Nuclear Fuel Waste: Questions and Challenges

A Slide Show

Prepared for the

Citizen's Liaison Committee

White River, Ontario

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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"

Photo: Robert Del Tredici

Chemical energy involves only the outer electrons.

Battlefield explosion

Forest fire

Nuclear energy comes directly from the nucleus – it is millions of times more powerful than chemical energy.

H-Bomb Blast

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

Detecting radioactivity requires special equipment & protection

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

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

A Model of the Uranium Atom

uranium is special

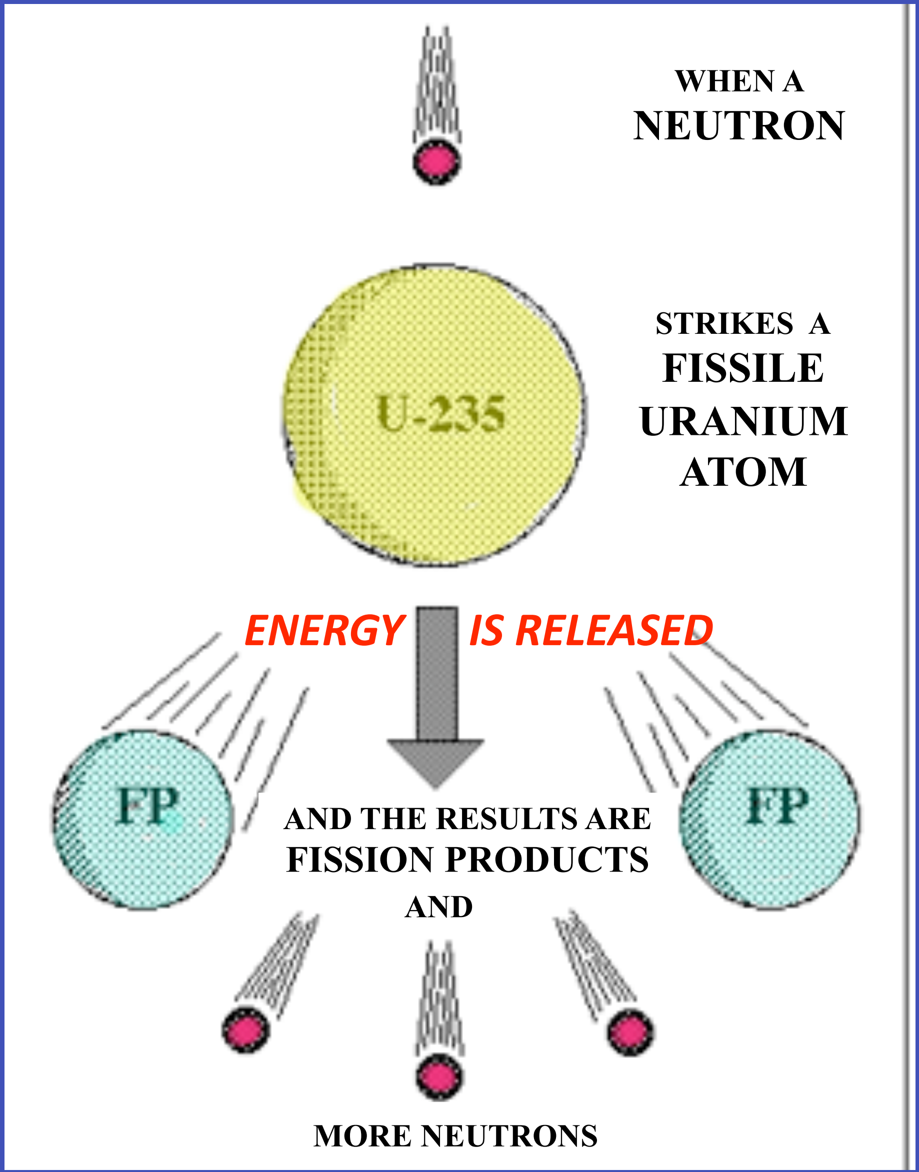
it is the key element behind all nuclear fission technology

and

it gives rise to all the nuclear fuel waste

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.

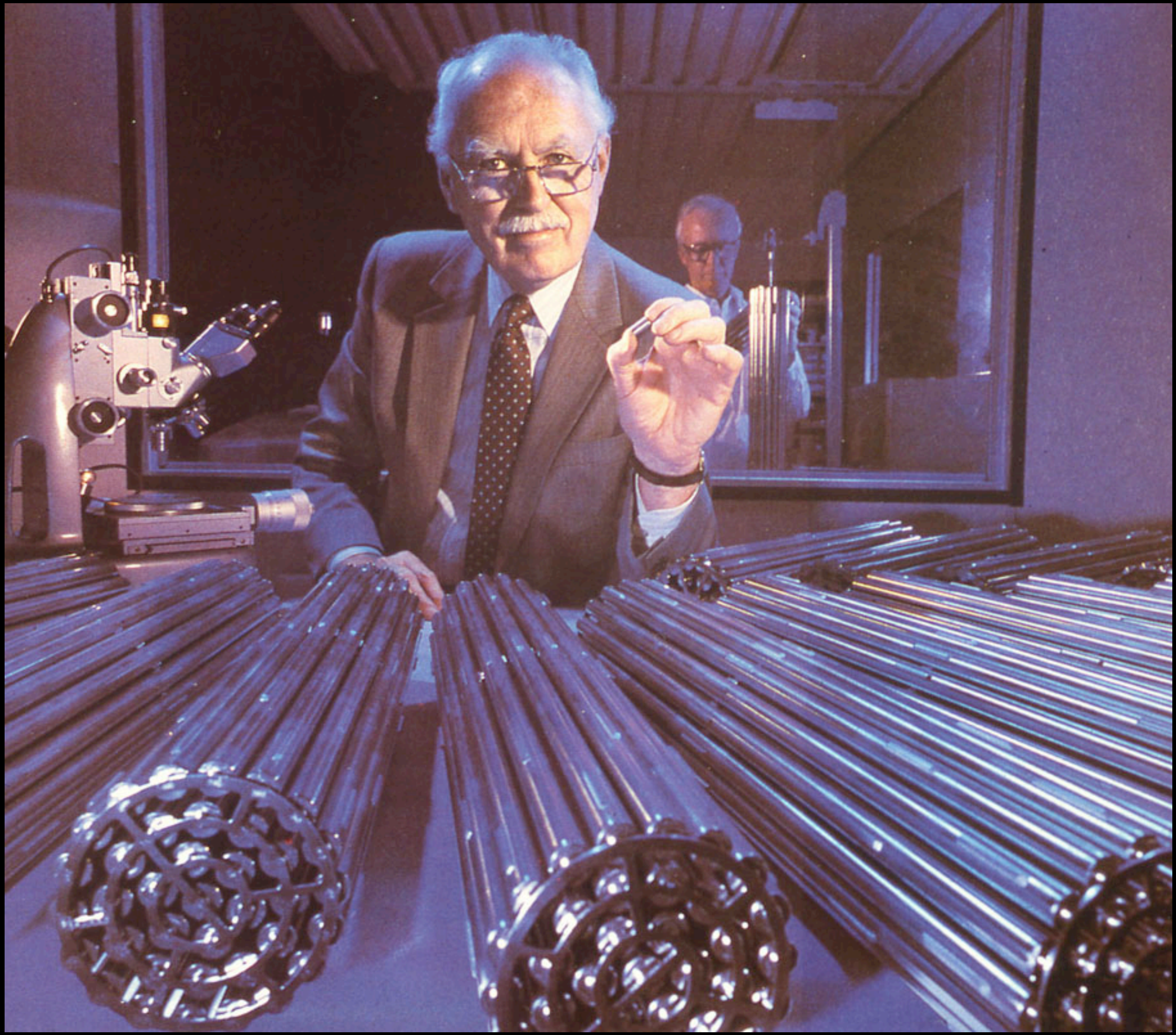
The 2 broken pieces are new radioactive nuclei called "fission products".

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

a soviet-era monument to the splitting of the uranium atom

Photo: Robert Del Tredici

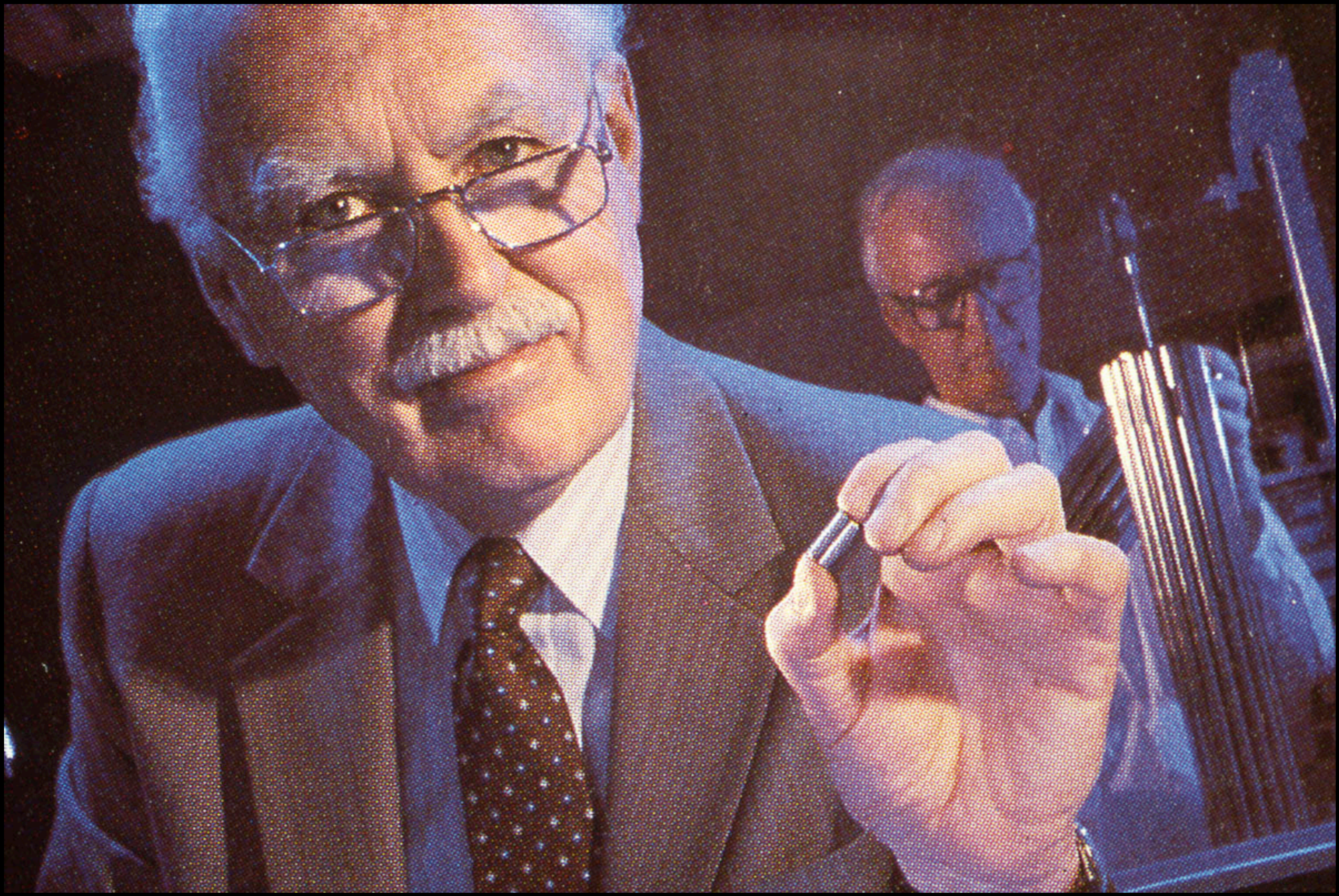
When the nucleus is “split” enormous energy is released (shown by the semicircles)
“Fission Products” – broken pieces of split atoms – remain (shown by 2 hemispheres)



"Small Wonder" : Canadian Nuclear Association Ad

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.

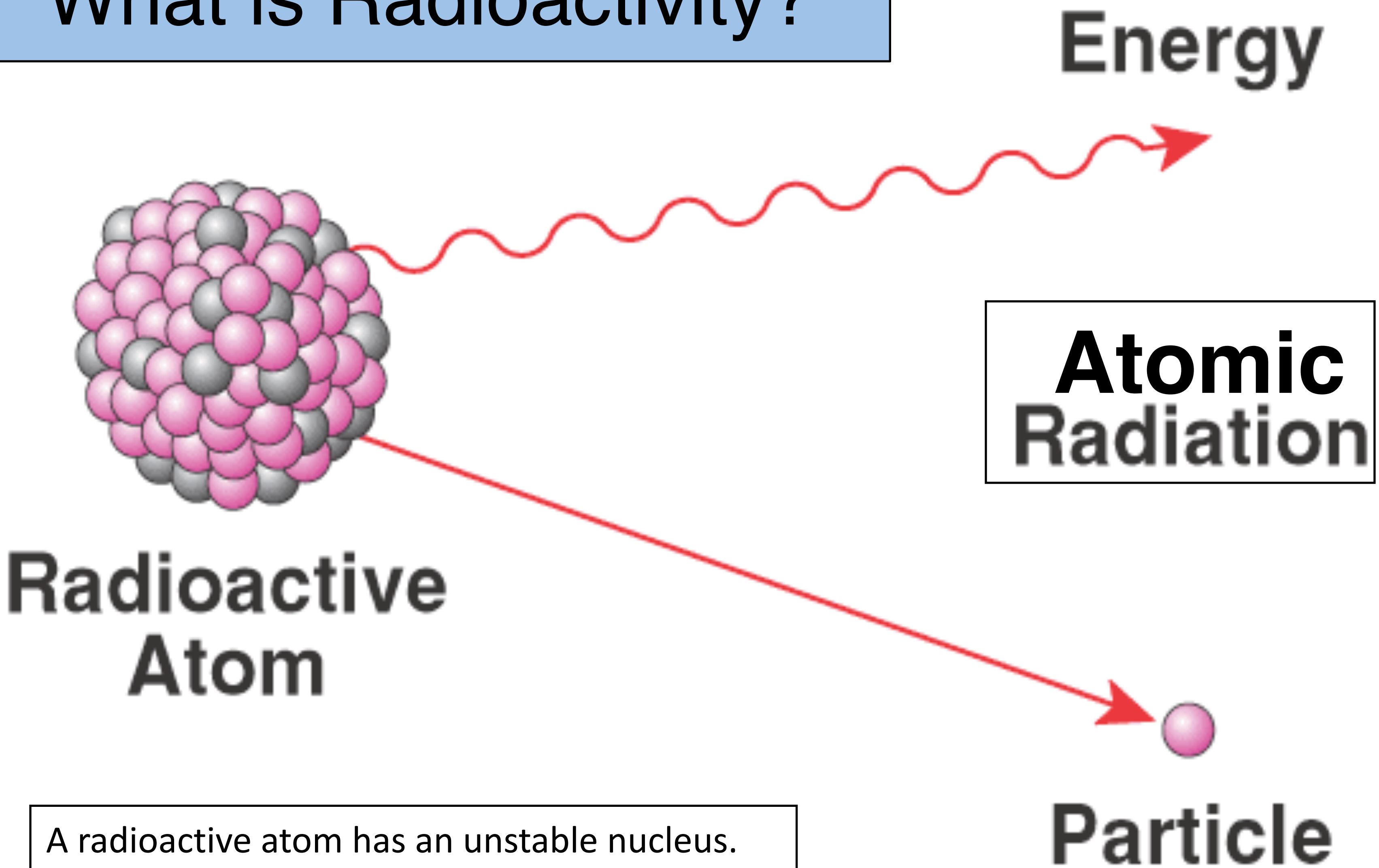
The Dangers of Nuclear Fuel Wastes

“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**.”

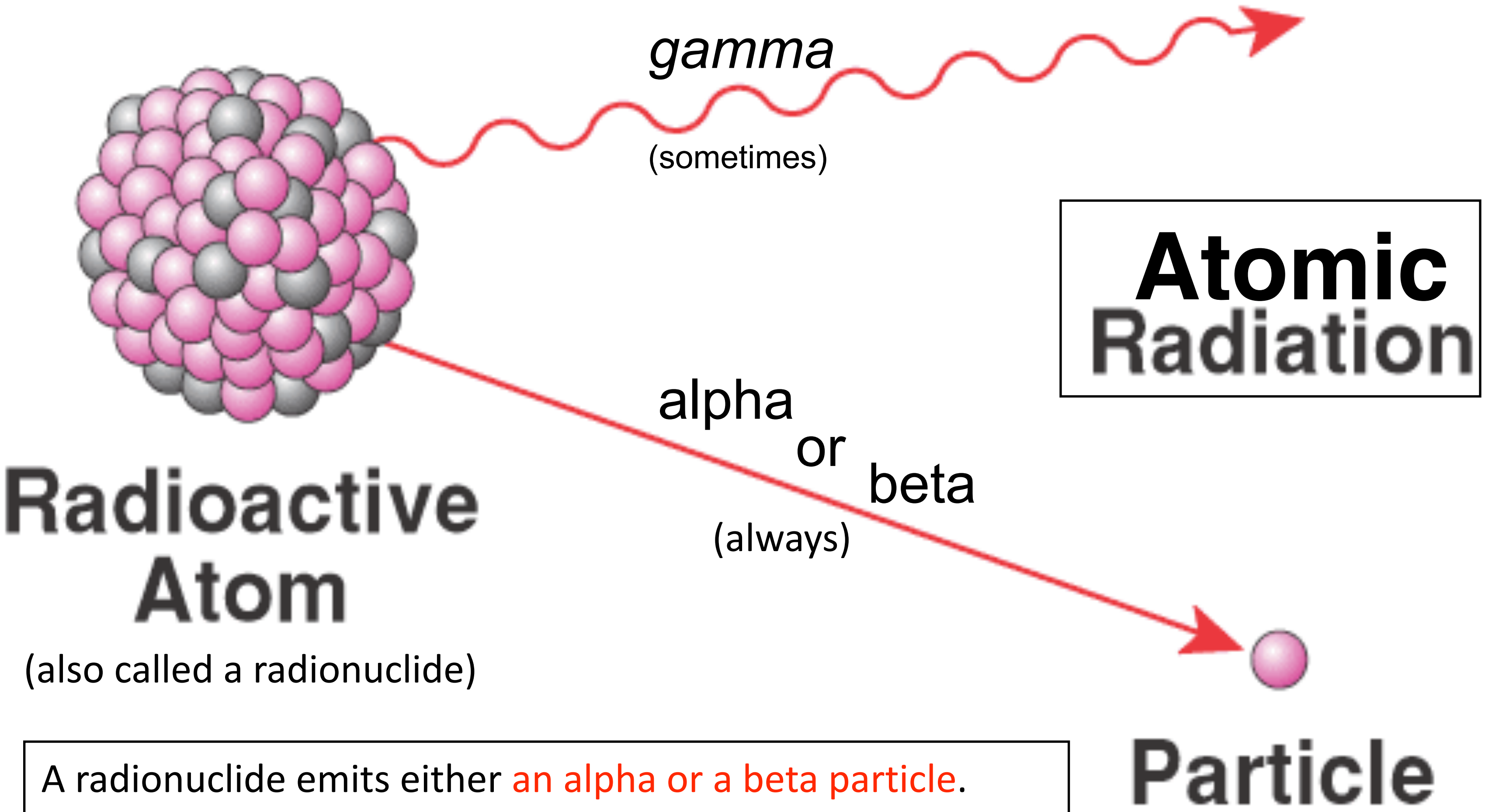
“Backgrounder on Transportation of Spent Fuel”
US NRC (Nuclear Regulatory Commission)
http://tinyurl.com/oz2p3bb

What is Radioactivity?



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.

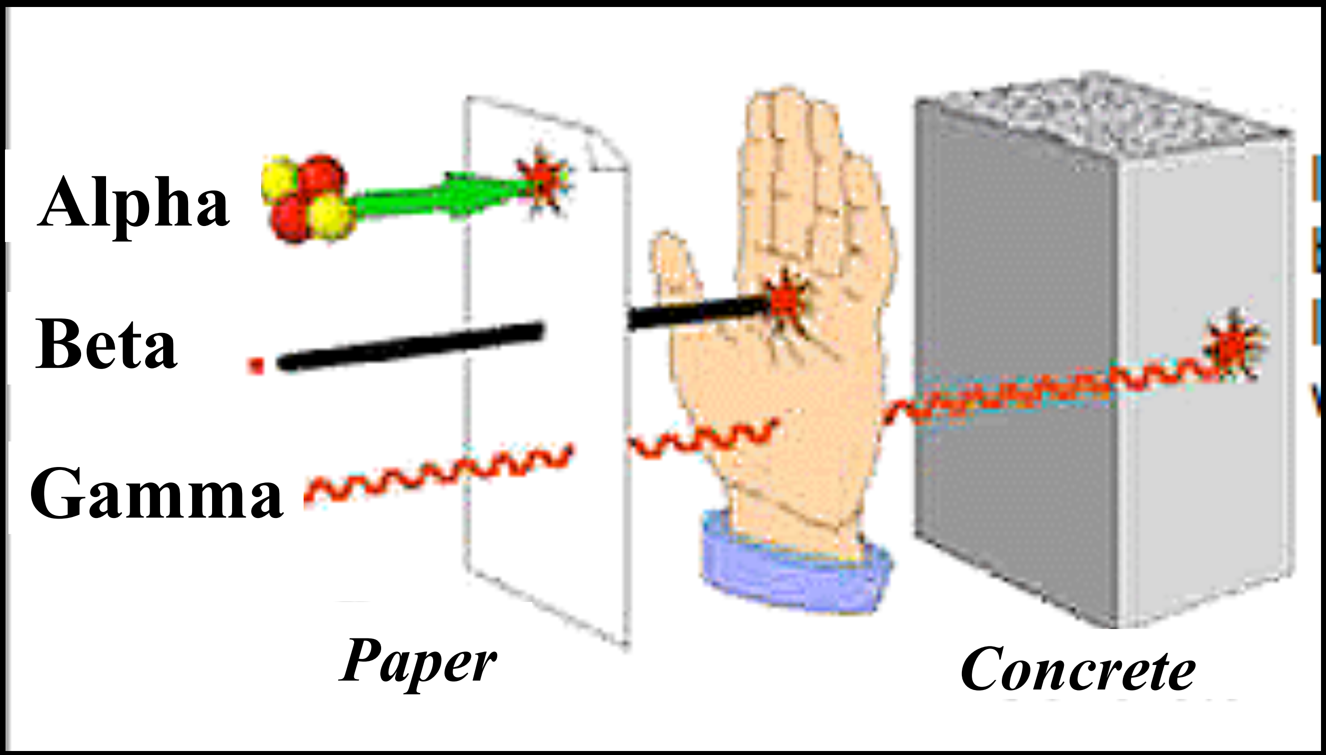
A gamma ray is like an x-ray, but more powerful.
highly penetrating ~ easily detected

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

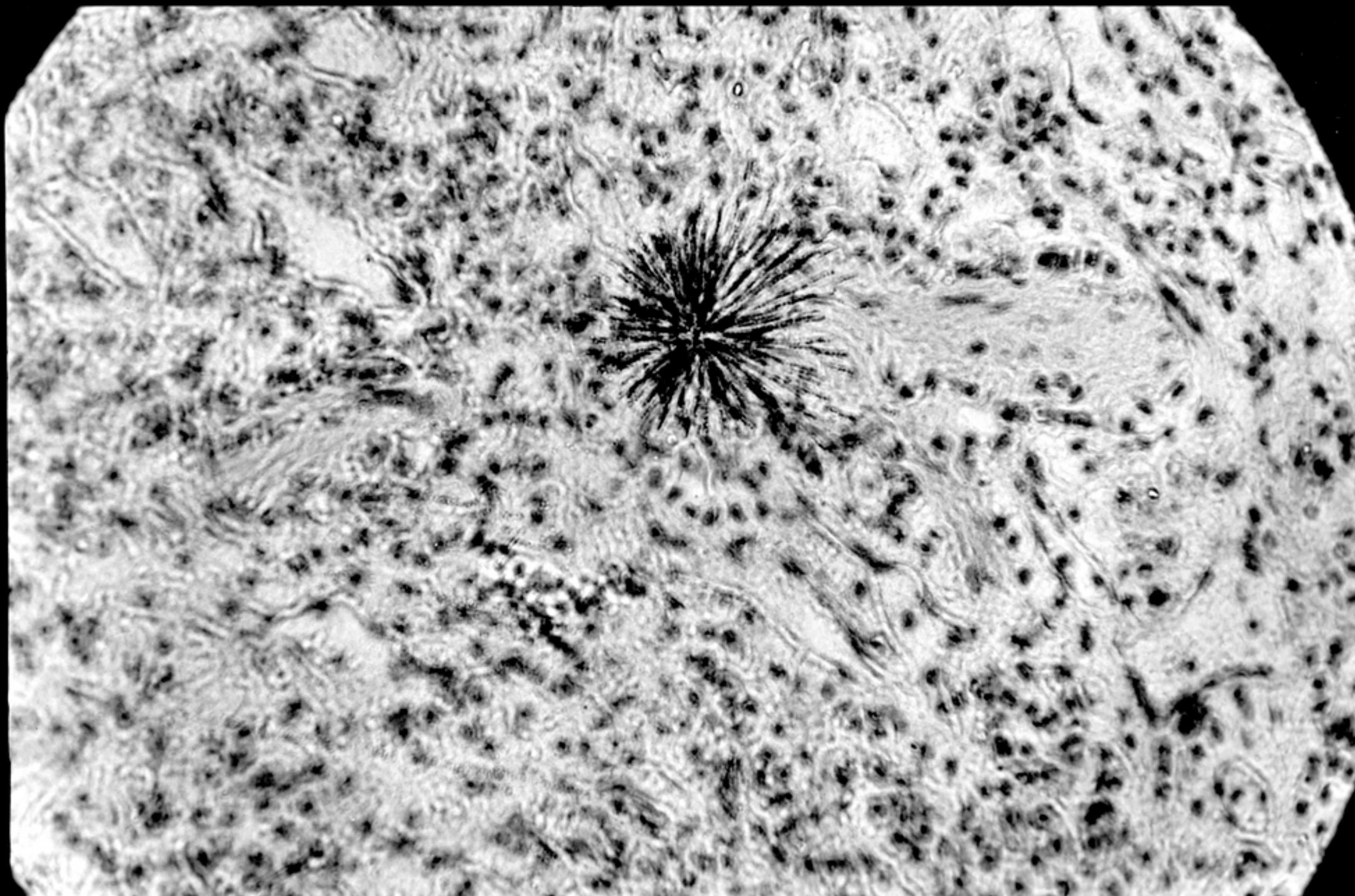


Photo: Robert Del Tredici

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

1977 – Federal Report: "Managing Canada's Nuclear Waste"
perhaps burial in a "deep geologic repository" (DGR)

1978 – Porter Commission Report : "A Race Against Time"
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

UK: Sir Brian Flowers, Nuclear Physicist

"... 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

USA: Report to US Congress

"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."

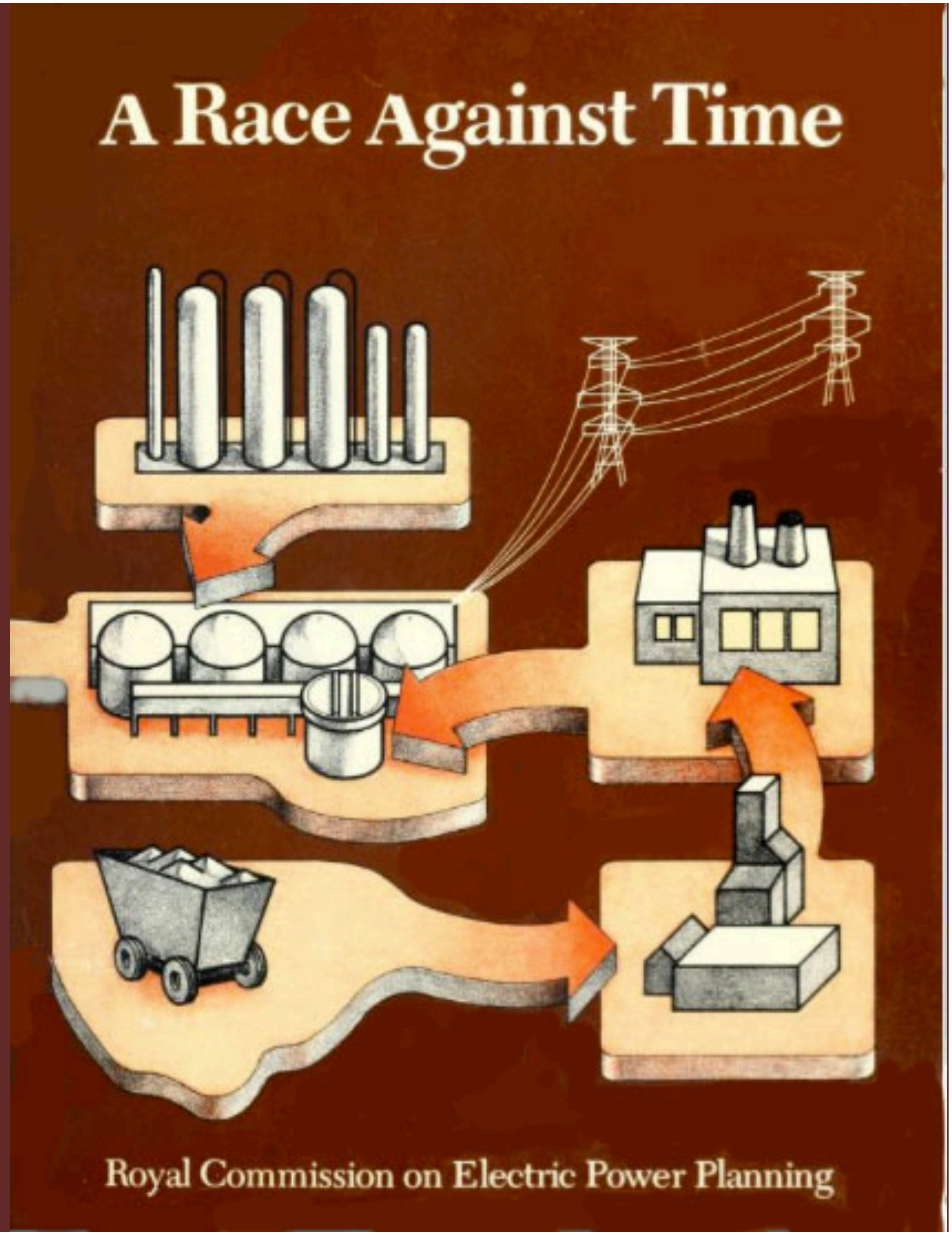
Nuclear Energy's Dilemma:
Disposing of Hazardous Radioactive Waste Safely
Washington DC September 9 1977

Ontario: Porter Commission

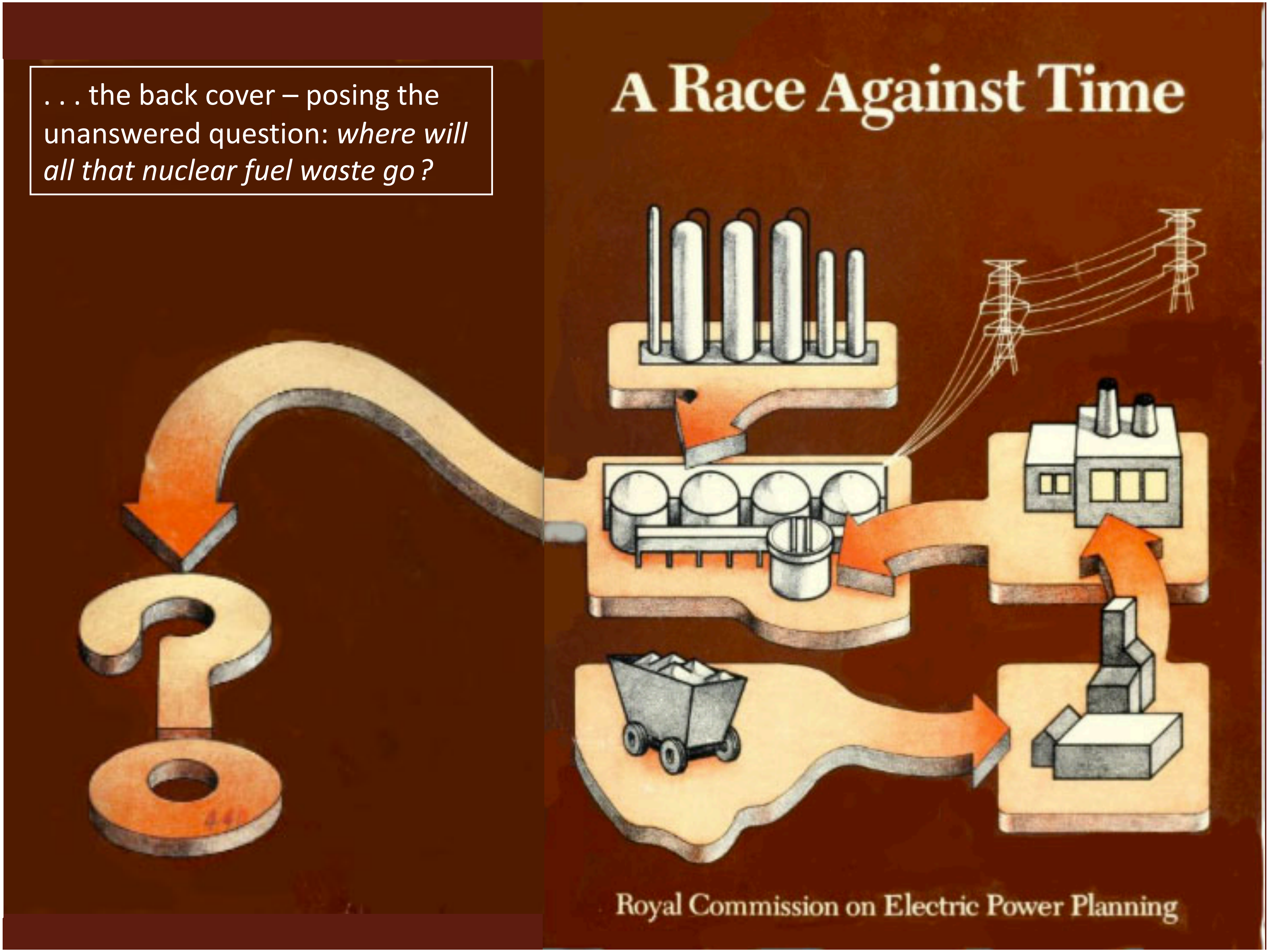
"Continuous monitoring of waste disposal research should be undertaken by an **independent** panel of experts. If adequate progress is not being made, say, by 1985, then nuclear power should be reassessed and a **moratorium on additional nuclear stations** should be considered."

A Race Against Time, Report of the
Ontario Royal Commission on Electric Power Planning
(The Porter Commission) September 1978

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

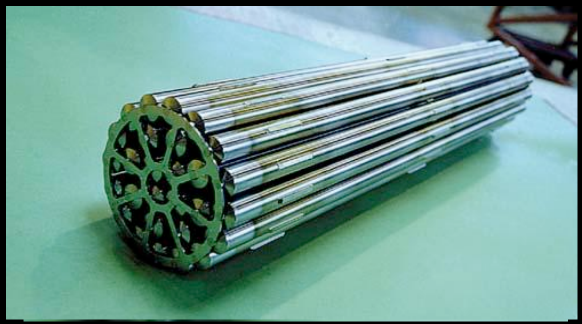
or

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.

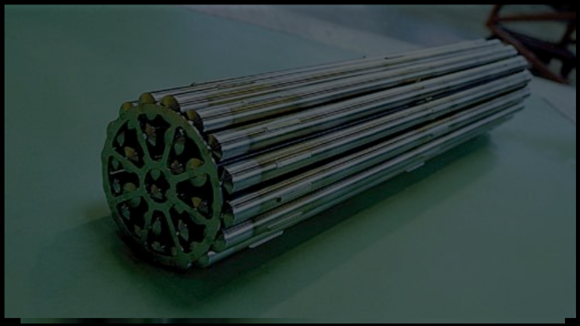
Each CANDU fuel bundle weighs about 20 kilograms,
and is about the size of a fireplace log



CANDU Fuel Bundle

nuclear fuel waste

Irradiated CANDU fuel is intensely radioactive, and so hot that it has to be cooled by circulating water for 10 years



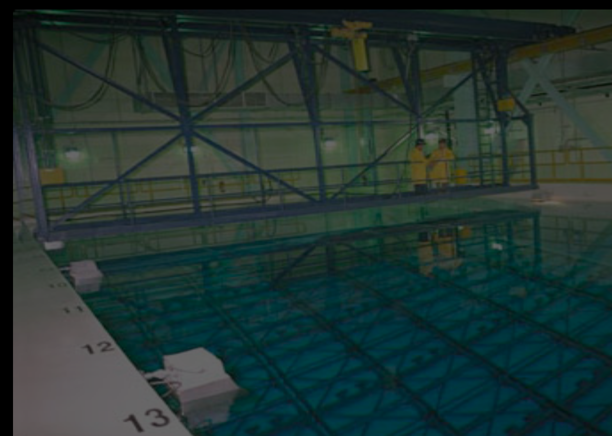
CANDU Fuel Bundle

Wet Storage (10 yrs)

nuclear fuel waste

After 10 years the irradiated fuel can be robotically transferred to air-cooled "dry storage" containers

CANDU Fuel Bundle

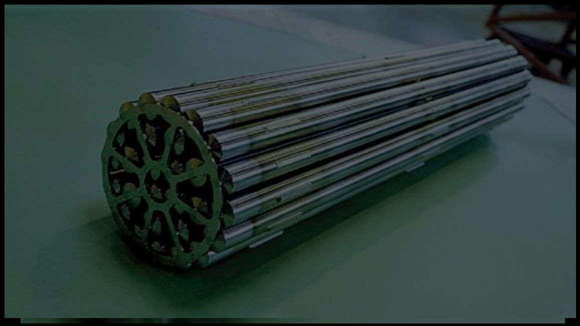


Wet Storage (10 yrs)

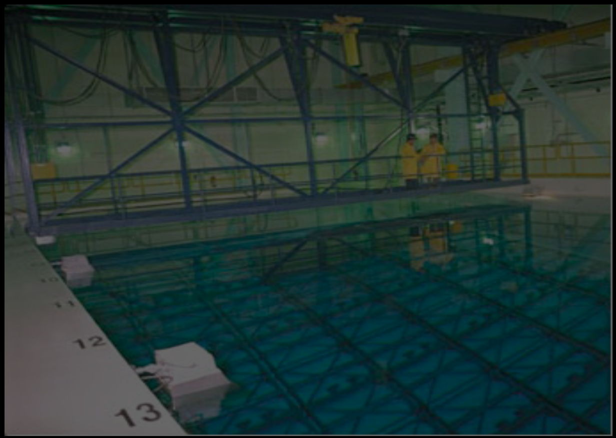
Dry Storage (decades)

nuclear fuel waste

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



CANDU Fuel Bundle



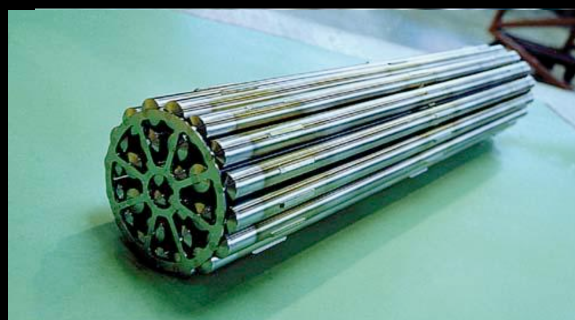
Wet Storage (10 yrs)

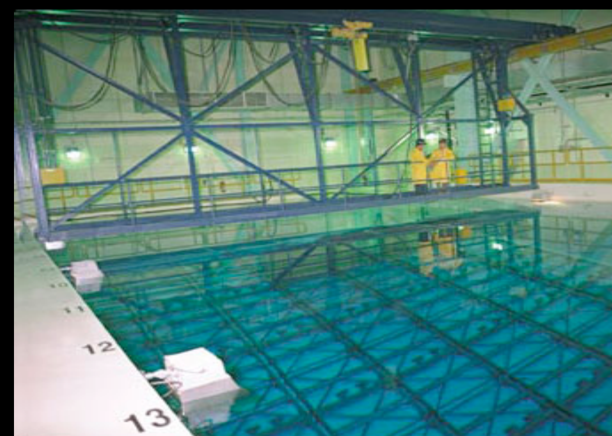
Dry Storage (decades)

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

1998 – Report of the Seaborn Panel: Independent Waste Agency Needed

"*DGR Concept is not ready to be adopted as Canada's approach;*
waste agency is needed that is independent of industry and gov't "

2002 – Government passes Nuclear Fuel Waste Act and creates NWMO

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

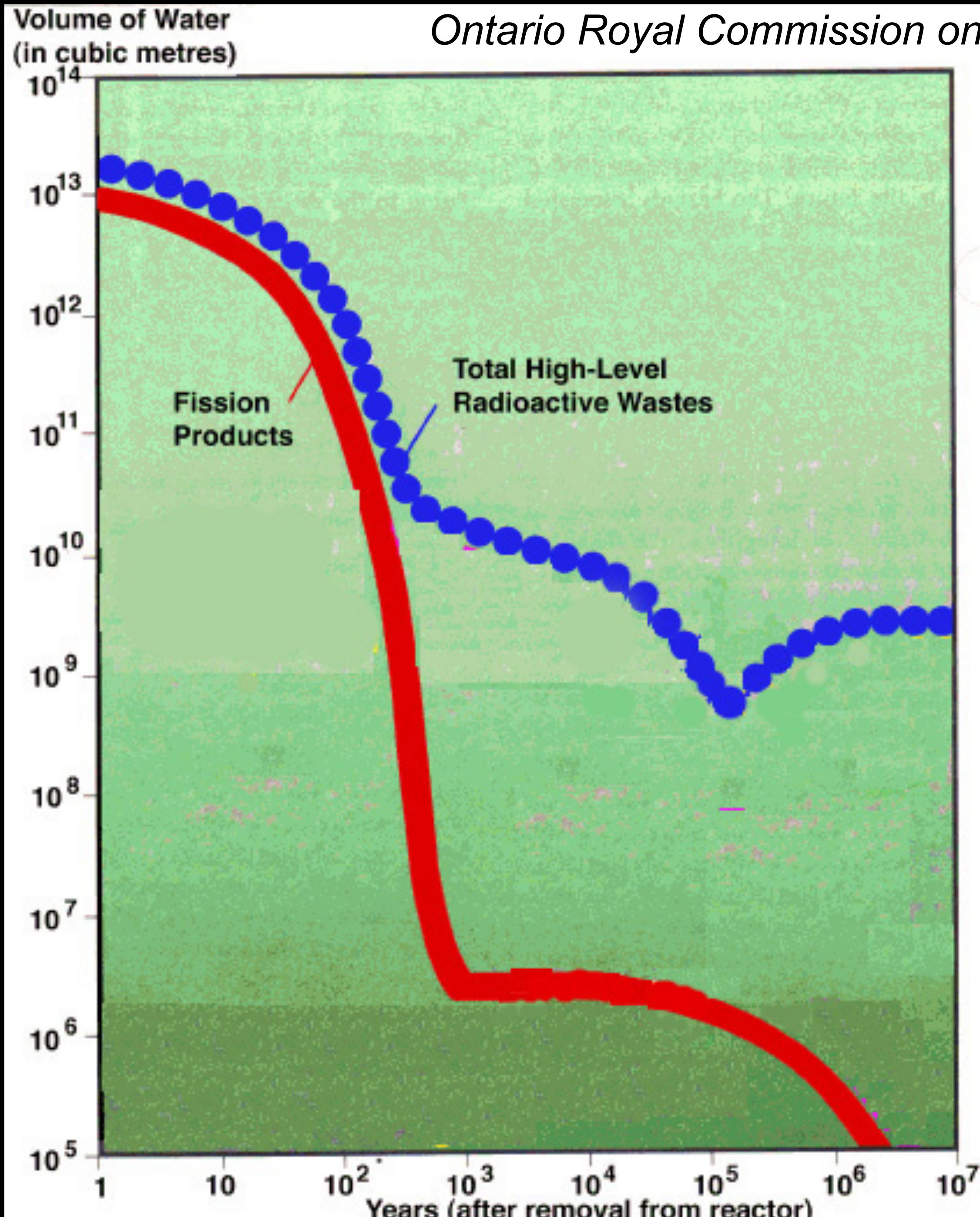
How toxic is nuclear fuel waste?

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?



Ontario Royal Commission on Electric Power Planning (1978)

This graph shows the radiotoxicity of one year's worth of spent CANDU fuel from one reactor over a period of ten million years

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

Standard Chemical Symbol	Common Name of element	Atomic Mass Number	**F.P.** Fission Product	**F.I.A.P.** Activation Product	**Z.A.P.** Activation Product	**Actinide** (includes progeny)
H (T)	Hydrogen (Tritium)	3	¥ ¥ ¥	¥	¥	
Be	Beryllium	10		¥	¥	
C	Carbon	14		¥ ¥ ¥	¥ ¥ ¥	
Si	Silicon	32		¥	¥	
P	Phosphorus	32		¥	¥	
S	Sulphur	35		¥		
Cl	Chlorine	36		¥		
Ar	Argon	39		¥	¥	
Ar	Argon	42		¥	¥	
K	Potassium	40		¥		
K	Potassium	42			¥	
Ca	Calcium	41		¥		
Ca	Calcium	45			¥	
Sc	Scandium	46		¥		
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	**F.P.** Fission Product	**F.I.A.P.** Activation Product	**Z.A.P.** Activation Product	**Actinide** (includes progeny)
V	Vanadium	50			¥	
Mn	Manganese	54		¥	¥ ¥ ¥	
Fe	Iron	55		¥ ¥ ¥	¥ ¥ ¥	
Fe	Iron	59			¥	
Co	Cobalt	58		¥	¥	
Co	Cobalt	60		¥ ¥ ¥	¥ ¥ ¥	
Ni	Nickel	59		¥	¥ ¥ ¥	
Ni	Nickel	63		¥ ¥ ¥	¥ ¥ ¥	
Zn	Zinc	65		¥	¥	
Se	Selenium	79	¥ ¥ ¥			
Kr	Krypton	81	¥			
Kr	Krypton	85	¥ ¥ ¥			
Rb	Rubidium	87	¥			
Sr	Strontium	89	¥		¥	
Sr	Strontium	90	¥ ¥ ¥	¥	¥	
Y	Yttrium	90	¥ ¥ ¥	¥	¥	

F.I.A.P. = fuel impurity activation product Z.A.P. = zirconium cladding activation product [source: AECL]

Y	Yttrium	91	¥		¥	
Zr	Zirconium	93	¥¥¥	¥	¥¥¥	
Zr	Zirconium	95	¥	¥	¥	
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Nb	Niobium	92			¥	
Nb	Niobium	93m	¥¥¥	¥	¥¥¥	
Nb	Niobium	94	¥	¥	¥¥¥	
Nb	Niobium	95	¥	¥	¥	
Nb	Niobium	95m	¥		¥	
Mo	Molybdenum	93		¥	¥	
Tc	Technetium	99	¥¥¥	¥	¥	
Ru	Ruthenium	103	¥			
Ru	Ruthenium	106	¥¥¥			
Rh	Rhodium	103m	¥			
Rh	Rhodium	106	¥¥¥			
Pd	Palladium	107	¥¥¥			
Ag	Silver	108	¥	¥	¥	
Ag	Silver	108m	¥	¥¥¥	¥	
Ag	Silver	109m	¥	¥	¥	
Ag	Silver	110	¥	¥	¥	
Ag	Silver	110m	¥	¥	¥	
Cd	Cadmium	109	¥	¥	¥	
Cd	Cadmium	113	¥		¥	
Cd	Cadmium	113m	¥¥¥		¥	
Cd	Cadmium	115	¥			
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
In	Indium	113m			¥	
In	Indium	114	¥	¥	¥	
In	Indium	114m			¥	
In	Indium	115			¥	
Sn	Tin	113			¥	
Sn	Tin	117m	¥	¥	¥	
Sn	Tin	119m	¥¥¥		¥¥¥	
Sn	Tin	121m	¥		¥¥¥	
Sn	Tin	123	¥		¥	

Sn	Tin	125	¥¥¥		¥	
Sn	Tin	126				
Sb	Antimony	124	¥		¥	
Sb	Antimony	125	¥¥¥		¥¥¥	
Sb	Antimony	126	¥		¥	
Sb	Antimony	126m	¥¥¥			
Te	Tellurium	123	¥		¥	
Te	Tellurium	123m	¥		¥	
Te	Tellurium	125m	¥¥¥		¥¥¥	
Te	Tellurium	127	¥		¥	
Te	Tellurium	127m	¥		¥	
I	Iodine	129	¥		¥	
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Cs	Cesium	134	¥			
Cs	Cesium	135	¥¥¥			
Cs	Cesium	137	¥¥¥			
Ba	Barium	137m	¥¥¥			
La	Lanthanum	138	¥			
Ce	Cerium	142	¥			
Ce	Cerium	144	¥¥¥			
Pr	Praseodymium	144	¥¥¥			
Pr	Praseodymium	144m	¥¥¥			
Nd	Neodymium	144	¥			
Pm	Promethium	147	¥¥¥			
Sm	Samarium	147	¥			
Sm	Samarium	148	¥	¥		
Sm	Samarium	149	¥			
Sm	Samarium	151	¥¥¥			
Eu	Europium	152	¥¥¥	¥		
Eu	Europium	154	¥¥¥	¥		
Eu	Europium	155	¥¥¥	¥		
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Gd	Gadolinium	152	¥	¥		
Gd	Gadolinium	153	¥	¥		
Tb	Terbium	157		¥		

Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Tb	Terbium	160		¥		
Dy	Dysprosium	159		¥		
Ho	Holmium	166m	¥	¥		
Tm	Thulium	170		¥		
Tm	Thulium	171		¥		
Lu	Lutetium	176			¥	
Lu	Lutetium	176			¥	
Lu	Lutetium	176			¥	
Hf	Hafnium	175			¥	
Hf	Hafnium	181			¥	
Hf	Hafnium	182			¥	
Ta	Tantalum	180			¥	
Ta	Tantalum	182			¥	
W	Tungsten	181			¥	
W	Tungsten	185			¥	
W	Tungsten	188			¥	
Re	Rhenium	187			¥	
Re	Rhenium	188			¥	
Os	Osmium	194			¥	
Ir	Iridium	192			¥	
Ir	Iridium	192m			¥	
Ir	Iridium	194			¥	
Ir	Iridium	194m			¥	
Pt	Platinum	193			¥	
Tl	Thallium	206			¥	
Tl	Thallium	207				¥
Tl	Thallium	208				¥
Tl	Thallium	209				¥
Pb	Lead	204			¥	
Pb	Lead	205			¥	
Pb	Lead	209				¥
Pb	Lead	210				¥
Pb	Lead	211				¥
Pb	Lead	212				¥
Pb	Lead	214				¥

Chemical Symbol	element	Number	Fission Product	Activation Product	Activation Product	(includes progeny)
Bi	Bismuth	208			¥	
Bi	Bismuth	210			¥	¥
Bi	Bismuth	210m				¥
Bi	Bismuth	211				¥
Bi	Bismuth	212				¥
Bi	Bismuth	213				¥
Bi	Bismuth	214				
Po	Polonium	210			¥	¥
Po	Polonium	211				¥
Po	Polonium	212				¥
Po	Polonium	213				¥
Po	Polonium	214				¥
Po	Polonium	215				¥
Po	Polonium	216				¥
Po	Polonium	218				¥
At	Astatine	217				¥
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Rn	Radon	219				¥
Rn	Radon	220				¥
Rn	Radon	222				¥
Fr	Francium	221				¥
Fr	Francium	221				¥
Ra	Radium	223				¥
Ra	Radium	224				¥
Ra	Radium	225				¥
Ra	Radium	226				¥
Ra	Radium	228				¥
Ac	Actinium	225				¥
Ac	Actinium	227				¥
Ac	Actinium	228				¥
Th	Thorium	227				¥
Th	Thorium	228				¥
Th	Thorium	229				¥
Th	Thorium	230				¥
Th	Thorium	231				¥
Th	Thorium	232				¥

Th	Thorium	234				¥ ¥ ¥
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Pa	Protactinium	231				¥
Pa	Protactinium	233				¥ ¥ ¥
Pa	Protactinium	234				¥
Pa	Protactinium	234m				¥ ¥ ¥
U	Uranium	232				¥
U	Uranium	233				¥
U	Uranium	234				¥ ¥ ¥
U	Uranium	235				¥
U	Uranium	236				¥ ¥ ¥
U	Uranium	237				¥ ¥ ¥
U	Uranium	238				¥ ¥ ¥
U	Uranium	240				¥
Np	Neptunium	237				¥ ¥ ¥
Np	Neptunium	238				¥
Np	Neptunium	239				¥ ¥ ¥
Np	Neptunium	240				¥
Np	Neptunium	240m				¥
Pu	Plutonium	236				¥
Pu	Plutonium	238				¥ ¥ ¥
Pu	Plutonium	239				¥ ¥ ¥
Pu	Plutonium	240				¥ ¥ ¥
Pu	Plutonium	241				¥ ¥ ¥
Pu	Plutonium	242				¥ ¥ ¥
Pu	Plutonium	243				¥
Pu	Plutonium	244				¥
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Am	Americium	241				¥ ¥ ¥
Am	Americium	242				¥ ¥ ¥
Am	Americium	242m				¥ ¥ ¥
Am	Americium	243				¥ ¥ ¥
Am	Americium	245				¥
Cm	Curium	242				¥ ¥ ¥
Cm	Curium	243				¥ ¥ ¥

Cm Cm Cm Cm Cm Cm	Curium Curium Curium Curium Curium Curium	244 245 246 247 248 250				¥¥¥ ¥ ¥ ¥ ¥ ¥
Bk Bk	Berkelium Berkelium	249 250				¥ ¥
Cf Cf Cf Cf	Californium Californium Californium Californium	249 250 251 252				¥ ¥ ¥ ¥
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	**F.P.** Fission Product	**F.I.A.P.** Activation Product	**Z.A.P.** Activation Product	**Actinide** (includes progeny)

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

This list of 211 radionuclides contained in irradiated nuclear fuel is by no means complete. (AECL)

CAN Geological Storage Solve the Waste Problem?

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.

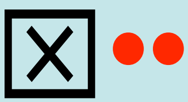
Will this solve the nuclear waste problem?

The following series of graphics explores the possibility in very simple diagrams.

IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

ONE
REACTOR

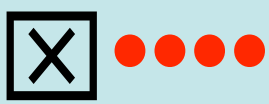


AFTER 2 YEARS

The “X” represents a single nuclear reactor.
Each dot represents one year’s production of irradiated nuclear fuel

IRRADIATED NUCLEAR FUEL ACCUMULATION

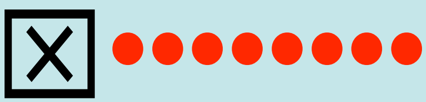
WITHOUT GEOLOGIC DISPOSAL



AFTER 4 YEARS

IRRADIATED NUCLEAR FUEL ACCUMULATION

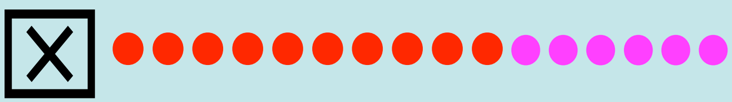
WITHOUT GEOLOGIC DISPOSAL



AFTER 8 YEARS

IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

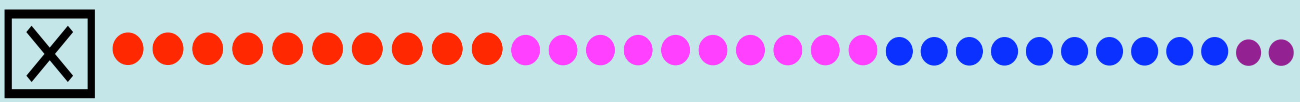


AFTER 16 YEARS

As the years go by, more and more nuclear waste accumulates beside the reactor.

IRRADIATED NUCLEAR FUEL ACCUMULATION

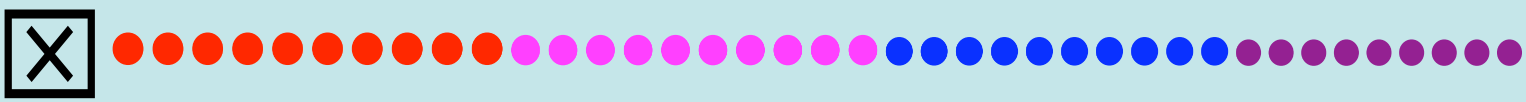
WITHOUT GEOLOGIC DISPOSAL



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"]*

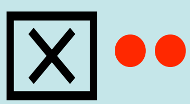
Can we get rid of all the nuclear waste beside the reactors?

Common sense says "no" – not if we keep on producing it!

HERE’S HOW THE PICTURE LOOKS. . .

WITH GEOLOGIC DISPOSAL?

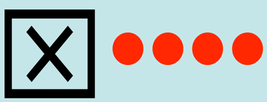
AFTER 2 YEARS



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

WITH GEOLOGIC DISPOSAL

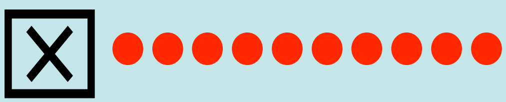
AFTER 4 YEARS



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

WITH GEOLOGIC DISPOSAL

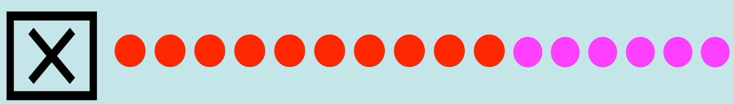
AFTER 10 YEARS



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.

WITH GEOLOGIC DISPOSAL

AFTER 16 YEARS



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.

WITH GEOLOGIC DISPOSAL

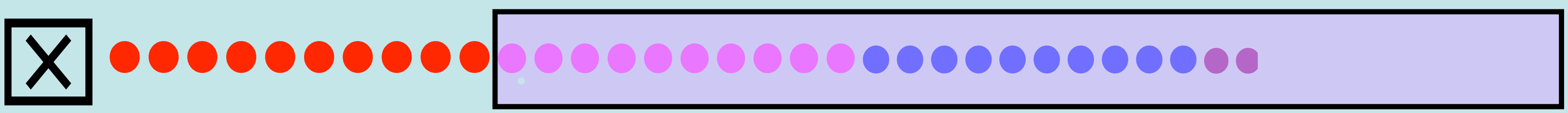
THIS PORTION MAY BE TRANSPORTED -- HOORAY !

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

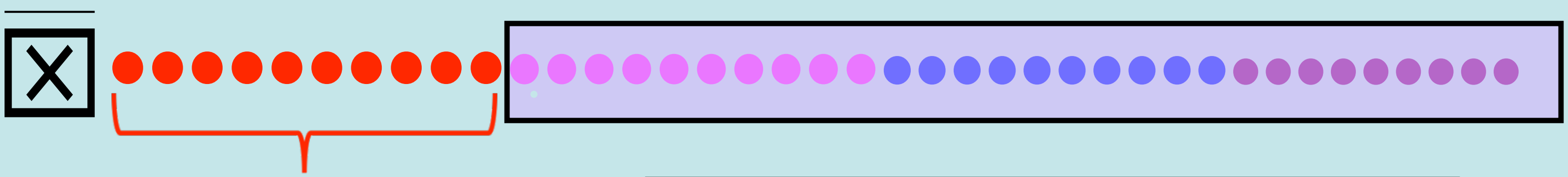
AFTER 32 YEARS



ONLY THIS PORTION MAY BE TRANSPORTED!

WITH GEOLOGIC DISPOSAL

AFTER 40 YEARS



THIS IS NOT REMOVED!

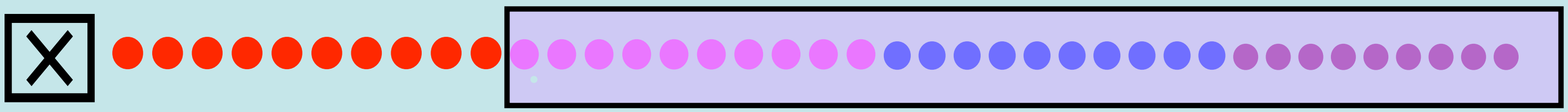
ONLY THIS MAY BE TRANSPORTED!

*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. . . .

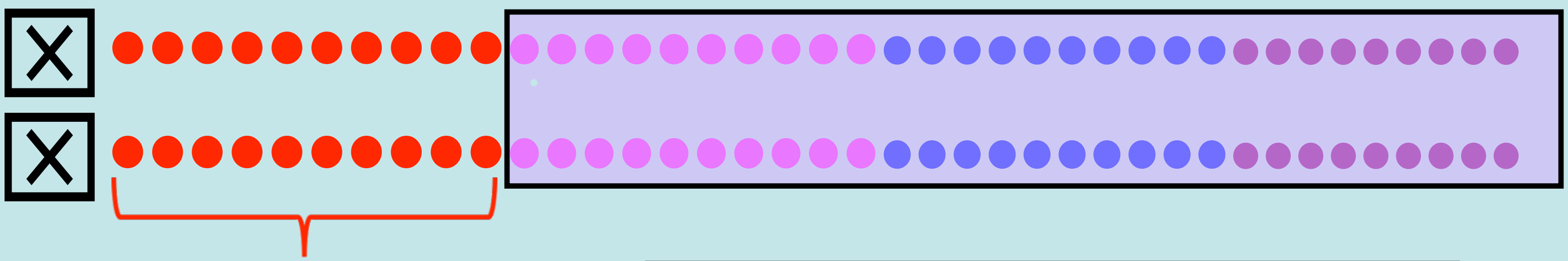


Once the nuclear waste problem is "solved"
the nuclear industry says it is
TIME FOR A "NUCLEAR RENAISSANCE" –

MORE REACTORS, PLEASE !

But building more reactors ***just adds to the problem of UNBURIED waste,***

EVEN WITH GEOLOGIC DISPOSAL

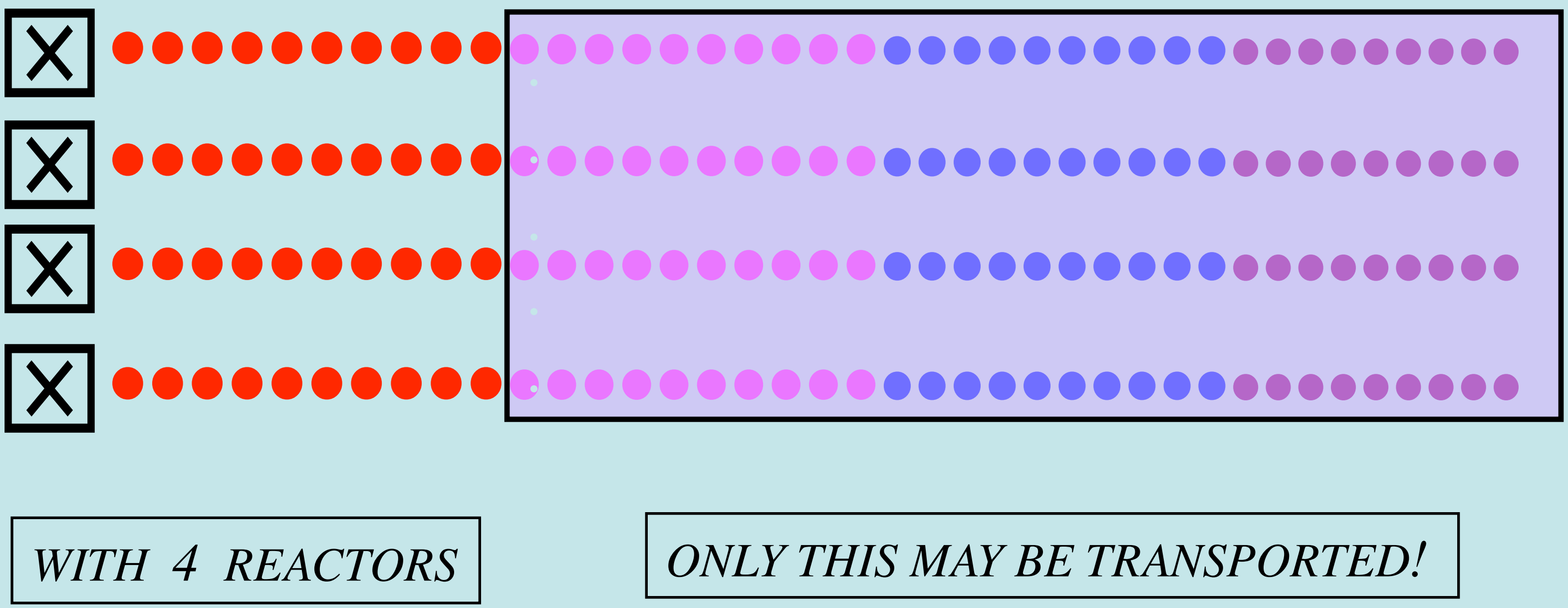


THIS IS NOT REMOVED!

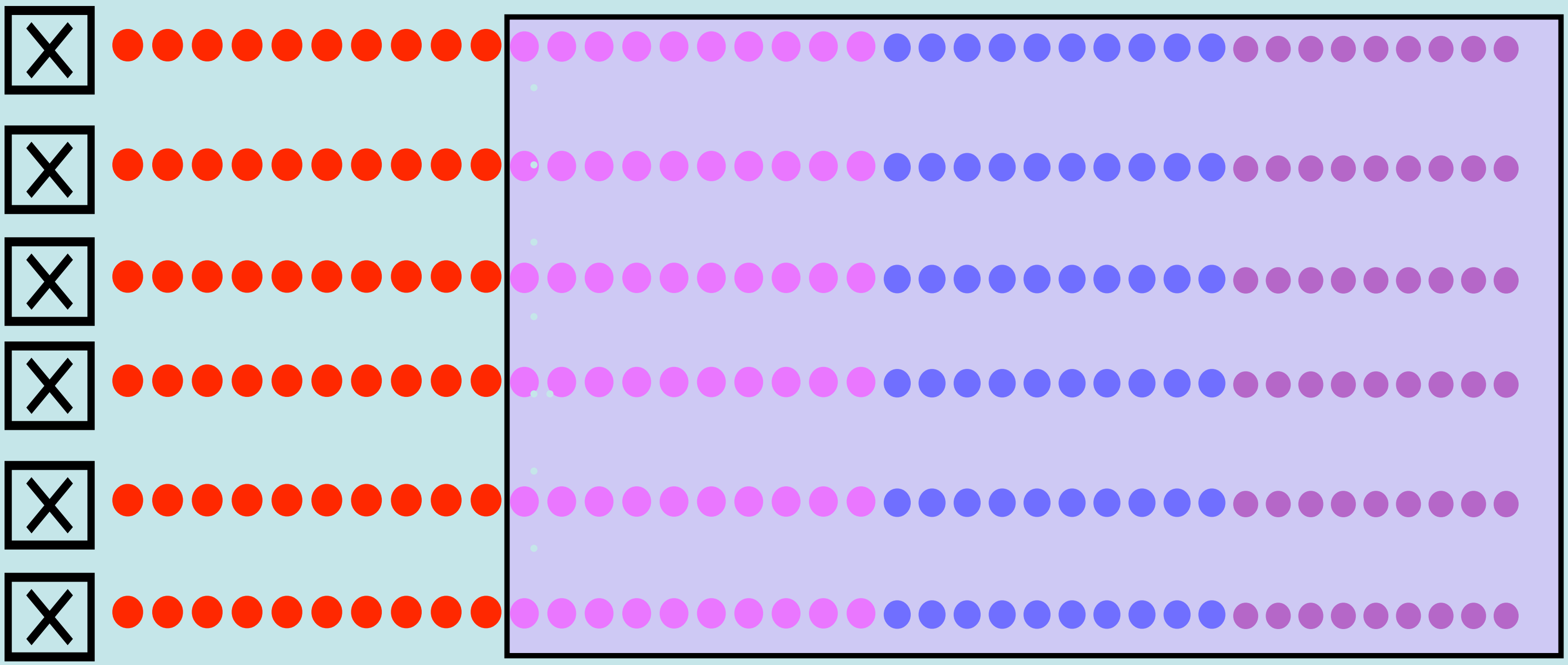
ONLY THIS MAY BE TRANSPORTED!

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

WITH GEOLOGIC DISPOSAL



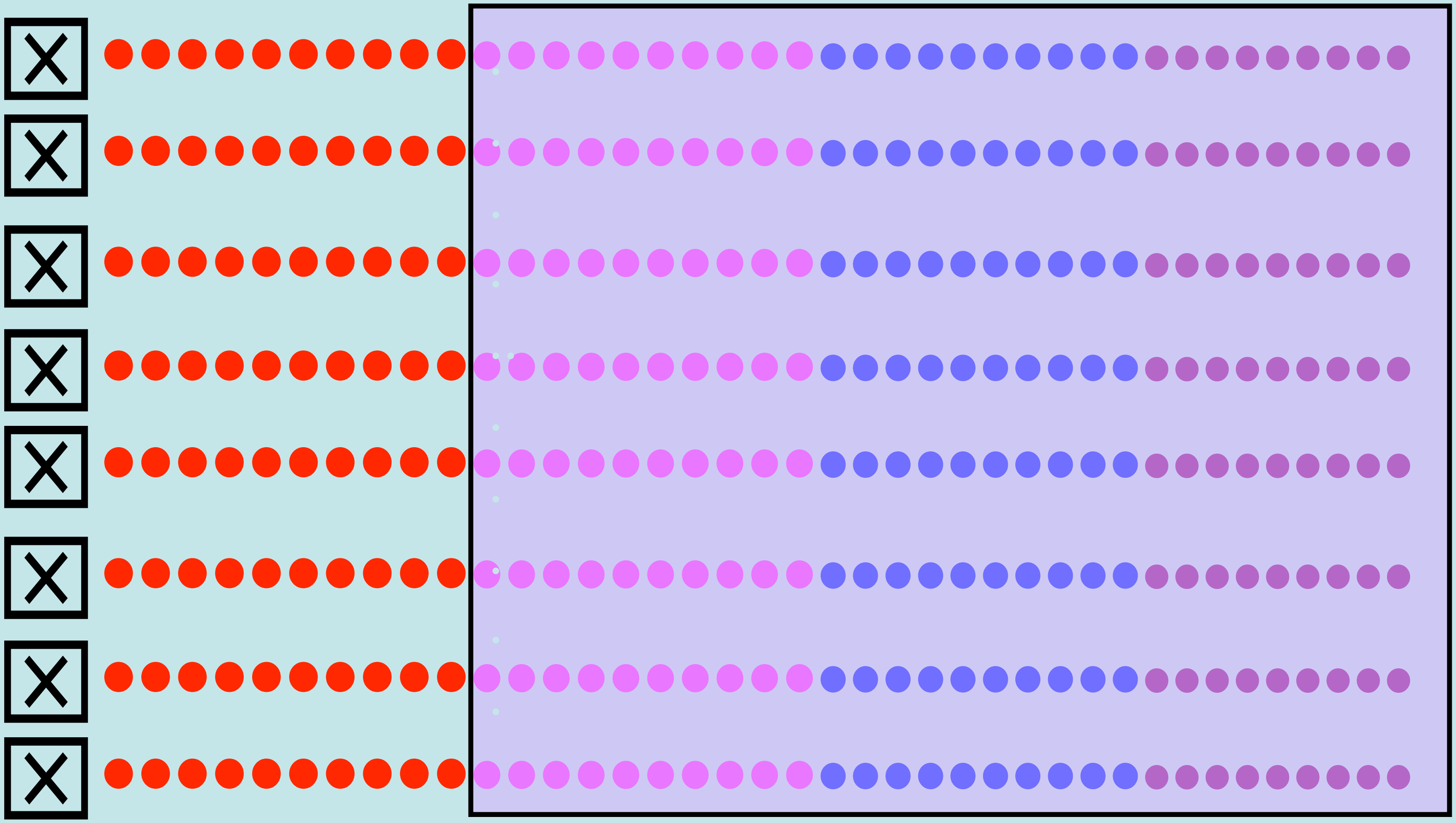
WITH GEOLOGIC DISPOSAL



WITH 6 REACTORS

ONLY THIS MAY BE TRANSPORTED!

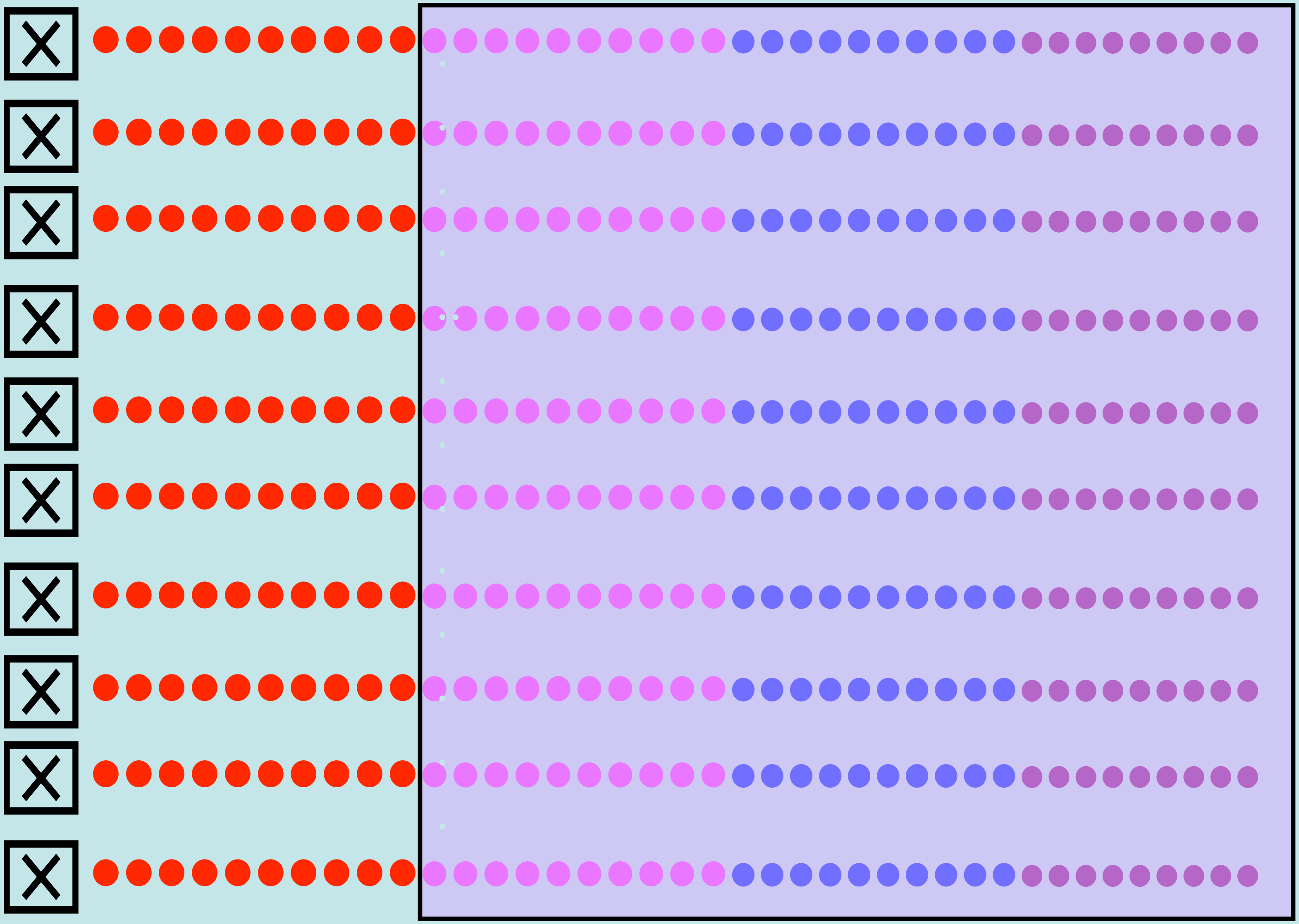
WITH GEOLOGIC DISPOSAL



WITH 8 REACTORS

ONLY THIS MAY BE TRANSPORTED!

SO EVEN WITH GEOLOGIC DISPOSAL . . .



. . . THERE IS AN EVER- GROWING INVENTORY OF UNBURIED WASTE!!

HOW is this a solution?

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

Porter Commission nixes reprocessing

"**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."

A Race Against Time, Report of the
Ontario Royal Commission on Electric Power Planning
("The Porter Commission") September 1978

Reprocessing Remains AECL's Goal

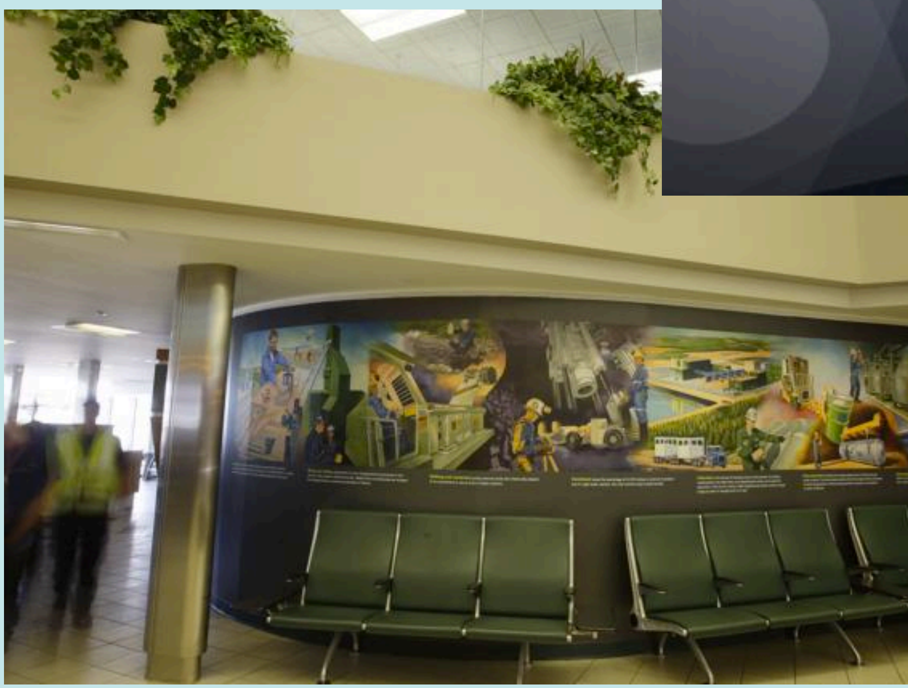
"What's even more exciting . . . is the prospect of **recycling used nuclear fuel** to extract some of the 99% remaining energy potential that it retains after leaving the reactor. . . . The potential for future societies to elect to pursue this route has been ***entrenched in the proposed program of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

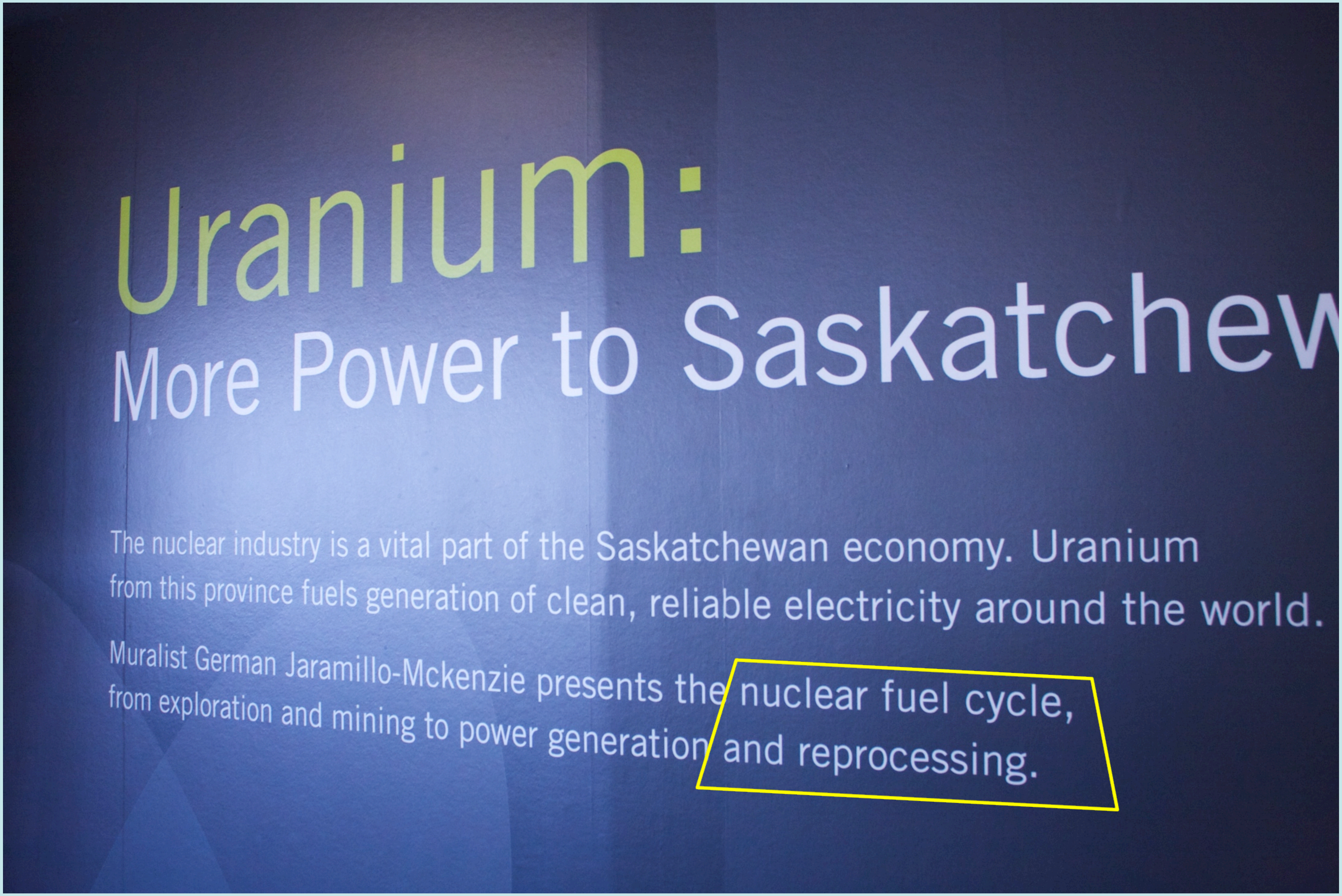
CAMECO is one of the world's
largest uranium mining companies.
It is based in Saskatoon, Saskatchewan.



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.

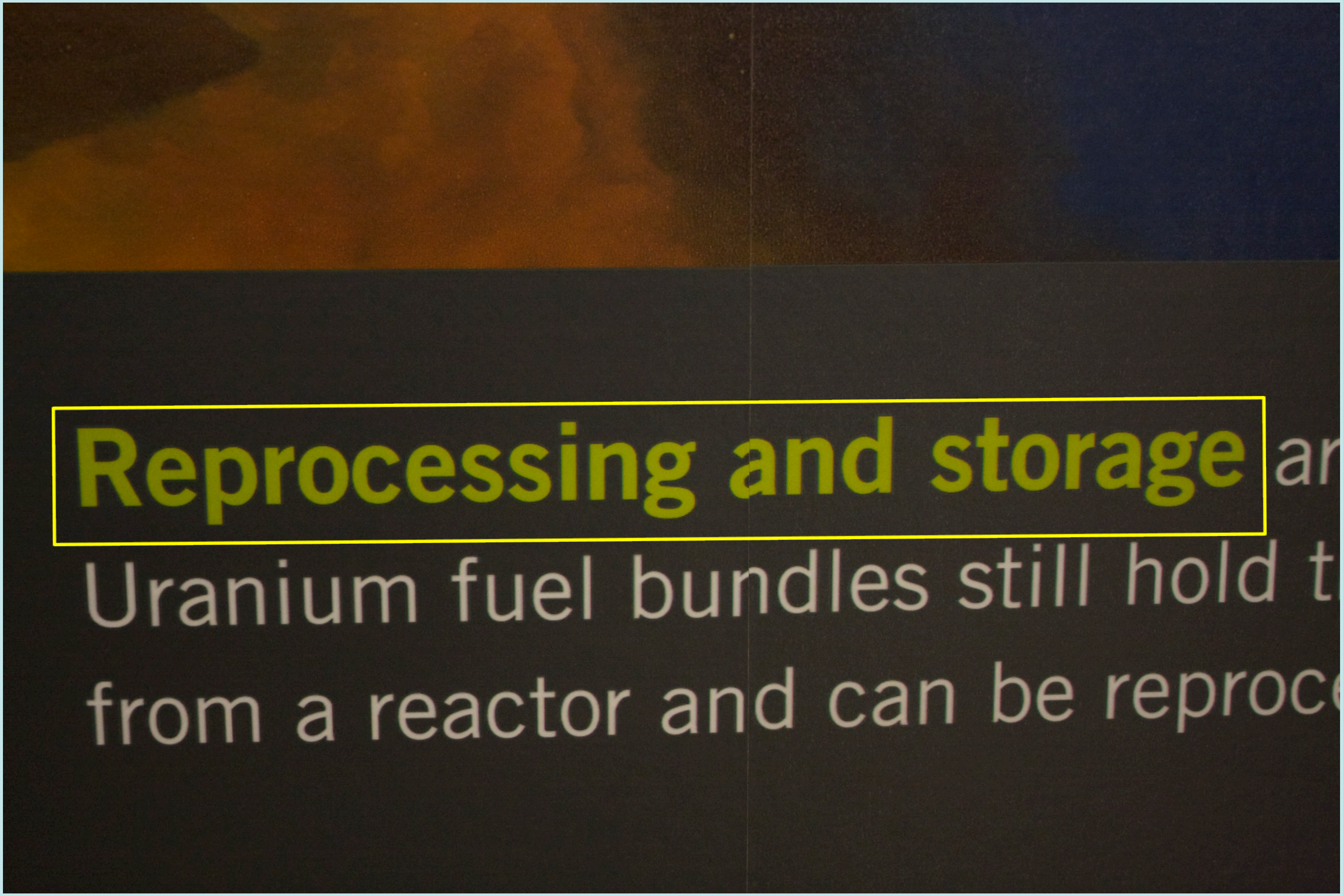


Cameco Mural, 2008

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 …



… for anyone who can read **the writing on the wall**.

TEXT OF LAST PANEL

> **"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)

But burial implies abandonment

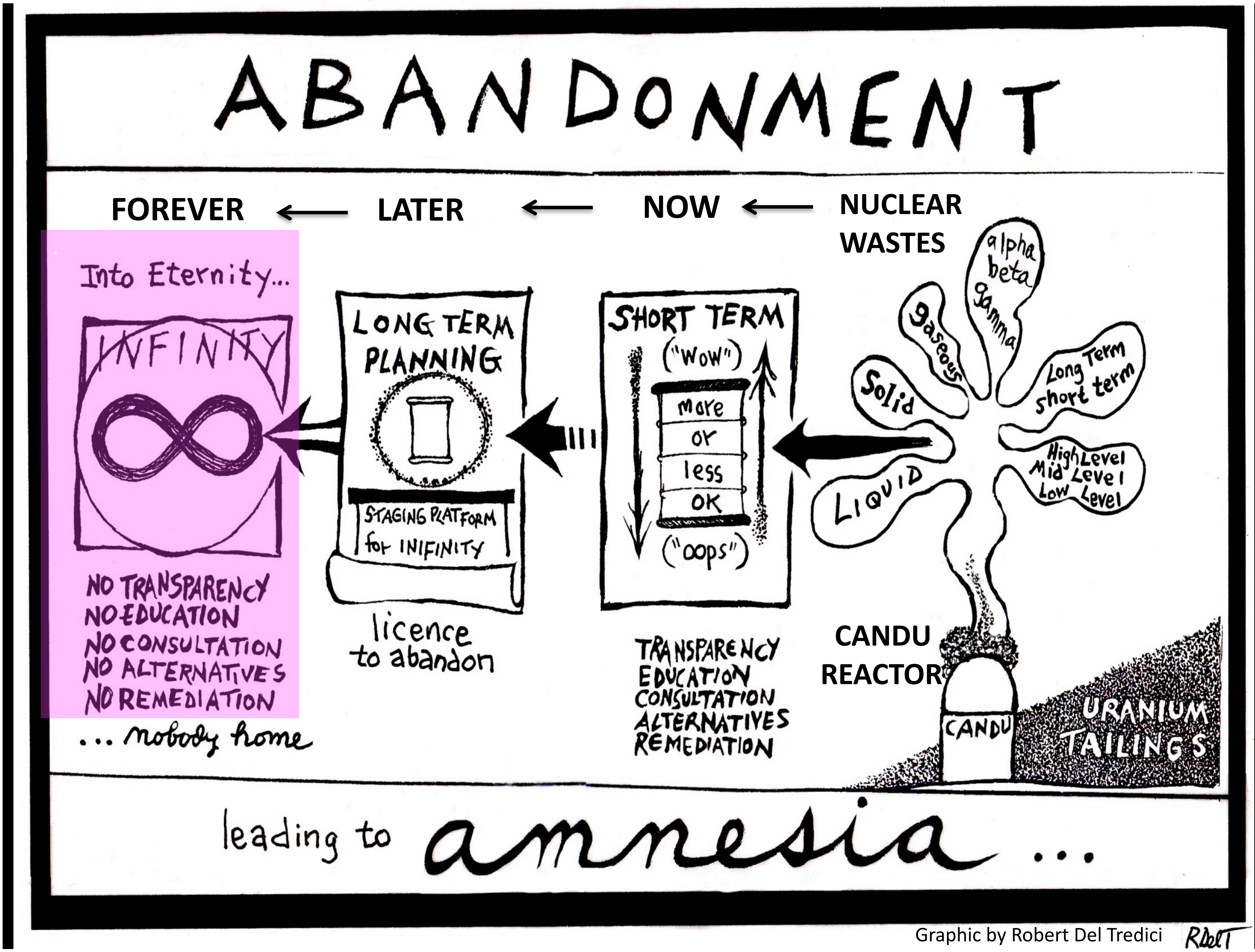
Ultimately, industry wants to abandon the nuclear waste.

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.



Graphic by Robert Del Tredici

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.

Rolling Stewardship

is a nuclear waste policy ***based on pragmatism***

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**.

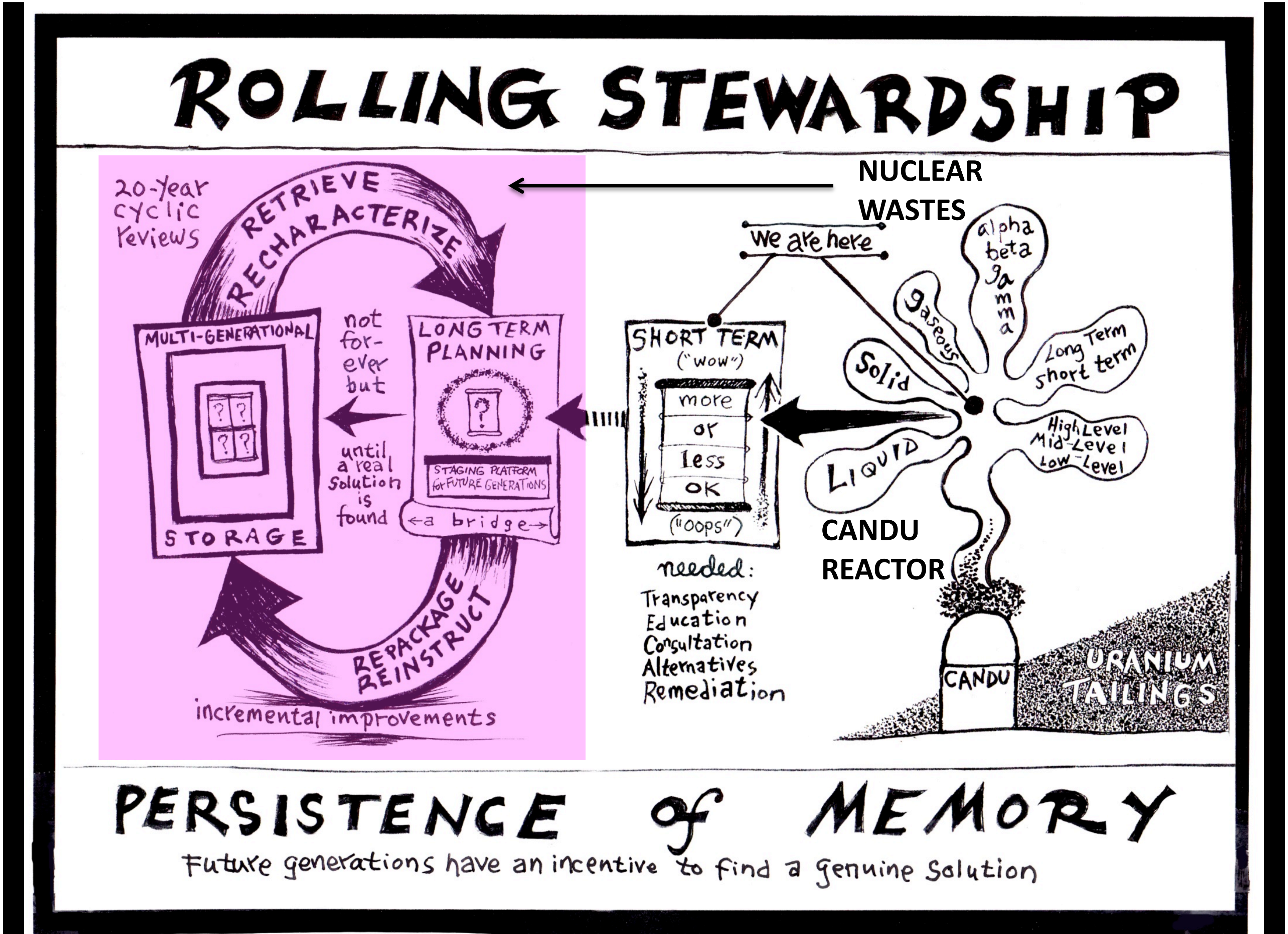
Wastes are packaged safely for long periods & **repackaged as needed**.

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

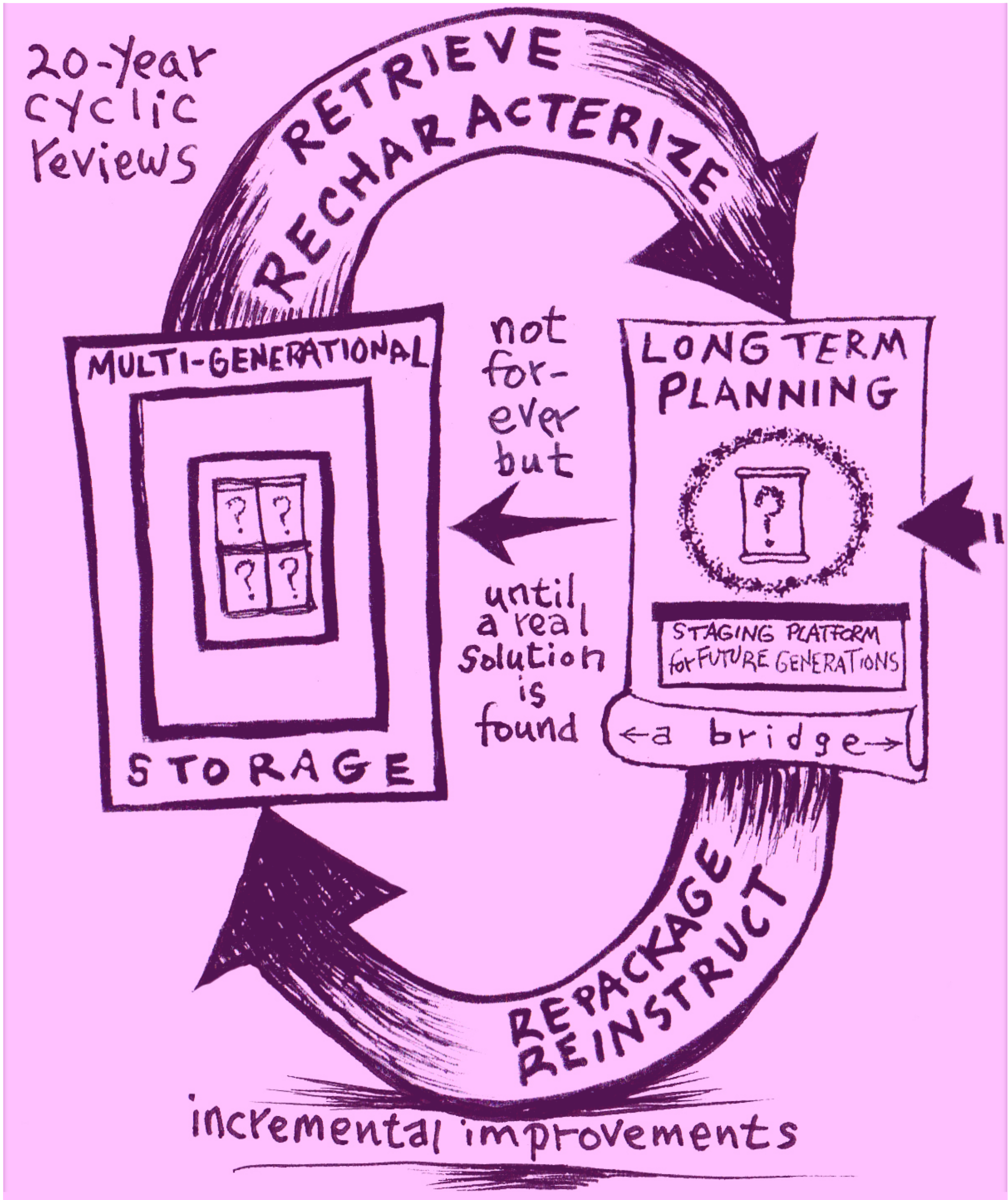
Rolling Stewardship is needed **until a “genuine solution” is found**.

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

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



Graphic by Robert Del Tredici



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 should be **independent** of the nuclear industry.

Graphic by Robert Del Tredici

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.*

Lesson Two

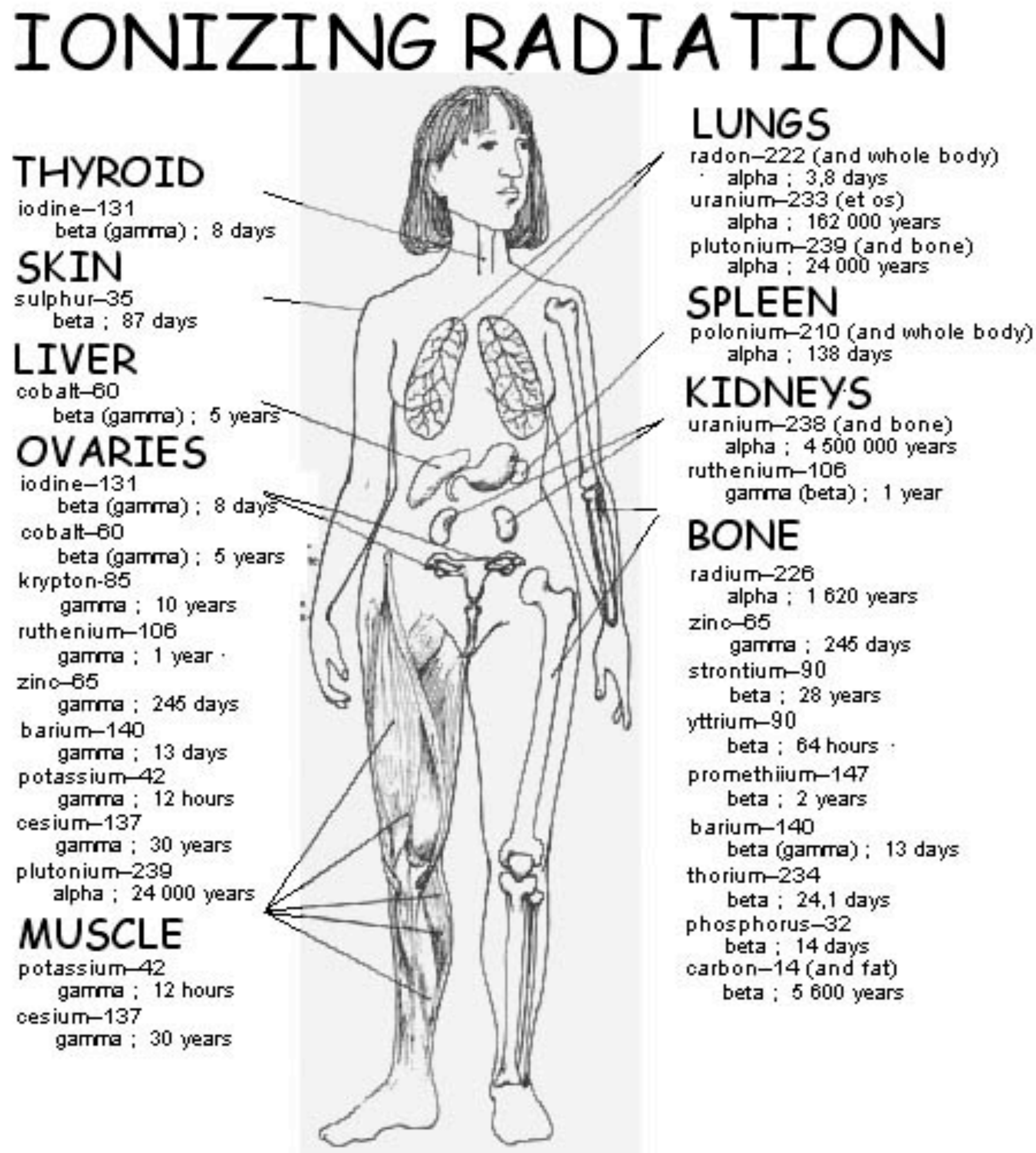
Radioactive elements have distinct pathways through the human body

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.

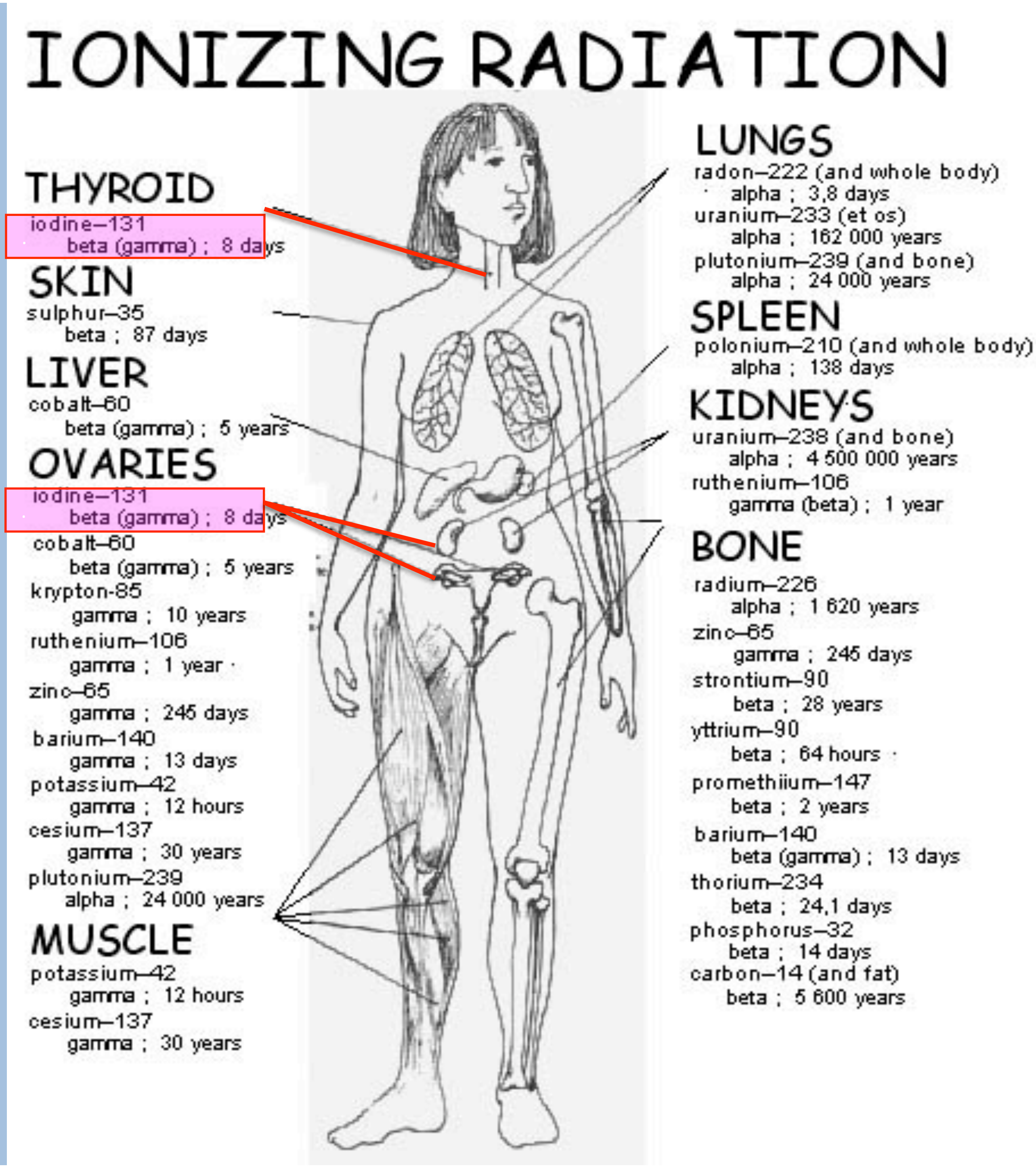
They all have their own unique pathways through the environment and through the human body.



Iodine-131 goes to the thyroid gland (in the throat) and damages it

thyroid cancer, mental retardation, and stunted growth can result

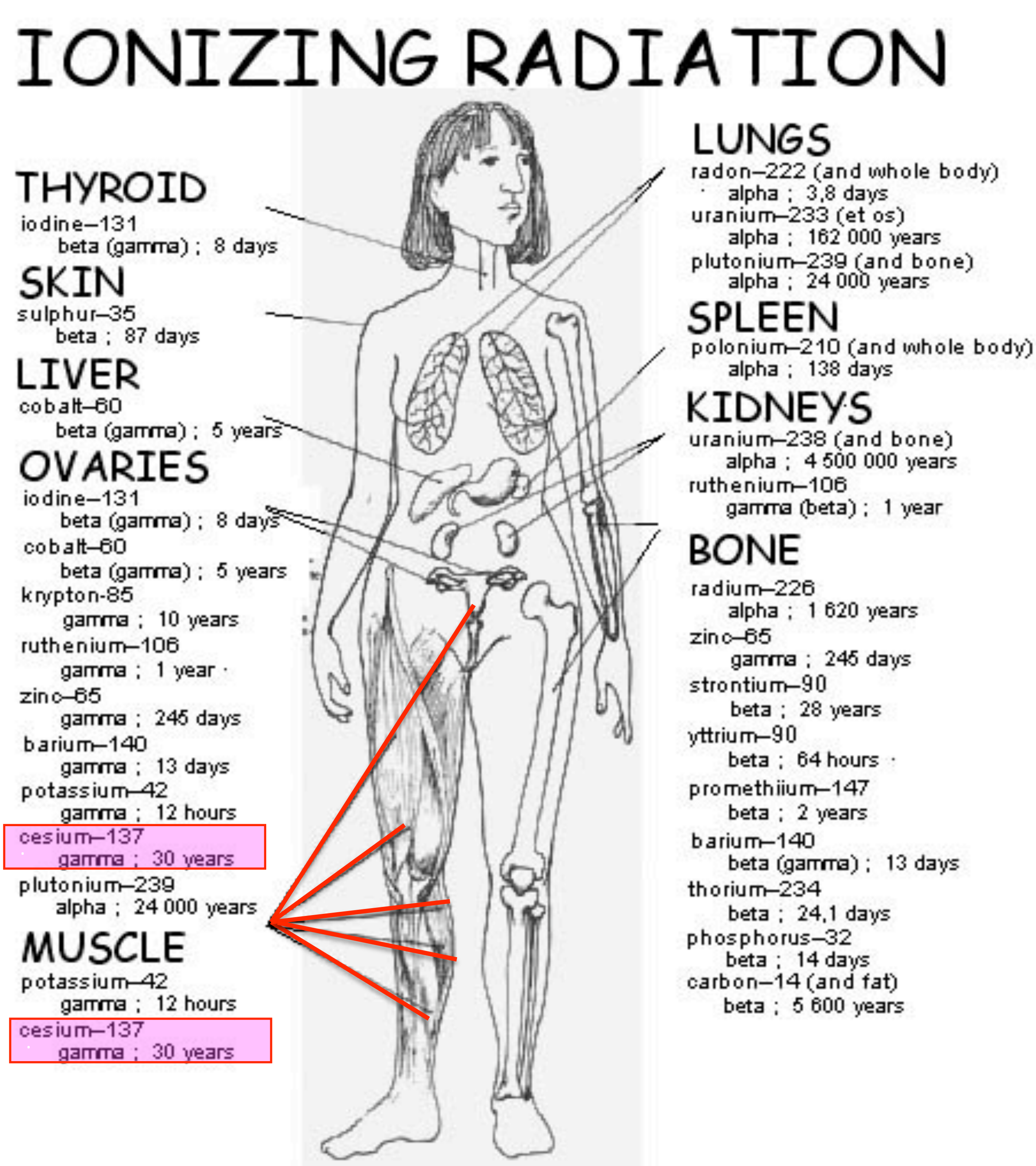
young children are especially at risk

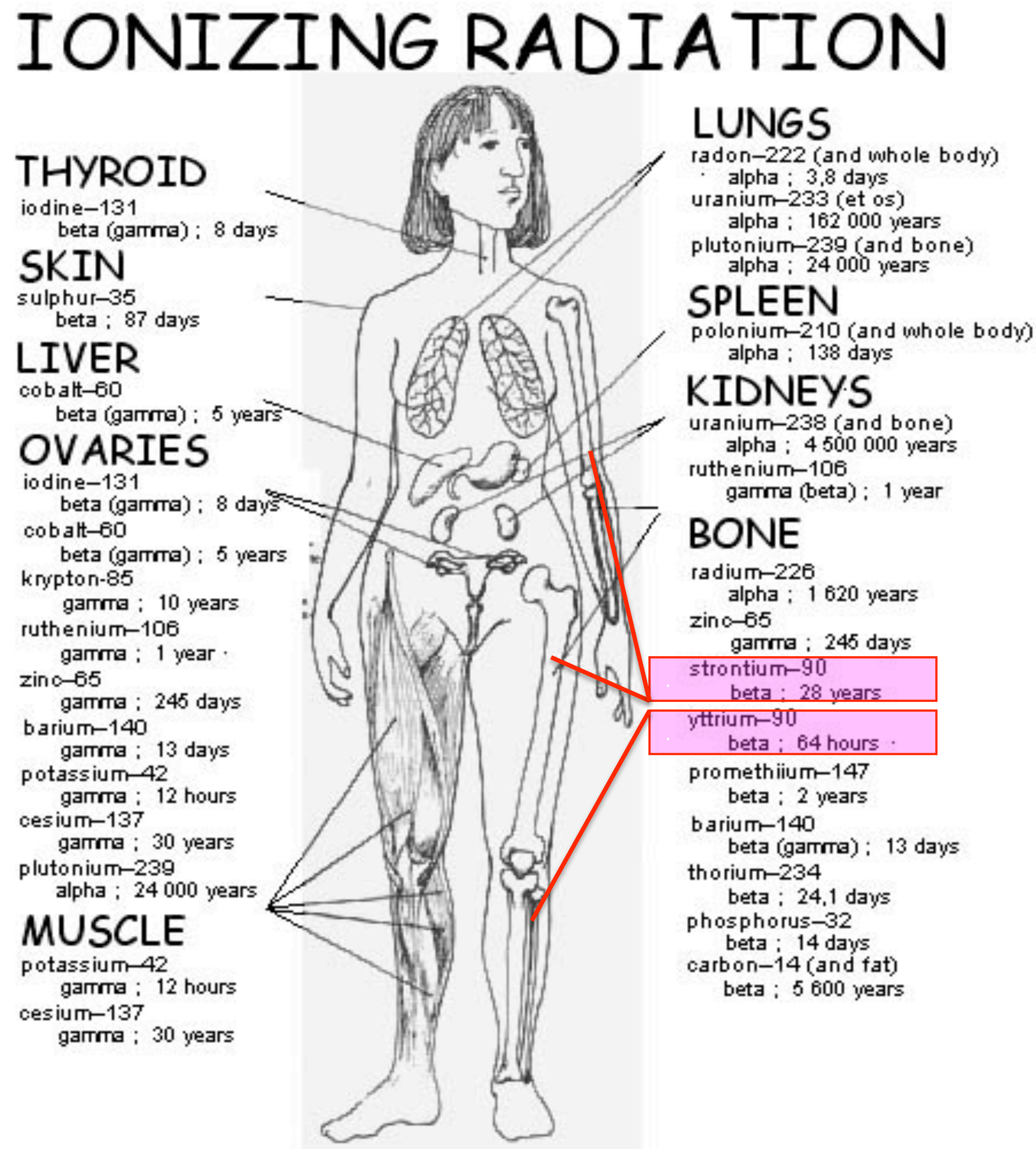


Cesium-137 goes to the soft tissues

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

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 .

Radium Dial Painters 1920

radium-226

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

Underground Miner (Navajo)
with lung cancer

Radon Gas

*Photo:
Robert Del Tredici*

radioactive **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 …

US Environmental Protection Agency

Radon exposure in homes

kills 20,000 to 30,000 Americans

every year by lung cancer

radon is a lung-seeker

Alexander Litvinenko 2006

polonium-210

murdered by polonium poisoning in London England
(a tiny amount added to a cup of tea)

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 …

American Health Physics Society

polonium-210

is probably the cause of

up to 90 percent of the deaths

attributed to tobacco

polonium is a blood-seeker

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

Lesson Four

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.

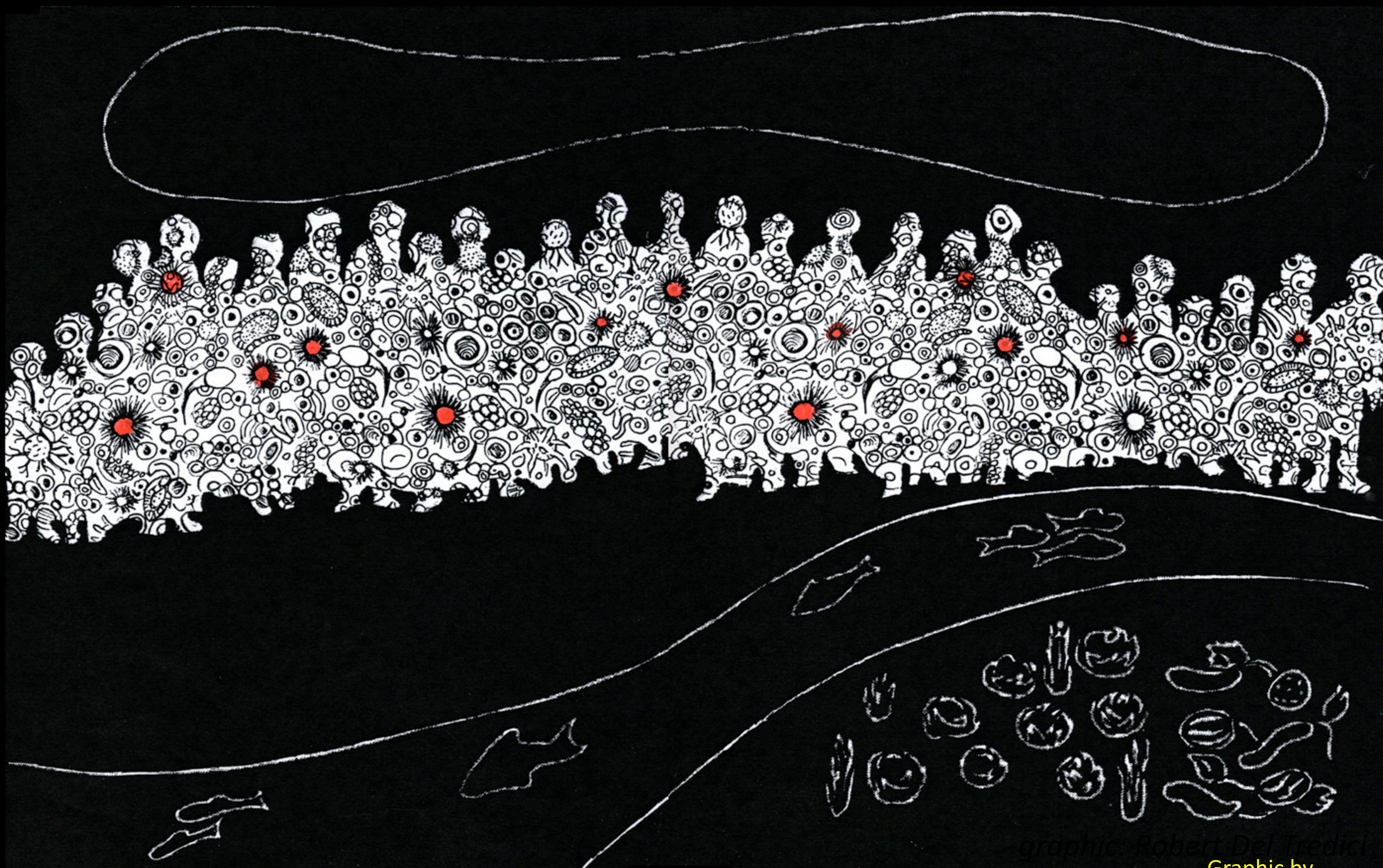
A small fraction of the population will develop cancer years later. Infants and children are especially vulnerable.

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 heath effects – like cancer – will be seen.

Graphic by
Robert Del Tredici

At low levels, radioactivity does not attack humans directly – it damages cells. A population is like an ocean of cells.



Graphic by
Robert Del Tredici

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

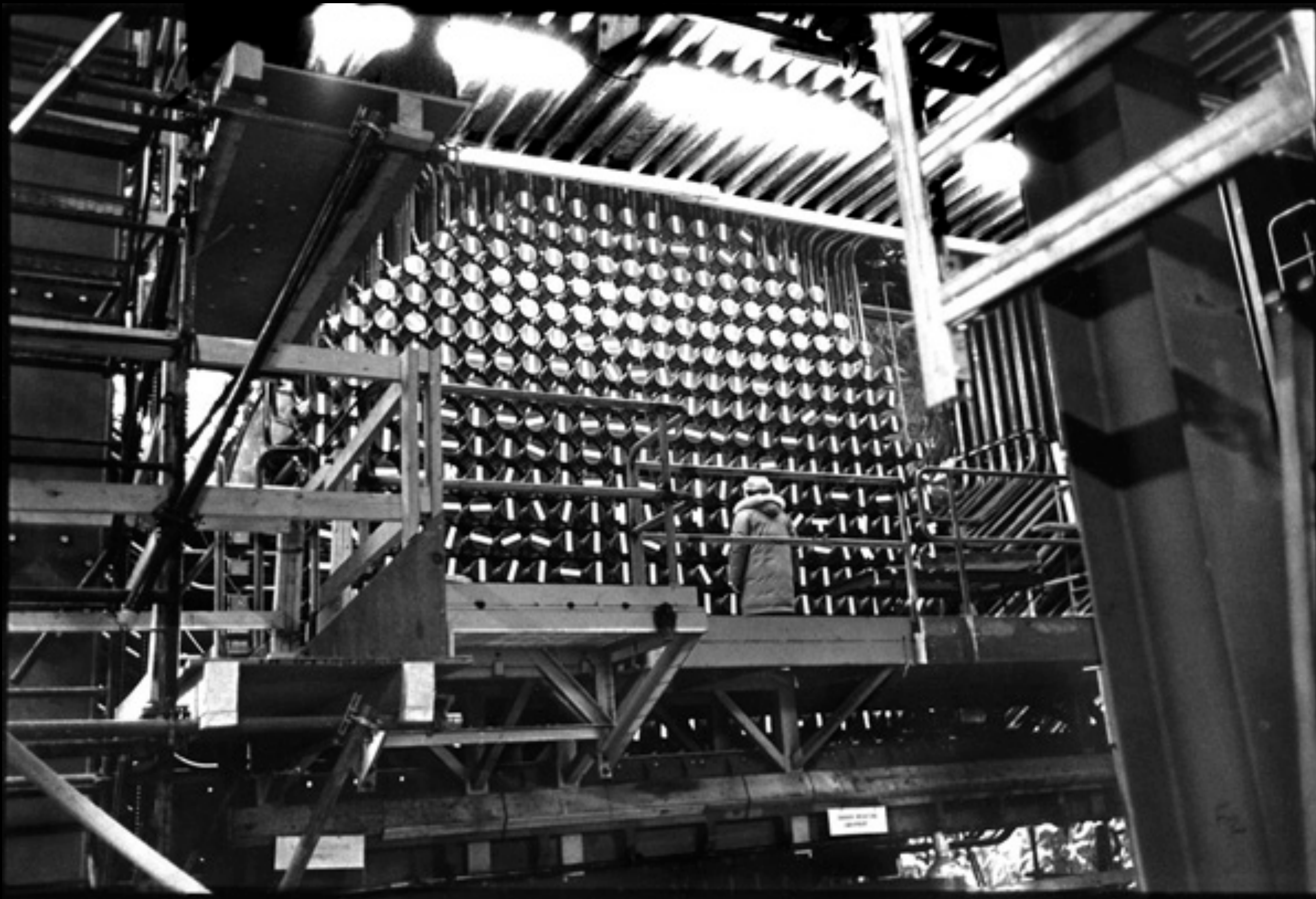
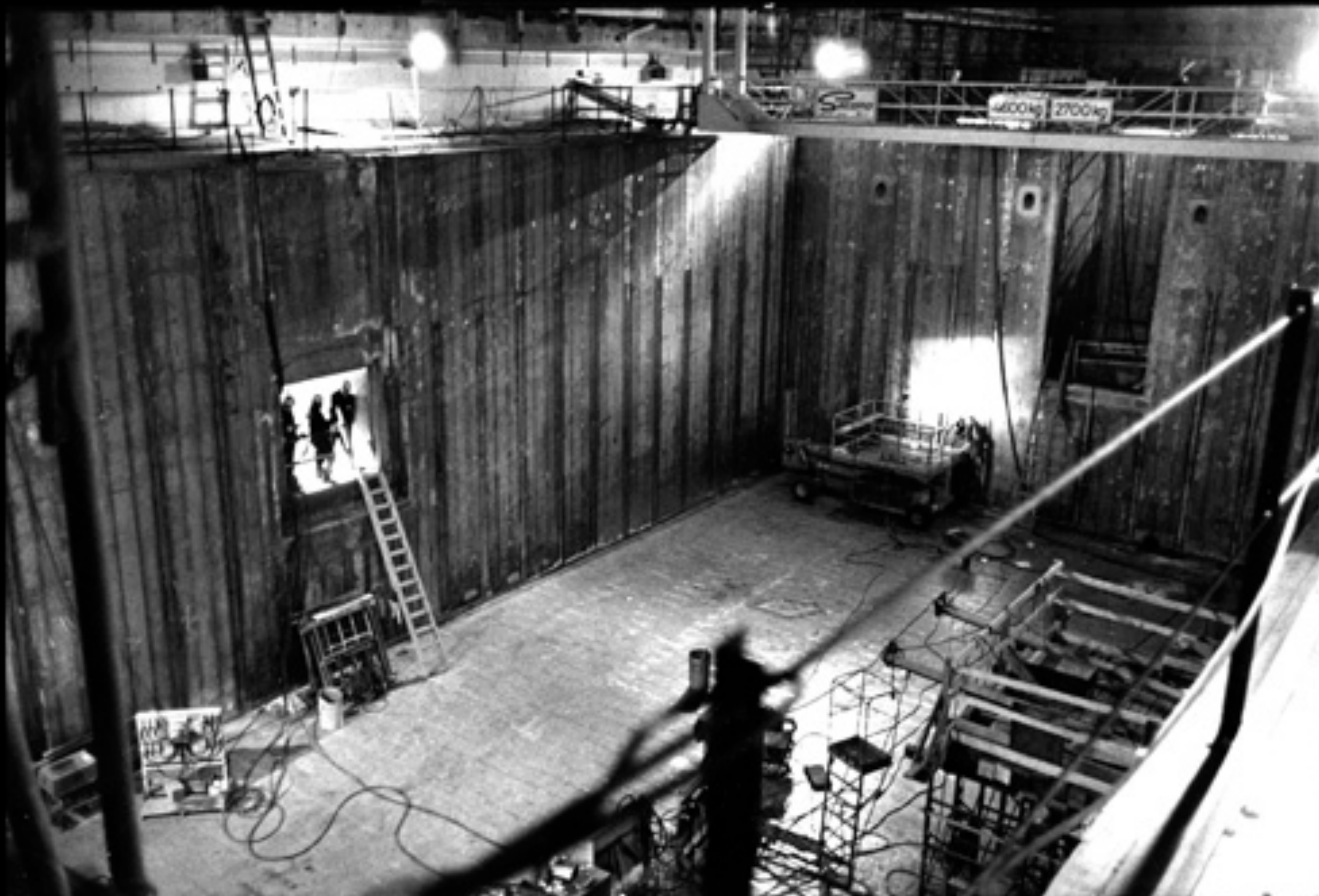


Photo: Robert Del Tredici

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.



Robert Del Tredici

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.

. . . but the heat of the nuclear fuel waste caused enormous damage

Three hydrogen gas explosions were caused by nuclear fuel waste

(heat + ionization → chemical reactions → hydrogen gas buildup → explosion)

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

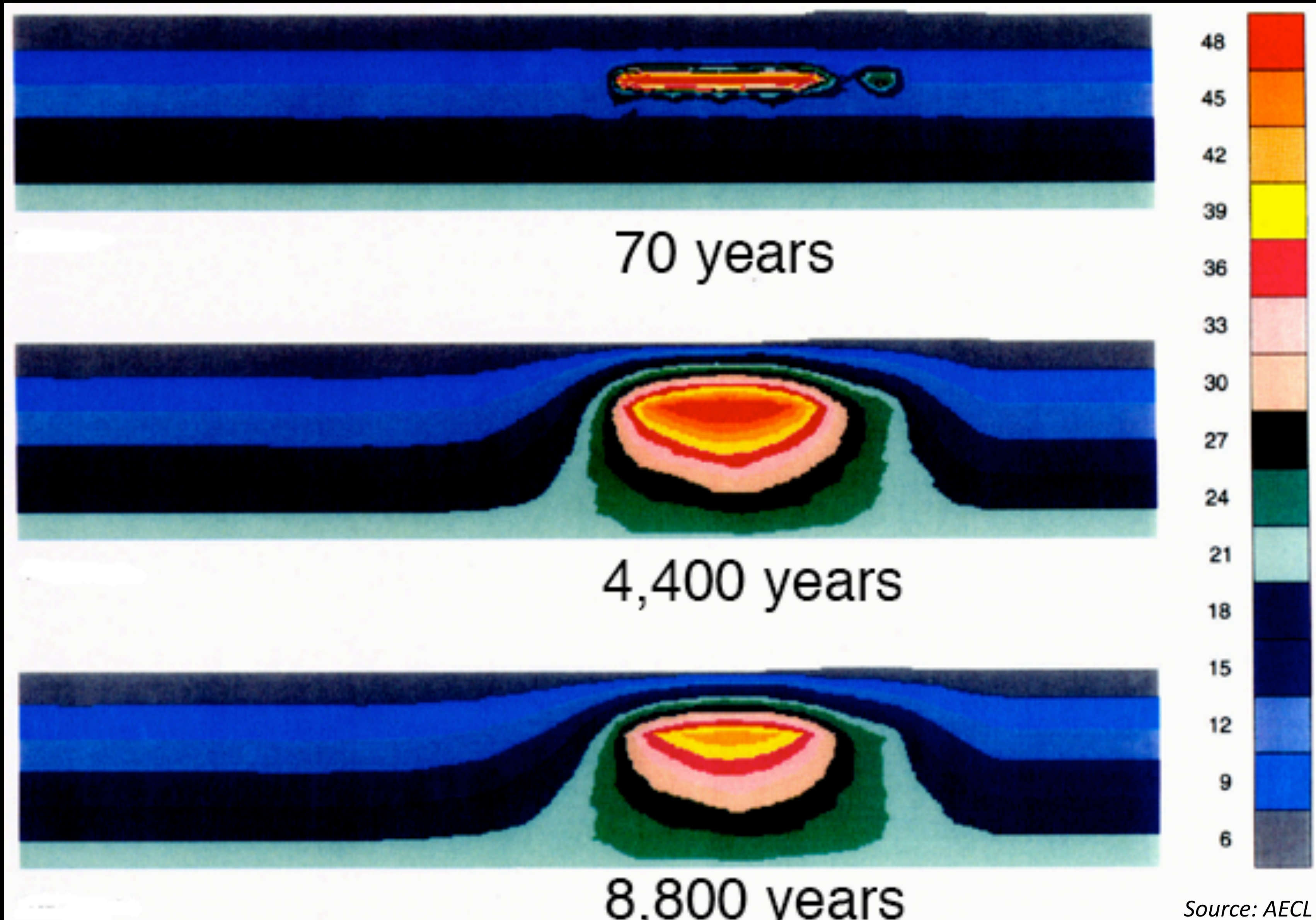
Gordon Edwards interviewed on CTV News about radioactive water stored at Fukushima

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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Citizen's Liaison Committee

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