”

~ Stan Hatcher, AECL Vice-President

“I have not said much about the waste disposal aspect. It is extremely important; but it is a part of the total program. It cannot be dissociated from the fuel cycle program. . . . Plutonium is an extremely useful material and we will be dealing in it.”

~ John Foster, AECL President

“Proposed Canadian Fuel Cycle Centre”
A Day-Long Briefing of Senior Civil Servants by AECL
Ottawa, February 28 1977
“Spent fuel reprocessing . . . should not be part of Ontario Hydro's system planning. Hence, there is no need for a central interim storage facility for spent fuel. All spent fuel should be stored at nuclear generating station sites.”

“We believe that a central facility would presuppose the reprocessing of spent fuel; it would also involve more transportation and social and environmental problems.”

“What's even more exciting . . . is the prospect of recycling used nuclear fuel to extract some of the 99% remaining energy potential that it retains after leaving the reactor. . . . The potential for future societies to elect to pursue this route has been entrenched in the proposed program of Canada's Nuclear Waste Management Organization.”

Jeremy Whitlock, AECL, Aug 3 2005

. . . “recycling” is industry code for reprocessing (plutonium recovery) . . .
This CAMECO mural is painted on the walls of Saskatoon’s Airport

CAMECO is one of the world’s largest uranium mining companies. It is based in Saskatoon, Saskatchewan.

The mural celebrates the many Steps in “The Nuclear Fuel Cycle”

...but there is no “cycle” – until you “recycle” the plutonium!
FIRST PANEL: The nuclear fuel cycle presupposes reprocessing – not burial – of irradiated fuel.
Burying nuclear fuel waste *without reprocessing* means *an early end to nuclear power*...  

...because *uranium supplies* will not outlast *oil supplies* in the long run.
LAST PANEL: The Cameco mural makes the fate of nuclear fuel waste plain ...

Reprocessing and storage
Uranium fuel bundles still hold the secrets from a reactor and can be reprocessed...

... for anyone who can read the writing on the wall.
“Reprocessing and storage are the final stages of the nuclear fuel cycle. Uranium fuel bundles still hold tremendous potential energy when removed from a reactor and can be reprocessed to recover it.”

_Cameco Mural on the Wall of the Saskatoon Airport (2008)_
Reprocessing plants are among the most radioactively contaminated sites on Earth.

- Hanford, Washington, USA – $113 billion cleanup
- Savannah River Site, USA – $109 billion cleanup
- West Valley, NY State, USA – $13 billion cleanup
- Sellafield, UK – $82 billion cleanup
- La Hague, France – $7 billion cleanup
- Mayak, Russia – a vast “no man’s land” from 1957
What happens to liquid waste left over from reprocessing?

- **Hanford** – millions of gallons have leaked into the soil
- **West Valley** – highly radioactive sludge still remains
- **La Hague** – liquid waste is “vitrified” (resolidified)
- **Mayak** – tank of reprocessing liquid exploded in 1957

In Canada, “nuclear fuel waste” refers to EITHER
solid irradiated fuel bundles without reprocessing, or the resolidified post-reprocessing liquid waste.

In either case the industry wants to BURY the final waste product in a Deep Geologic Repository (DGR)
Ultimately, industry wants to abandon the nuclear waste. Once abandoned, it is no longer the industry’s problem, and the regulator no longer has to monitor it. The “DGR” becomes a “DUD” = Deep Underground Dump.

After the waste is abandoned amnesia sets in. Future generations will have no knowledge or resources to deal with failed repositories.

By the time buried nuclear waste finds its way back into the environment, it’s too late to fix.
ABANDONMENT

Into Eternity...
INFINITY

FOREVER ← LATER ← NOW ← NUCLEAR WASTES

LONG TERM PLANNING
STAGING PLATFORM FOR INFINITY
licence to abandon

SHORT TERM ("Wow")
more or less OK ("oops")

TRANSPARENCY EDUCATION CONSULTATION ALTERNATIVES REMEDIATION

CANDU REACTOR
CANDU URANIUM TAILINGS

NUCLEAR WASTES
alpha beta gamma
solid gas liquid
high level mid level low level
LONG TERM SHORT TERM

... nobody home

leading to amnesia...
Must the waste be moved?

No. The industry says irradiated fuel is safe where it is.
The nuclear waste packages can be made stronger and more durable.
Wastes can be repackaged and storage sites “hardened” as needed.

*Why move nuclear waste from A to B, when it is *no safer* at B than at A?*

Moving waste adds an additional waste site to those already existing.
And transportation poses new risks all along the transportation route.
Doesn’t this just complicate the waste problem instead of solving it?

*The industry sees nuclear waste as its biggest public relations challenge.*
*Getting the waste “out of sight, out of mind” allows OPG to keep producing it.*
*Without stopping production, burial does not solve but perpetuates the problem.*
An alternative to abandonment

The concept of Rolling Stewardship was introduced in 1985 by the US Academy of Sciences.

- It is a management procedure for safeguarding persistent toxic materials.
- It is an alternative to the Abandonment Strategy that underlies the proposal for a Deep Geologic Repository.
We begin by admitting that we have at present no proven solution.

The only ethical alternative to abandonment is Rolling Stewardship.

Wastes are kept monitored and retrievable for the indefinite future.

Wastes are packaged safely for long periods & repackaged as needed.

This is not a “solution” – but it is an ethical waste management policy.

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

A genuine solution would neutralize the waste, but we don’t know how.

Meanwhile, the production of more wastes can/should be phased out.
ROLLING STEWARDSHIP

NUCLEAR WASTES

SHORT TERM ("wow")

more
or
LESS
("oops")

NEEDED:

- Transparency
- Education
- Consultation
- Alternatives
- Remediation

CANDU REACTOR

High Level
Mid Level
Low Level

MEMENTO

Future generations have an incentive to find a genuine solution

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

Those in charge should be independent of the nuclear industry.

Rolling Stewardship is an intergenerational management strategy.
Summary:

For the first 30 years of the nuclear age, decision makers were kept unaware of the special challenges posed by nuclear waste.

In the late 1970s, when the waste problem became apparent, the future of the industry was tied to solving this problem.

Instead of creating an independent body, disconnected from the nuclear industry, our government put the industry in charge.

The industry sees reprocessing nuclear waste as an important aspect of nuclear waste management in the very long term.

Reprocessing will take place wherever the waste DGR is built.

As long as nuclear reactors keep operating the catastrophe potential at the surface will remain essentially unchanged.

There isn’t enough water in the Great Lakes Basin to dissolve our nuclear waste to permissible levels of contamination.

The fundamental choice is: abandonment? or stewardship?
Nuclear Fuel Waste: Questions and Challenges

THE END

But – see Appendices A and B for further information.

Gordon Edwards, Ph.D., President, Canadian Coalition for Nuclear Responsibility
E-mail: ccnr@web.ca

www.ccnr.org
Appendix A

LESSONS ABOUT RADIOACTIVITY –

WHAT IS IT?

WHY IS IT HARMFUL?
Lesson One

A radioactive atom is unstable

It will disintegrate

suddenly and violently,

giving off “atomic radiation”
The unit of radioactivity is the "BECQUEREL".

One becquerel indicates that
one atomic disintegration
is taking place every second.

Thus, for a long-lived radioactive material,
“1000 becquerels of radioactivity” indicates
• one thousand disintegrations per second;
• sixty thousand disintegrations per minute;
• over three and a half million disintegrations per hour;
• over eight and a half billion disintegrations per day.
Radioactive elements have distinct pathways through the human body

They are “ionizing agents”, because their emissions break molecular bonds

This creates charged fragments (ions) – thus the expression “ionizing radiation”
Radioactive Materials are chemical substances which are also radioactive.

They all have their own unique pathways through the environment and through the human body.
Iodine-131 goes to the thyroid gland (in the throat) and damages it. Thyroid cancer, mental retardation, and stunted growth can result. Young children are especially at risk.
Cesium-137 goes to the soft tissues.

It makes meat unfit for human consumption.

It stays in the food chain for decades.
Strontium-90 behaves like calcium; it goes to the bones, the teeth and mother’s milk. Bone cancer or blood diseases may result.
Lesson Three

Chronic radiation exposure at low doses increases the incidence of cancer, leukemia, genetic damage, strokes, heart attacks, and low intelligence but there is a “latency period”: the onset of disease occurs years or decades after exposure.
she discovered radium and polonium,  
-- two radioactive byproducts of uranium
Radium Dial Painters 1920

Girls hired to use radioactive paint to make numerals on watch dials glow in the dark ...

... ingested minute amounts of radium when they licked the tips of their brushes to get a very fine point.
Deaths of Radium Dial Painters
from ingesting minute amounts of radium

Fatal anemias
Bone cancers
Head cancers

radium is a bone-seeker

radium (like calcium) – goes to bones and teeth
dial painters developed severe dental damage called “radium jaw”
radium also damaged blood-forming organs in their bone marrow
many died of anemia (as did Marie Curie and her daughter Irene) and others of bone cancer
radon gas (produced by radium) was carried by blood to the head and caused cancers there
Radon gas is produced when radium atoms disintegrate.

Radon is the leading cause of lung cancer among non-smokers.

Radon causes lung cancers and other lung diseases in uranium miners.

Radon gas deposits solid radioactive materials in lung tissue.

Radon is seven times heavier than air and travels great distances ...

Photo: Robert Del Tredici
Radon exposure in homes
kills 20,000 to 30,000 Americans
every year by lung cancer
Alexander Litvinenko 2006

*polonium* is chemically similar to potassium – it attaches itself to the *red blood* corpuscles ...

*polonium* travels throughout the body damaging *soft organs* ...

*polonium* is 250 billion times *more toxic than hydrogen cyanide* ...

*polonium* is the only material that can deliver a dose of *whole-body alpha radiation* ...

*polonium* is produced by the *disintegration of radon* atoms ...

murdered by *polonium poisoning in London England* (a tiny amount added to a cup of tea)
polonium is a blood-seeker

polonium-210

is probably the cause of

up to 90 percent of the deaths

attributed to tobacco

radon gas from soil and uranium-rich fertilizer builds up under a canopy of tobacco leaves ...

radon disintegrates to form radioactive lead-210 that sticks to the resinous hairs on tobacco leaves ...

harvested tobacco has very minute amounts of radioactive lead-210 ...

lead-210 disintegrates to form polonium-210 that is inhaled by smoker ...

polonium-210 damages the lung to cause cancer and enters the blood to cause strokes and heart attacks...
by the way . . .

these deadly radionuclides
~ radium, radon, and polonium ~
are all alpha emitters

harmless outside the body, but deadly inside

uranium and plutonium
are also alpha emitters
The incidence of radiation-induced disease depends on the “population dose”.

The larger the population, the larger the number of cases of illness.
At low levels of exposure, harmful biological effects like cancer do not occur until many years after exposure.
Radioactive materials enter into the air, water and soil. They get into fish, plants, animals, and humans.
A small fraction of the population will develop cancer years later. Infants and children are especially vulnerable.
If a larger population is exposed to the same level of contamination, we say that the “population dose” is greater.
The greater the population dose, the more cases of adverse health effects – like cancer – will be seen.
At low levels, radioactivity does not attack humans directly – it damages cells. A population is like an ocean of cells.
A fraction of those cells will develop into cancers. It is largely a matter of chance whose body the cancer is in.
Appendix B

CHARACTERISTICS OF NUCLEAR WASTE

HEAT GENERATION

CHEMICAL REACTIONS
The face of a CANDU reactor loaded with fresh (unused) fuel bundles. After a reactor is shut off the radioactivity of the nuclear fuel waste continues.
Irradiated fuel must be cooled for ten years by circulating water in a spent fuel pool. Heat is being generated by the radioactive disintegrations of the fission products.
Fukushima Dai-Ichi Nuclear Power plant, Units 1 – 4
All reactors were shut down safely when earthquake struck on March 11, 2011.
Three hydrogen gas explosions were caused by nuclear fuel waste
(heat + ionization → chemical reactions → hydrogen gas buildup → explosion)

... but the heat of the nuclear fuel waste caused enormous damage
Nuclear Fuel Waste led to three core meltdowns and four demolished reactor buildings. Without cooling, *the radioactive heat drives temperatures up to 2800 degrees Celsius*. 
Although the reactors were shut down immediately after the earthquake, the heat generated by the radioactivity of the nuclear waste melted 300 tonnes of nuclear fuel.
Flowing groundwater – 300 tonnes per day – washes melted nuclear fuel debris into the ocean.
Four years after the accident: 400 tonnes of cold water pumped down to the melted fuel every day and back up again to cool the fuel and prevent over-heating – this water is too contaminated to be released to the environment. Over 280,000 tonnes are stored.
Huge steel tanks are used to hold the radioactively contaminated water; workers try to prevent radioactive leaks.
1500 tanks of highly radioactive water are already stored in above-ground areas near the plant.
Fact: nuclear fuel waste generates heat and causes chemical reactions long after it is buried.

In this graph from Atomic Energy of Canada Ltd., the horizontal lines indicate rock layers. Heat generated by buried nuclear fuel waste raises the temperature of surrounding rock.
Closing thoughts:

Nuclear waste is active, it is not inert. It produces heat and releases ionizing energy that causes chemical reactions to occur.

In 2014, chemical reactions inside a nuclear waste container in a DGR located near Carlsbad, New Mexico, led to an explosion.

Radioactive plutonium-contaminated dust travelled vertically upwards over 700 metres and contaminated 22 workers at the surface, then drifted downwind 20 miles to the town.

In Germany, two DGRs for nuclear waste (much less radioactive than irradiated nuclear fuel) are collapsing – and the German Government is now working to retrieve the buried nuclear waste.

There is no operating DGR for nuclear fuel waste anywhere in the world.
Nuclear Fuel Waste: Questions and Challenges

End of the Slide Show

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