Radioactive Wastes:

and Nuclear Demolition

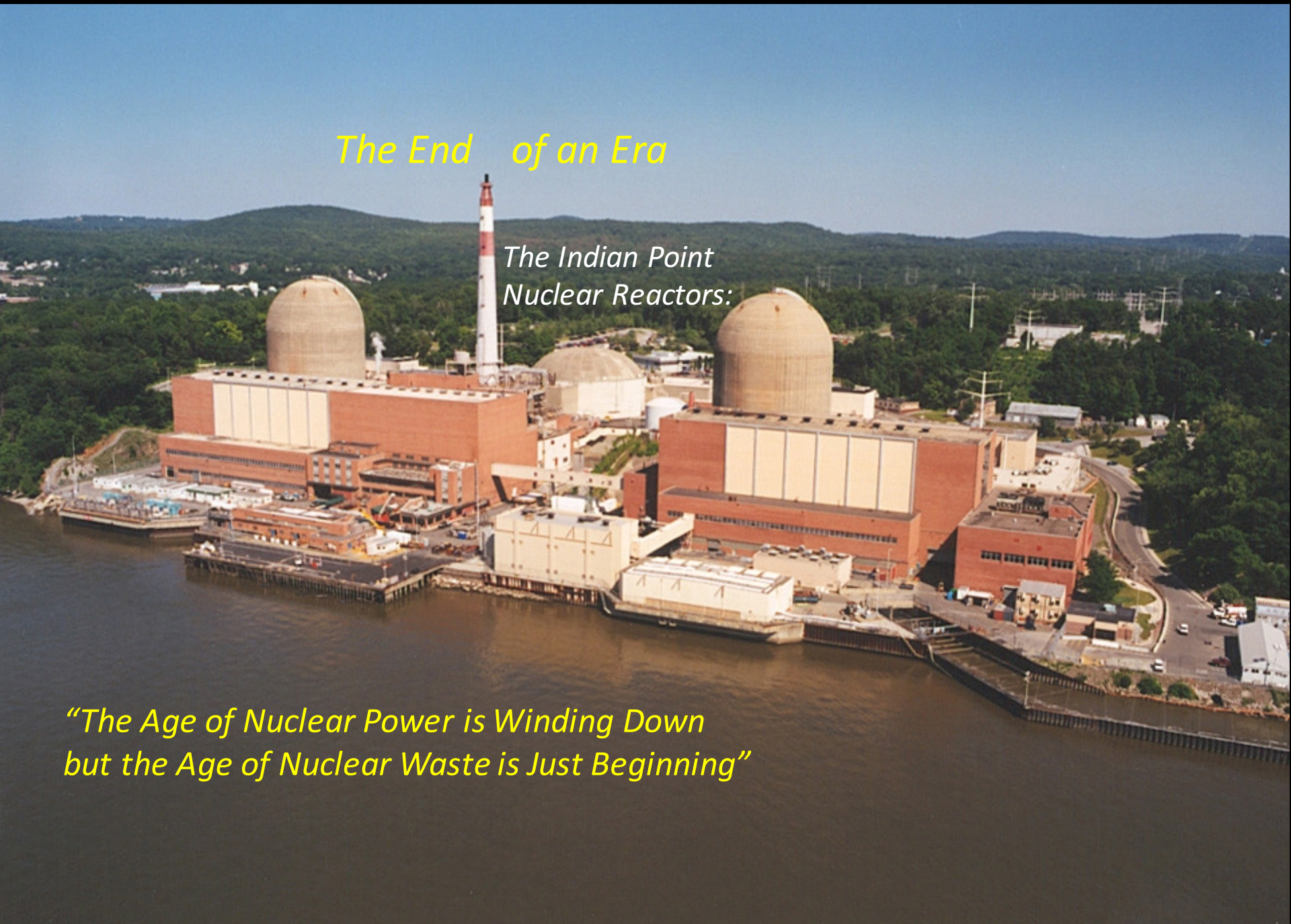
A Slide Show

prepared for
Decommissioning Symposium
June 12 2017

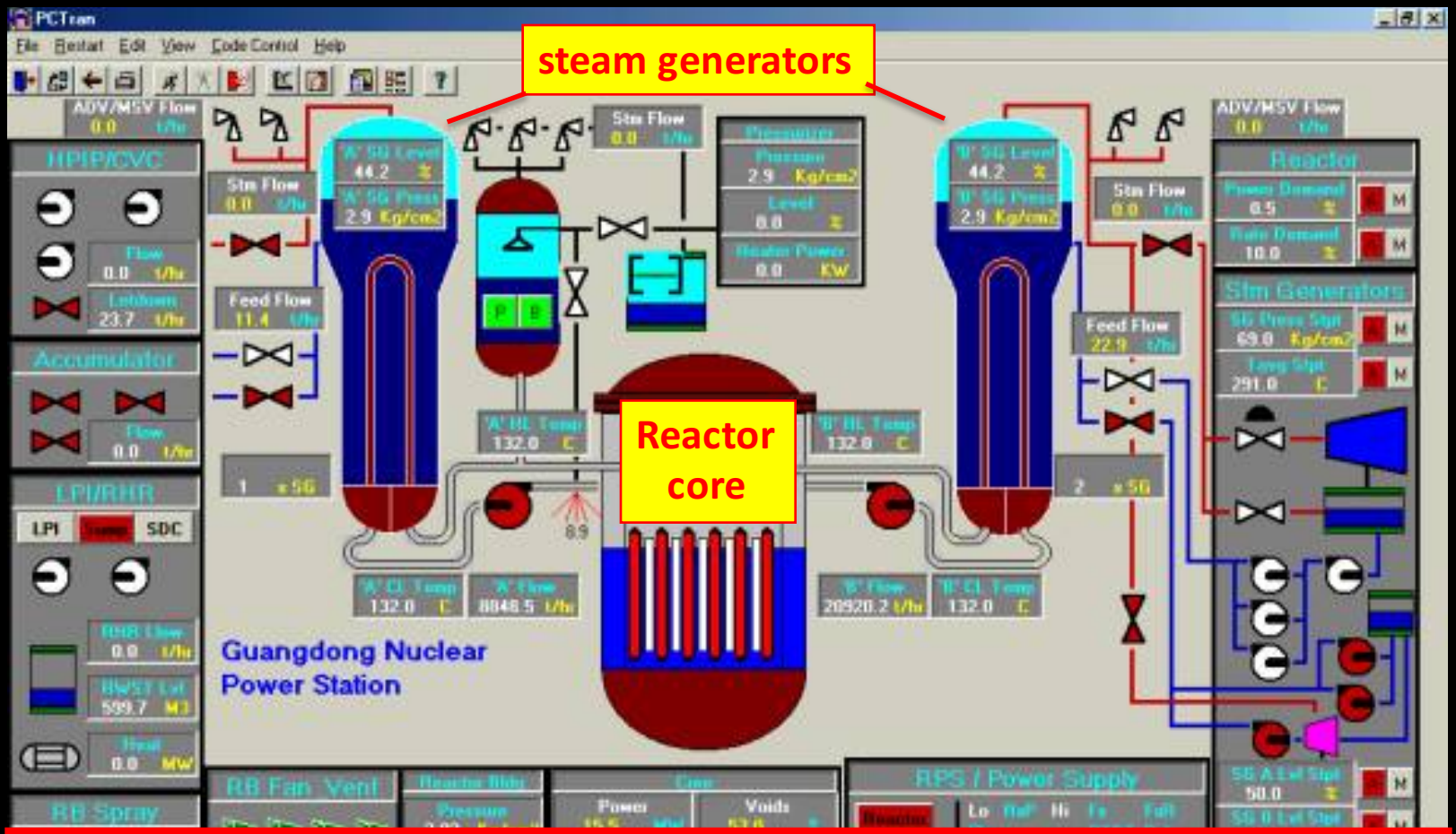
Gordon Edwards, Ph.D., President,
Canadian Coalition for Nuclear Responsibility

e-mail: ccnr@web.ca

www.ccnr.org


The End of an Era
The Indian Point
Nuclear Reactors:
"The Age of Nuclear Power is Winding Down
but the Age of Nuclear Waste is Just Beginning"

How a PWR nuclear reactor works



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.

Chemical energy involves only the electrons . . .

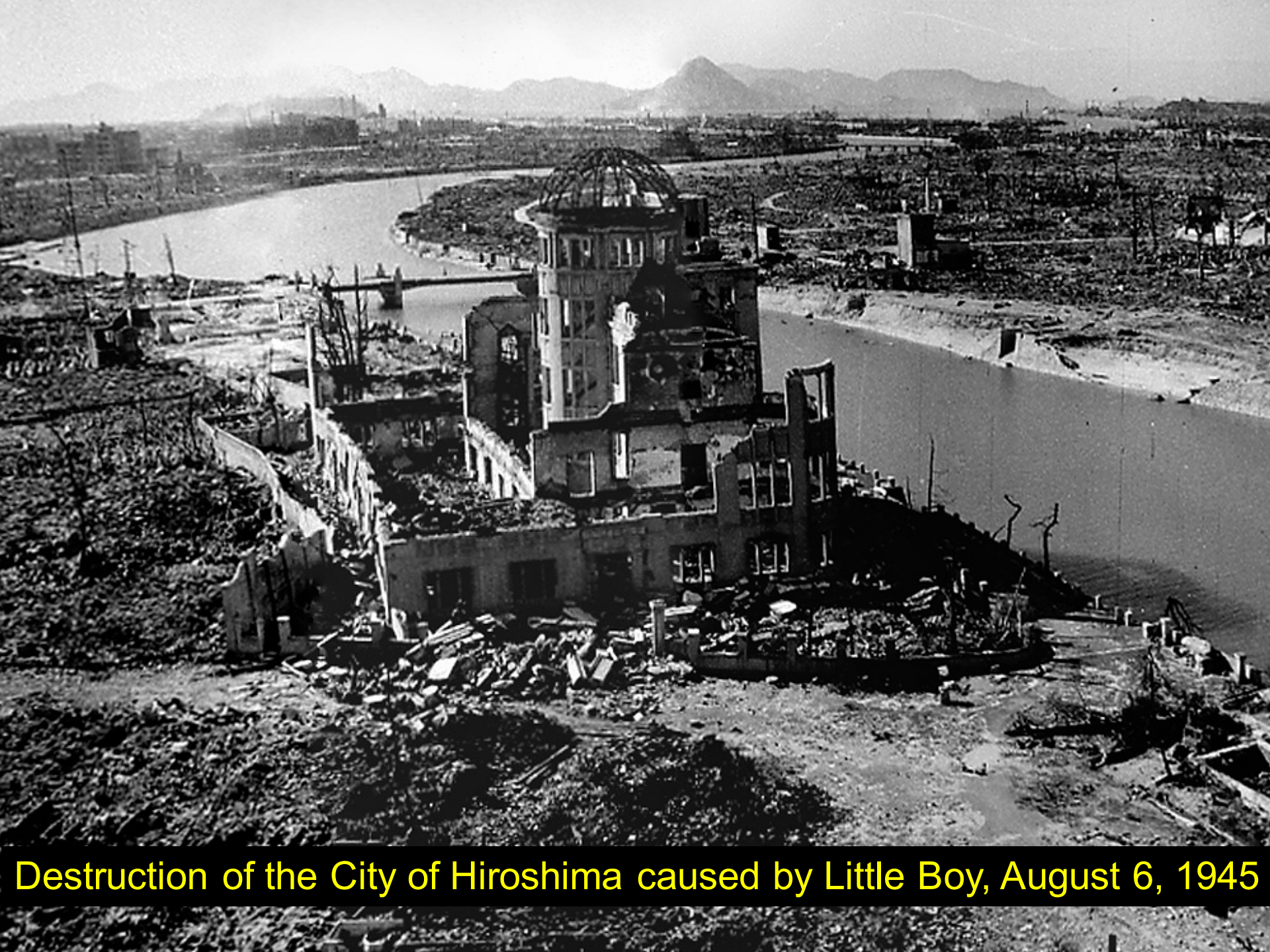
Battlefield explosion

Forest fire

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

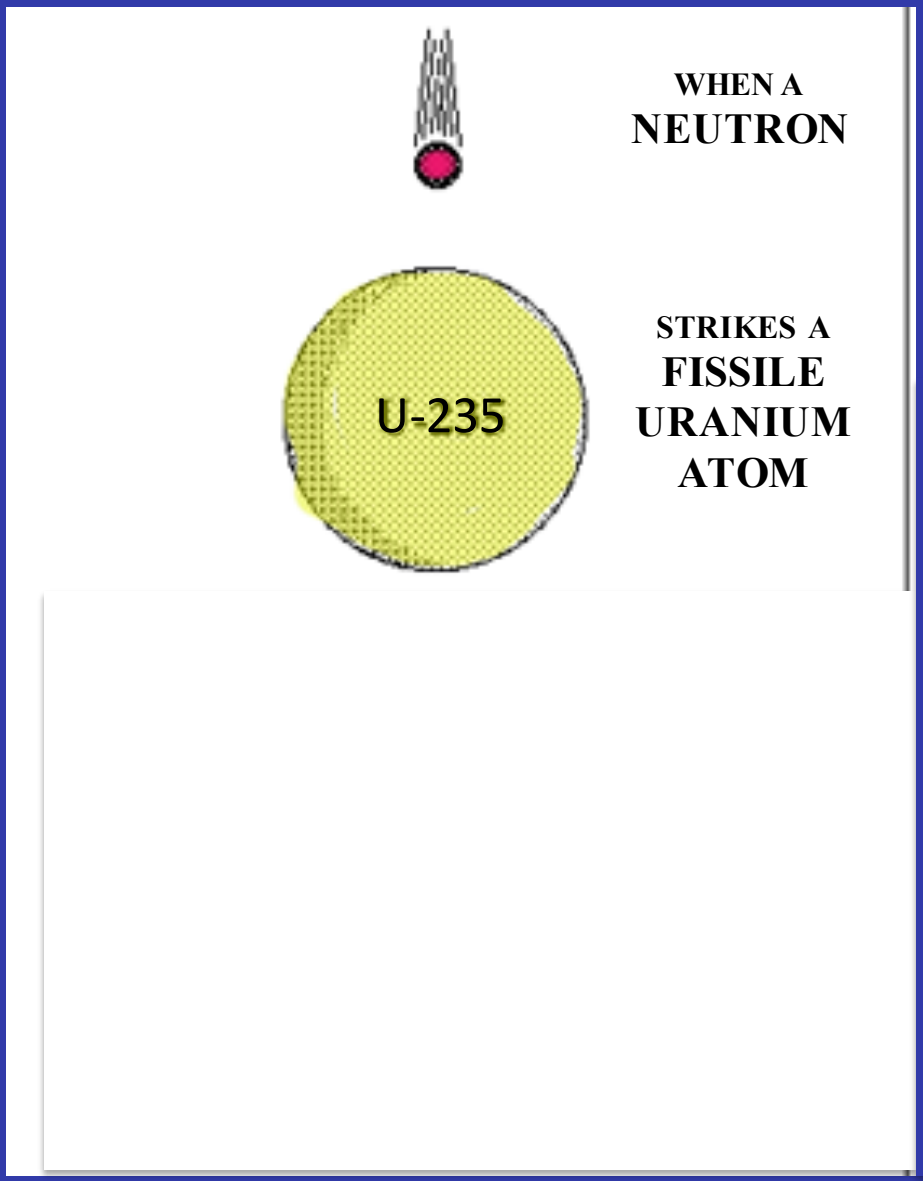
H-Bomb Blast

NUCLEAR FISSION:
ONLY 78 YEARS
OF SCIENTIFIC
EXPERIENCE !



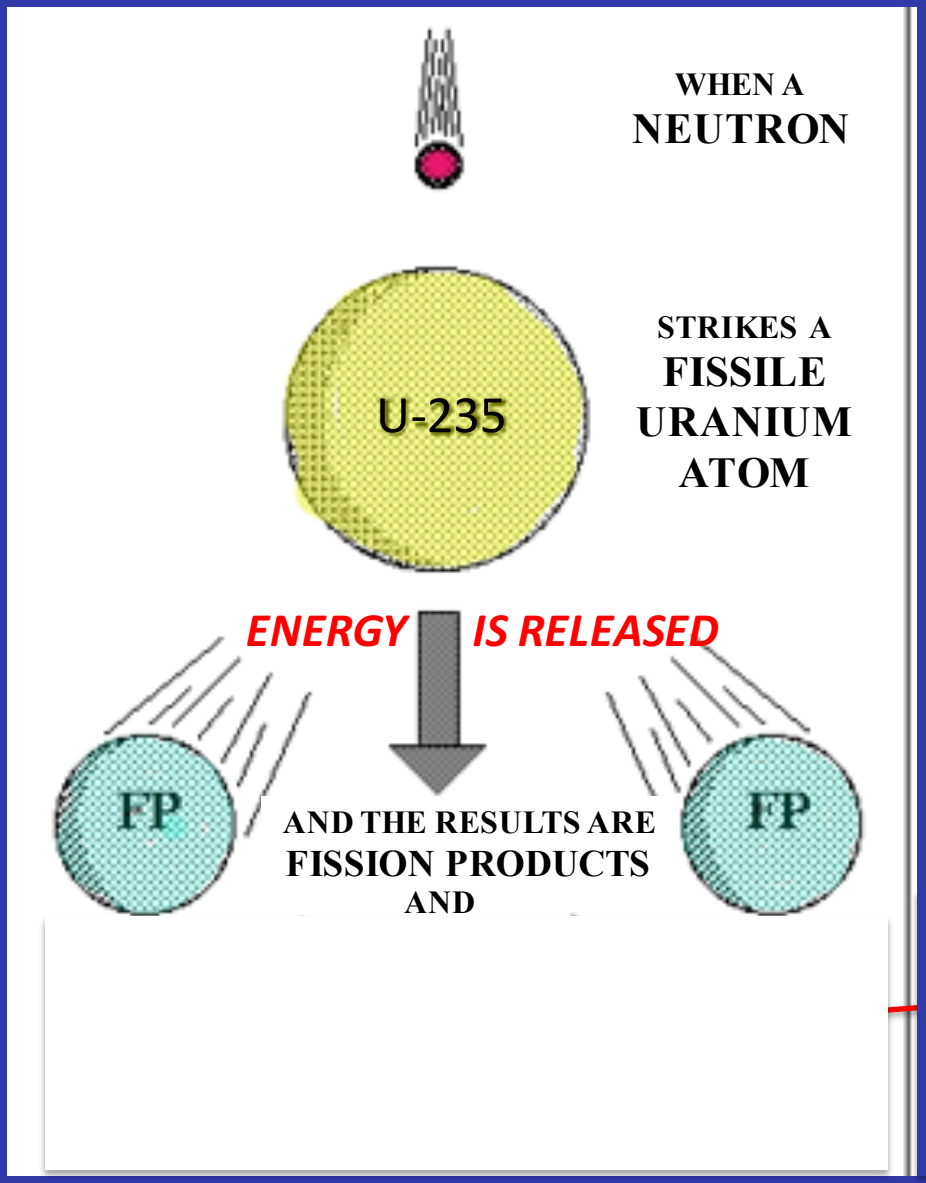
Destruction of the City of Hiroshima caused by Little Boy, August 6, 1945

Nuclear Fission



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

Nuclear Fission

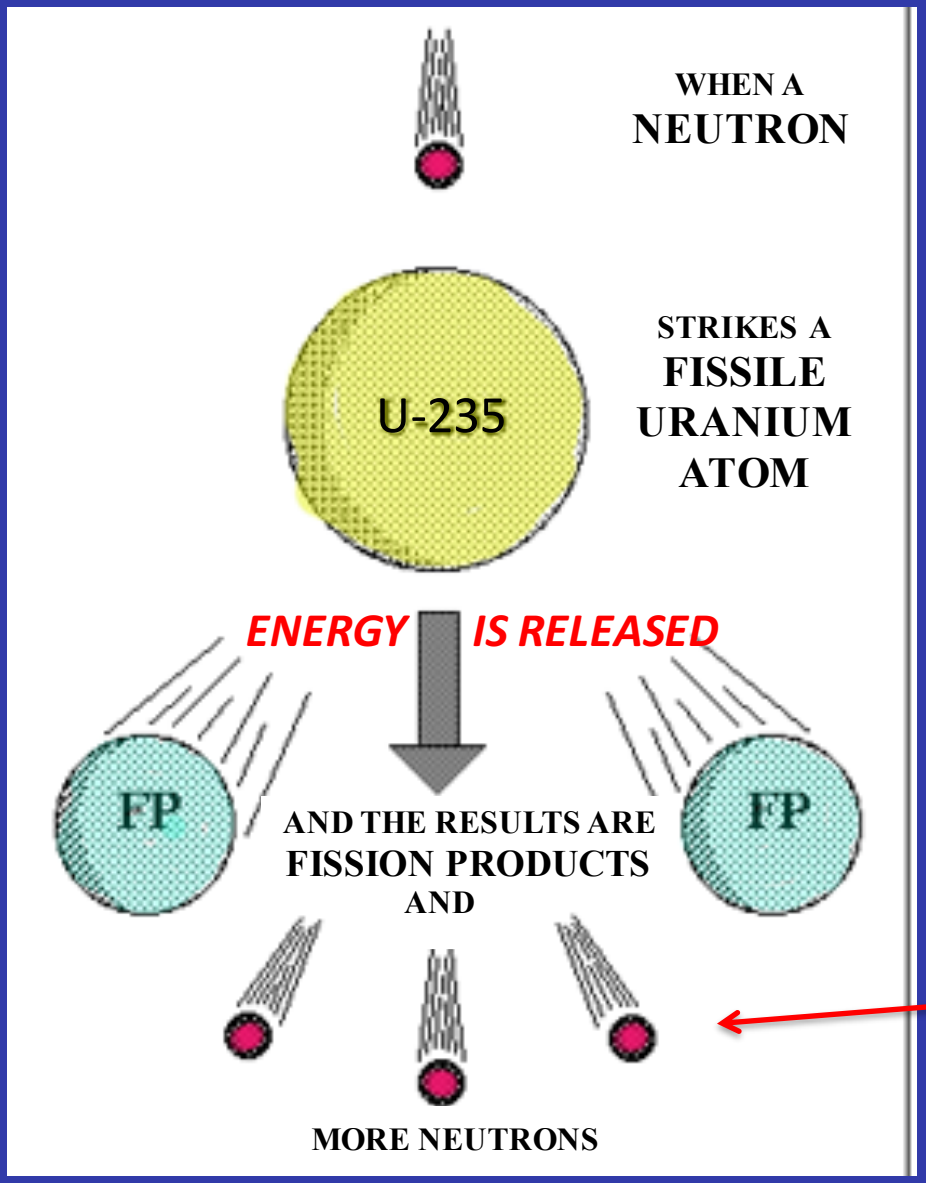


A subatomic projectile called a neutron starts a nuclear chain reaction by splitting a nucleus of "fissile uranium" (U-235).

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".

Nuclear Fission



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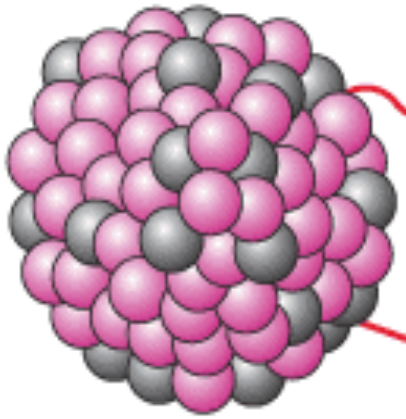
More neutrons trigger more fissions and so the energy release is multiplied enormously.

Radioactivity



Radioactive Nucleus

gamma (sometimes)

Energy

alpha or beta

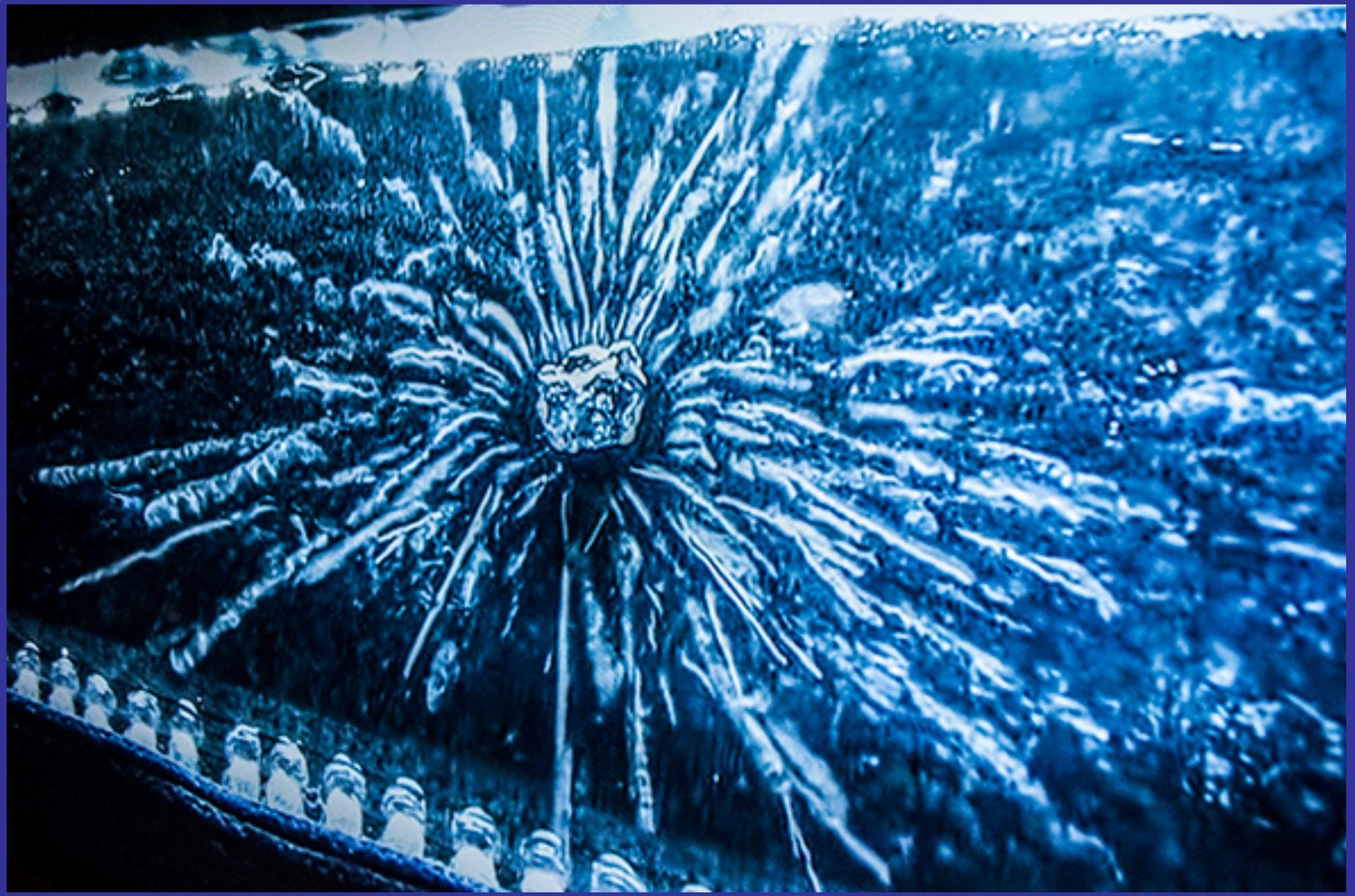
(always)

Particle

Atomic Radiation

- ***unstable – unlike most atoms it cannot last***
- ***it will suddenly and violently disintegrate***

Alpha, Beta, and Gamma “rays” are normally invisible



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.

RADIOACTIVE MATERIALS

THYROID
iodine–131
beta (gamma) ; 8 days

SKIN
sulphur–35
beta ; 87 days

LIVER
cobalt–60
beta (gamma) ; 5 years

OVARIES
iodine–131
beta (gamma) ; 8 days
cobalt–60
beta (gamma) ; 5 years
krypton-85
gamma ; 10 years
ruthenium–106
gamma ; 1 year
zinc–65
gamma ; 245 days
barium–140
gamma ; 13 days
potassium–42
gamma ; 12 hours
cesium–137
gamma ; 30 years
plutonium–239
alpha ; 24 000 years

MUSCLE
potassium–42
gamma ; 12 hours
cesium–137
gamma ; 30 years

LUNGS
radon–222 (and whole body)
alpha ; 3,8 days
uranium–233 (et os)
alpha ; 162 000 years
plutonium–239 (and bone)
alpha ; 24 000 years

SPLEEN
polonium–210 (and whole body)
alpha ; 138 days

KIDNEYS
uranium–238 (and bone)
alpha ; 4 500 000 years
ruthenium–106
gamma (beta) ; 1 year

BONE
radium–226
alpha ; 1 620 years
zinc–65
gamma ; 245 days
strontium–90
beta ; 28 years
yttrium–90
beta ; 64 hours
promethiium–147
beta ; 2 years
barium–140
beta (gamma) ; 13 days
thorium–234
beta ; 24,1 days
phosphorus–32
beta ; 14 days
carbon–14 (and fat)
beta ; 5 600 years

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.

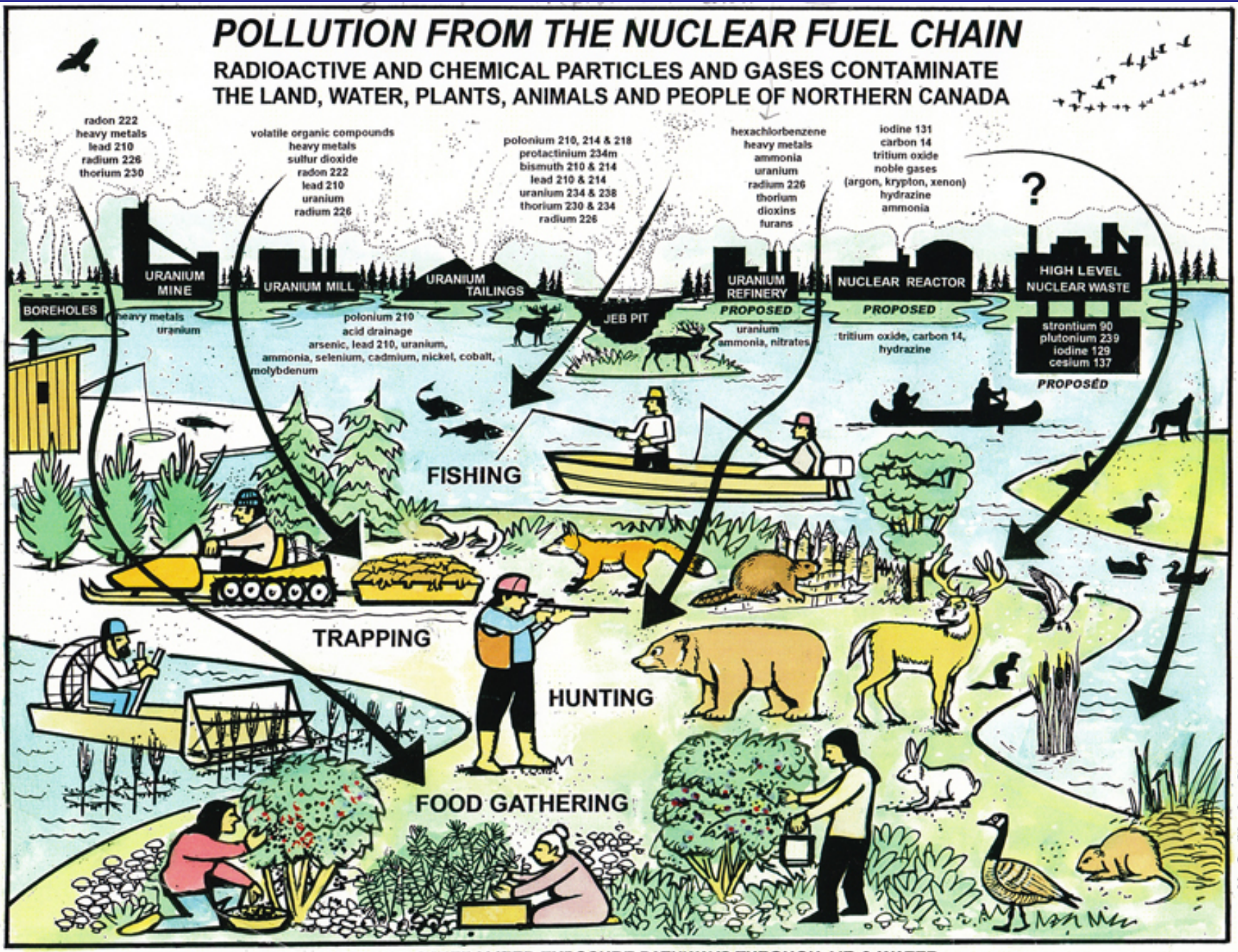
All radioactive materials

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



ARROWS SHOW GENERALIZED EXPOSURE PATHWAYS THROUGH AIR & WATER

sources: *Nuclear Power In Canada: Questions & Answers, Canadian Nuclear Association & Nuclear Power In Canada: An Examination of Risks, Pembina Institute*

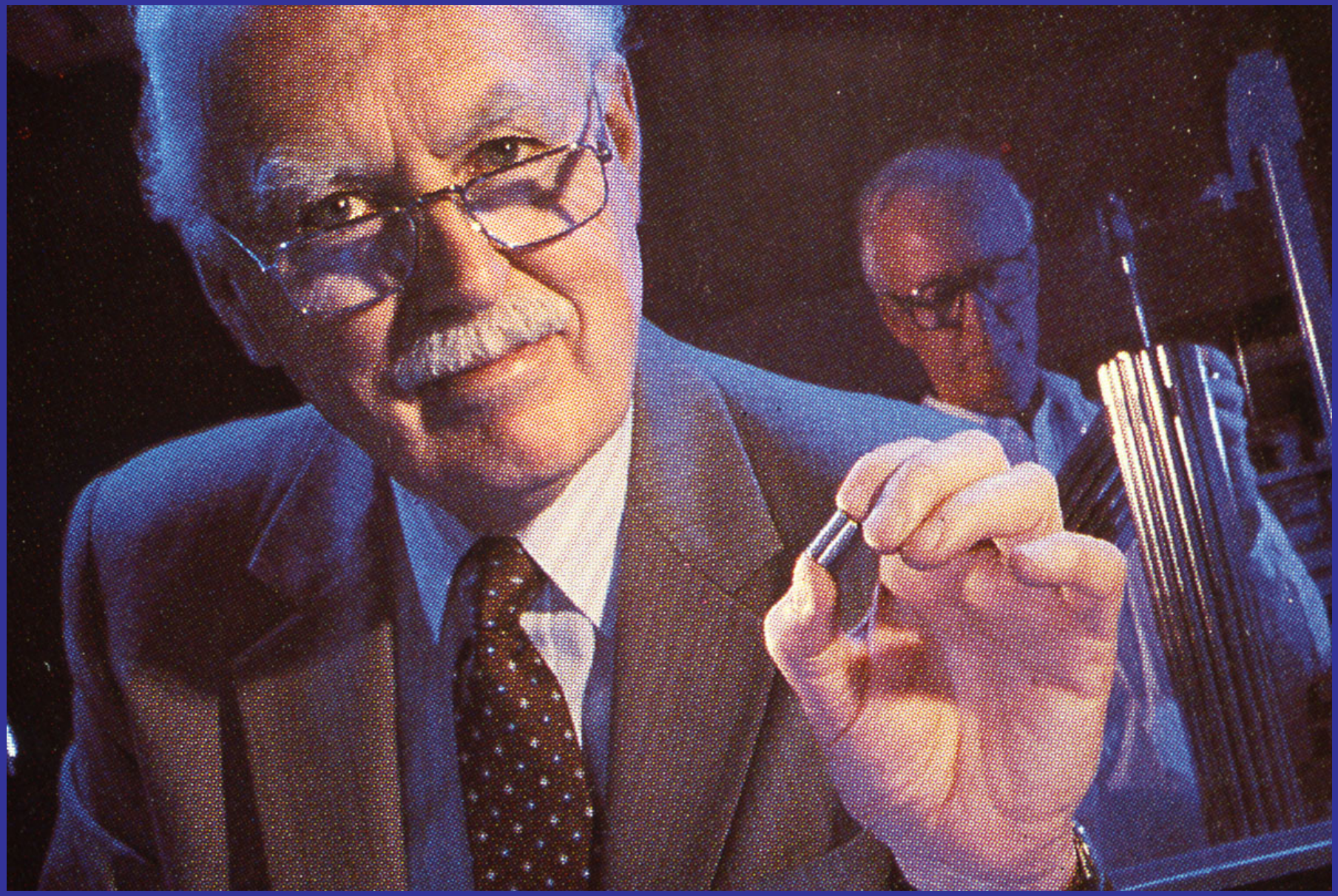
graphic: Coalition for a Clean Green Saskatchewan design group cleangreensask@yahoo.ca

Irradiated Fuel

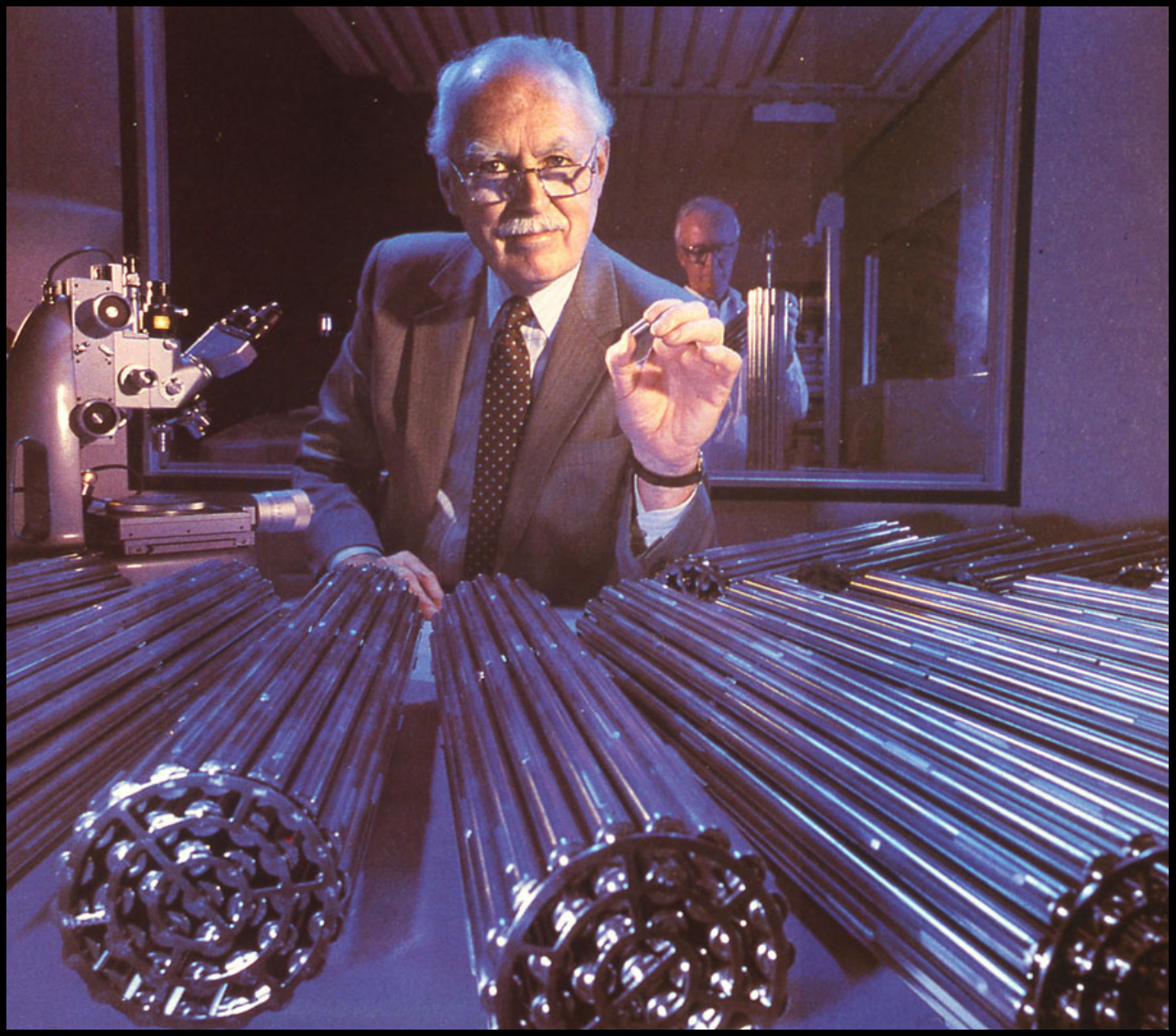
~ high level waste ~

Fission Products

Transurnics

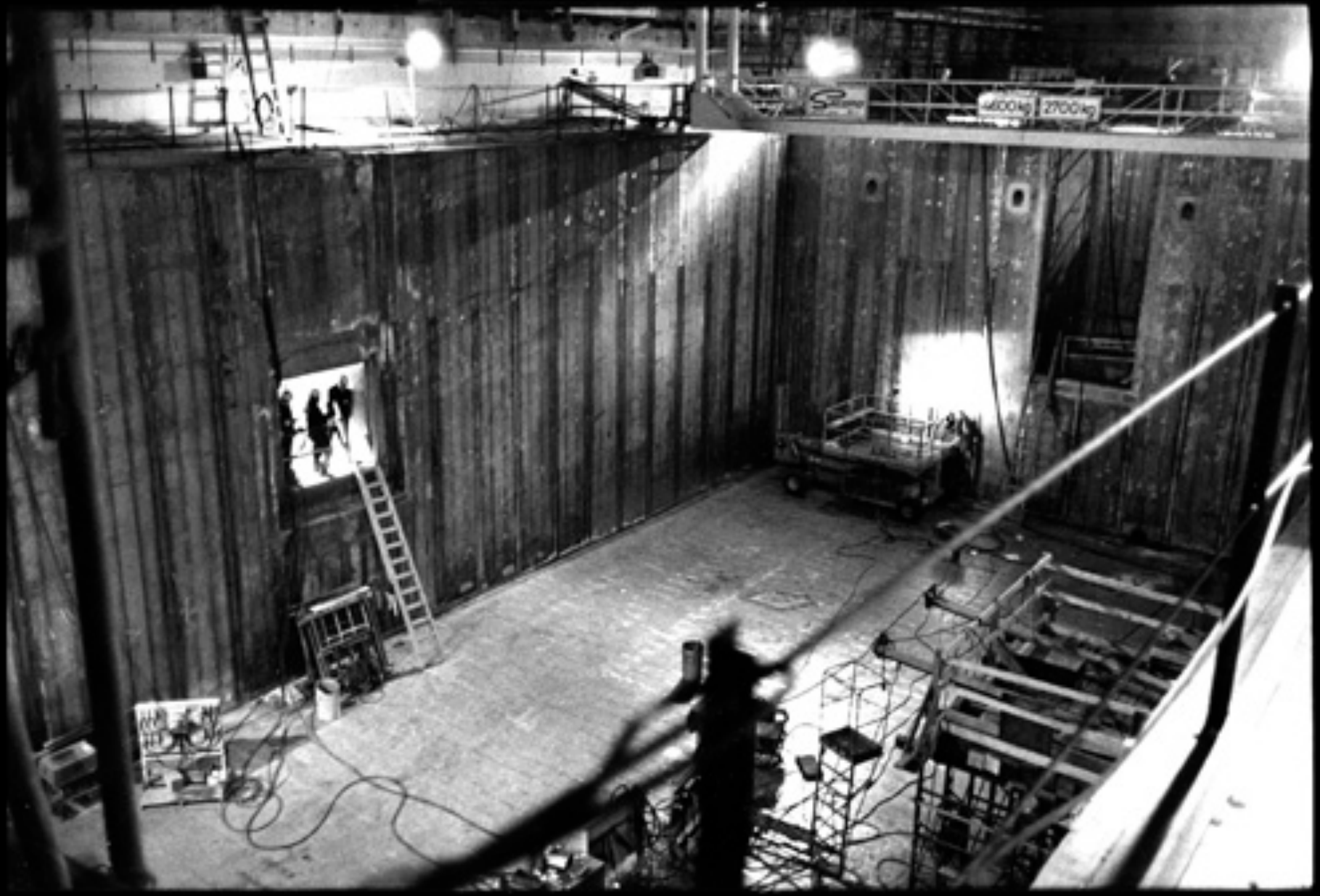


Canadian Nuclear Association ad: ´Small Wonder´



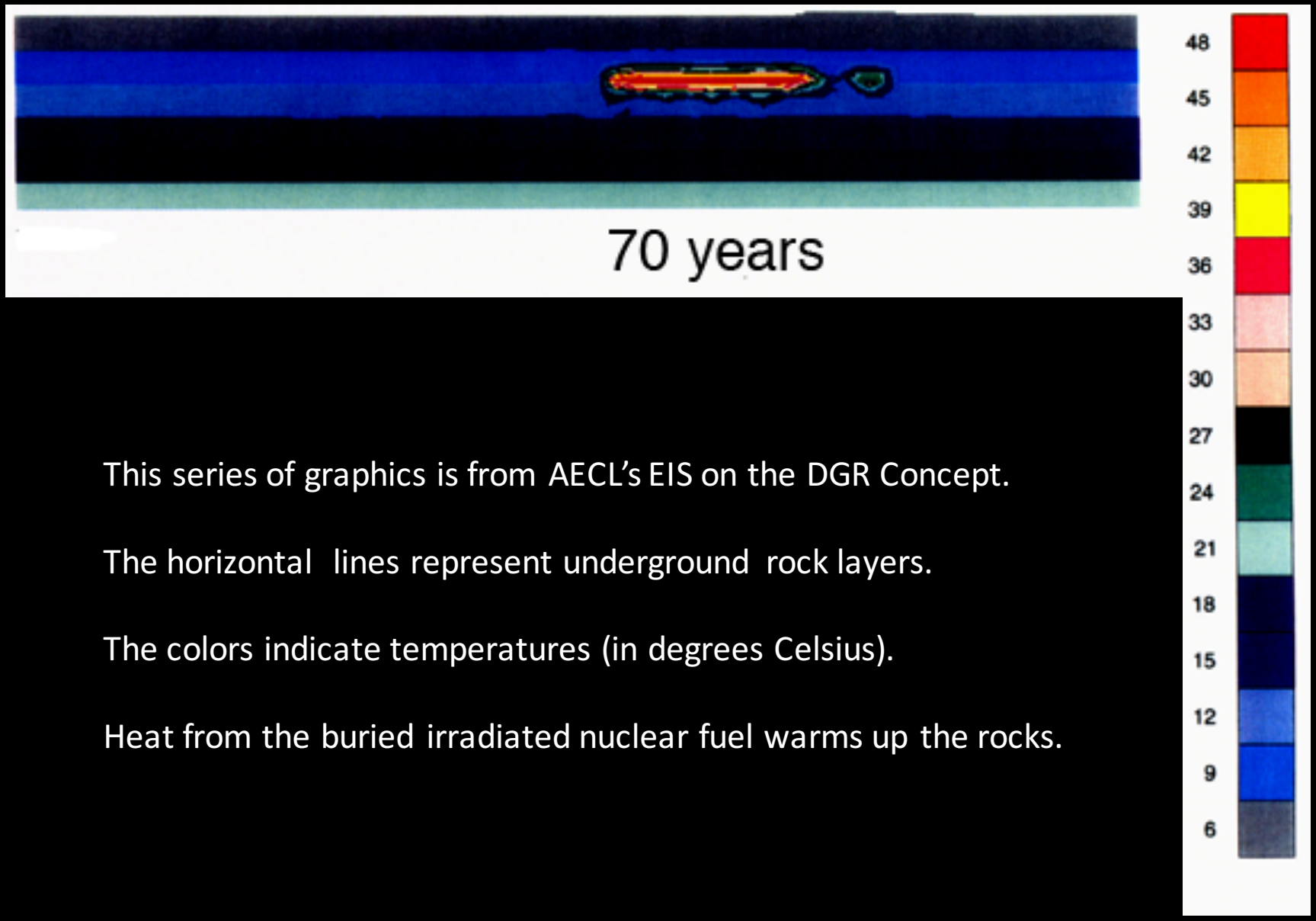
Nuclear fuel rods and pellets can be handled safely before use,
Once used, the fission products will deliver a lethal dose of radiation in seconds.

"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



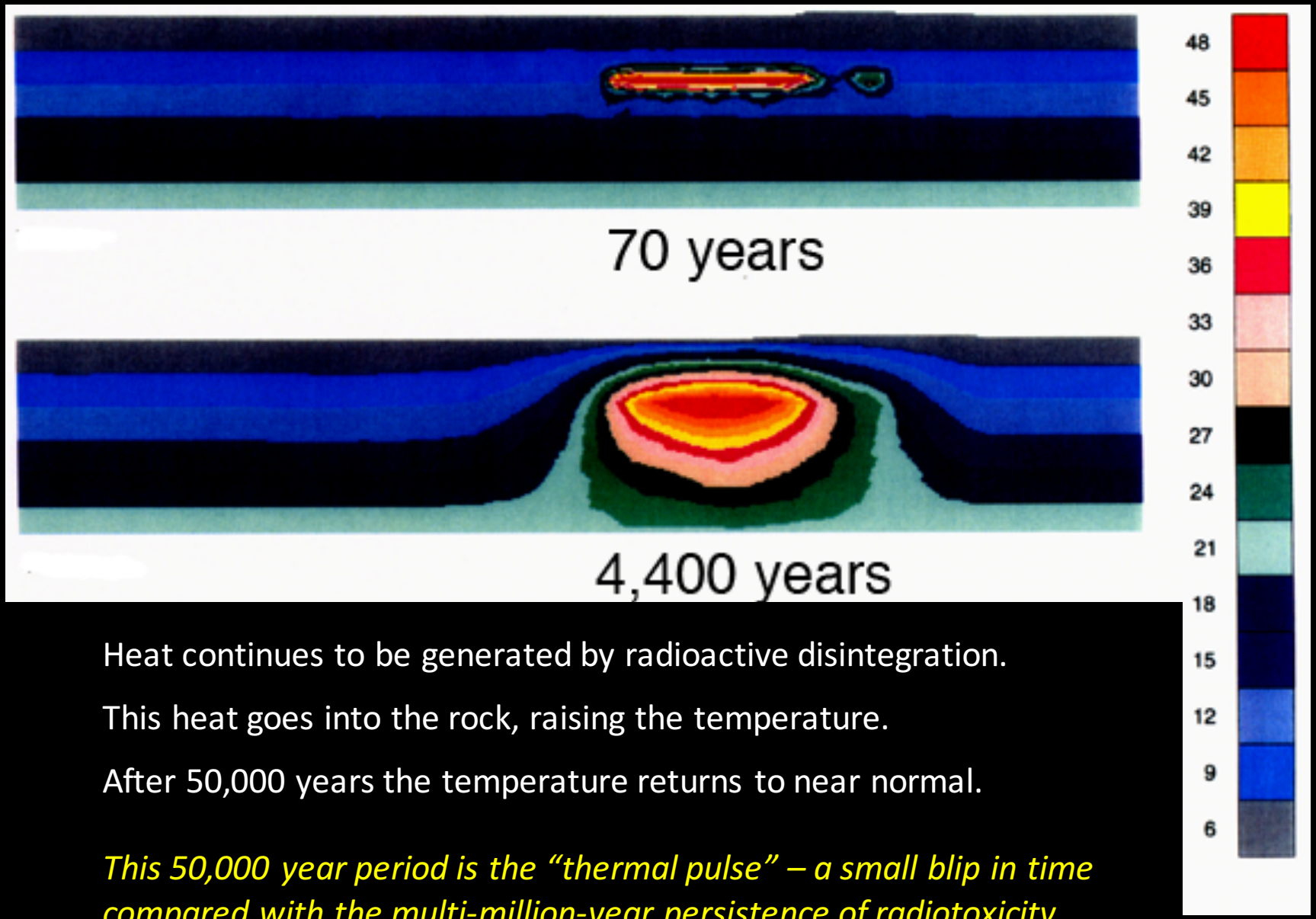
This series of graphics is from AECL's EIS on the DGR Concept.

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.



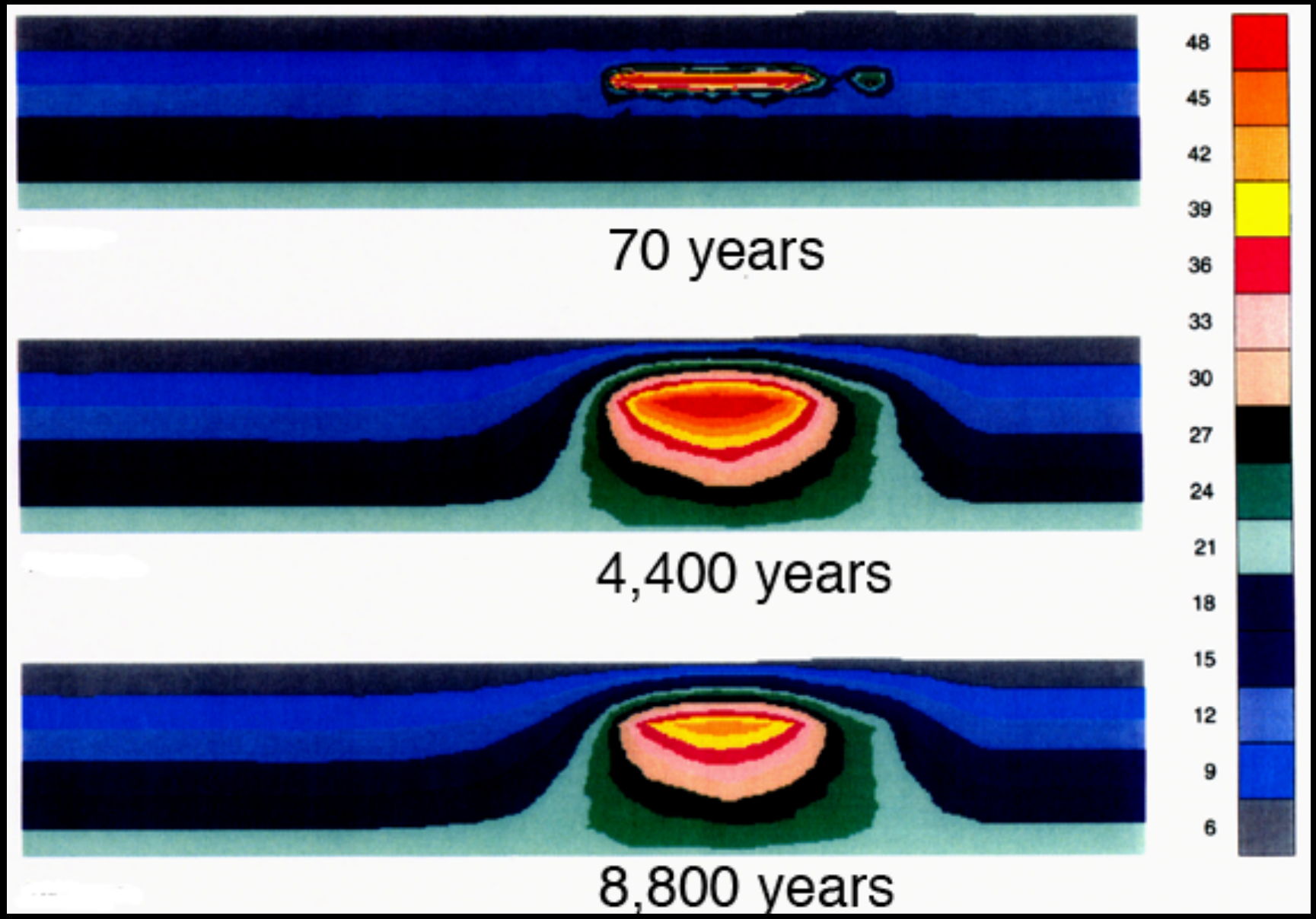
Heat continues to be generated by radioactive disintegration.

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.



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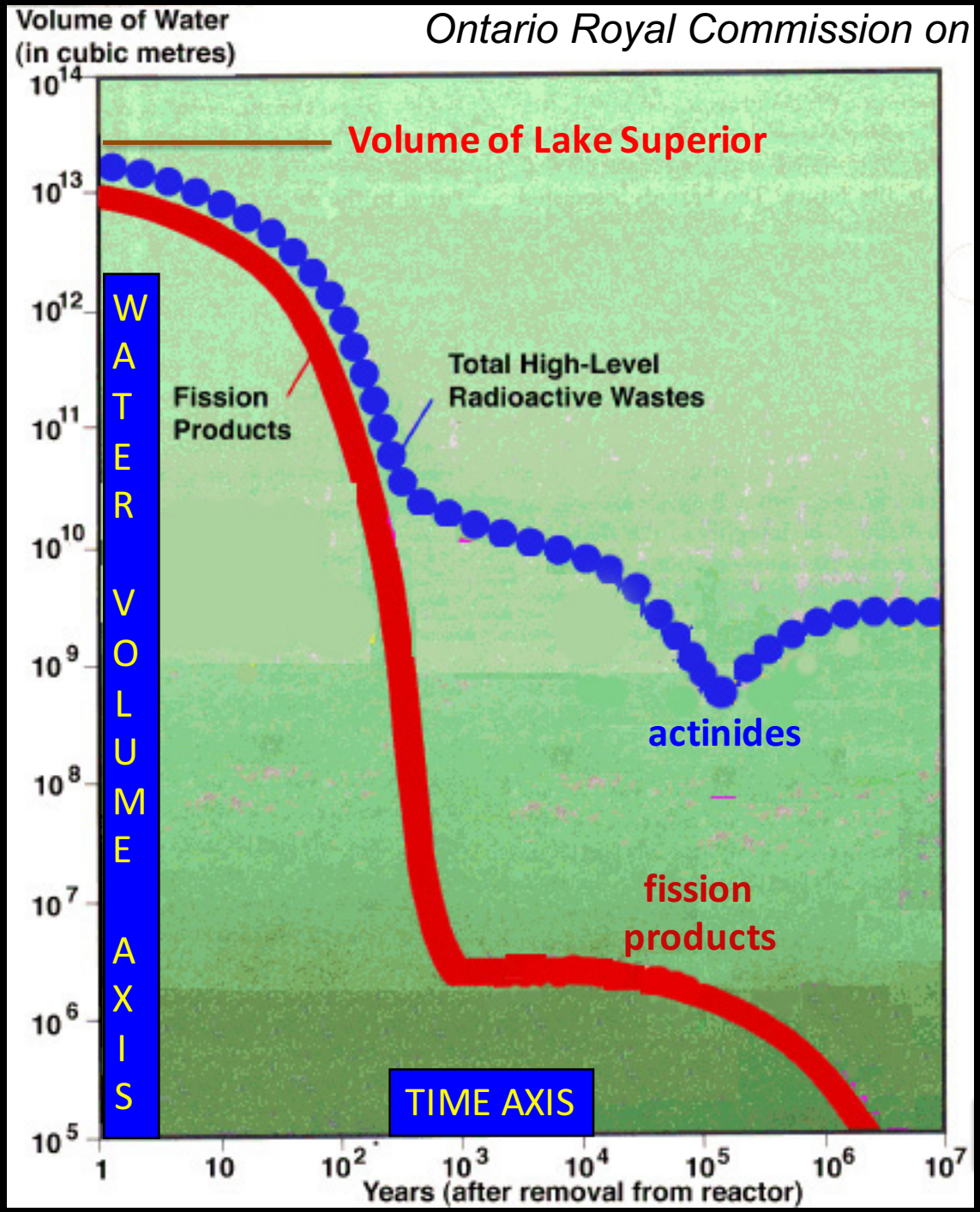
Ontario Royal Commission on Electric Power Planning (1978)

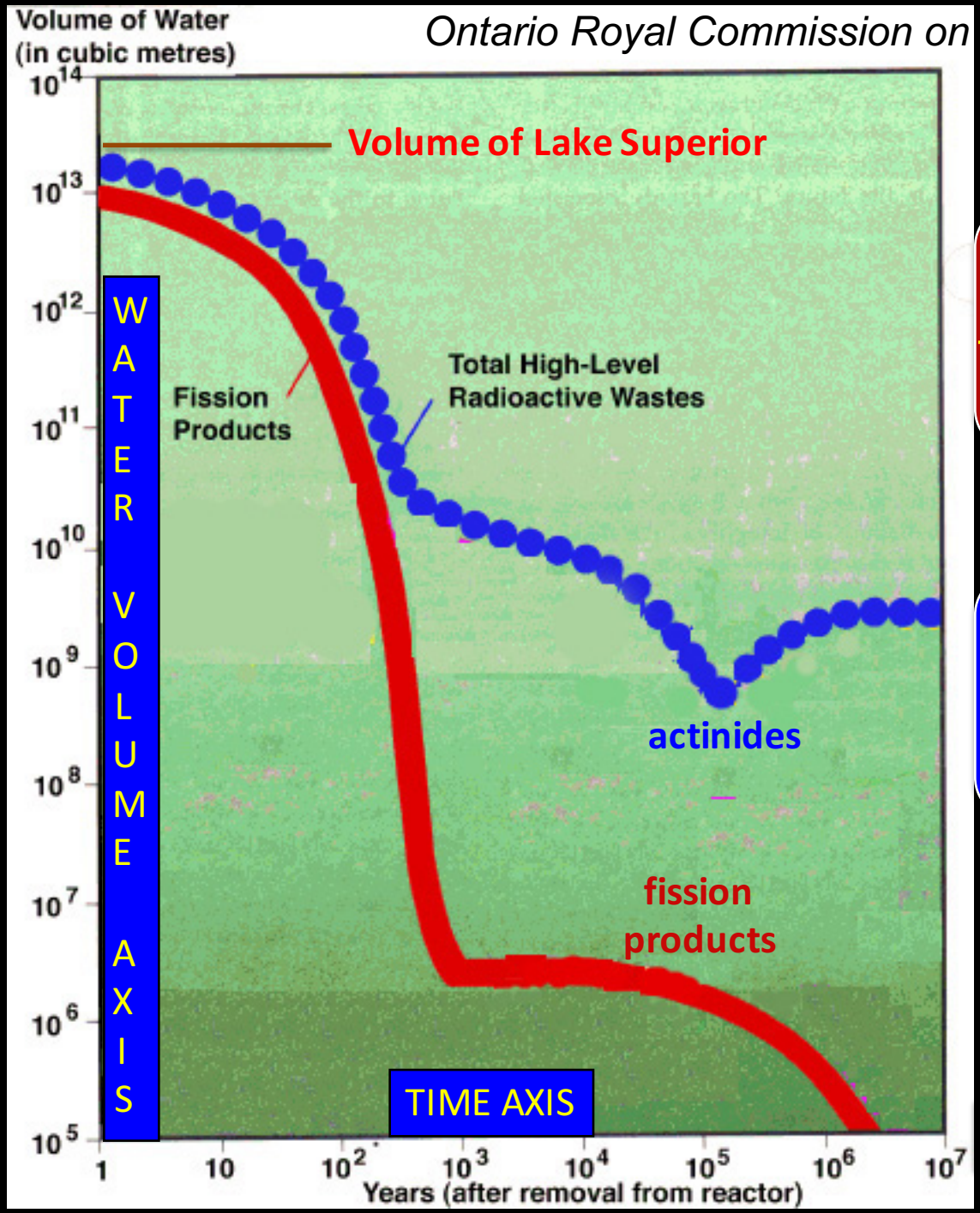


This graph shows the radiotoxicity of one year's worth of spent CANDU fuel from one reactor over a period of ten million years

The minimum amount of water needed to dilute (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

Ontario Royal Commission on Electric Power Planning (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.

Royal Commission Report, 1978

What is an Actinide?

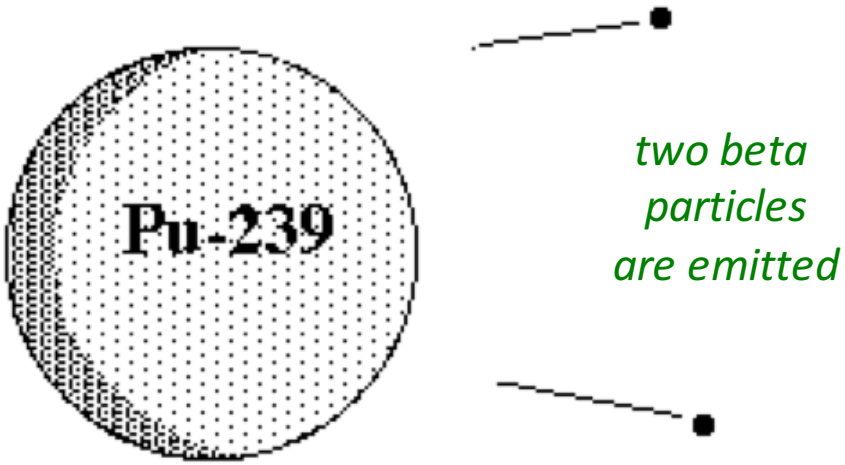
Actinides are heavy elements. They include uranium, thorium, and transuranic elements.

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 aneutron

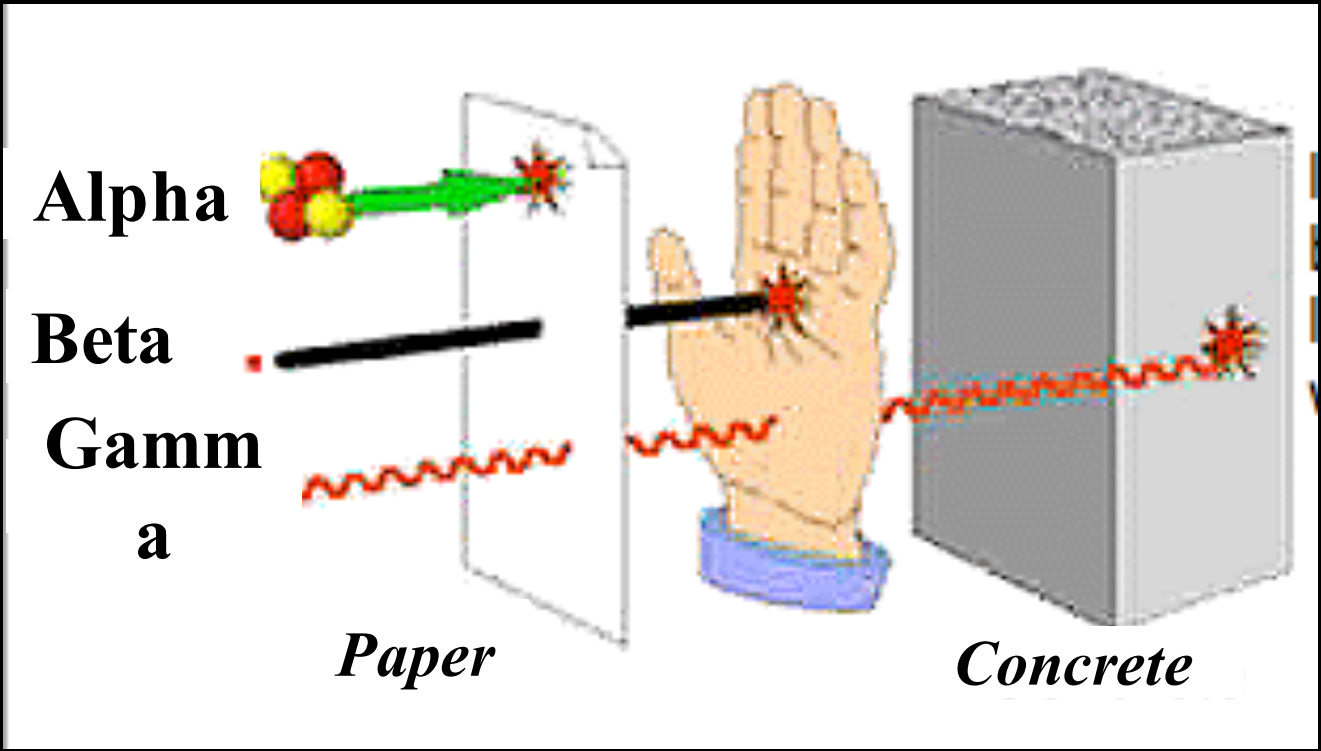


. . . it is transformed into an atom of plutonium-239

Other transuranic actinides are produced in a similar way.

Most actinides are alpha-emitting radioactive materials

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.



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.

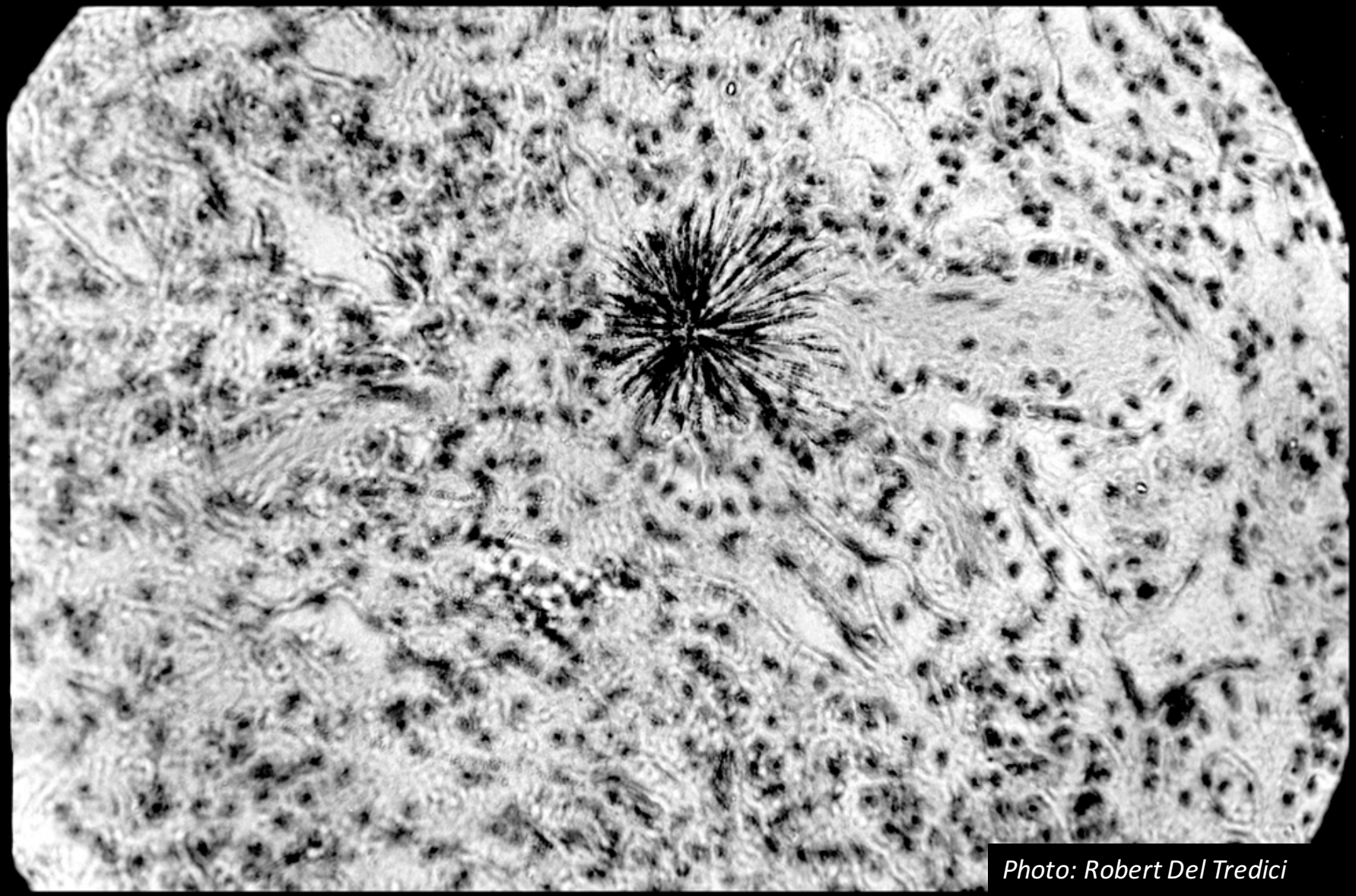
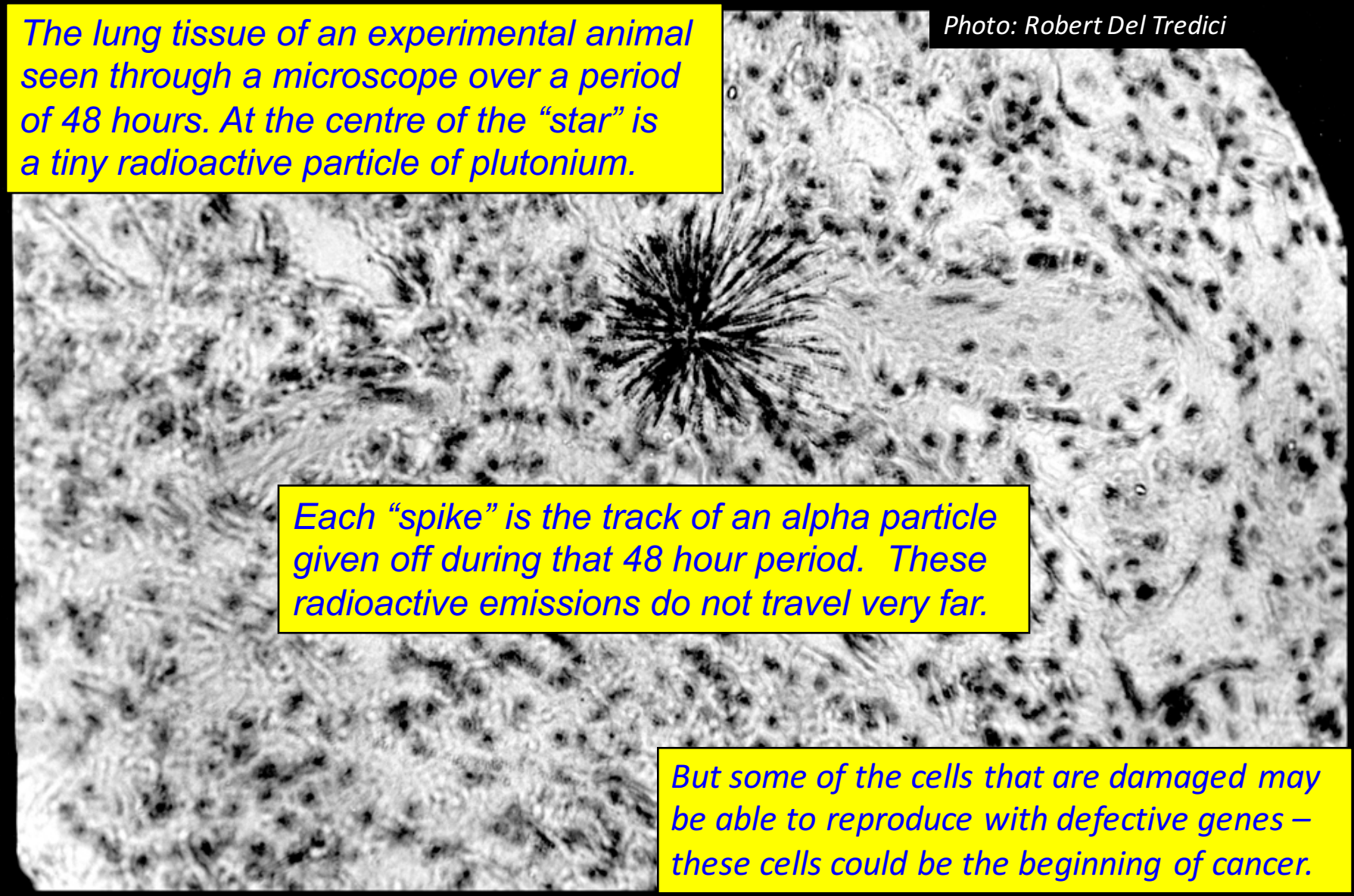


Photo: Robert Del Tredici

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



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.

Photo: Robert Del Tredici

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~

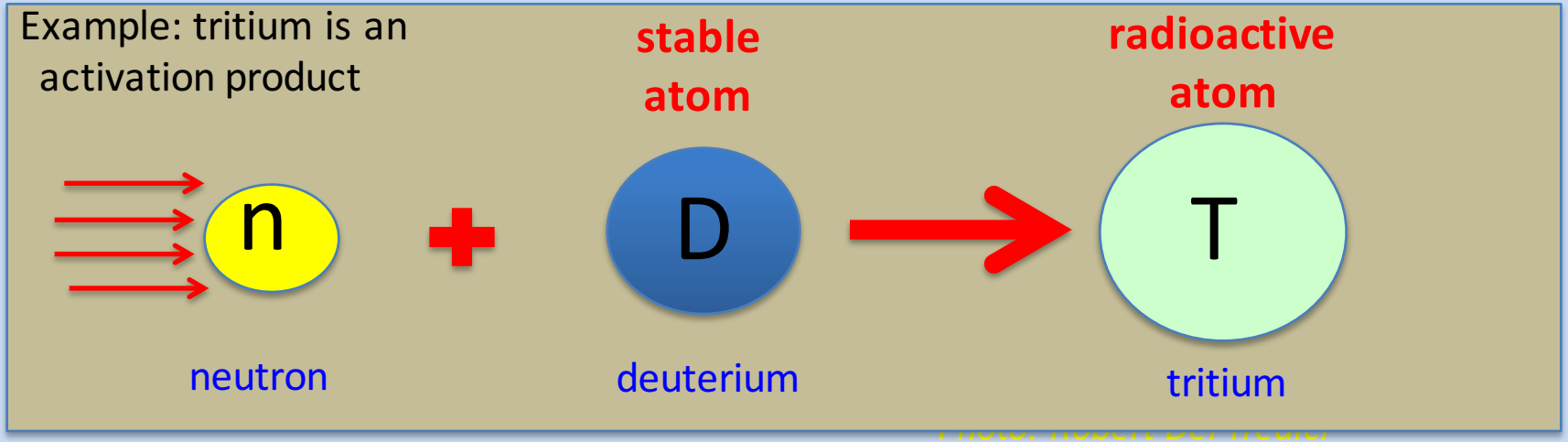
Air and Water

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



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

stable

Hydrogen

stable

Deuterium

unstable (radioactive)

Tritium

an activation product

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.

Splitting of the Atom

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.

Splitting of the Atom

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

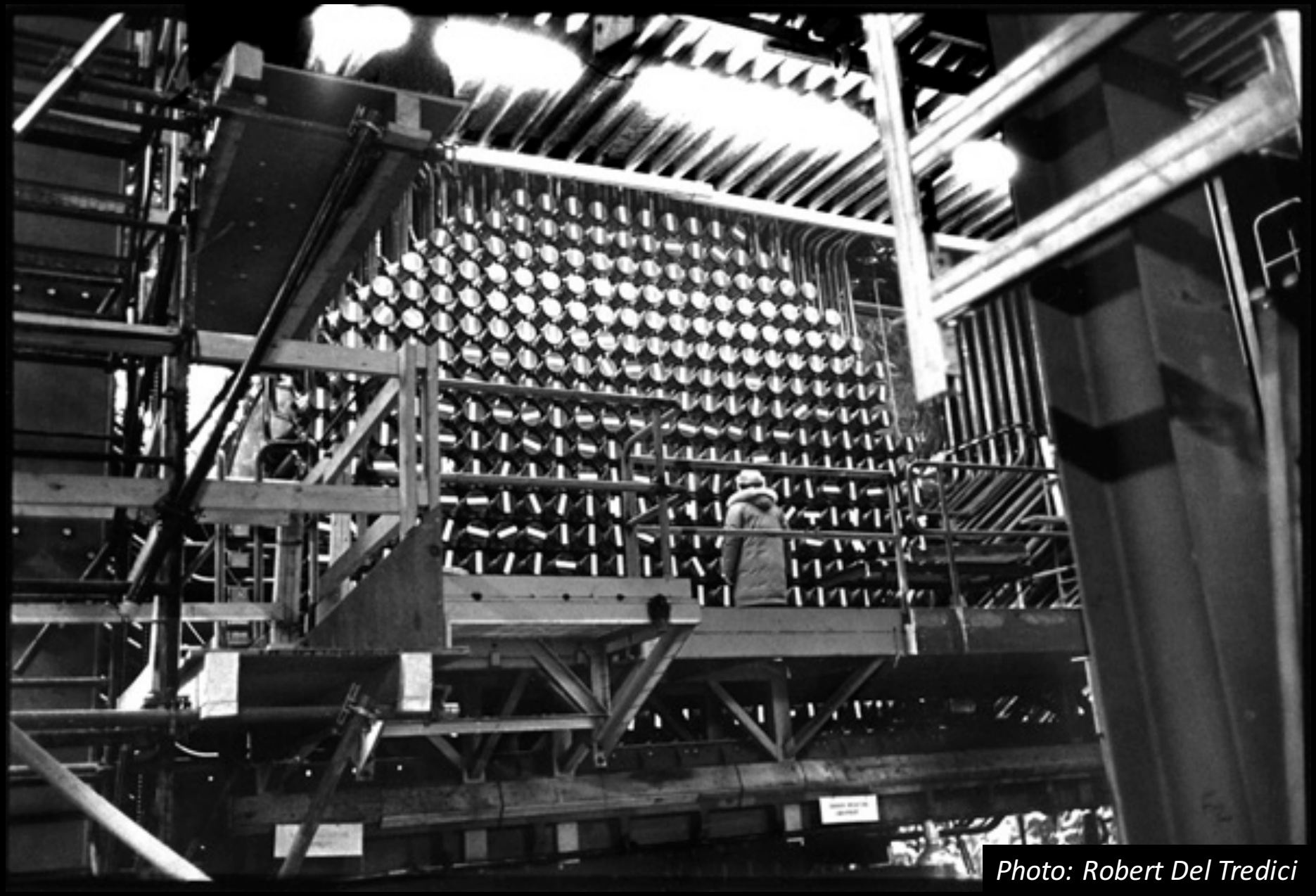


Photo: Robert Del Tredici

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.

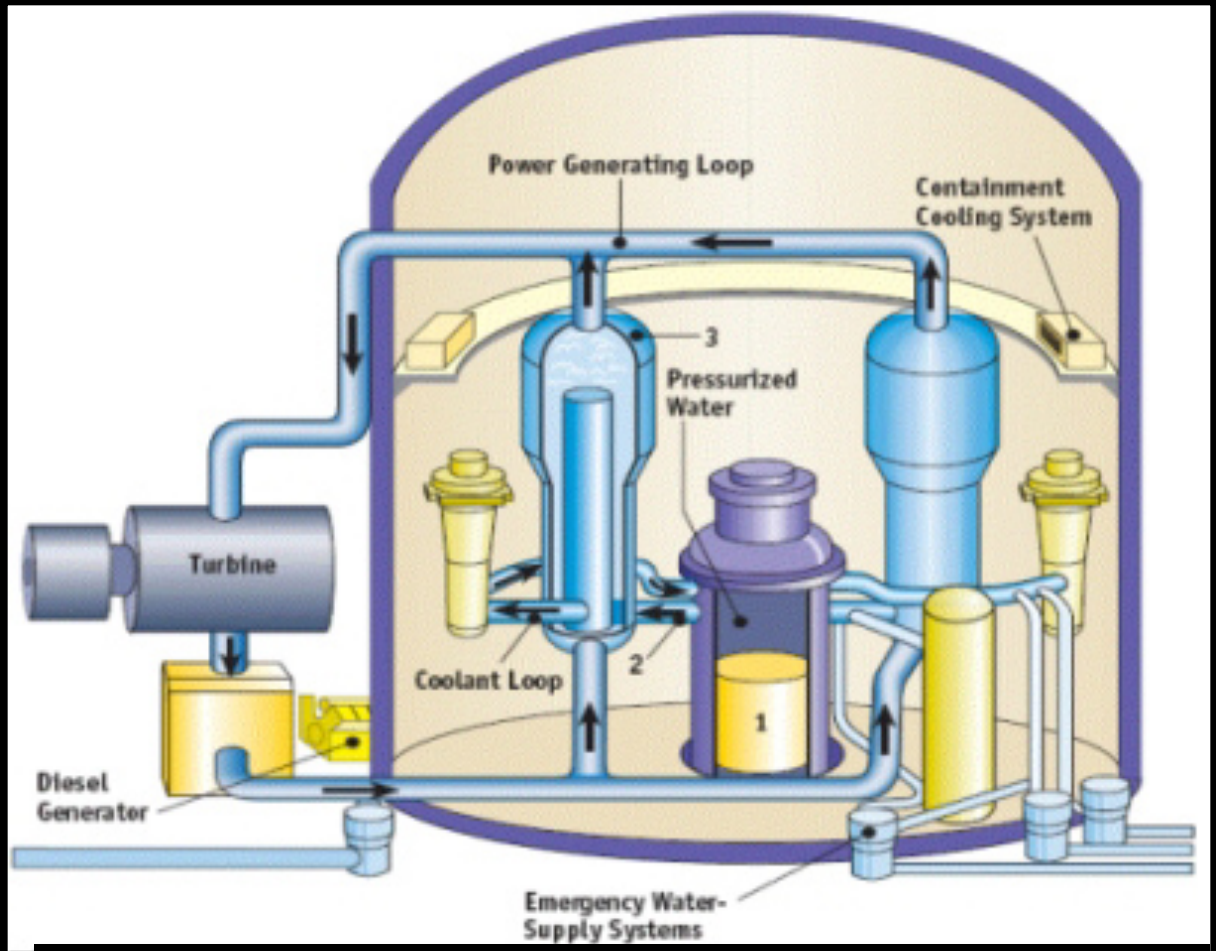
Decommissioning

~ 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.



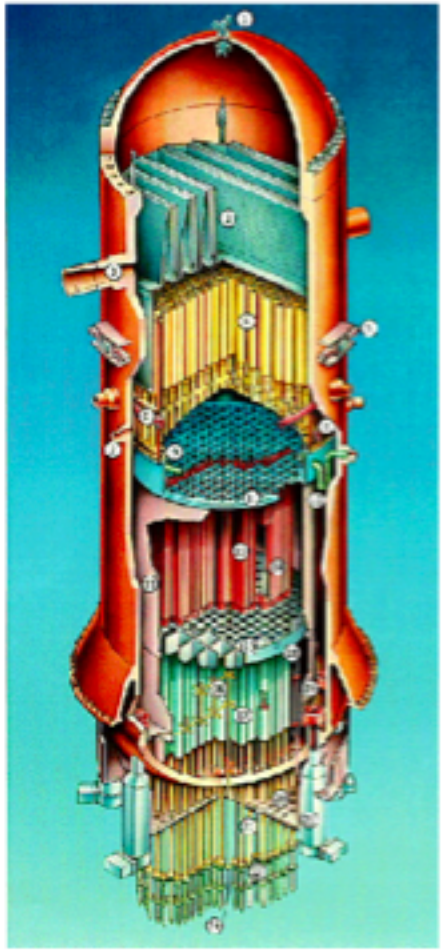
Steel vessels, concrete shields, pipes, boilers, heat exchangers, filters . . .
all these things become "intermediate level" radioactive waste

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).

Why are these tubes radioactive?

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_ReferenceLowandIntermediateWasteInventoryfortheDGR.pdf (p. 50)

For Scientists / Engineers			*For Citizens / Decision Makers*		
Symbol	Half-Life	Amount	Name	Half-Life	Amount
	(y)	(Bq/m3)		(years)	(becquerels per cubic metre)
Ag 108	1.3E+02	2.3E+02	Silver-108	130 y	230
Am-241	4.3E+02	5.9E+07	Americium-241	430 y	59 000 000
Am-243	7.4E+03	3.8E+04	Americium-243	7 400 y	38 000
C-14	5.7E+03	7.6E+07	Carbon-14	5 700 y	76 000 000
Cl-36	3.0E+05	1.4E+04	Chlorine-36	300 000 y	14 000
Cm-244	1.8E+01	1.4E+07	Curium-244	18 y	14 000 000
Co-60	5.3E+00	1.2E+09	Cobalt-60	5.3 y	1 200 000 000
Cs-134	2.1E+00	1.9E+06	Cesium-134	2.1 y	1 900 000
Cs-135	2.3E+06	2.2E+01	Cesium-135	2 300 000 y	22
Cs-137	3.0E+01	2.2E+07	Cesium-137	30 y	22 000 000
Eu-152	1.3E+01	1.8E+06	Europium-152	13 y	1 800 000
Eu-154	8.8E+00	1.6E+07	Europium-154	8.8 y	16 000 000
Eu-155	5.0E+00	3.0E+07	Europium-155	5 y	30 000 000
Fe-55	2.7E+00	5.8E+09	Iron-55	2.7 y	5 800 000 000
I-129	1.6E+07	6.3E+00	Iodine-129	16 000 000 y	6.3
Nb-94	2.0E+04	2.9E+05	Niobium-94	20 000 y	290 000
Ni-59	7.5E+04	2.0E+05	Nickel-59	75 000 y	200 000
Ni-63	9.6E+01	2.9E+07	Nickel-63	96 y	29 000 000
Np-237	2.1E+06	1.8E+03	Neptunium-237	2 100 000 y	1 800
Pu-238	8.8E+01	1.0E+07	Plutonium-238	88 y	10 000 000
Pu-239	2.4E+04	1.2E+07	Plutonium-239	24 000 y	12 000 000
Pu-240	6.5E+03	1.7E+07	Plutonium-240	6 500 y	17 000 000
Pu-241	1.4E+01	5.5E+08	Plutonium-241	14 y	550 000 000
Pu-242	3.8E+05	1.7E+04	Plutonium-242	380 000 y	17 000
Ru-106	1.0E+00	8.4E+08	Ruthenium-106	1 y	840 000 000
Sb-125	2.8E+00	2.1E+07	Antimony-125	2.8 y	21 000 000
Se-79	1.1E+06	7.6E+01	Selenium-79	1 100 000 y	76
Sm-151	1 9E+01	7.6E+01	Samarium-151	19 y	76
Sn-126	2.1E+05	1.2E+02	Tin-126	210 000 y	120
Sr-90	2.9E+01	1.8E+07	Strontium-90	29 y	18 000 000
Tc-99	2.1E+05	2.8E+03	Technetium-99	210 000 y	2 800
U-234	2.5E+05	1.9E+04	Uranium-234	250 000 y	19 000
U-235	7.0E+08	3.2E+02	Uranium-235	700 000 000 y	320
U-236	2.3E+07	3.6E+03	Uranium-236	23 000 000 y	24 000
U-238	4.5E+09	2.4E+04	Uranium-238	4 500 000 000 y	24 000
Zr-93	1.5E+06	3.8E+02	Zirconium-93	1 500 000 y	380
TOTALS					
Long half-lives only (> 1 y)		**8.7E+09**	**Long-lived only (> 1 y half-life)**		**8 700 000 000**
Including short half-lives		**1.6E+10**	**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.

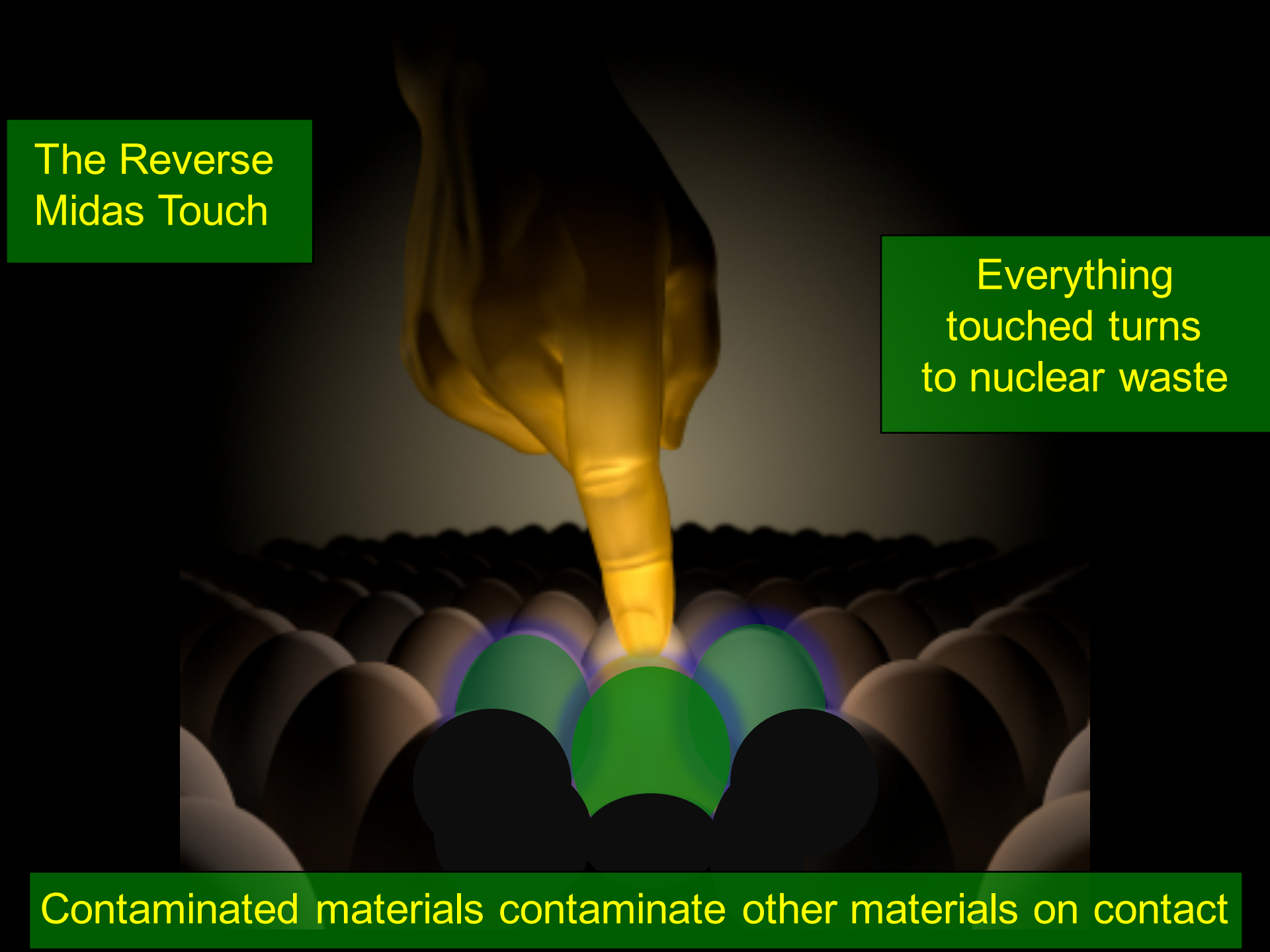
RADIONUCLIDE		***MASS***	
Name of Isotope (with Atomic Mass)	Half-Life (years)	Unit 1 (grams radioactive material)	Unit 2 (grams radioactive material)
Americium-241	430 y	0.103412	0.102412
Americium-243	7 400 y	0.002162	0.002432
Carbon-14	5 700 y	0.009065	0.072501
Curium-244	18 y	0.002644	0/000347
Cobalt-60	5.3 y	0.001781	0/000881
Cesium-137	30 y	0/000249	0.000238
Europium-154	8.8 y	0.000027	0.000290
Iron-55	2.7 y	0.000272	0.000290
Hydrogen-3 (Tritium)	13.0 y	0.000057	0.000051
Hafnium-181	2.7 y	0.000001	0.000001
Iodine-129	17 000 000 y	0.000060	0.000060
Niobium-94	20 000 y	0.002159	0.002158
Nickel-59	75 000 y	0.173601	0.036723
Nickel-63	96 y	0.030194	0.006526
Neptunium-237	2 100 000 y	0.028703	0.033295
Plutonium-238	*88 y*	*0.007507*	*0.004703*
Plutonium-239	*24 000 y*	*2.124977*	*2.471769*
Plutonium-240	*6 500 y*	*0.827304*	*0.957105*
Plutonium-241	*14 y*	*0.021309*	*0.030809*
Plutonium-242	*380 000 y*	*0.048762*	*0.056317*
Antimony-125	2.8 y	0.000001	0.000001
Strontium-90	29 y	0.009097	0.007581
Technetium-99	210 000 y	0.000143	0.000092
TOTALS			
Long-lived (> one year half-life)		**3.416108**	**3.787315**
Mass of plutonium isotopes only		**3.029859**	**3.520703**
Percent plutonium		**88.7%**	**93.0%**
TOTAL MASS			

(Source: CNSC)

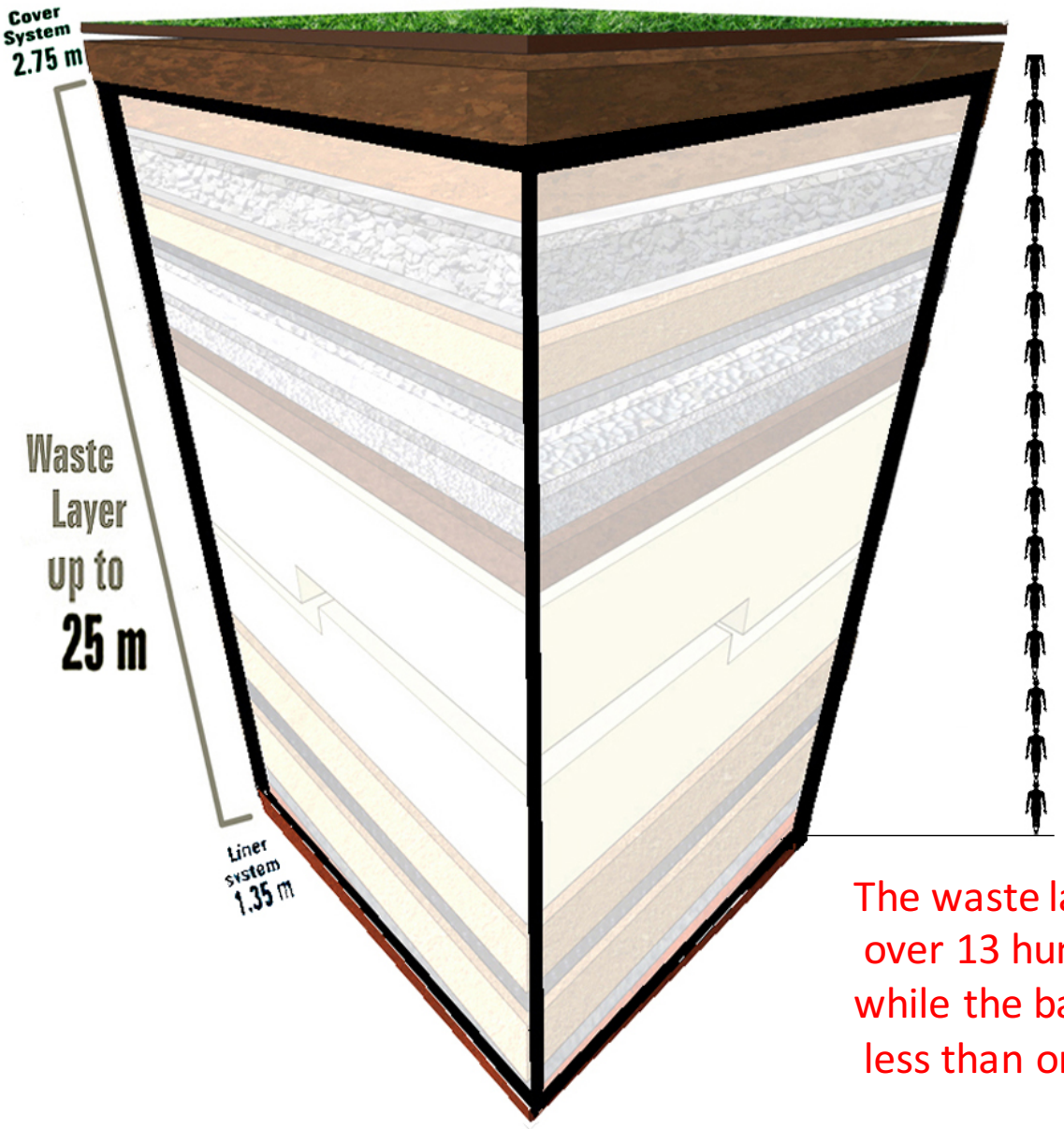
There are 5 plutonium isotopes present in the steam generators. In addition there are 18 other long-lived isotopes listed.

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.



total height
= 95 feet
= 29 metres

total height is
almost 16 humans,
each six feet tall.

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

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** ?

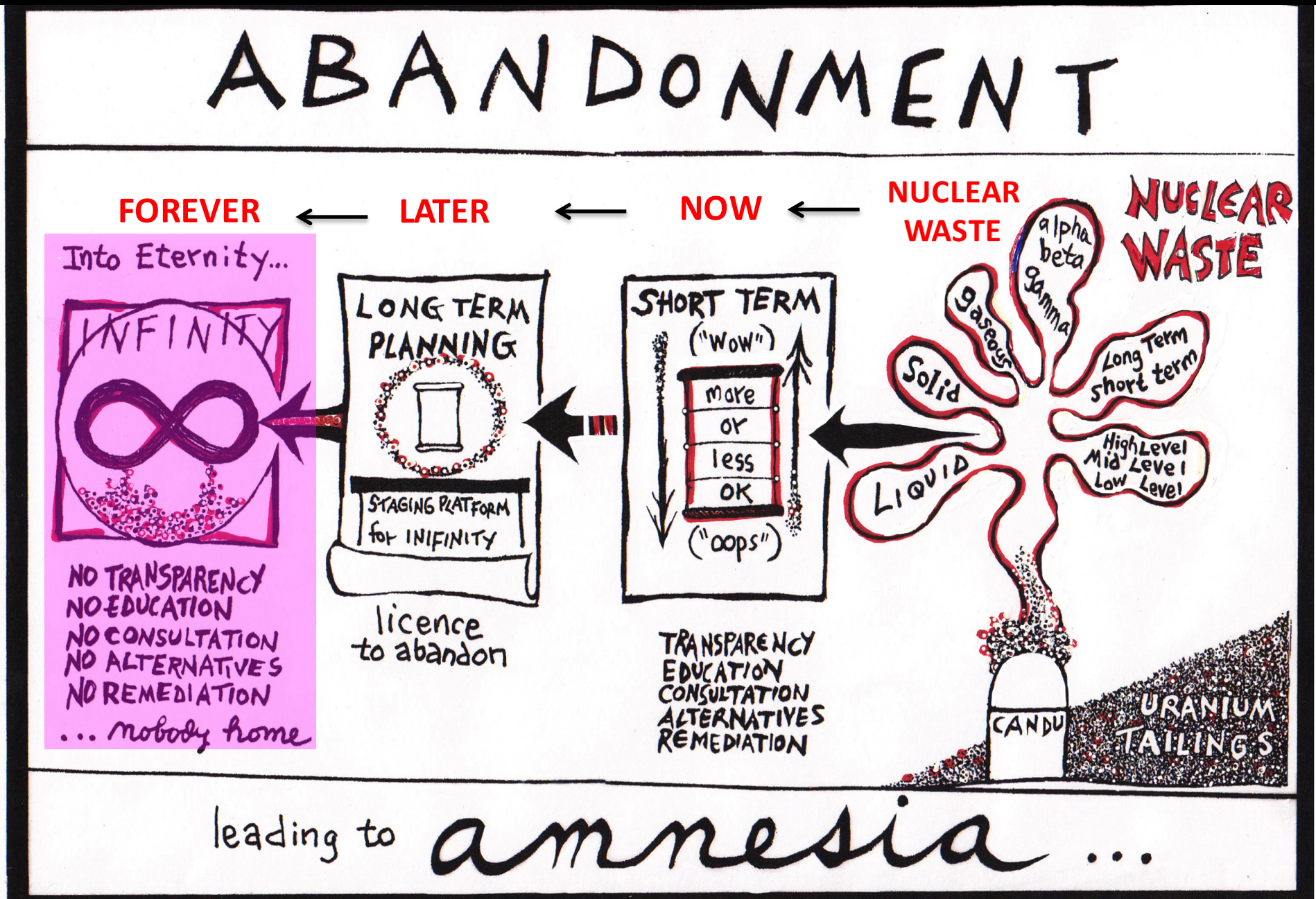
NO

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 !

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.

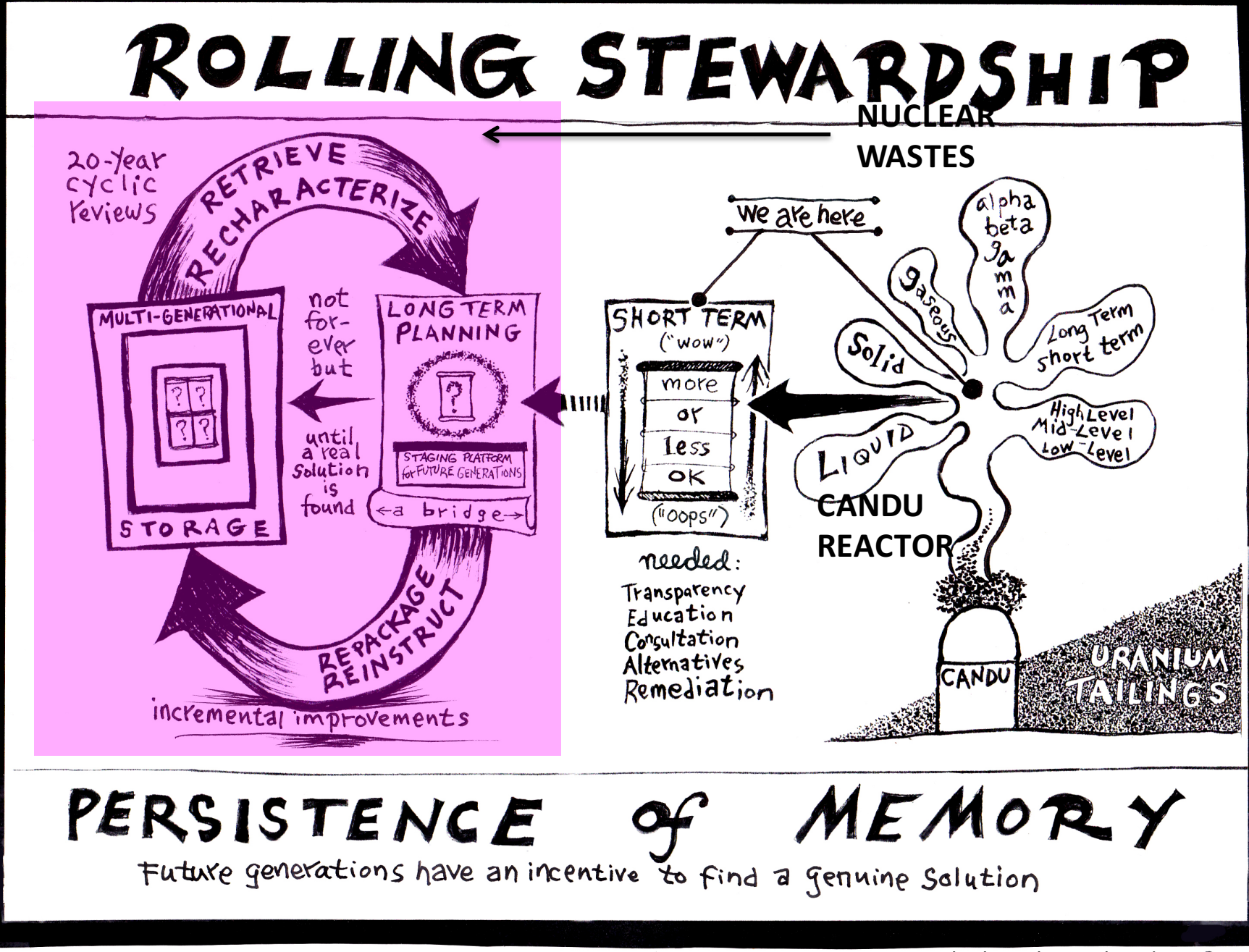
Wastes are **packaged safely** for extended periods & **repackaged later**.

*This is not a solution – but it is an **ethical waste management scheme**.*

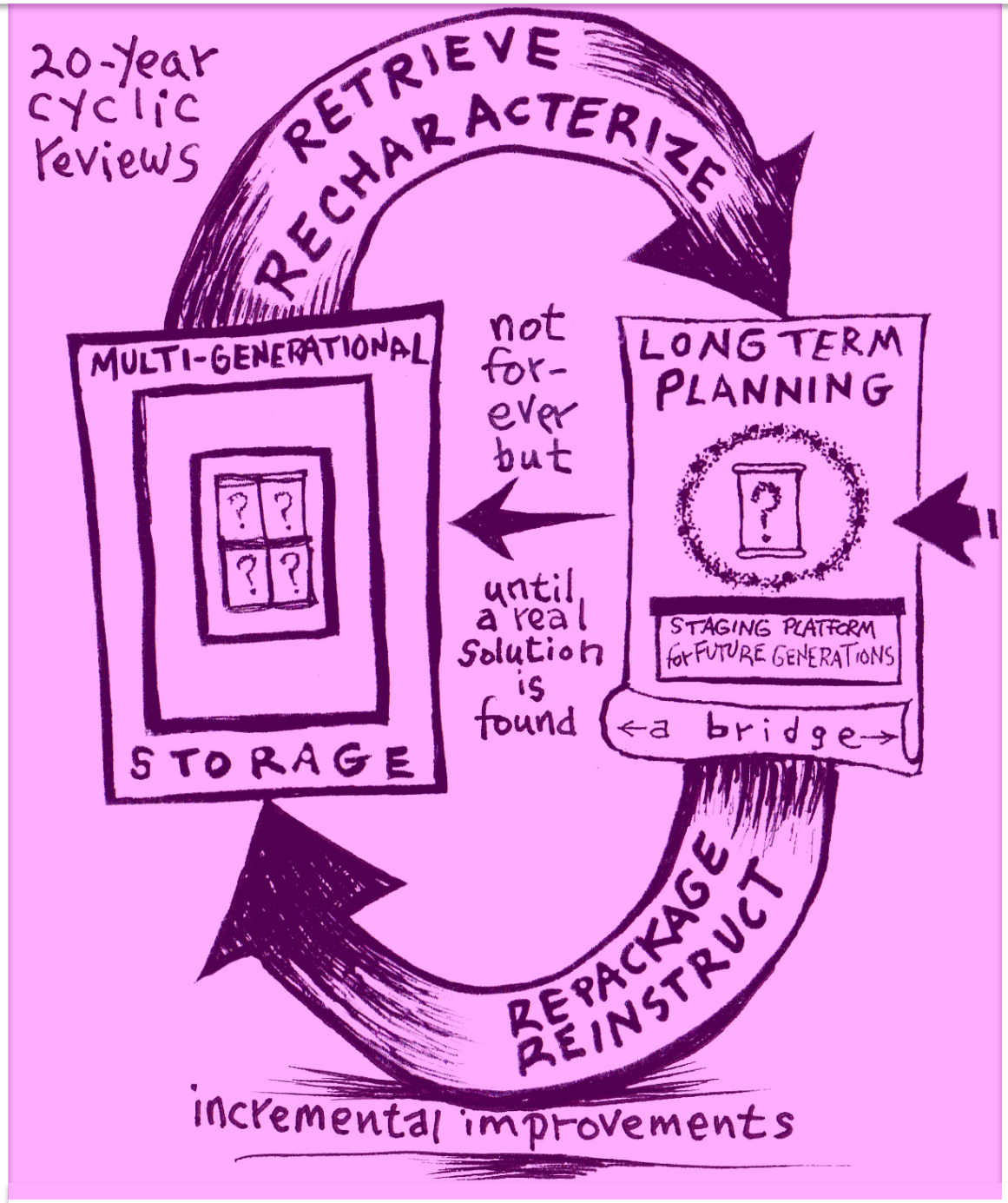
Rolling Stewardship is needed **until a "genuine solution" is found**.

The production of additional wastes can & should be stopped.

Rolling Stewardship is continuous; it is based on ensuring Persistence of Memory



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 must be

independent

of the nuclear industry.

graphic by Robert Del Tredici

ROLLING STEWARDSHIP

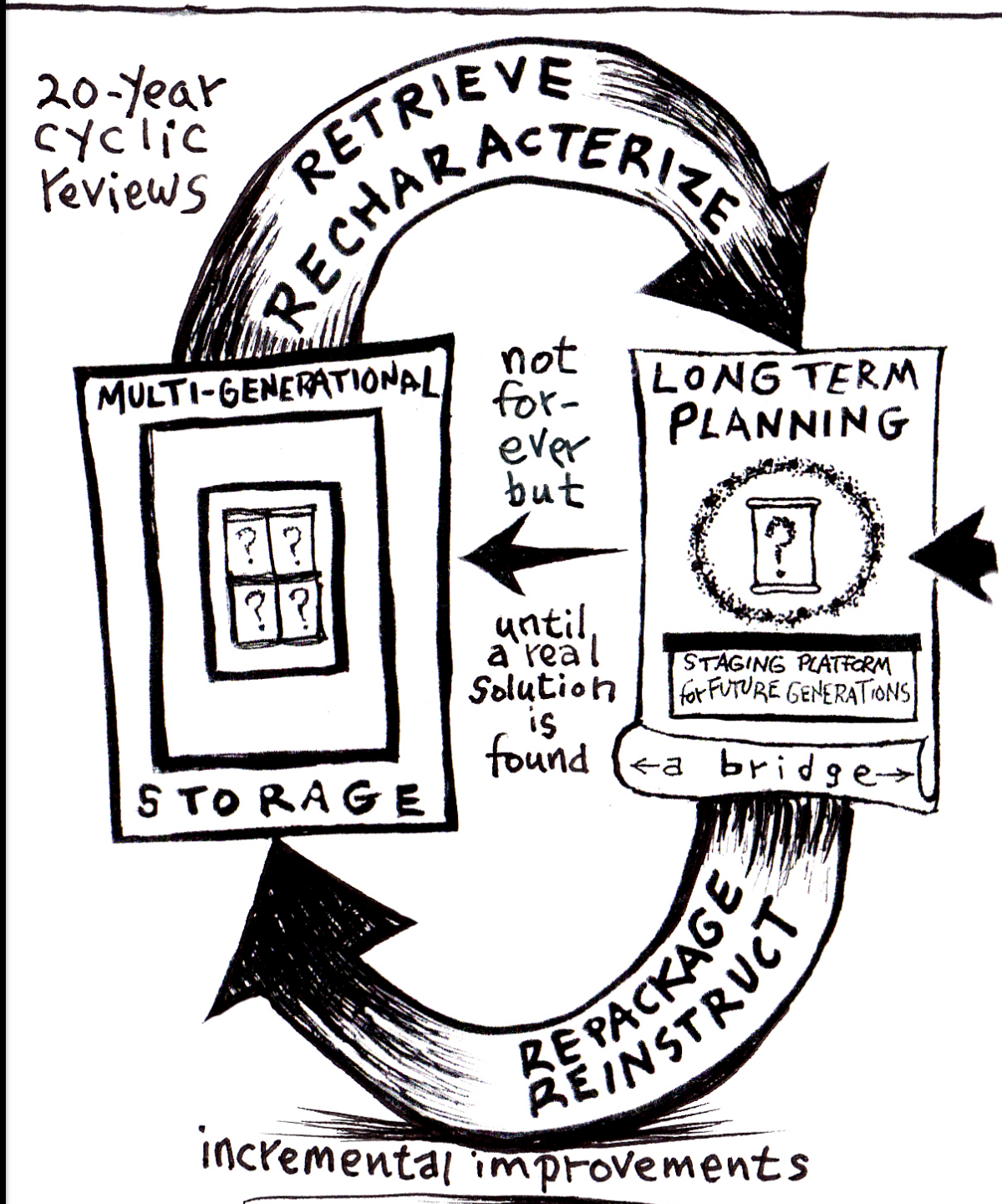


Photo: Robert Del Tredici

The End

ccnr@web.ca