The Age of Nuclear Waste:
From Fukushima to Indian Point

A Slide Show

prepared for
the Fukushima Anniversary
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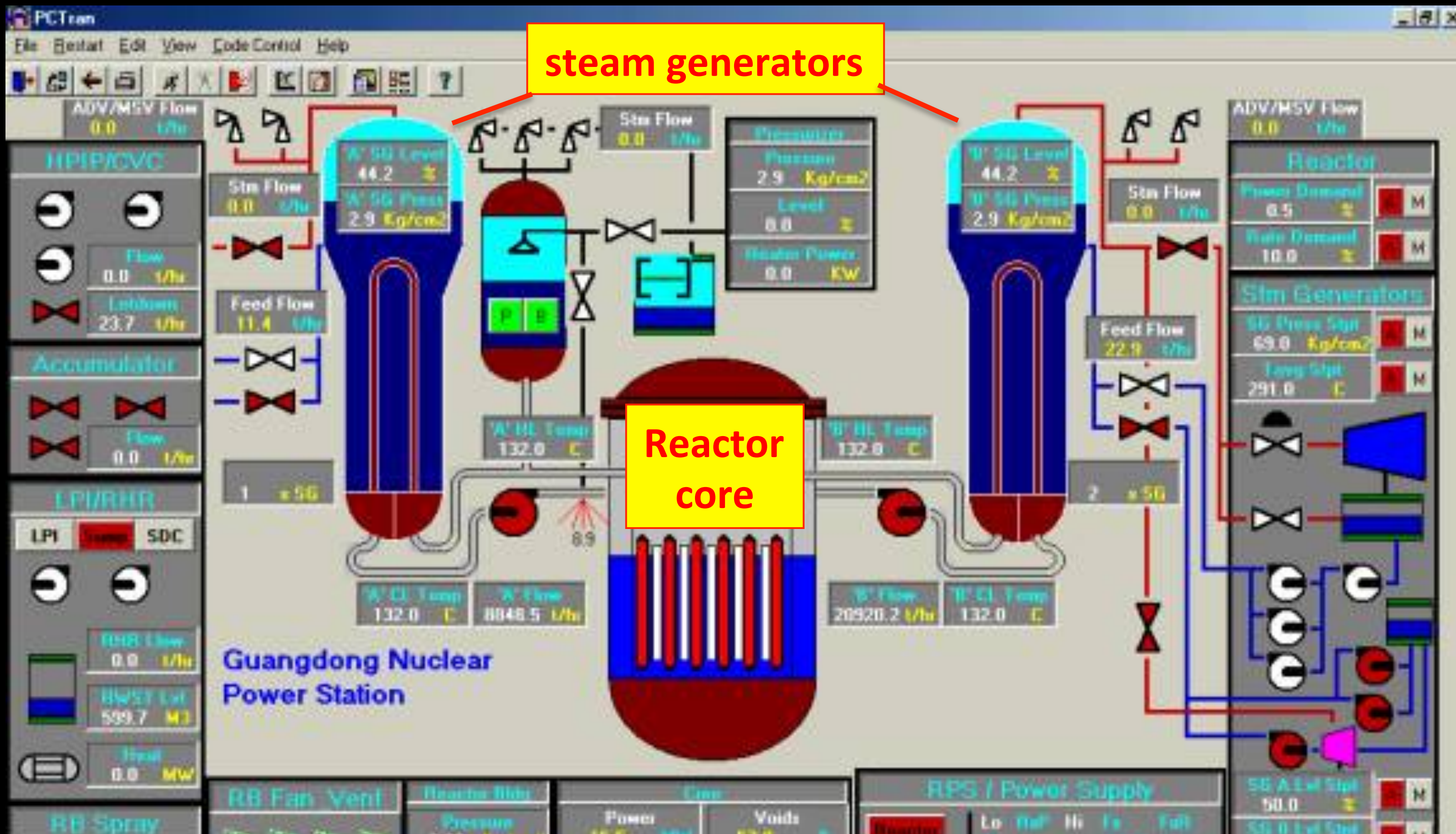
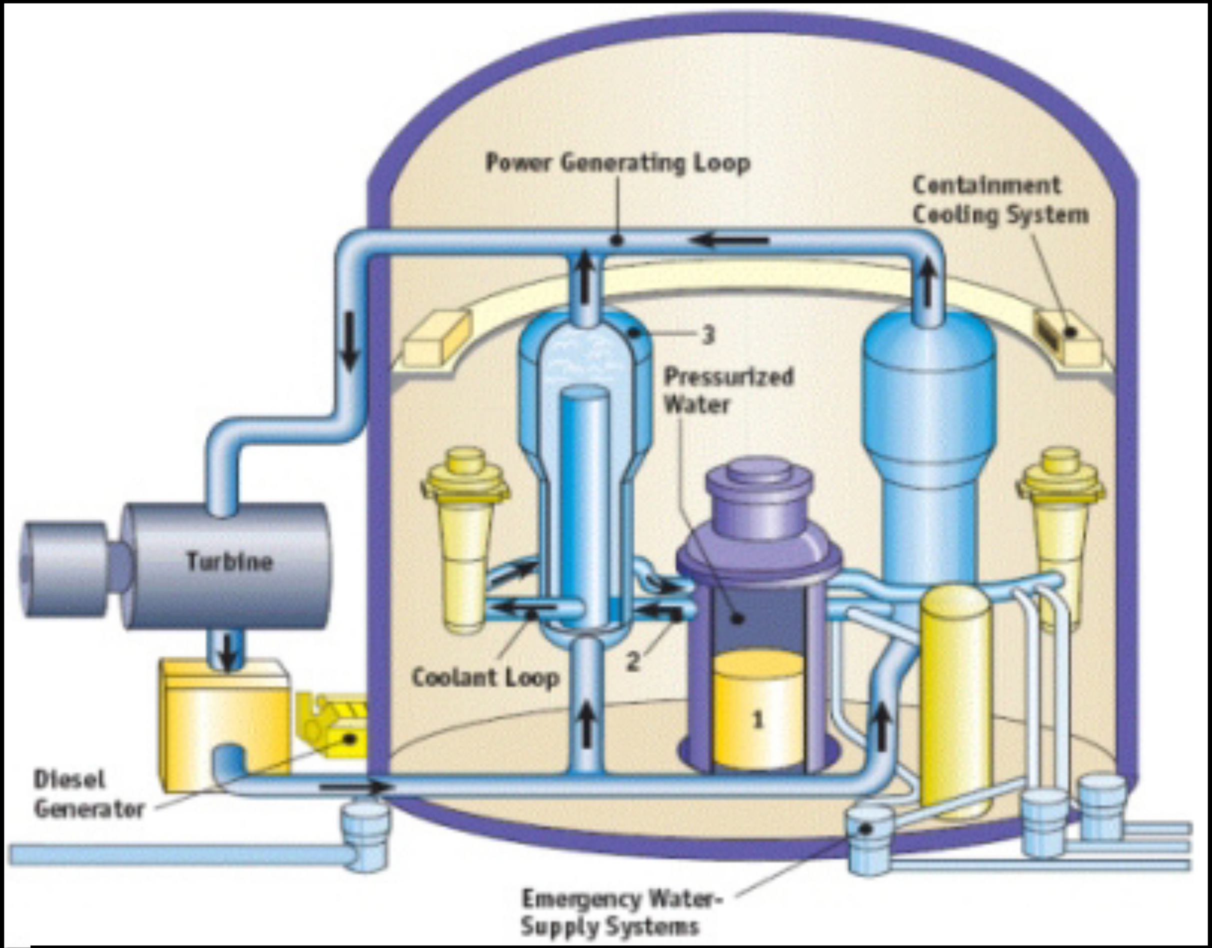
The Indian Point Nuclear Reactors:
"The Age of Nuclear Power is Winding Down
but the Age of Nuclear Waste is Just Beginning"

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***.

So: the only permanent output of a nuclear reactor is
hazardous nuclear waste that lasts millions of years . . .



. . . electricity is just a temporary byproduct (for a few short decades)

Why is nuclear fuel waste so 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 used nuclear fuel is called “High Level Waste”

High Level Nuclear Waste (HLW) refers only to :

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

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 exchange of electrons . . .

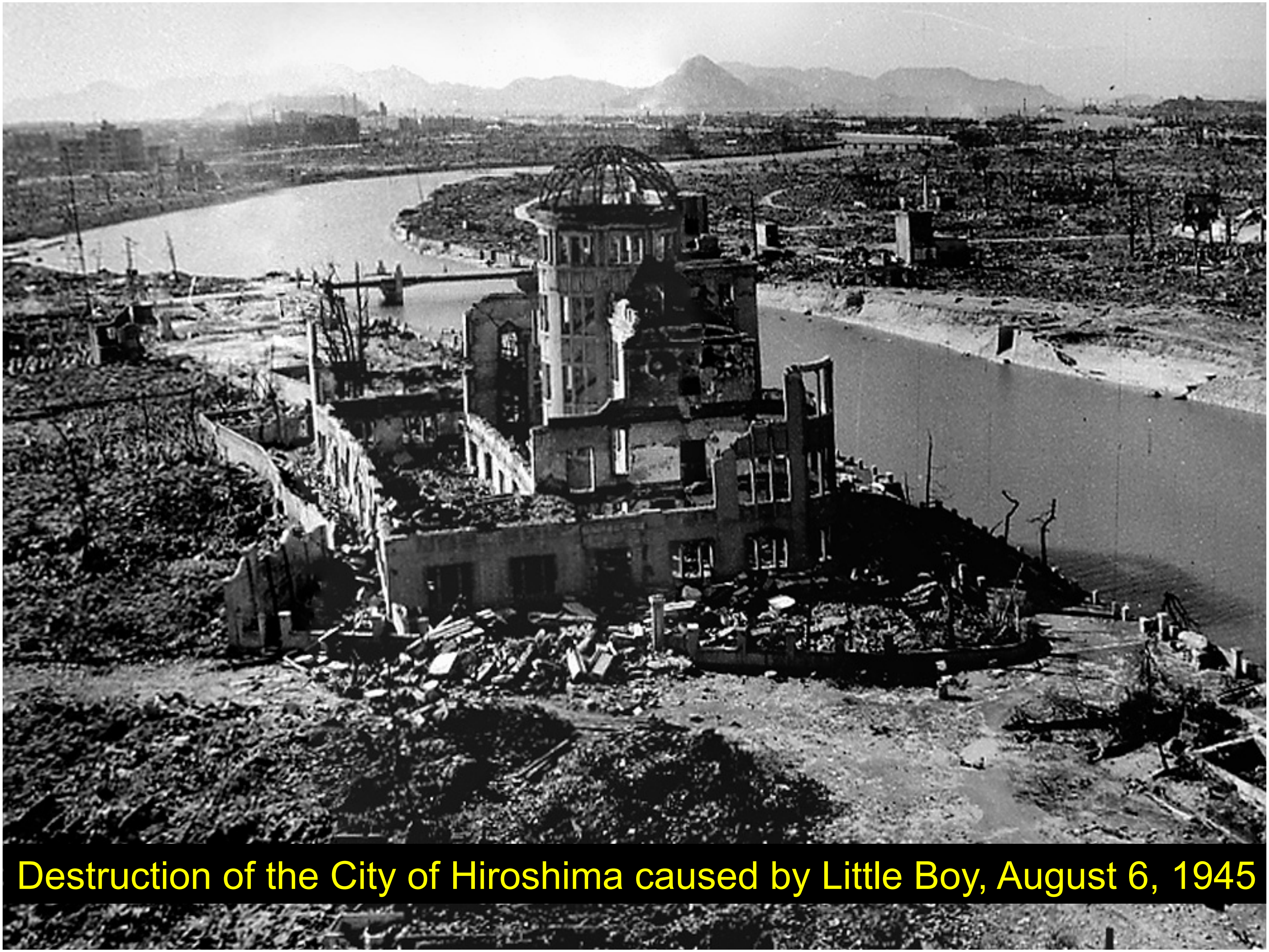

Battlefield explosion


Forest fire

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


H-Bomb Blast

NUCLEAR ENERGY:
ONLY 78 YEARS
OF SCIENTIFIC
EXPERIENCE !



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

TWO types of nuclear energy need to be understood:

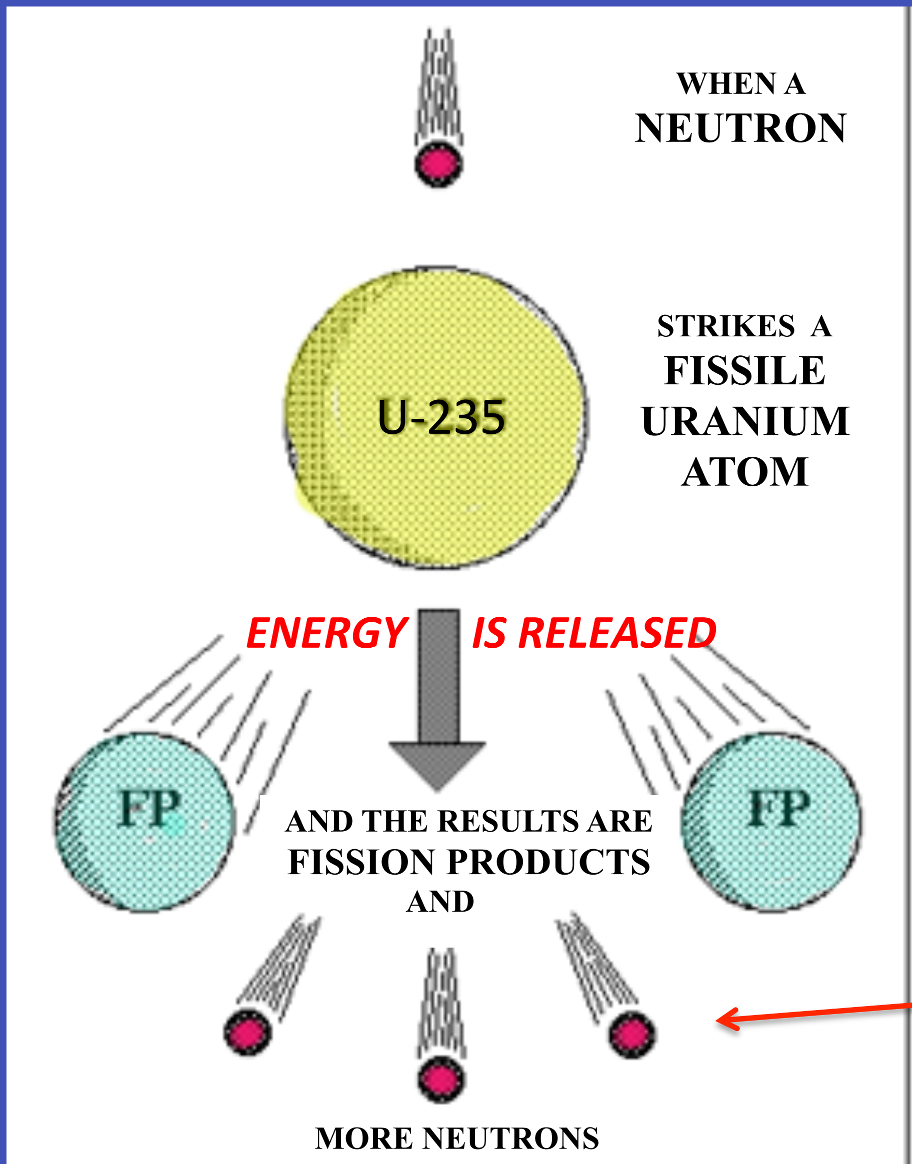
1. **NUCLEAR FISSION** –
   the nucleus is “split” by neutrons
   (nuclear bombs & nuclear reactors)
   DISCOVERED : DEC 1938 – JAN 1939

2. **RADIOACTIVITY** –
   the nucleus spontaneously “disintegrates”
   (“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.

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.

What are Fission Products?

Photo: Robert Del Tredici

Russian monument to the Splitting of the Atom

Fission Products are broken pieces of split atoms (shown here as hemispheres)

There are hundreds of different kinds of FP – all of them fiercely radioactive

What are Fission Products?

Fission products are unwanted byproducts of fission.

They are millions of times more radioactive than fresh fuel.

Unlike the nuclear chain reaction, based on the nuclear fission process, radioactivity cannot be shut off.

That's why we have a nuclear waste problem.

For the first 500 – 1000 years, the fission products are the most significant component of nuclear fuel waste.

What is Radioactivity?

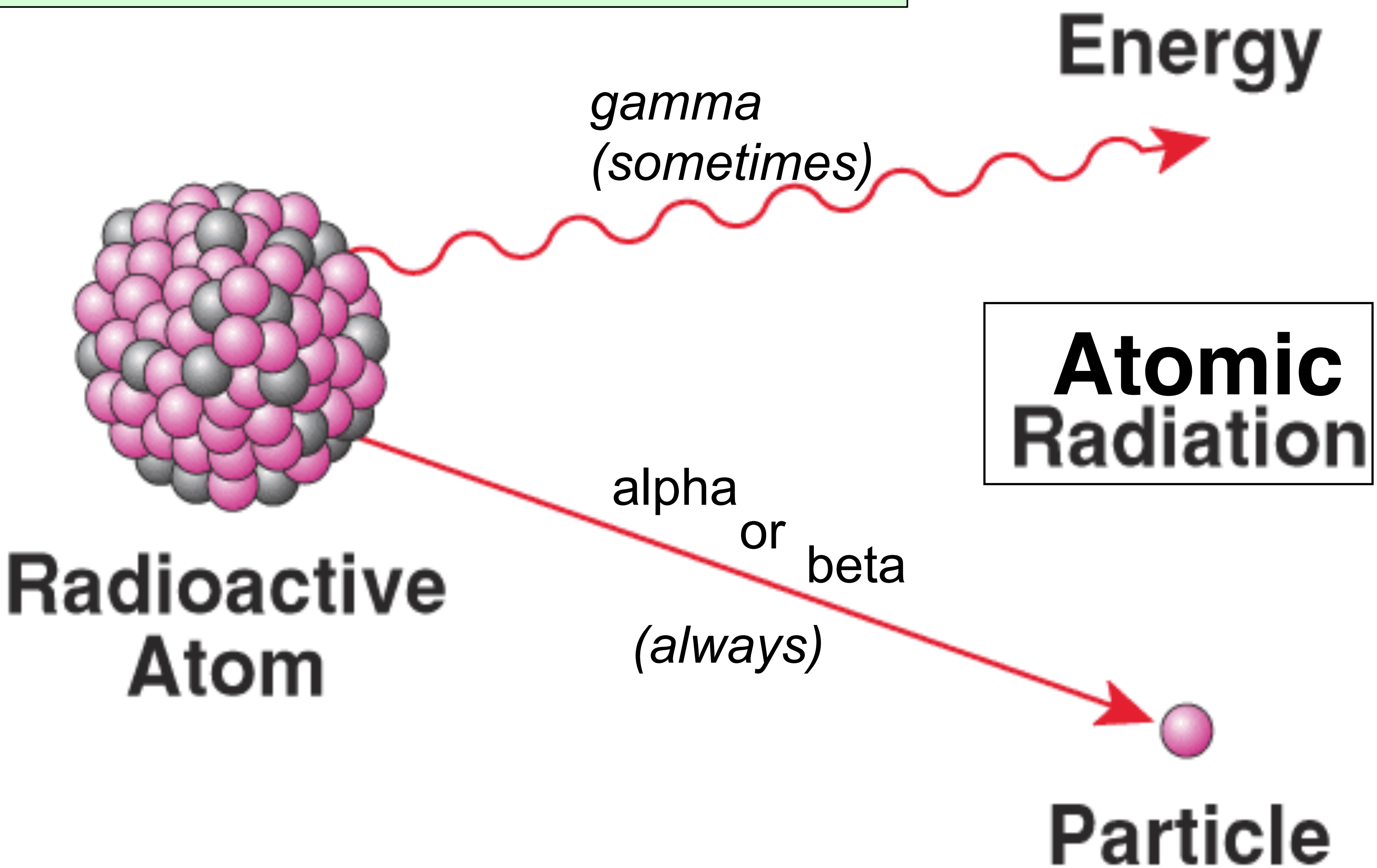
Radioactivity is

a form of nuclear energy

that cannot be shut off or slowed down.

RADIOACTIVITY is the spontaneous disintegration of an unstable nucleus, giving off highly energetic emissions that are able to break chemical bonds.

What is Atomic Radiation?



What is Atomic Radiation?

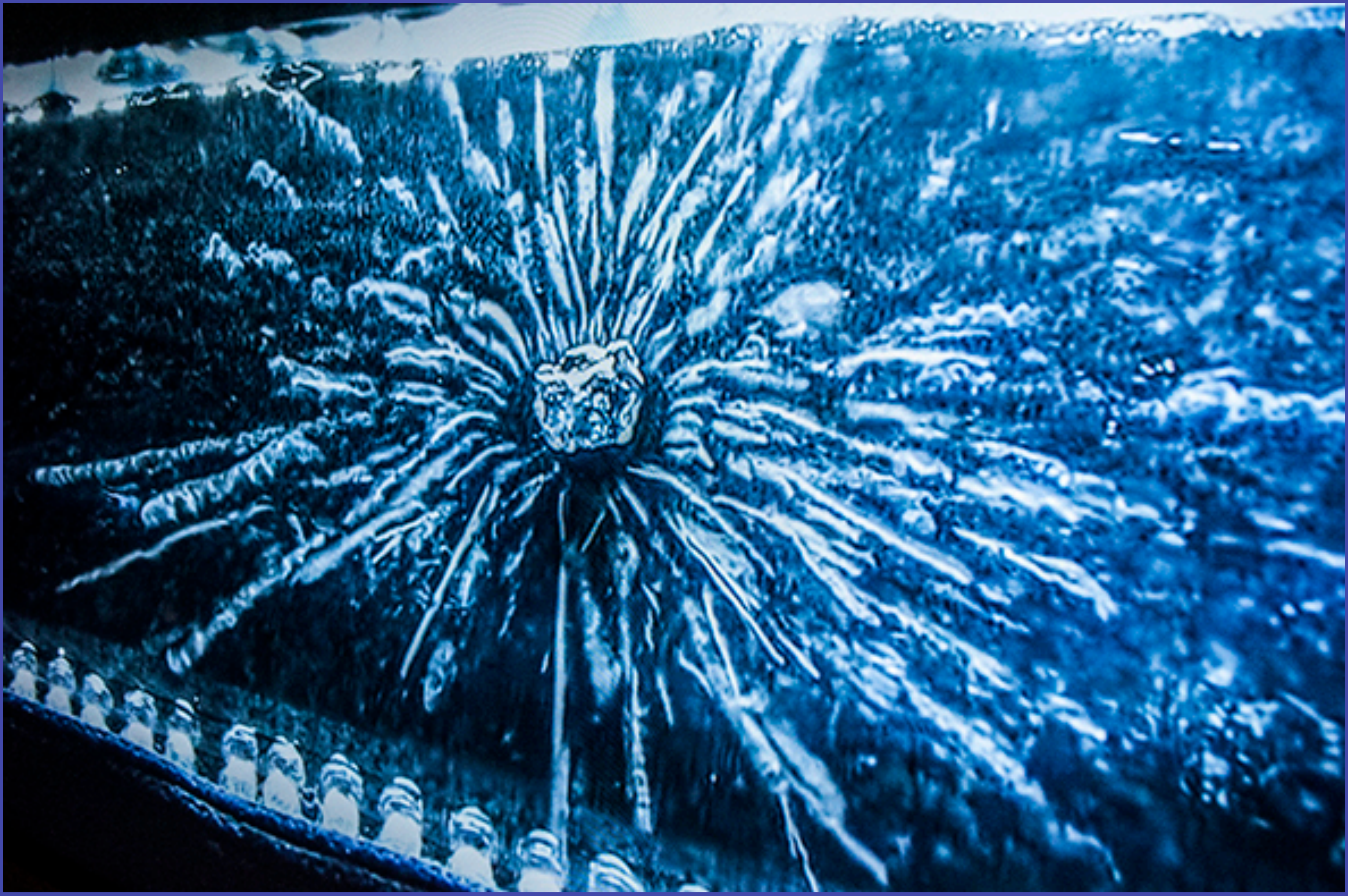
A gamma ray is like an x-ray, but more powerful.
highly penetrating

A beta particle is like a sub-atomic bullet.
moderately penetrating

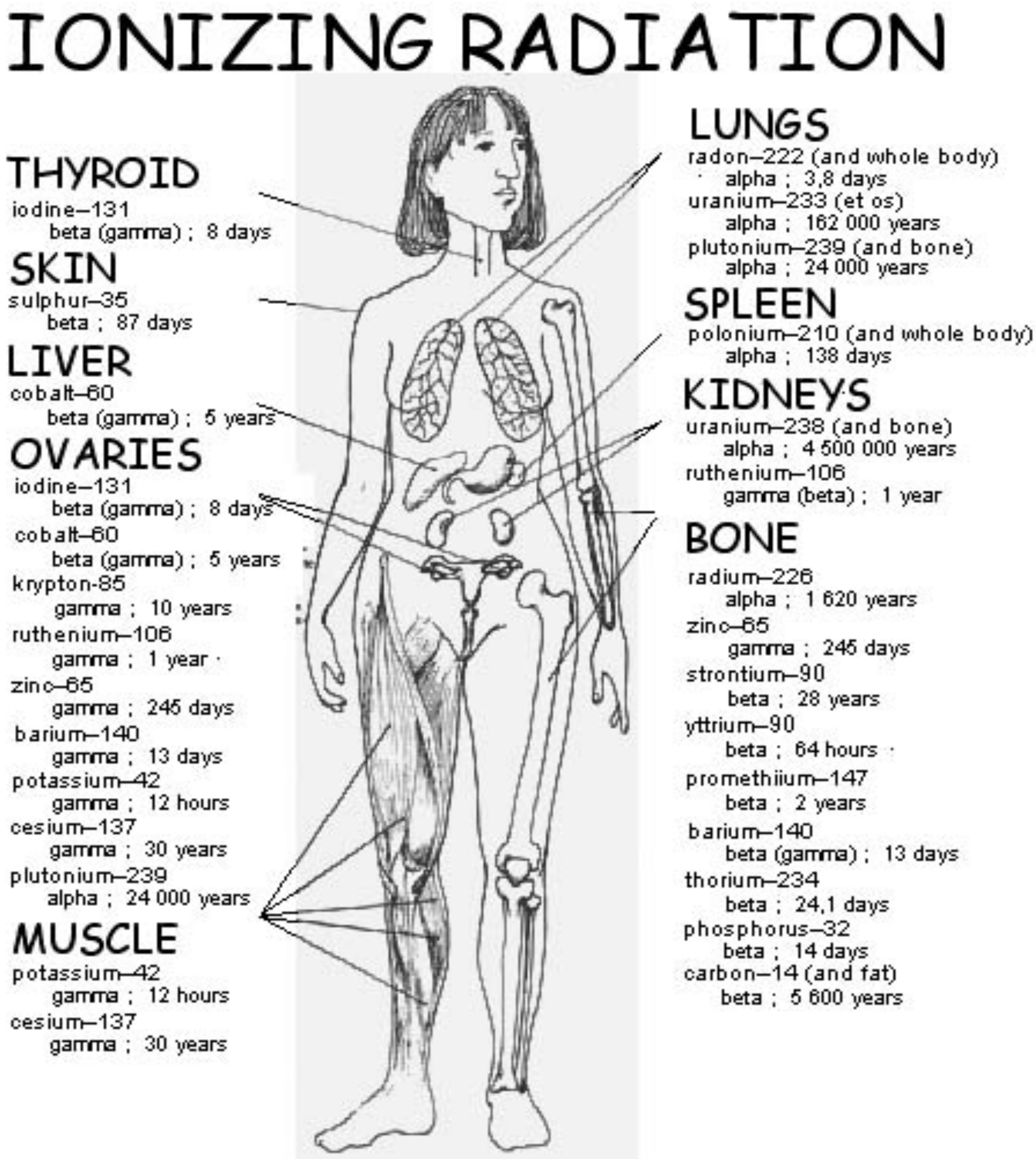
An alpha particle is like a subatomic cannon ball.
only slightly penetrating, but extremely damaging

Alpha and Beta particles are INTERNAL hazards.

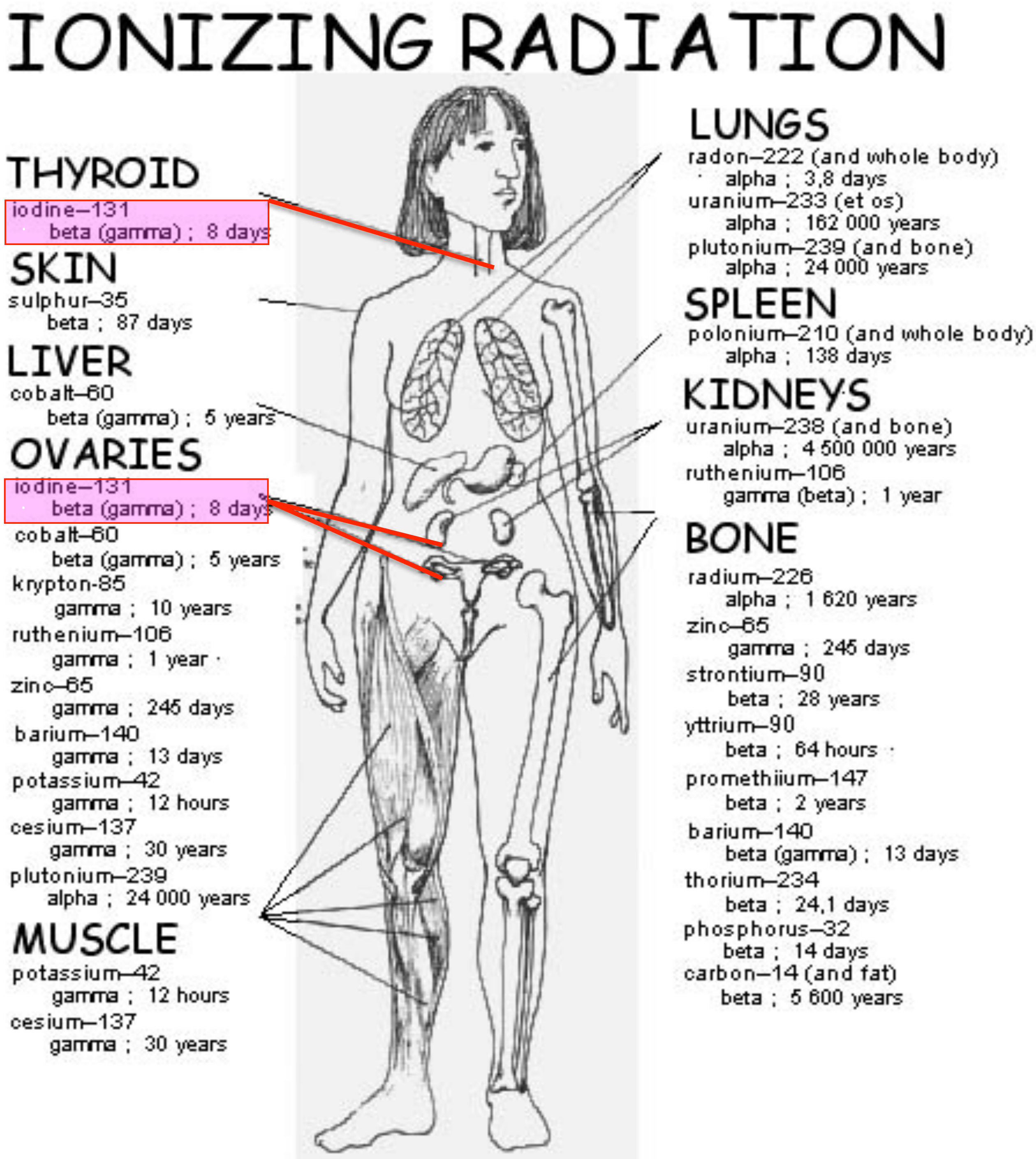
Alpha, Beta, and Gamma “rays” are normally invisible



But in a “cloud chamber” you can see the tracks of all 3 types of emissions from uranium ore



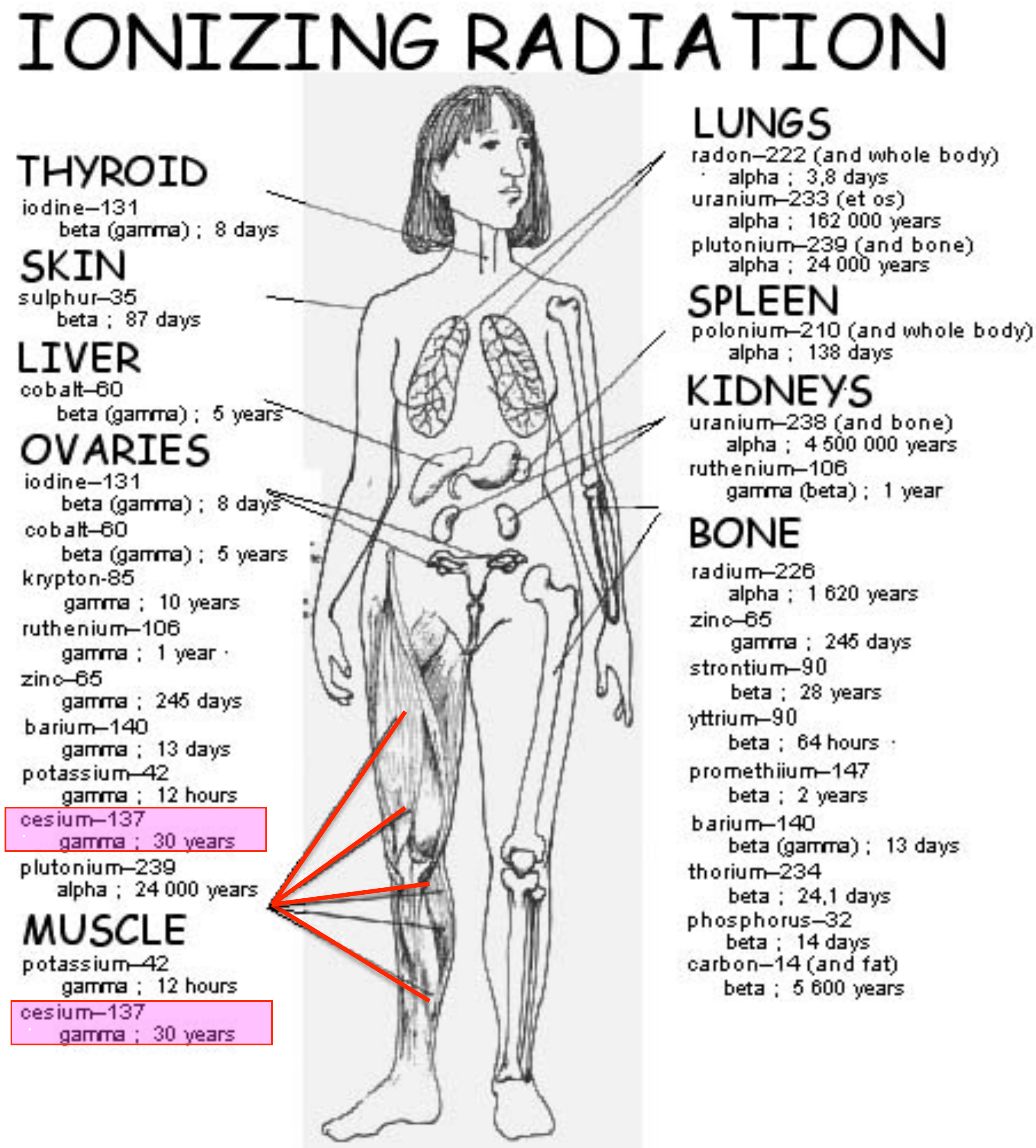
Fission Products are chemical substances which are also radioactive.

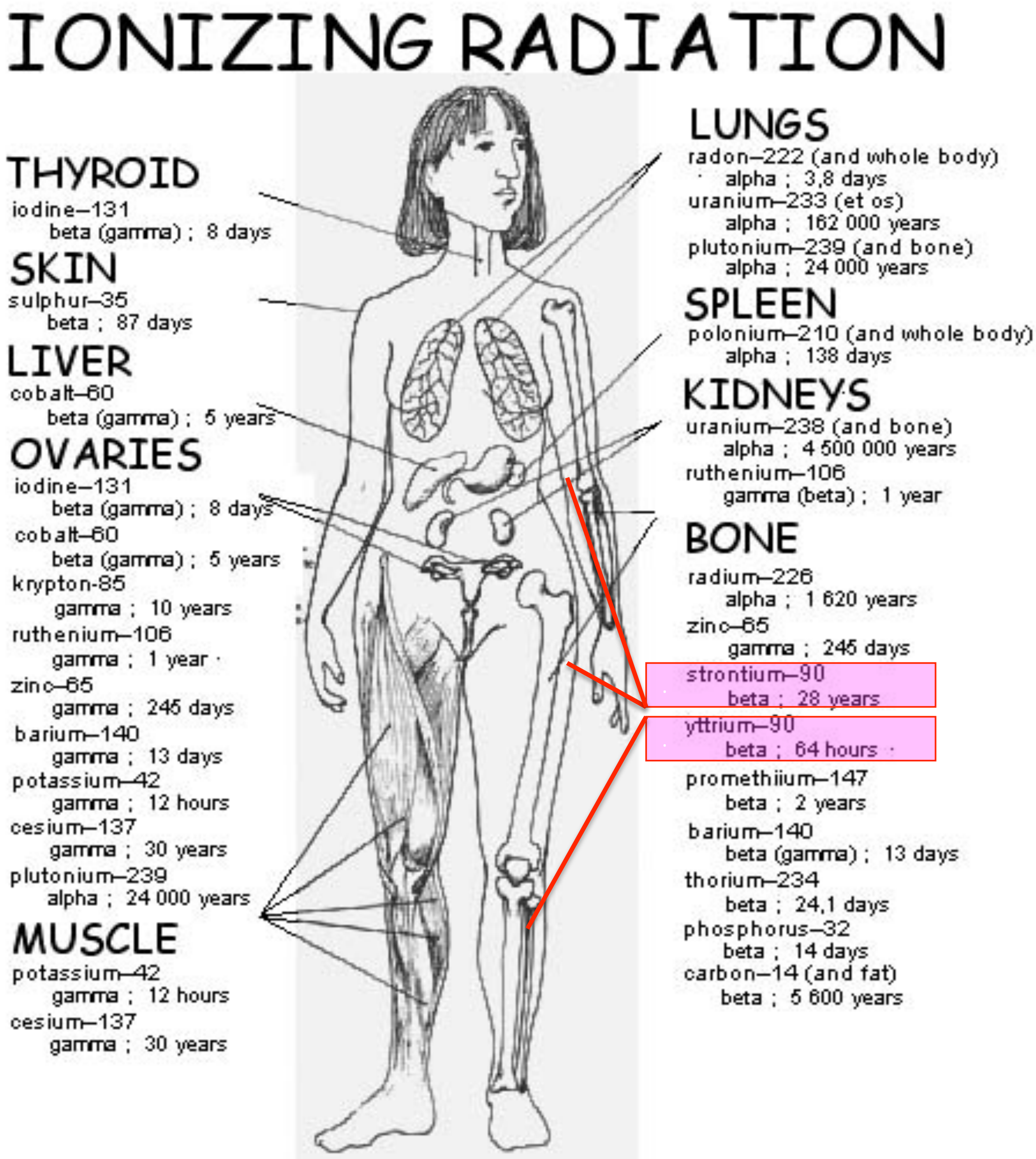


Iodine-131 goes to the thyroid gland (in the throat) and damages it.

Cesium-137 goes to the soft tissues

(makes meat unfit as food)





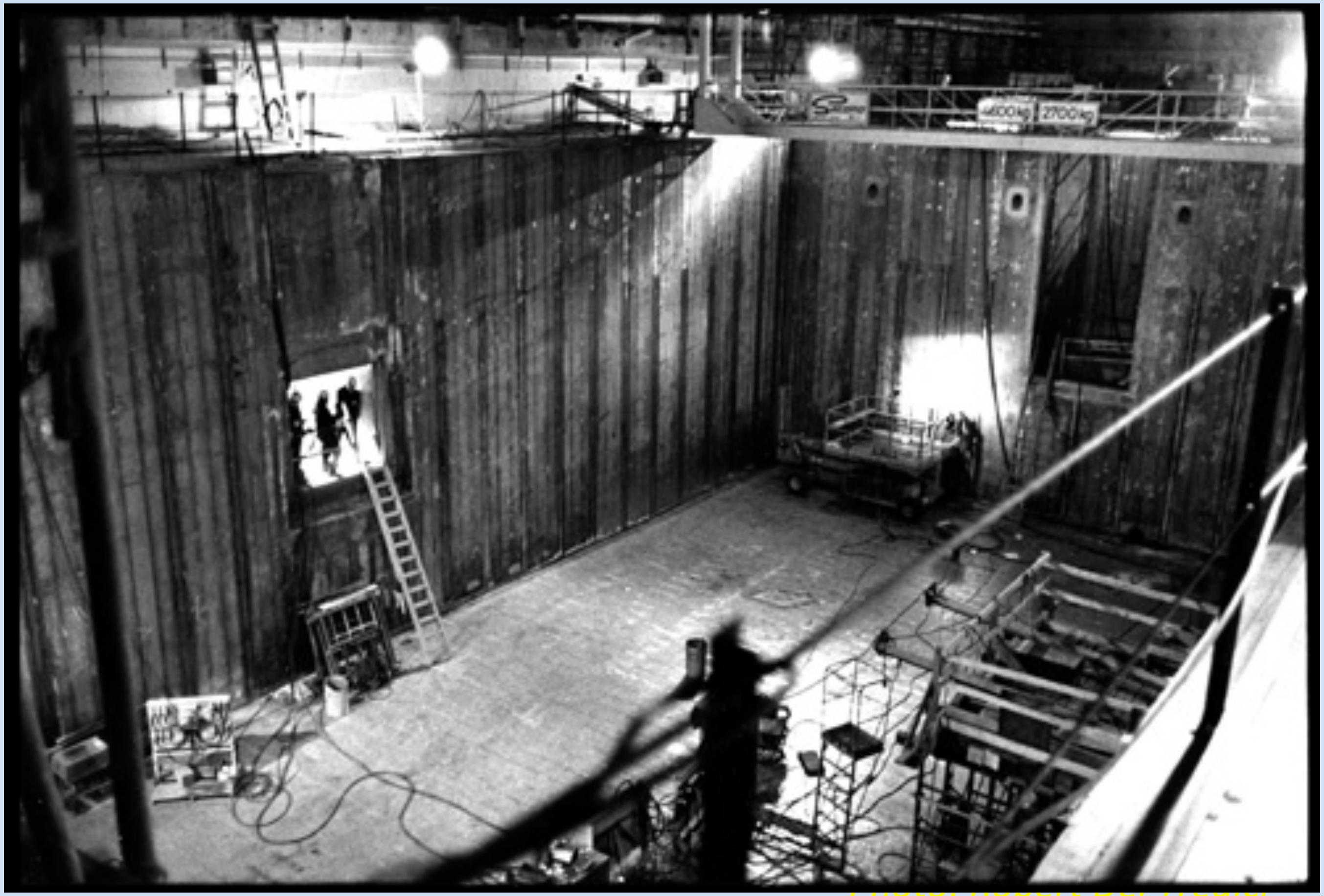
Strontium-90 behaves like calcium; it goes to the bones, the teeth and mother´s milk.

Chronic exposure to atomic radiation
increases the incidence of
cancer, leukemia, genetic damage,
strokes, heart attacks, & low intelligence

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

– the onset of disease occurs years
or decades after exposure.

What is Decay Heat?



Used nuclear fuel generates heat because radioactivity cannot be shut off.

Fuel removed from the reactor must be cooled in a pool for 5 to 10 years.

Units 1 to 4 of Fukushima Daiichi Nuclear Power Station – before earthquake

. . . all reactors were safely shut down immediately after earthquake
all looked exactly the same before and after the earthquake and tsunami

BUT RADIOACTIVE DECAY HEAT CONTINUES; IT CANNOT BE SHUT OFF

Decay heat causes hydrogen gas build up – powerful explosions occur DAYS LATER

and so fission products are released and are spread abroad

This damage is caused not by earthquake or tsunami, but by overheating nuclear waste

Without cooling to remove decay heat the fuel temperatures soars.
The nuclear fuel melts at 5000 degrees F (2800 degrees C).

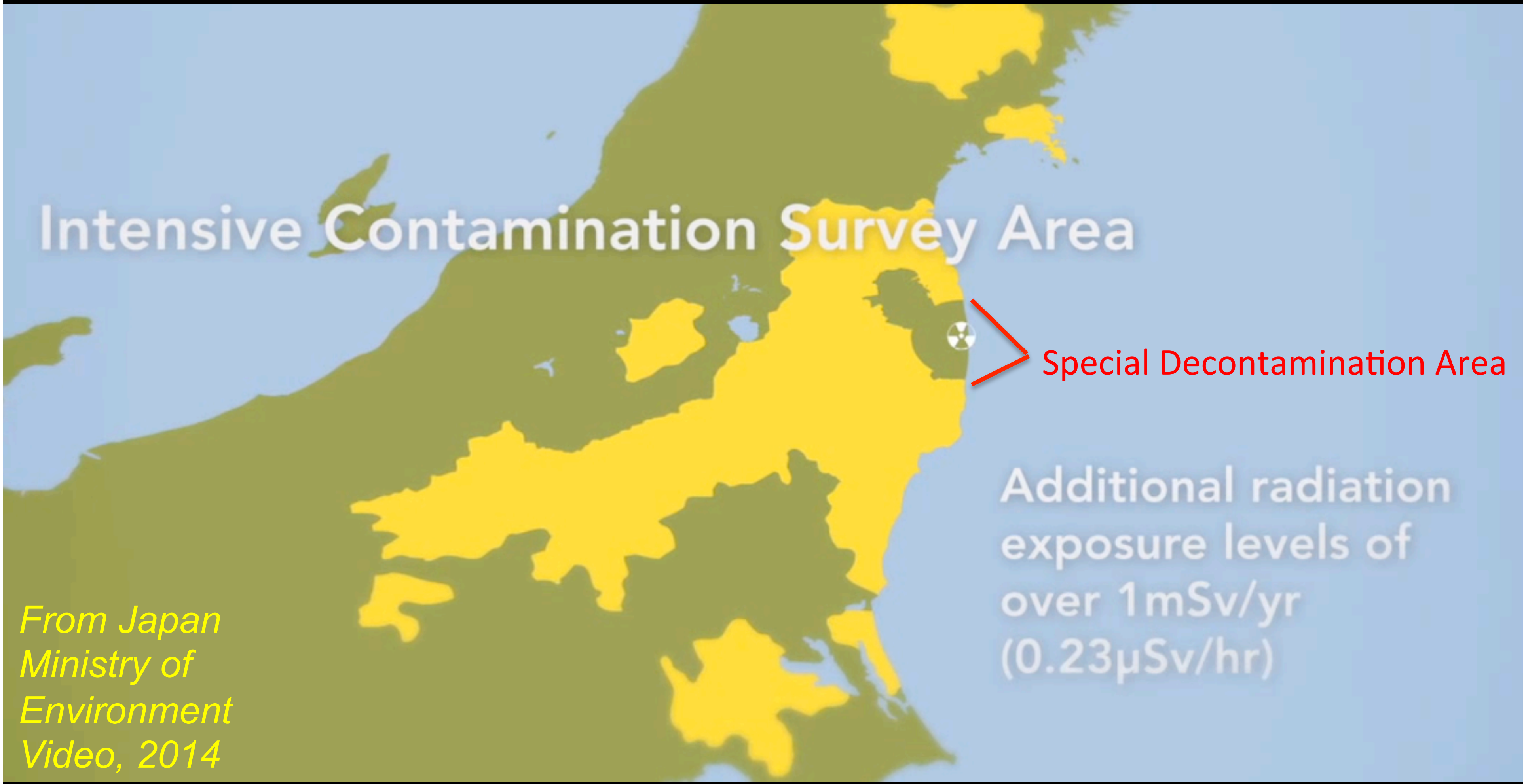
Radioactive decay heat causes three core meltdowns.
Hundreds of tonnes of radioactive waste remains in 4 pools and 3 melted cores

Forced Evacuation within 20 km, extended NW to include town of Iitate (30 km)

From Japan Ministry of Environment Video, 2014

20 millisieverts per year is the maximum allowed for atomic workers in the EU

Intensive contamination extends over 200 km south – right to the outskirts of Tokyo



1 millisievert per year is the maximum allowed for a member of the public in Canada

Contaminated soil removed from forest floor – but only within 200m of habitation

Tens of thousands of plastic bags filled with radioactive soil and debris are piled up.

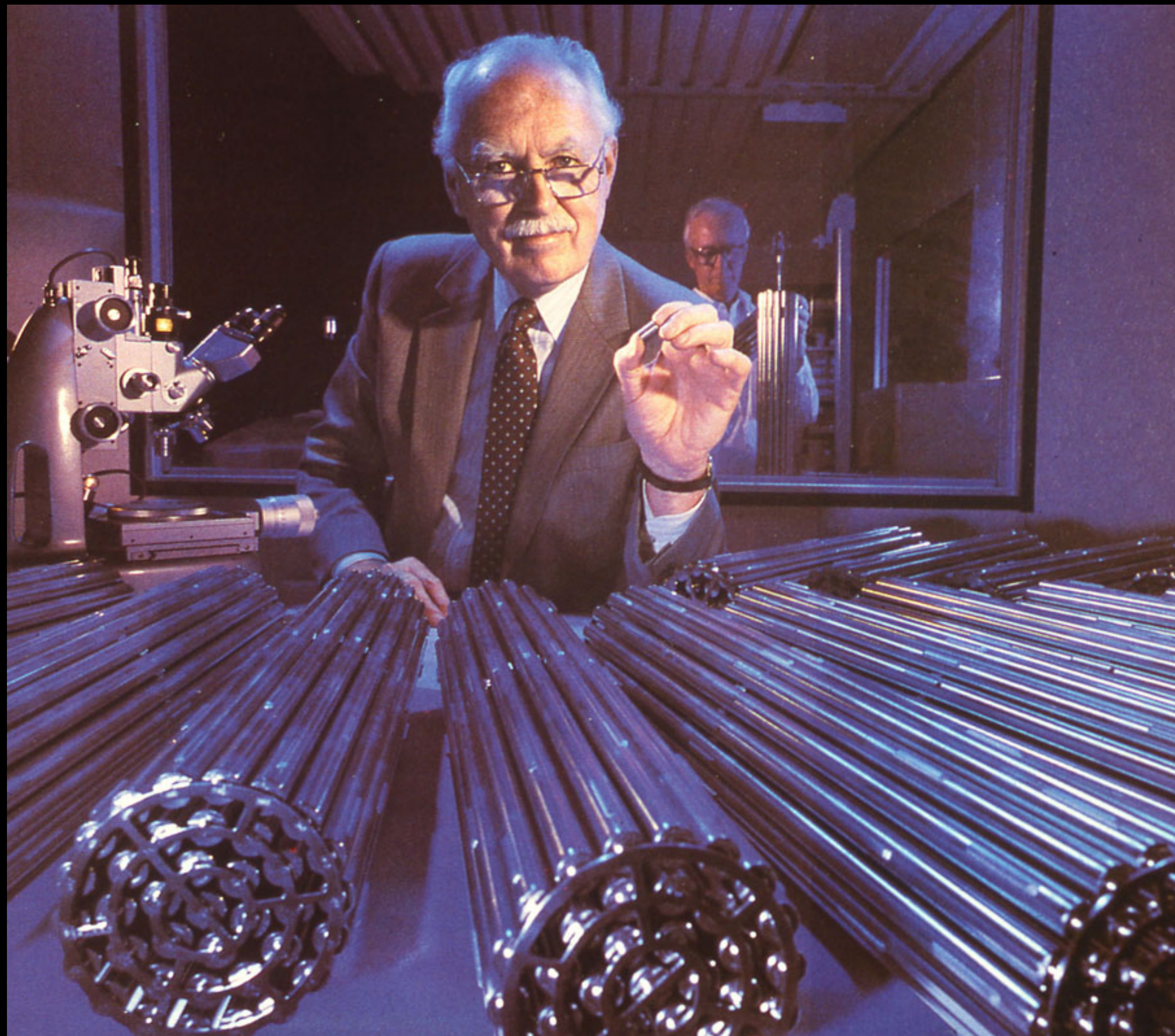
Every day 400 tons of water are pumped down into the melted cores to keep the fuel from overheating

When that water returns to the surface It is heavily contaminated with fission products.

It is far too radioactive to be released and would quickly over-dose workers

“Intermediate Level Waste” is contaminated with fission products

Over 1500 steel tanks are filled with radioactive water; more tanks built every week



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

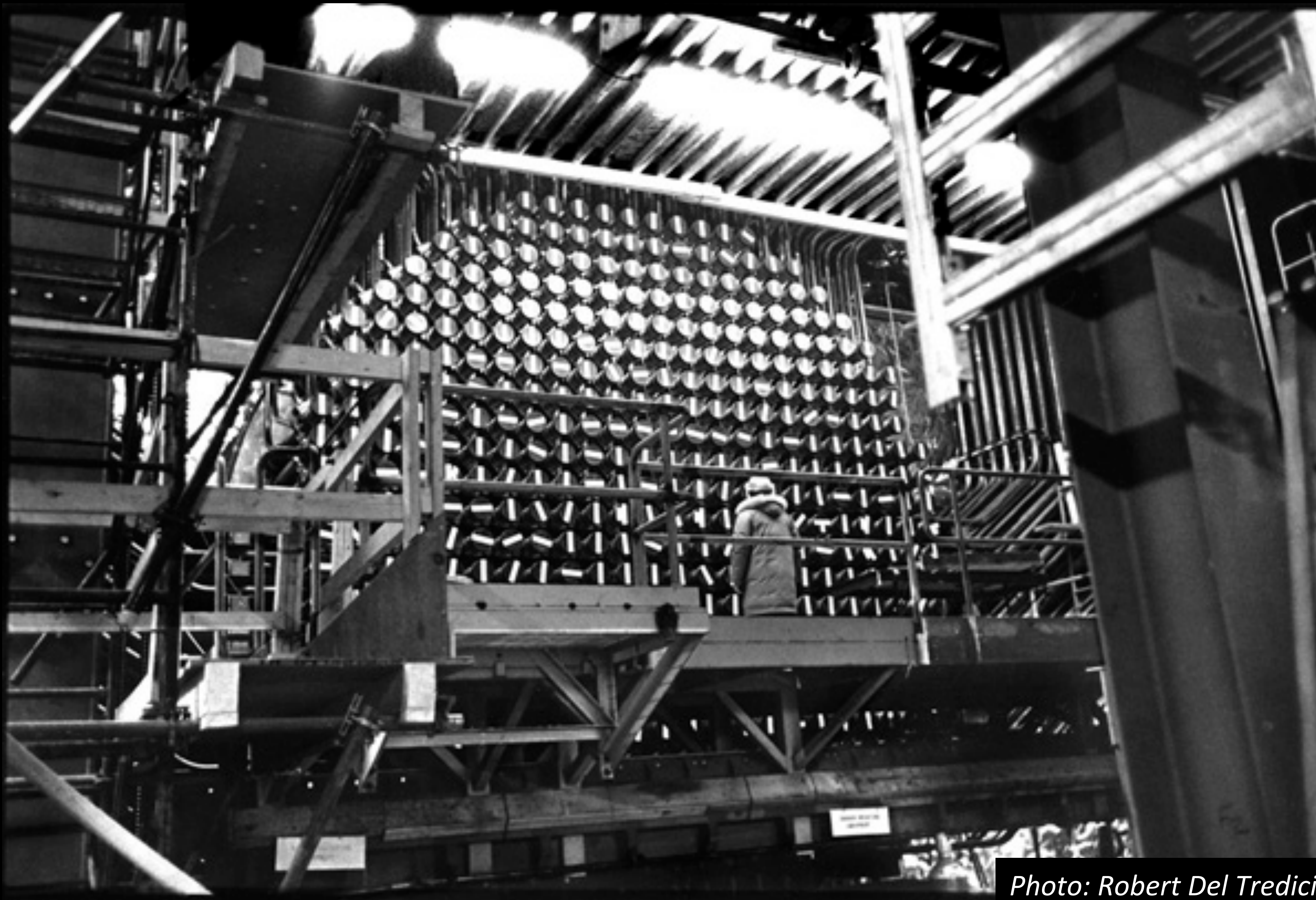
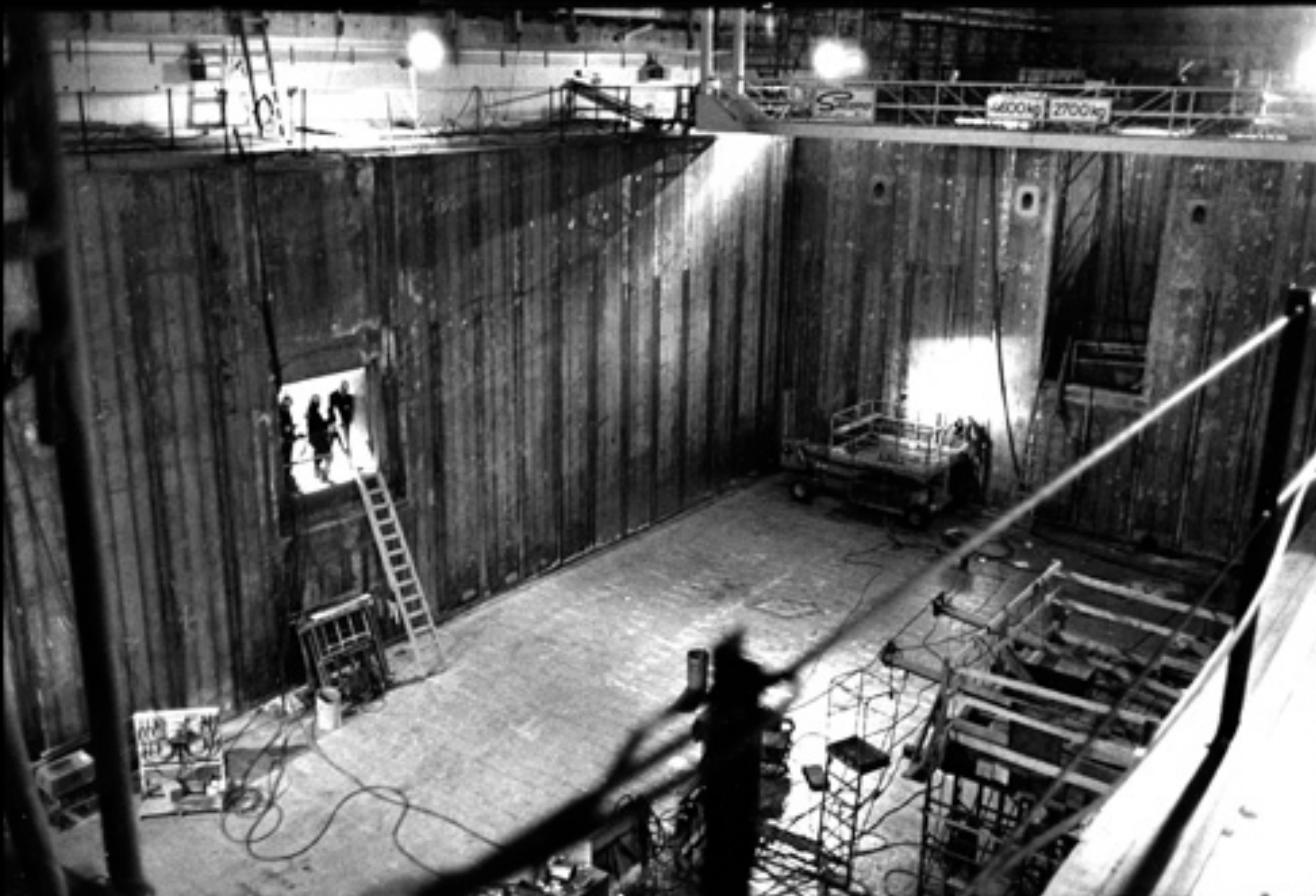


Photo: Robert Del Tredici

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.



Irradiated fuel must be cooled for years by circulating water in a spent fuel pool.

Photo: Robert Del Tredici

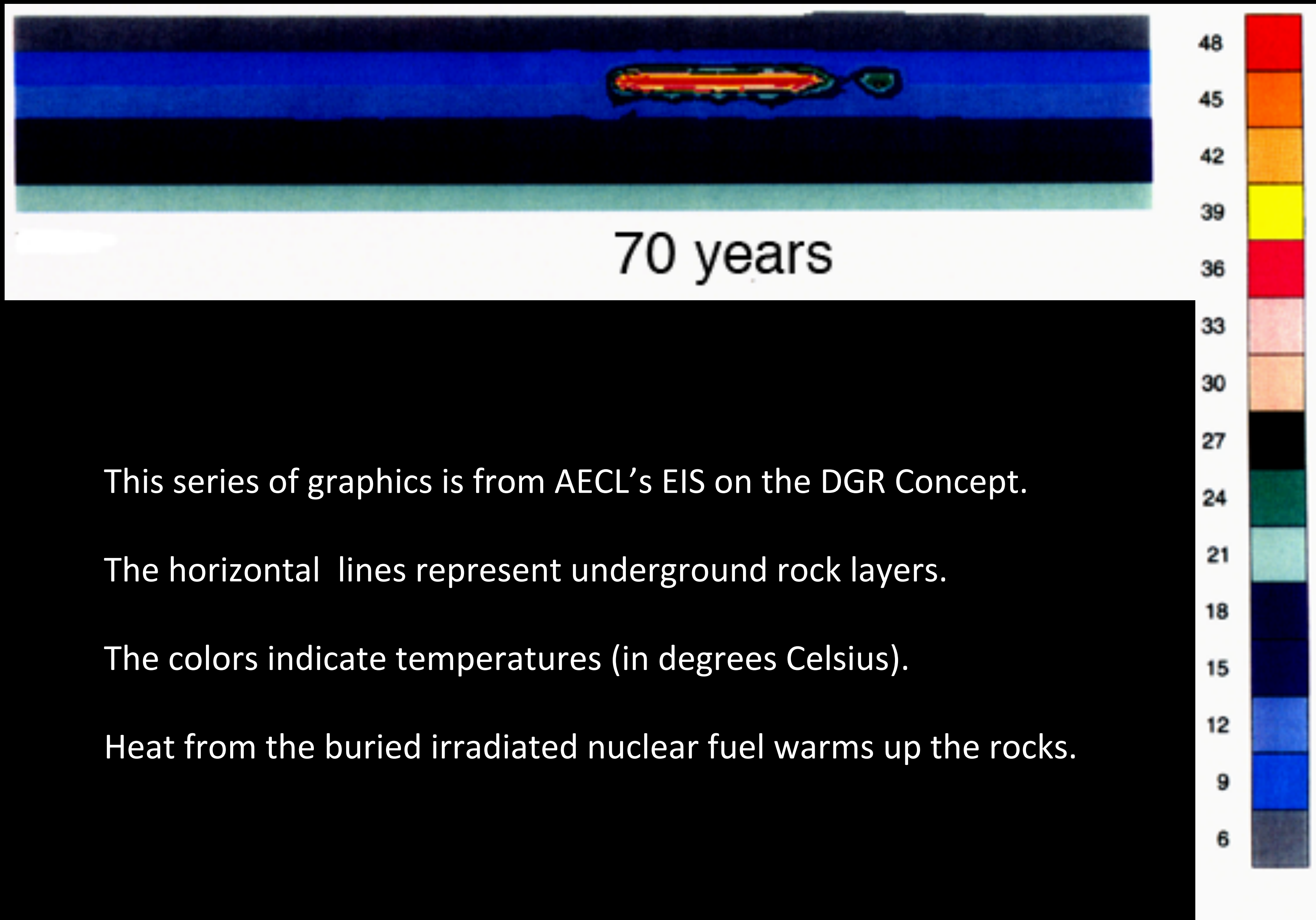
After 10 years in the pool, CANDU spent fuel is put into air-cooled "dry storage" containers.

Photo: Robert Del Tredici

The Nuclear Waste Management Organization will wait 30 years before putting irradiated fuel underground to prevent it from spontaneously overheating due to radioactive disintegrations.

The "Thermal Pulse"

(takes about 50,000 years)



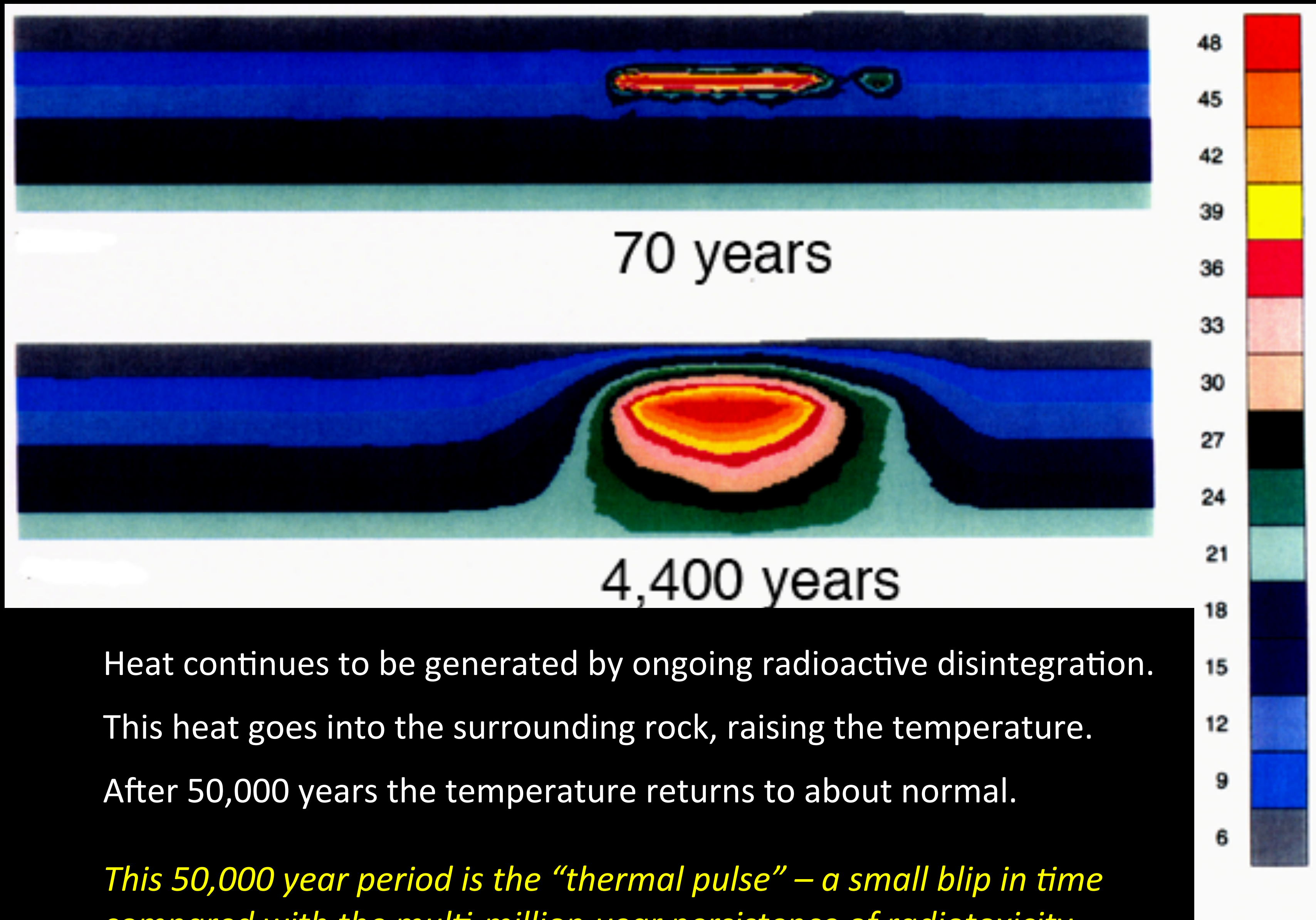
This series of graphics is from AECL's EIS on the DGR Concept.

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.



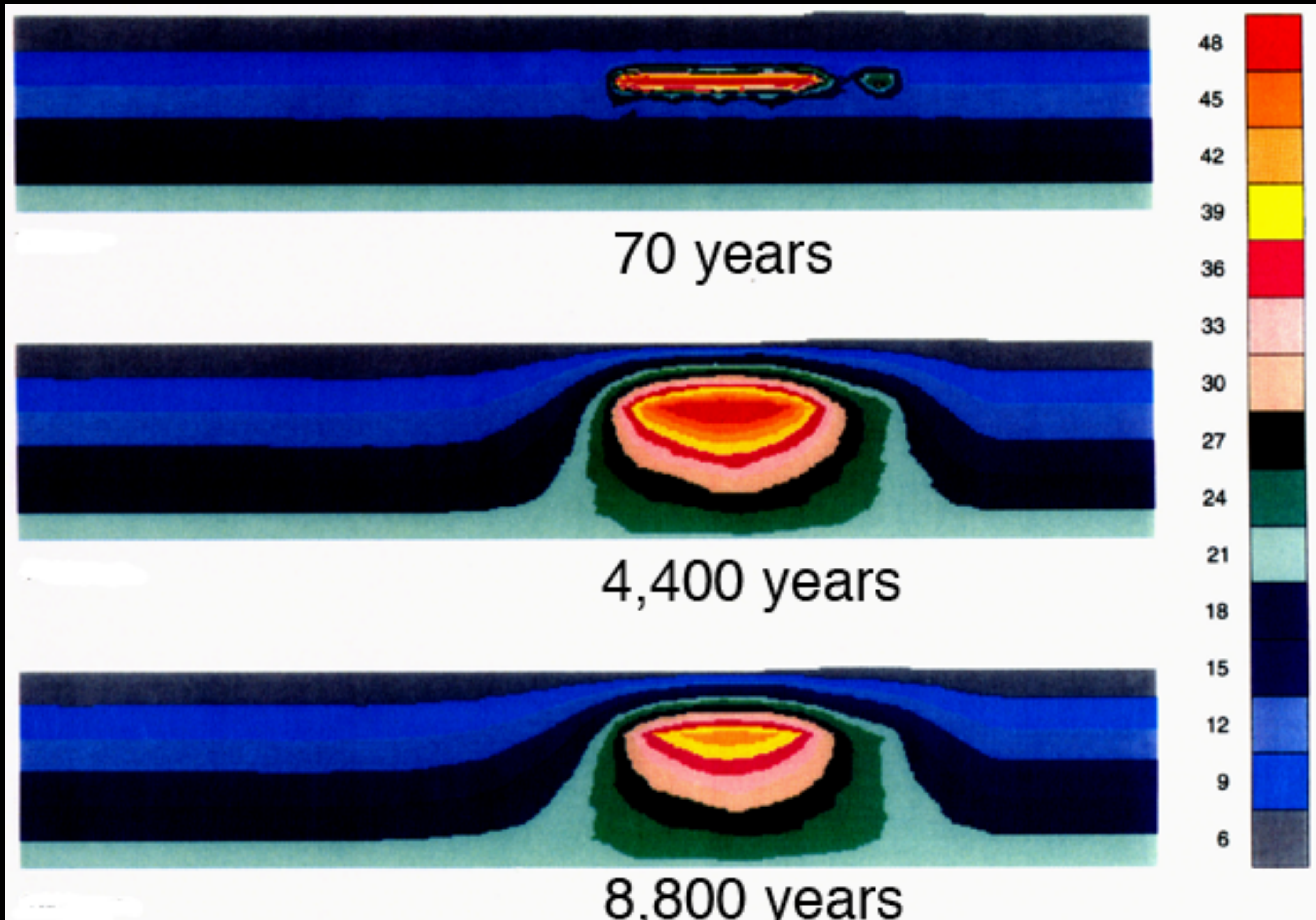
Heat continues to be generated by ongoing radioactive disintegration.

This heat goes into the surrounding rock, raising the temperature.

After 50,000 years the temperature returns to about normal.

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

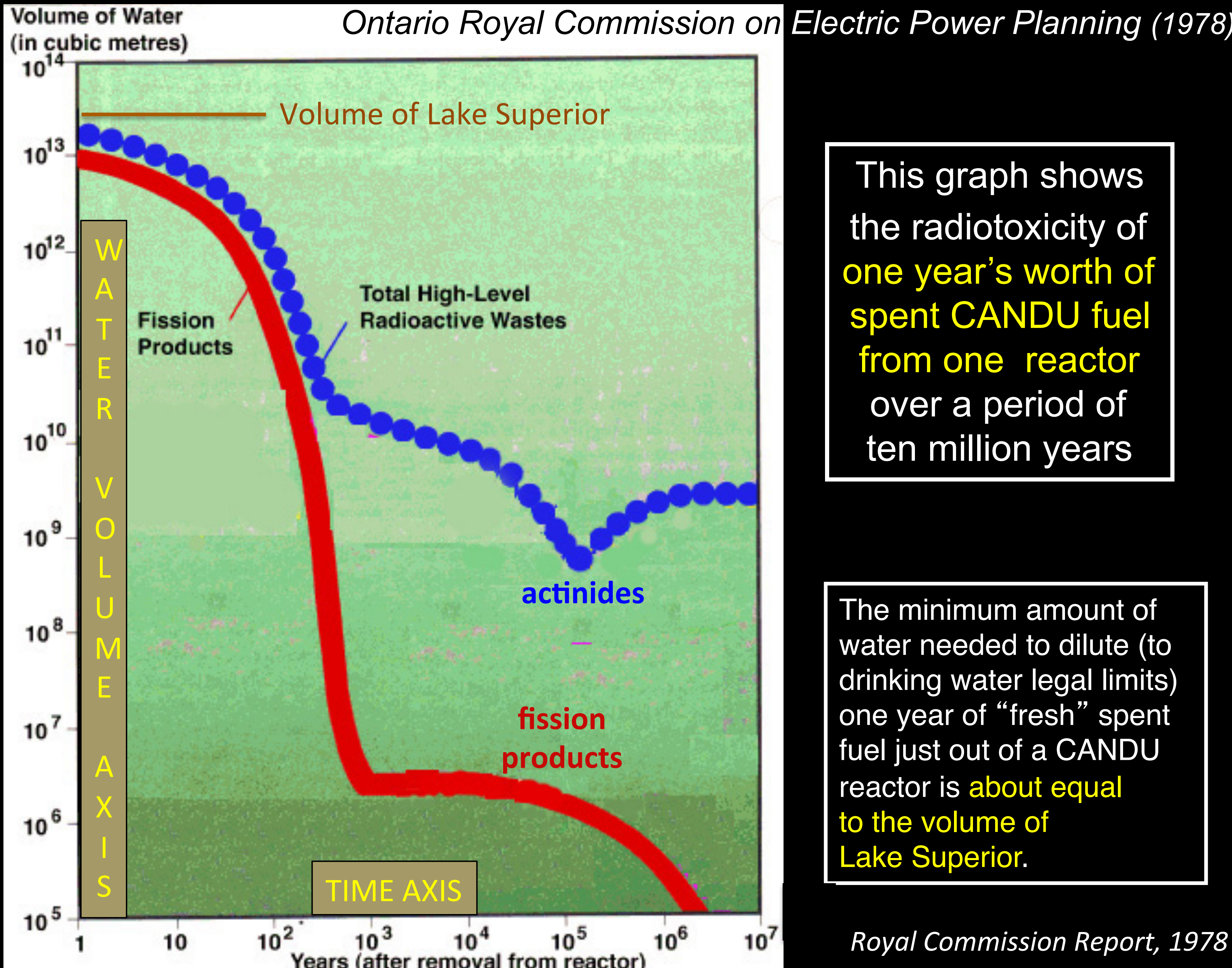
from AECL's EIS on the Geologic Disposal Concept, 1994.



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

Radiotoxicity

(10 million years and counting)

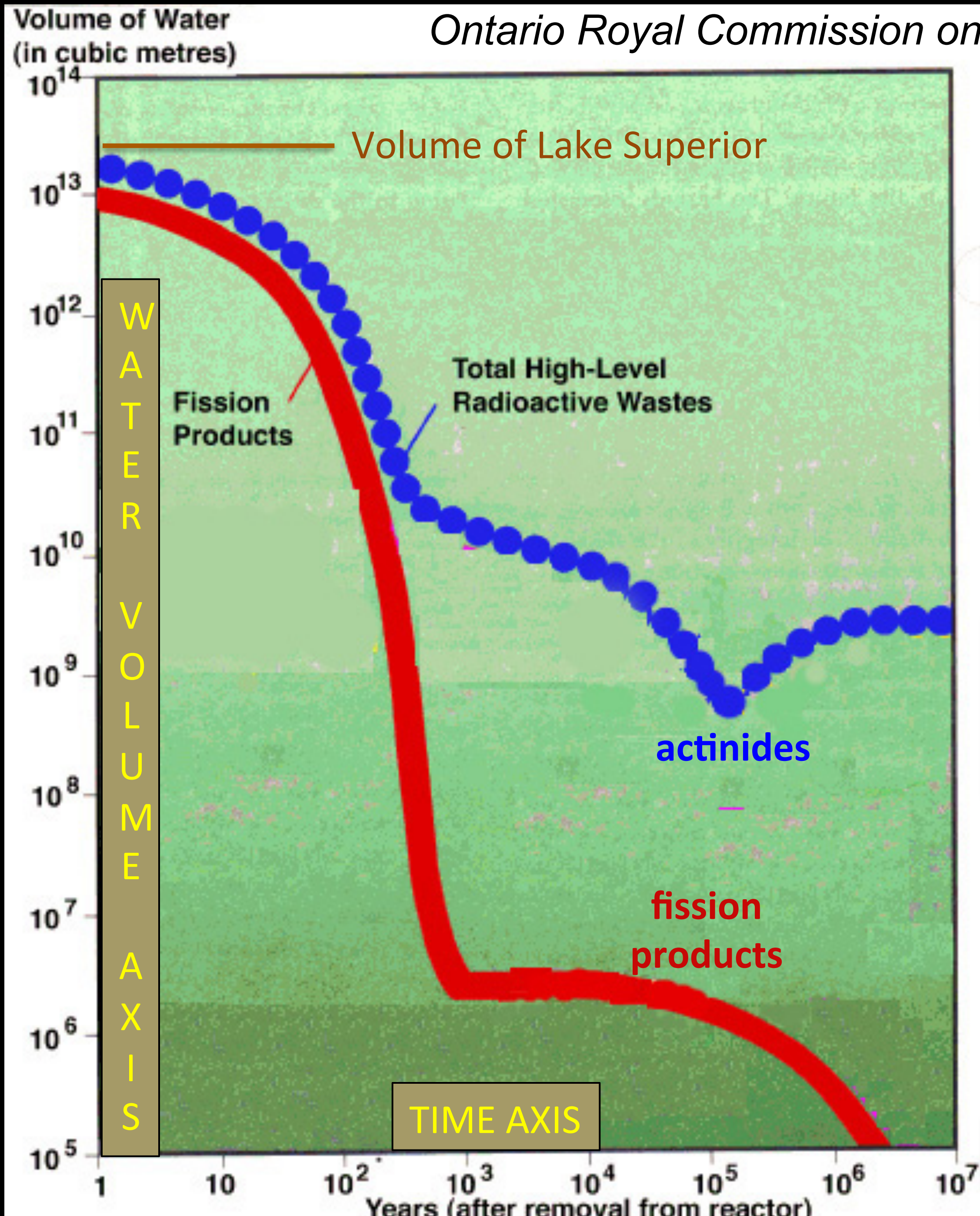


This graph shows the radiotoxicity of one year's worth of spent CANDU fuel from one reactor over a period of ten million years

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.

What is a Transuranic Element?

Uranium is the heaviest naturally occurring element.

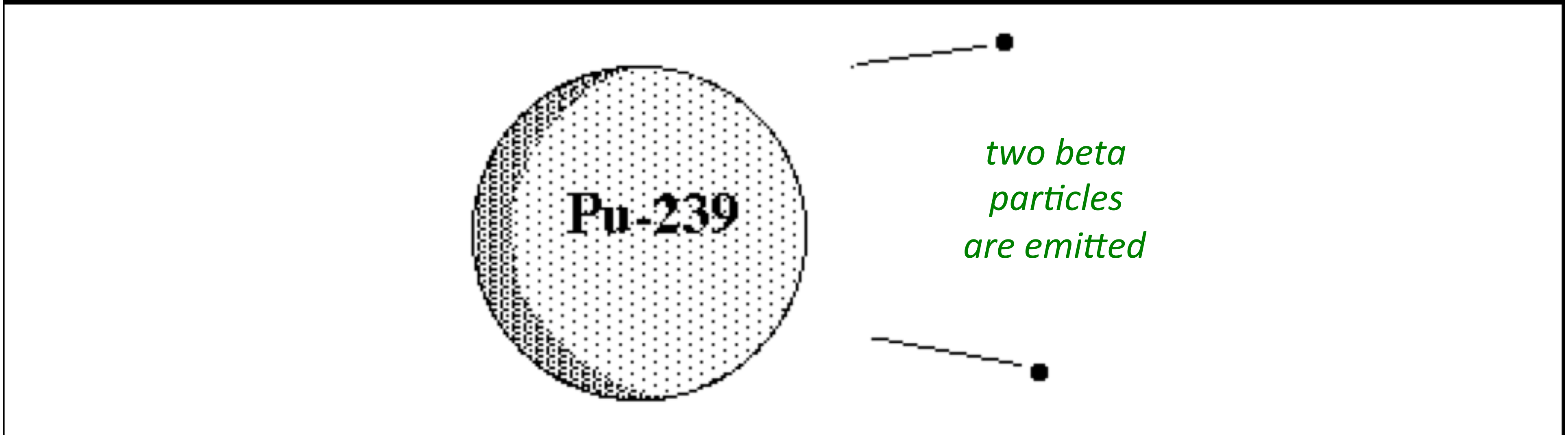
Inside a nuclear reactor, uranium atoms can absorb an extra neutron, or 2, or 3, to become a brand new super-heavy “transuranic” element.

The earliest example of this was PLUTONIUM, a nuclear explosive material used in the Nagasaki bomb and in most modern nuclear warheads.

Plutonium is mass-produced in every nuclear reactor on earth, and can be used for bombs at any time in the next 100,000 years.

Creation of plutonium inside a nuclear reactor …

. . . when an atom of uranium-238 absorbs aneutron

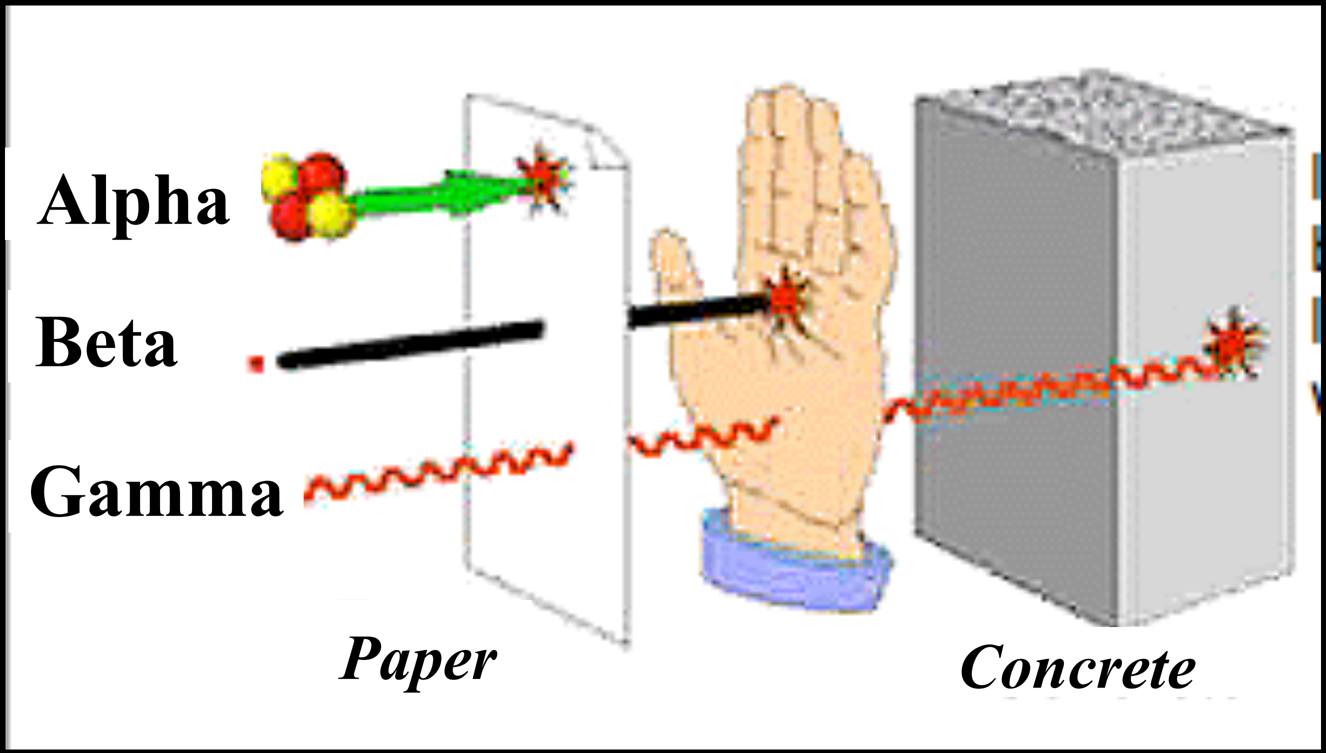


. . . it is transformed into an atom of plutonium-239

Other transuranic actinides are produced in a similar way.

Most actinides are alpha-emitting radioactive materials

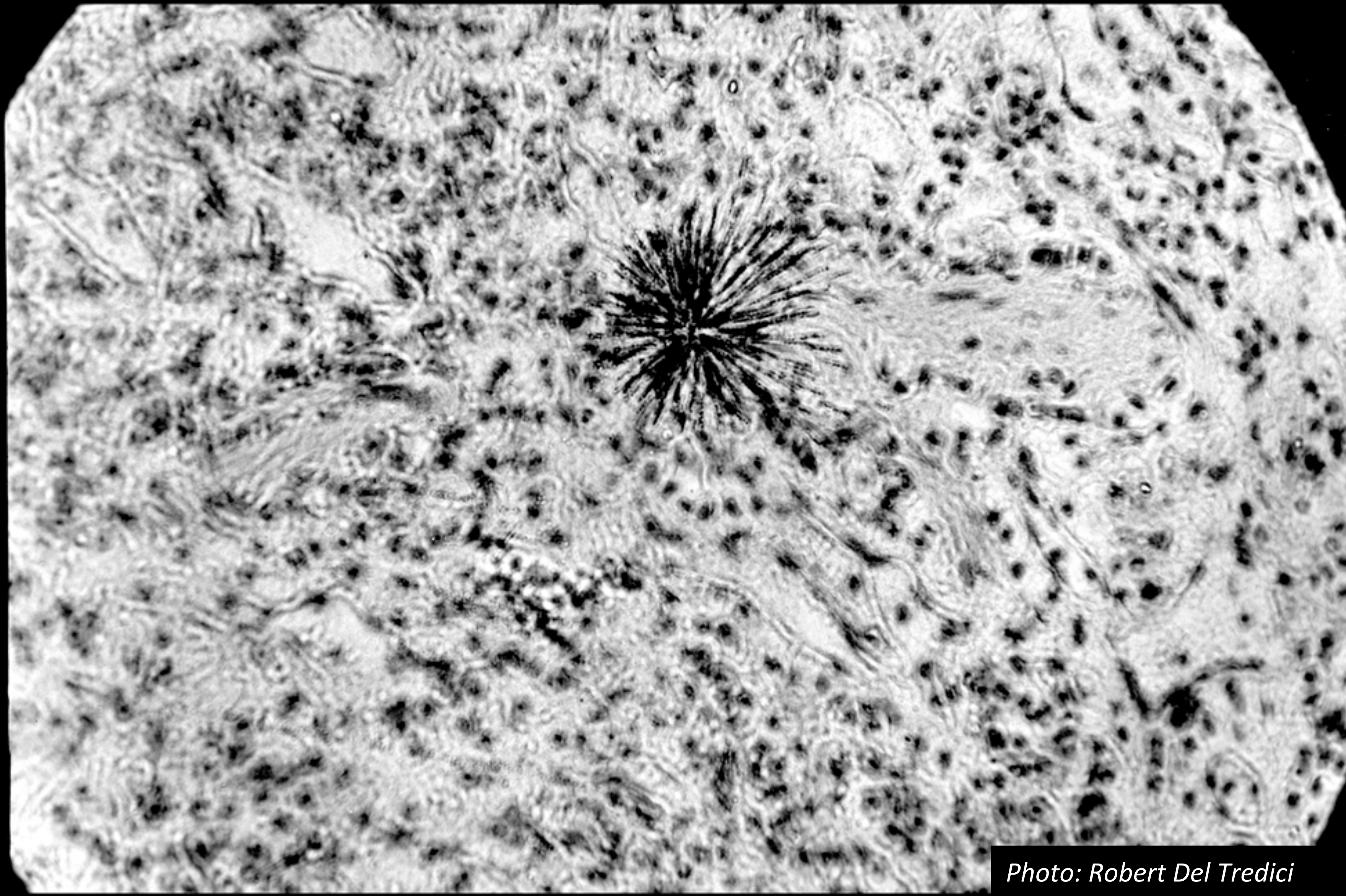
Alpha particles can be stopped by a sheet of paper.
Alpha emitters are harmless outside the body, but much more damaging than beta or gamma when ingested or inhaled.



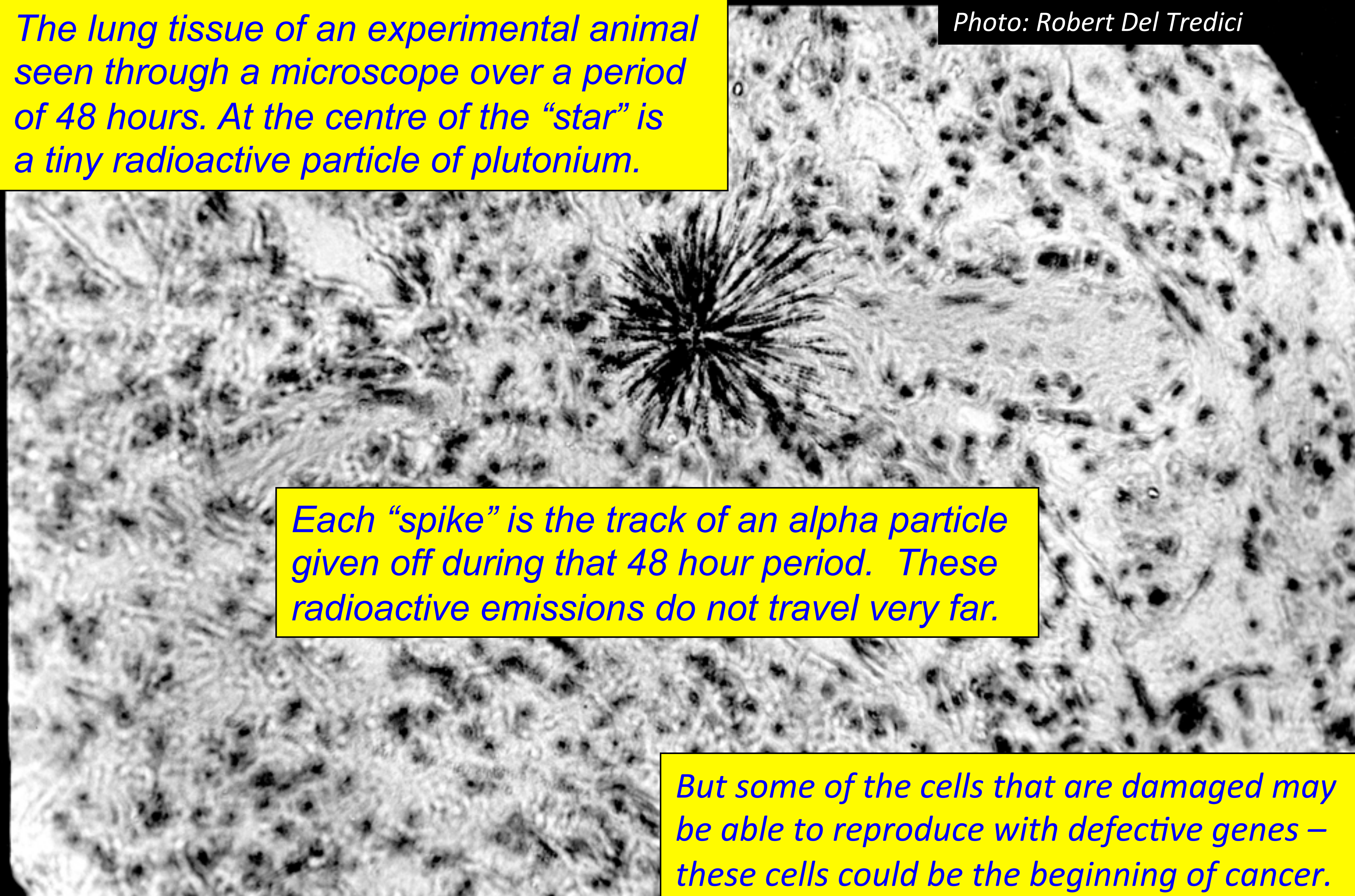
Beta particles penetrate only part-way.
They can damage eyes or skin externally but the main danger is internal exposure.

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.



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.

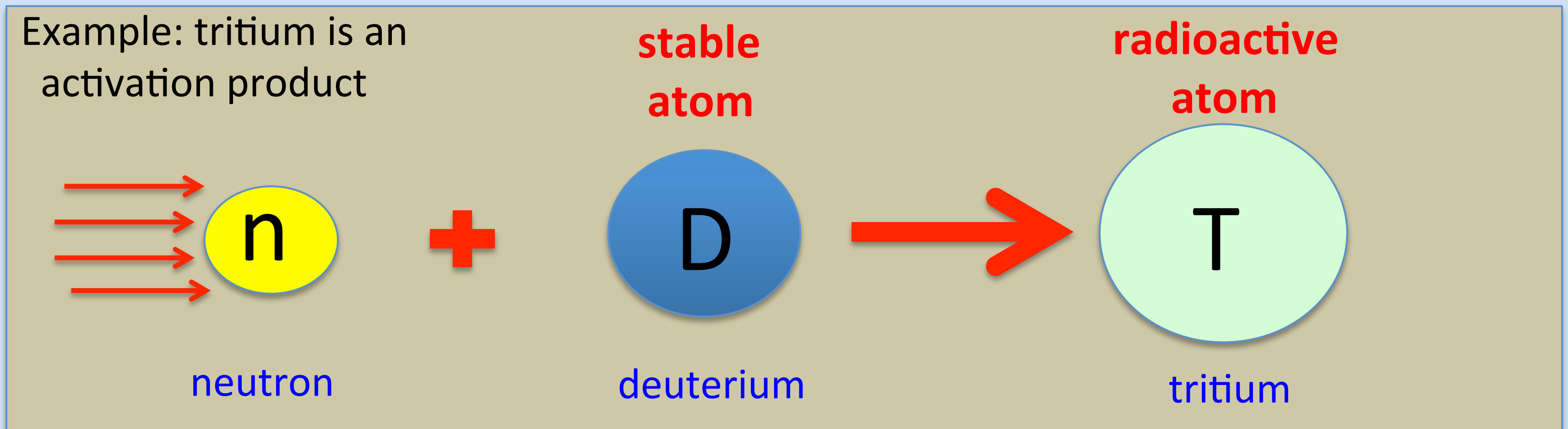
Each "spike" is the track of an alpha particle given off during that 48 hour period. These radioactive emissions do not travel very far.

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.

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”.



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 –
they have different masses, but are chemically identical

stable **stable** **unstable (radioactive)**

an activation product

They all have one proton in the nucleus (colored red)
and one solitary electron in orbit (colored gold)

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.

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

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

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

Three "sources" of nuclear waste materials:

1. Fission Products (e.g. cesium-137, iodine-131)

   ~ the broken bits of uranium atoms
   (lighter atoms ~ 1/3 to 2/3 the size of U)

2. Transuranics (Actinides) (e.g. plutonium, americium)

   ~ heavier-than-uranium elements that are
   created when uranium absorbs neutrons

3. Activation Products (e.g. cobalt-60, carbon-14)

   ~ transmuted versions of non-radioactive atoms
   that are "activated" by absorbing stray neutrons

These three categories are differentiated in the table of radionuclides that follows.

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

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

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	¥¥¥	¥	¥	

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

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	¥		¥	

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

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		¥		

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

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

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			¥	
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)
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				¥
Standard	**Common Name of**	**Atomic Mass**	**F.P.**	**F.I.A.P.**	**Z.A.P.**	**Actinide**

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

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

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				¥

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

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

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				¥¥¥

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

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

Cm	Curium	244				¥¥¥
Cm	Curium	245				¥
Cm	Curium	246				¥
Cm	Curium	247				¥
Cm	Curium	248				¥
Cm	Curium	250				¥
Bk	Berkelium	249				¥
Bk	Berkelium	250				¥
Cf	Californium	249				¥
Cf	Californium	250				¥
Cf	Californium	251				¥
Cf	Californium	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]*

This list of 211 man-made radionuclides contained in irradiated nuclear fuel is by no means complete! (AECL)

[AECL = Atomic Energy of Canada Limited]

What are Decommissioning Wastes?

Radioactive components and structures at the Zion plant are removed.

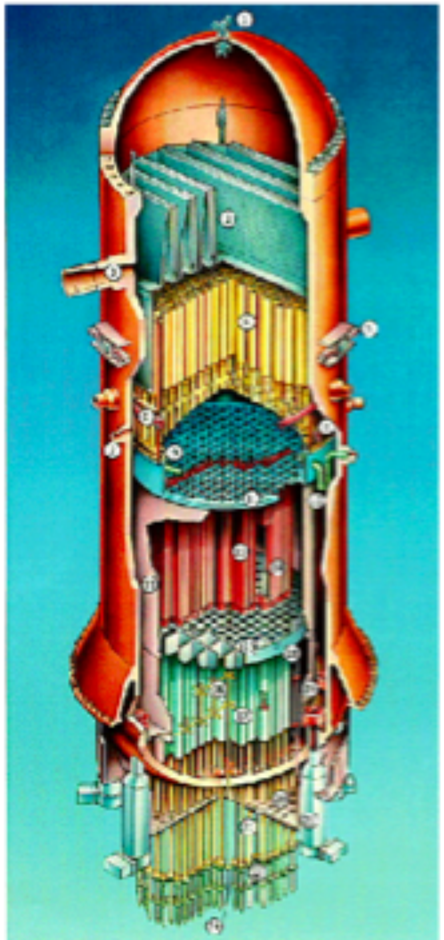
They will be stored as radioactive wastes for many centuries to come.

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?

These contaminated pipes contain --

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
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.

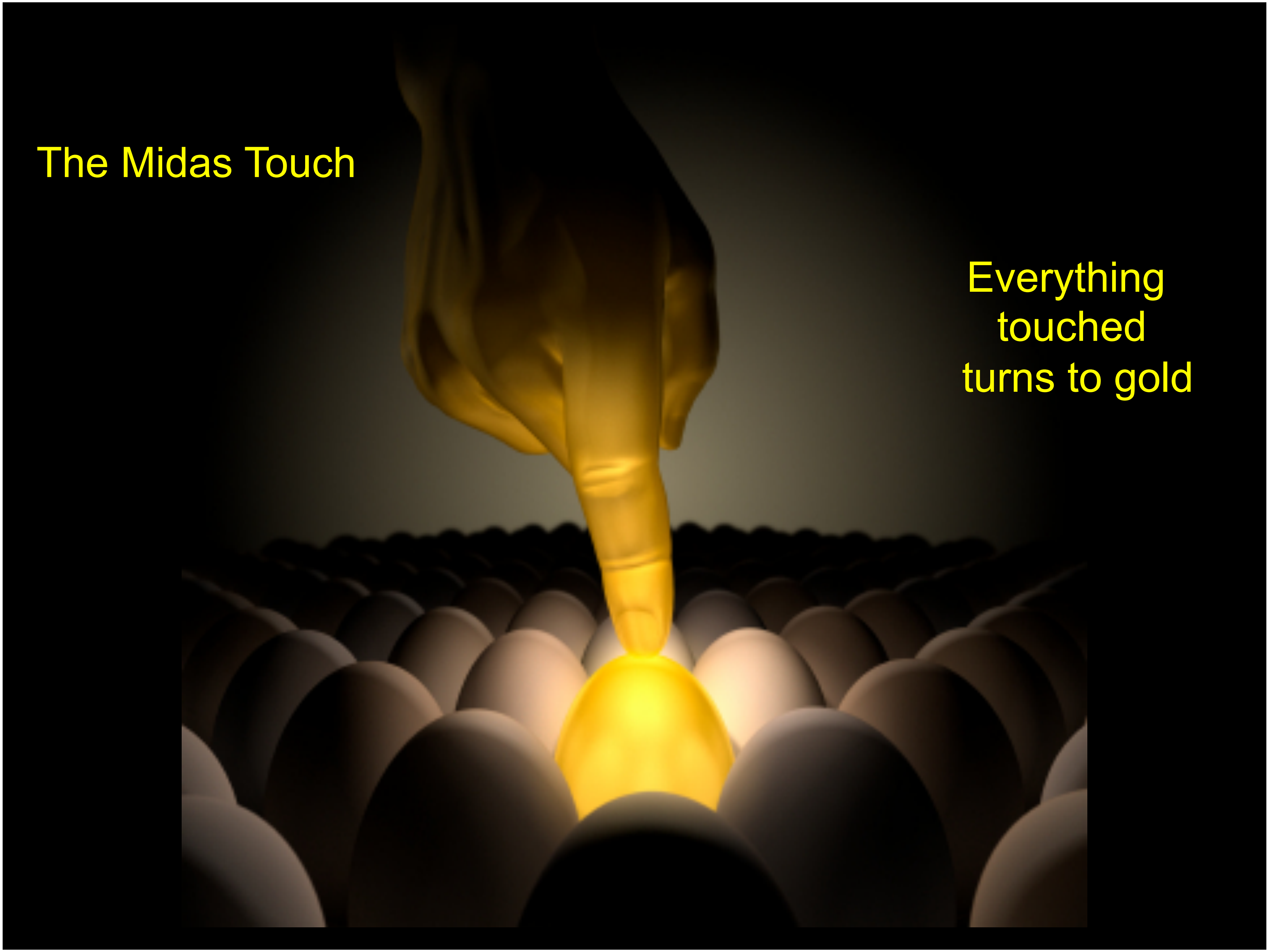
What becomes Contaminated?

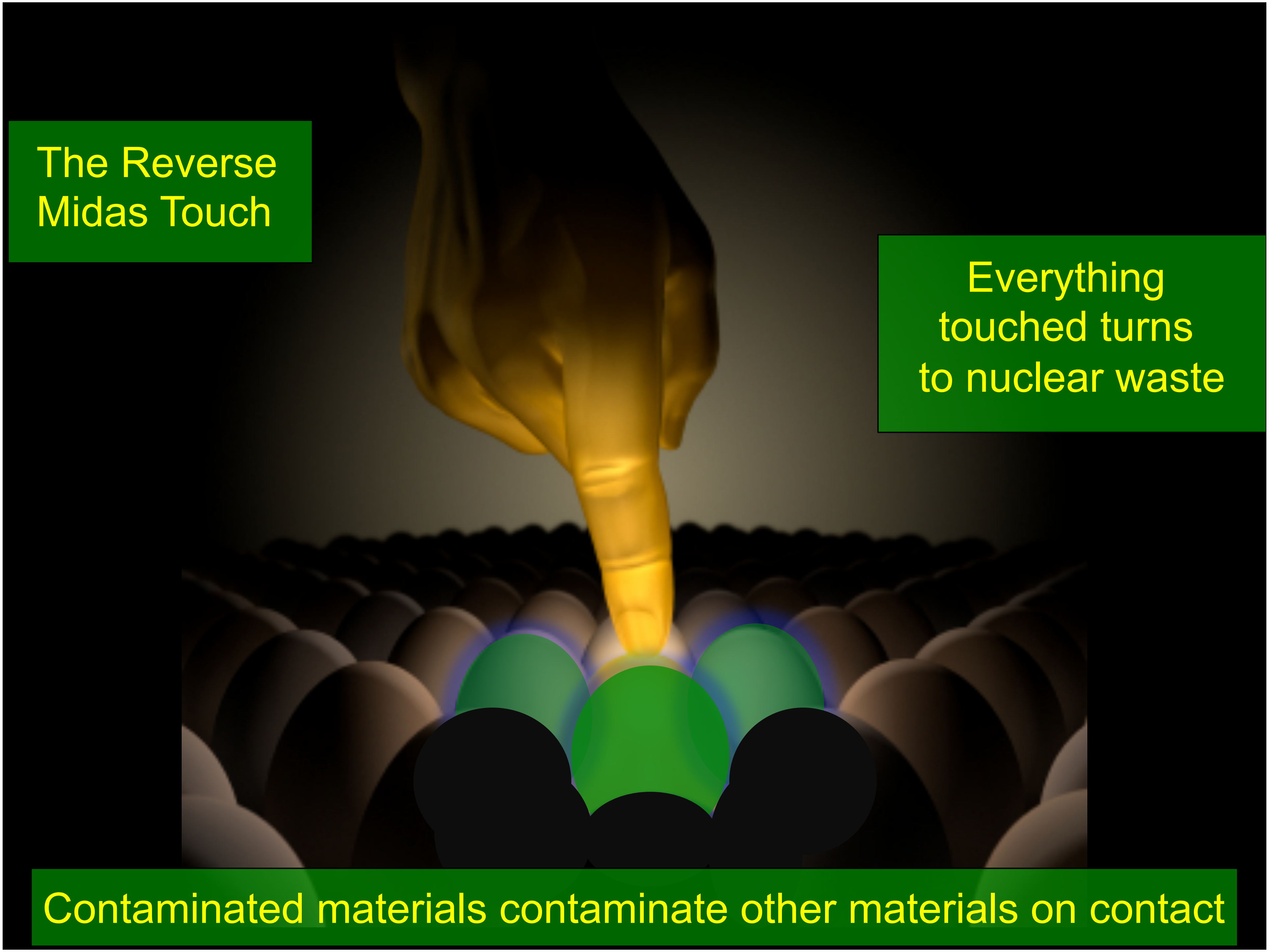
Large volumes of contaminated filters, clothing, mops, rags, pipes, equipment, including the entire "primary cooling circuit" of the reactor becomes radioactive waste by contamination.

If radioactive material is stored in a container, the container becomes contaminated and so it becomes radioactive waste.

If radioactive material spills on a roadway, that portion of the road becomes radioactive waste and has to be dug up.

In New Brunswick, refurbishment work on a reactor ended up producing five times more radioactive waste than anticipated because of inadvertent contamination of otherwise non-radioactive materials.


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

Should we bury nuclear waste?

How can we bury it in an undisturbed site without disturbing it ?

HLW remains incredibly toxic for millions of years.

Science cannot predict accurately over such time periods.

USA tried 8 times to find a DGR for HLW – and failed 8 times.

Germany has two failed DGRs for Low-Level Waste.

The only DGR in North America had a serious accident in 2014.

HLW = High Level Waste; DGR = Deep Geologic Repository

Nuclear Waste
as a word game

Clean-up: just moving nuclear waste from one place to another

Decontamination: collecting and repackaging, but not eliminating

Volume reduction: concentrating radioactivity into a smaller space

Nuclear waste disposal: abandoning nuclear waste somewhere

UK: Sir Brian Flowers

"... 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

CAN Geological Storage Solve the Waste Problem?

Why 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.

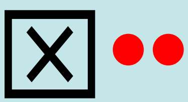
Will this solve the nuclear waste problem?

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

IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

ONE
REACTOR

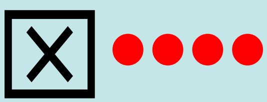


AFTER 2 YEARS

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

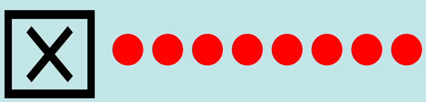


HELLO ROBERT

AFTER 4 YEARS

IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

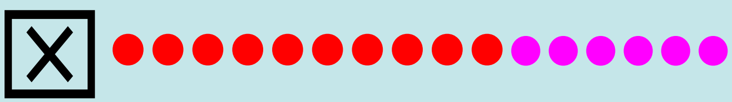


HELLO ROBERT

AFTER 8 YEARS

IRRADIATED NUCLEAR FUEL ACCUMULATION

WITHOUT GEOLOGIC DISPOSAL

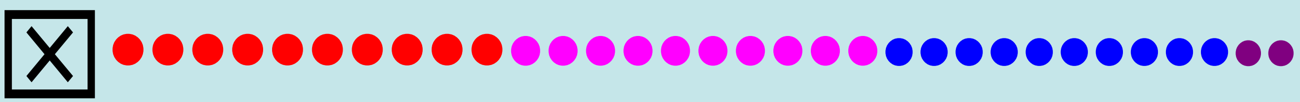


AFTER 16 YEARS

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

IRRADIATED NUCLEAR FUEL ACCUMULATION

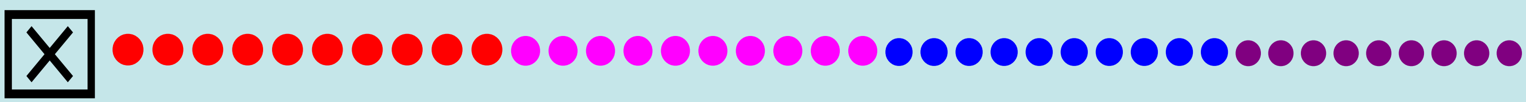
WITHOUT GEOLOGIC DISPOSAL



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.***

GEOLOGIC DISPOSAL : IS IT 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. . .

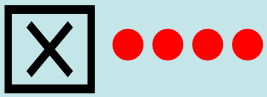
WITH GEOLOGIC DISPOSAL

HELLO ROBERT

AFTER 2 YEARS

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

WITH GEOLOGIC DISPOSAL

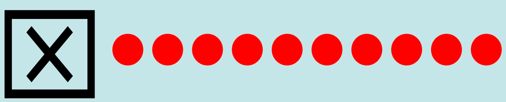


HELLO ROBERT

AFTER 4 YEARS

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

WITH GEOLOGIC DISPOSAL

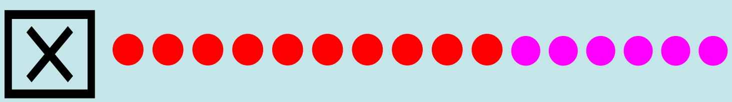


HELLO ROBERT

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.

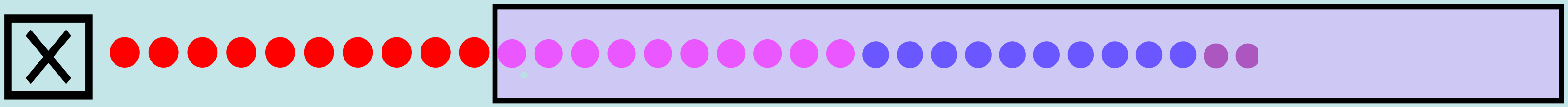
WITH GEOLOGIC DISPOSAL

THIS PORTION MAY BE TRANSPORTED -- HOORAY !

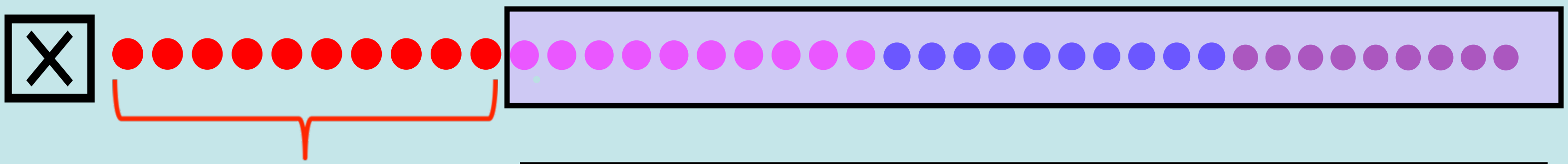
AFTER 16 YEARS

After 10 years the fuel might *be moved, but industry plans to wait for 30 years.*
So: 10 to 30 years worth of unburied nuclear waste stays right beside the reactor!

WITH GEOLOGIC DISPOSAL



WITH GEOLOGIC DISPOSAL



THIS IS NOT REMOVED!

ONLY THIS PORTION MAY BE TRANSPORTED!

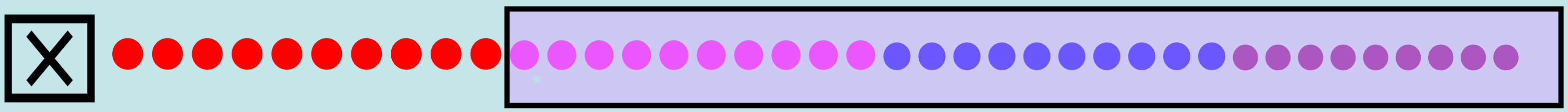
AFTER 40 YEARS

*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 citizens 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. . . .



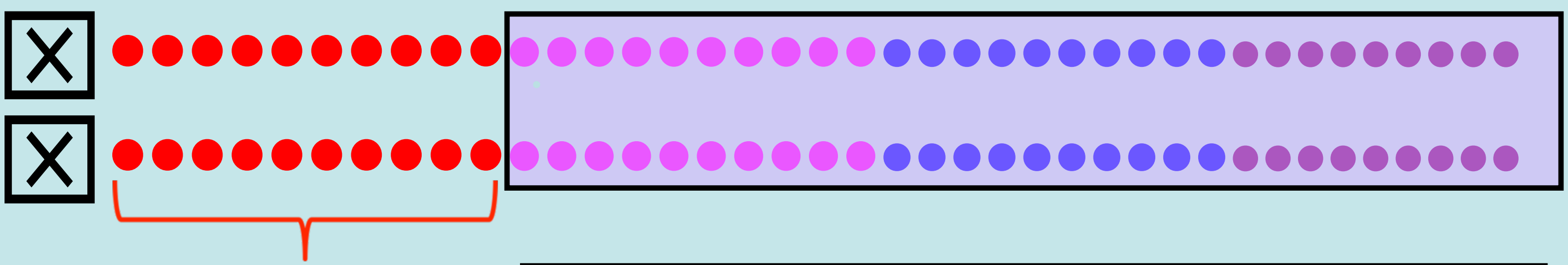
Once the nuclear waste problem is "solved"
the nuclear industry says it is

"TIME FOR A "NUCLEAR RENAISSANCE" –

MORE REACTORS, PLEASE !"

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

EVEN WITH GEOLOGIC DISPOSAL

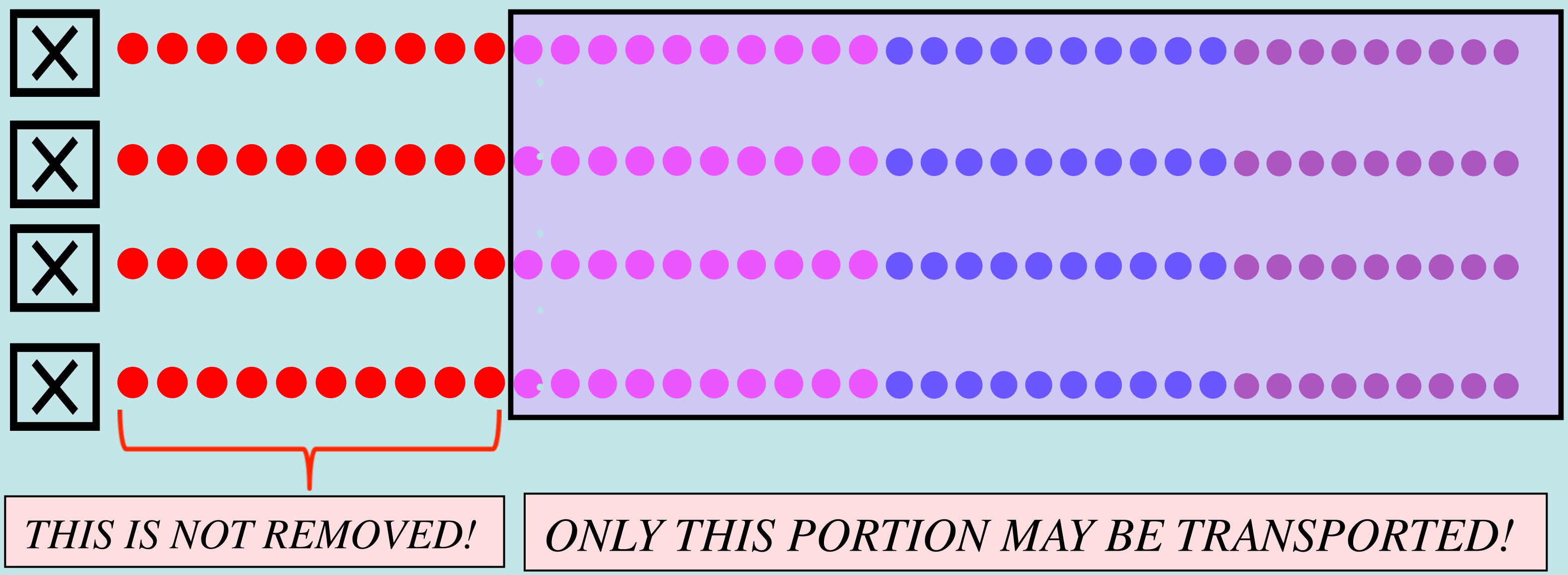


THIS IS NOT REMOVED!

ONLY THIS PORTION MAY BE TRANSPORTED!

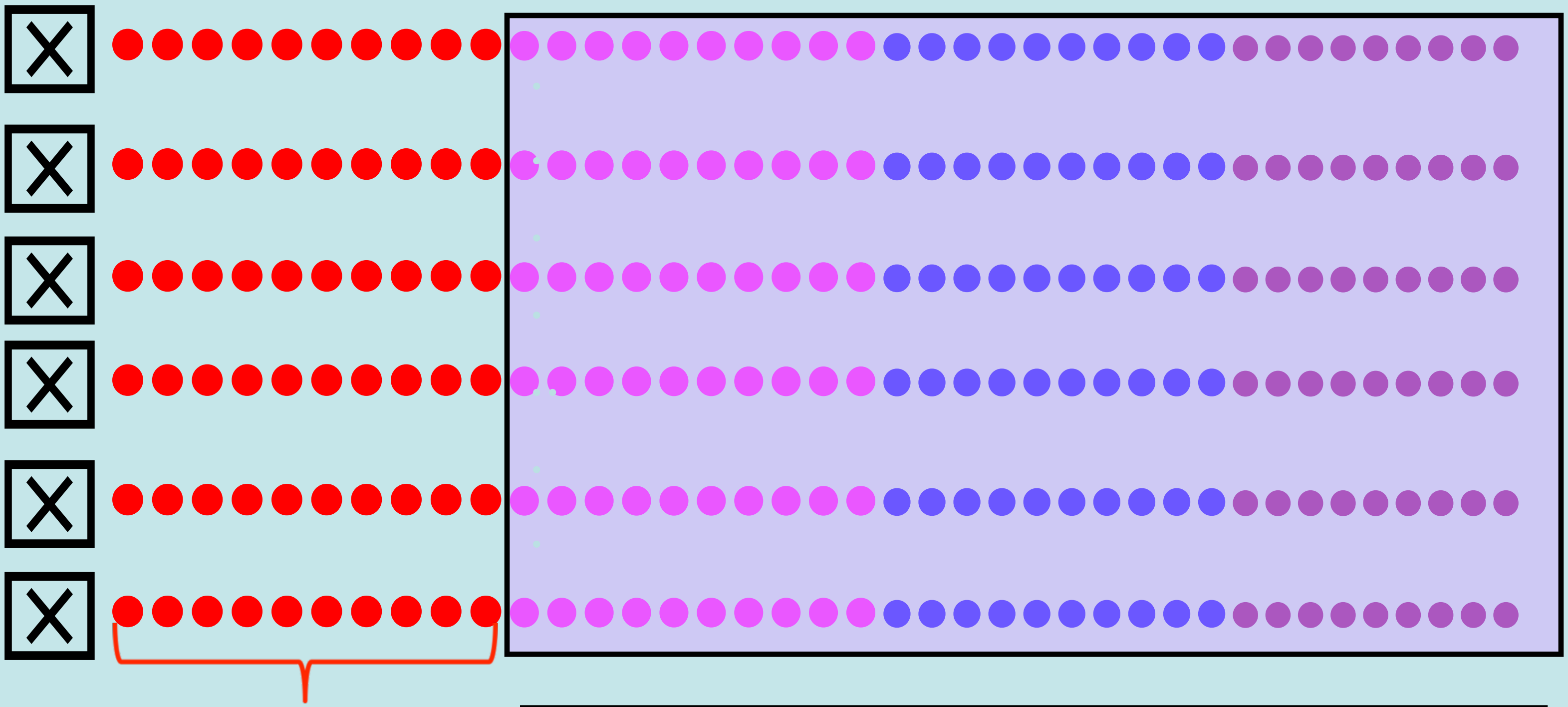
With 2 reactors, after 40 years there ***is*** ***TWICE AS MUCH UNBURIED NUCLEAR WASTE.***

WITH GEOLOGIC DISPOSAL



WITH 4 REACTORS

WITH GEOLOGIC DISPOSAL

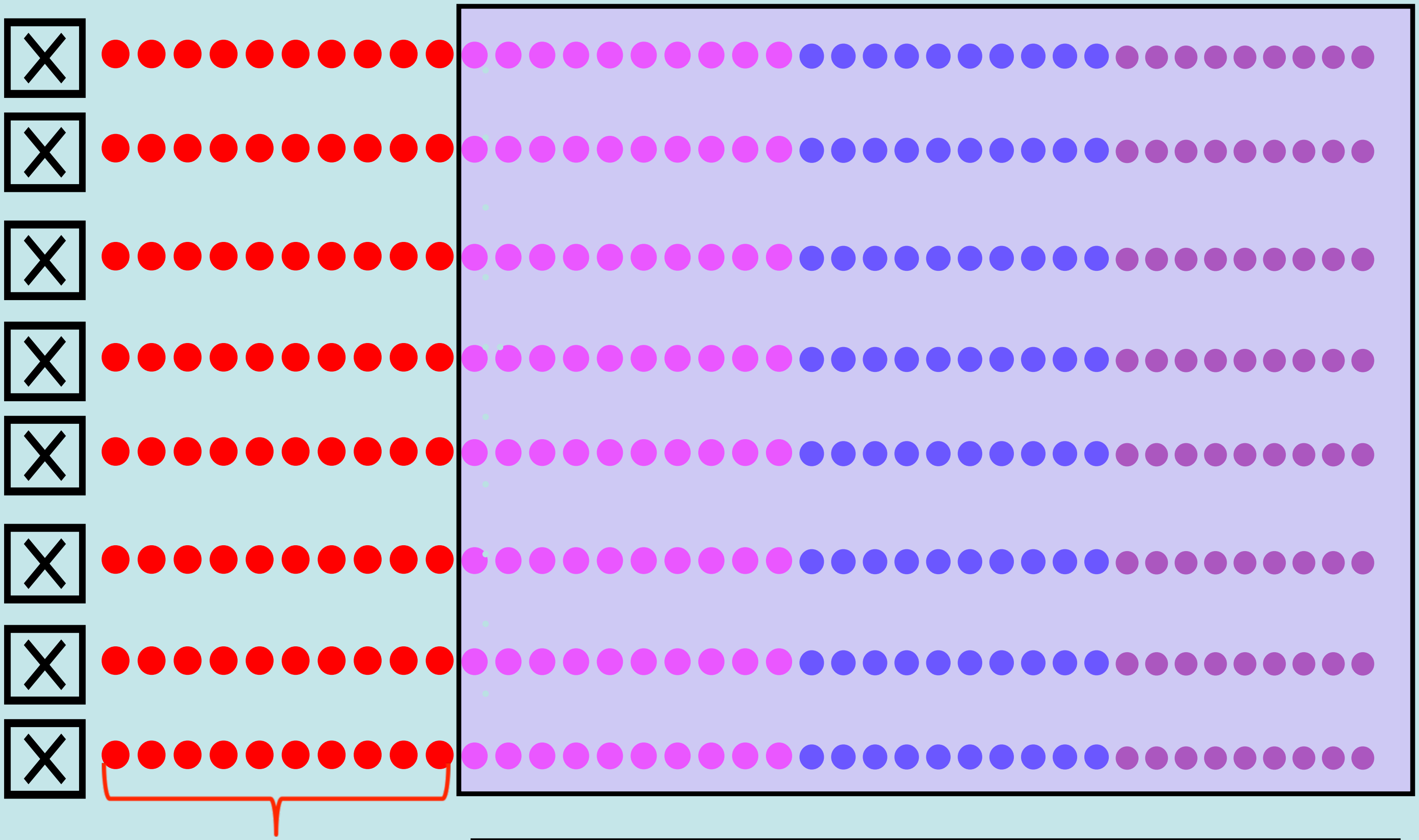


THIS IS NOT REMOVED!

ONLY THIS PORTION MAY BE TRANSPORTED!

WITH 6 REACTORS

WITH GEOLOGIC DISPOSAL

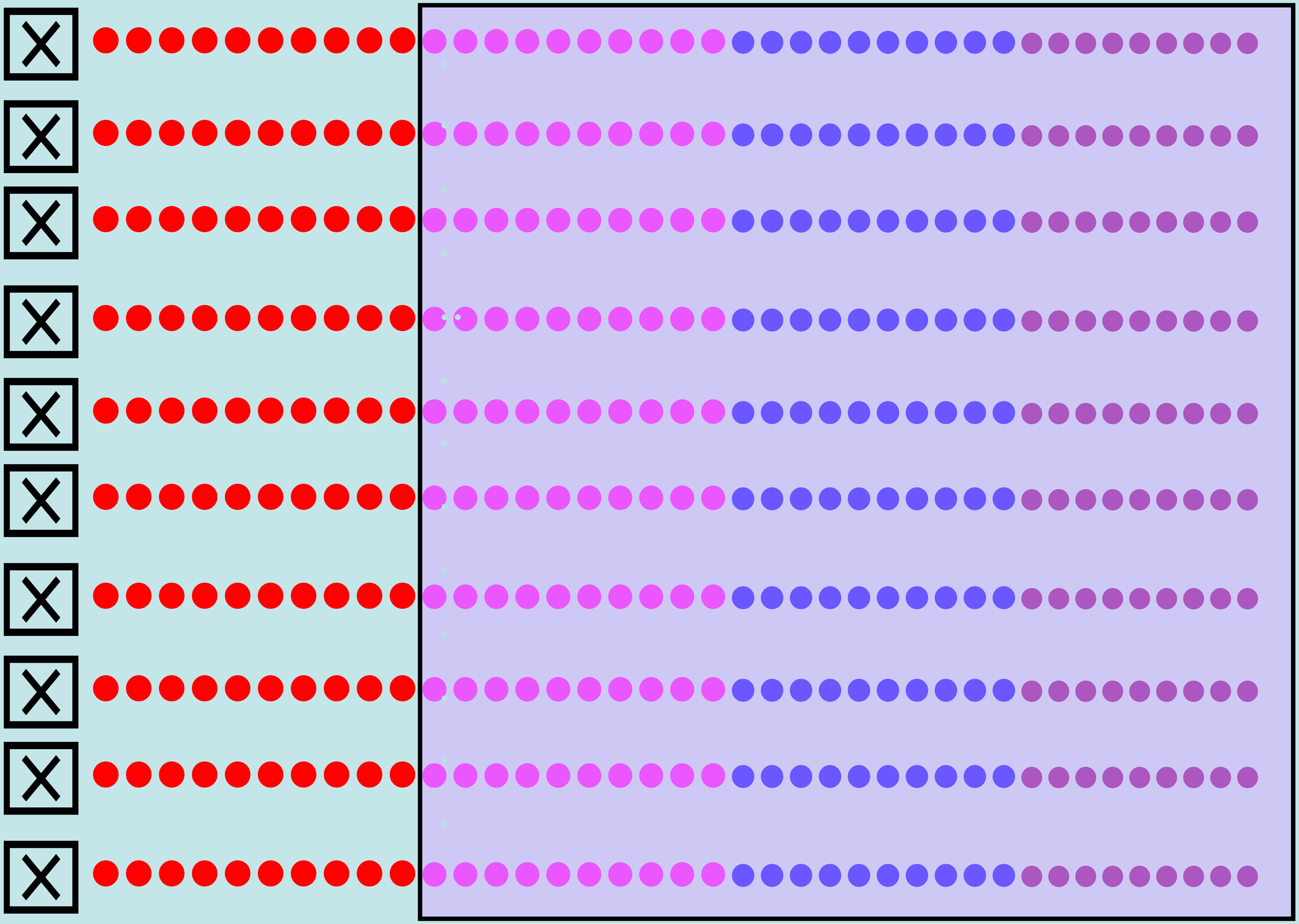


THIS IS NOT REMOVED!

ONLY THIS PORTION MAY BE TRANSPORTED!

WITH 8 REACTORS

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 builds up**.

With more reactors, **the stock of fresh unburied waste keeps growing**

– **even if the older, colder 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

Royal 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

. . . but reprocessing remains the 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 extraction) . . .*

Geologic Disposal
as an industry strategy

(1) **"Get it out of sight, out of mind"** : OBJECT: make more

"Clear the decks, we're running out of storage space."

(2) **"Get all the waste in one place"** : OBJECT: plutonium

"Plutonium is the fuel of the future and it is in the waste."

Our Nuclear Waste Dilemma:

There are **100s of radioactive poisons** with distinct biological pathways.

We **do not know how to destroy or neutralize** these wastes.

Nuclear wastes are **dangerous for millennia**, even millions of years.

Disposal = abandonment: this approach is **not scientifically certain**.

No precedent: humans have **never safely "disposed" of anything**.

USA tried 8 times to find a disposal site for HLW and **failed all 8 times**.

Germany has 2 failed underground repositories: Asse II, Morsleben.

WIPP, the **only Deep Geologic Repository in USA, recently failed**.

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** ?

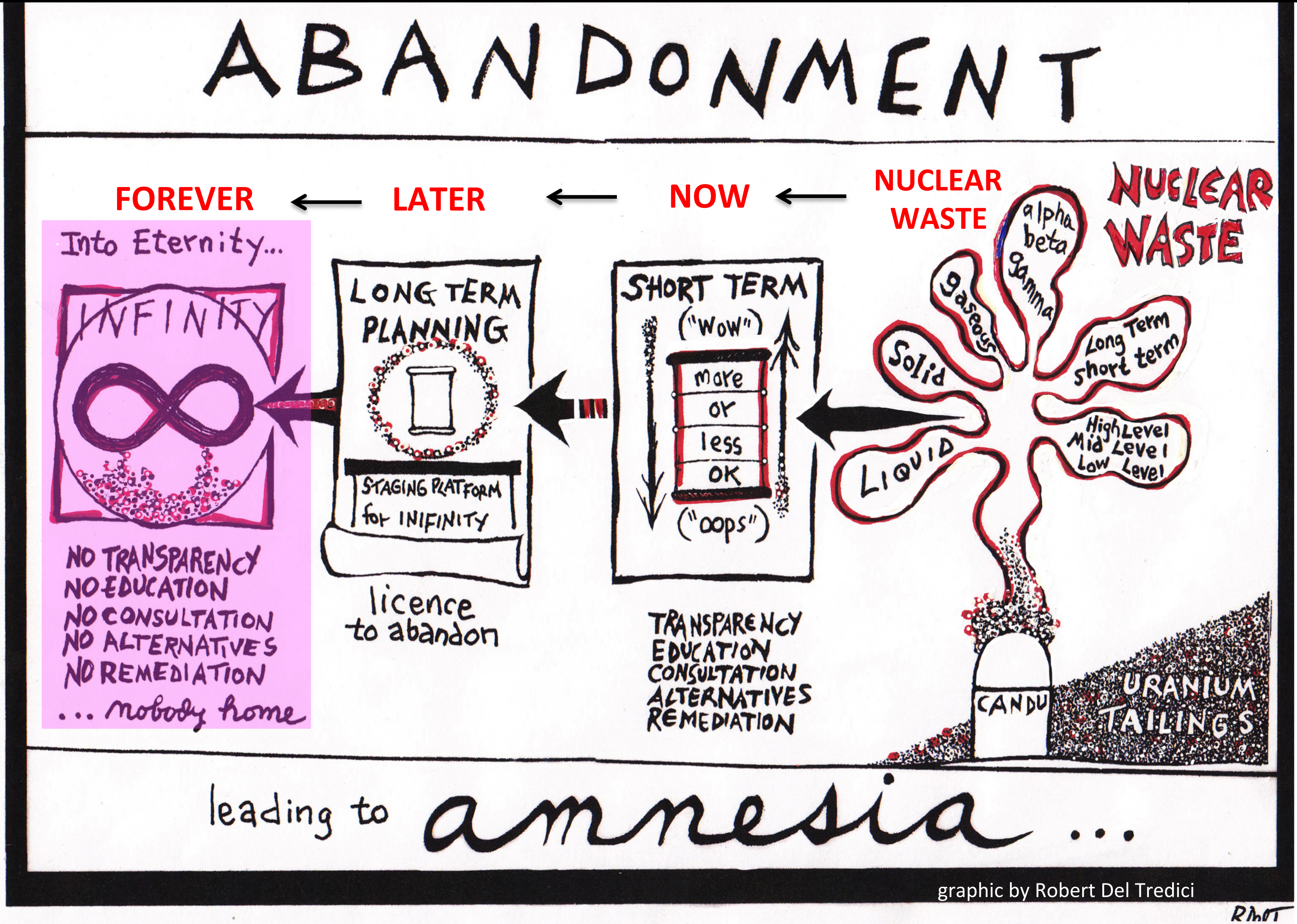
NO

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; future generations simply do not know …



after

abandonment ···

··· amnesia

sets in !

Is there an alternative to “Geological Disposal” ?

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.

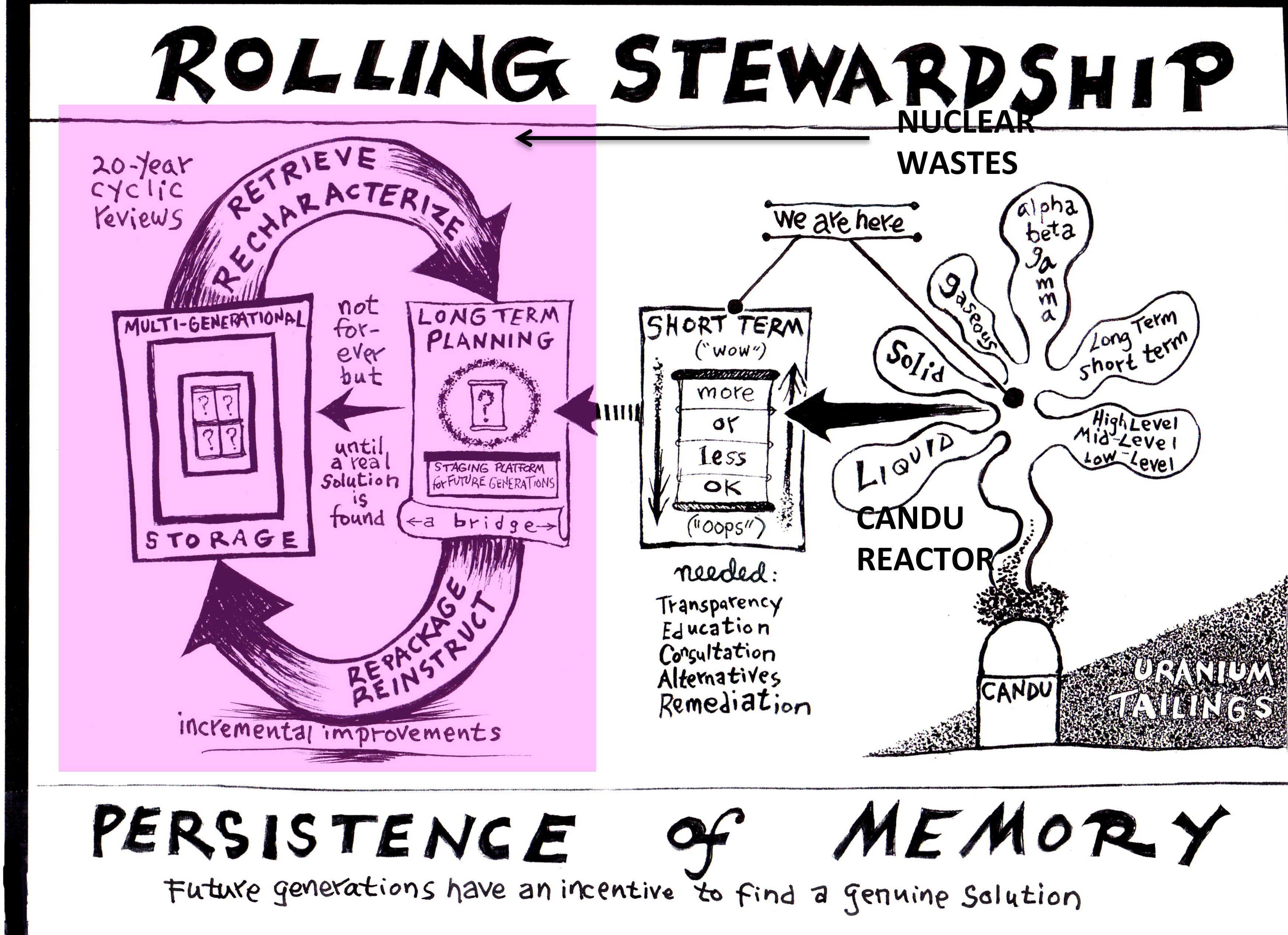
Wastes are **packaged safely** for extended periods & **repackaged later**.

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

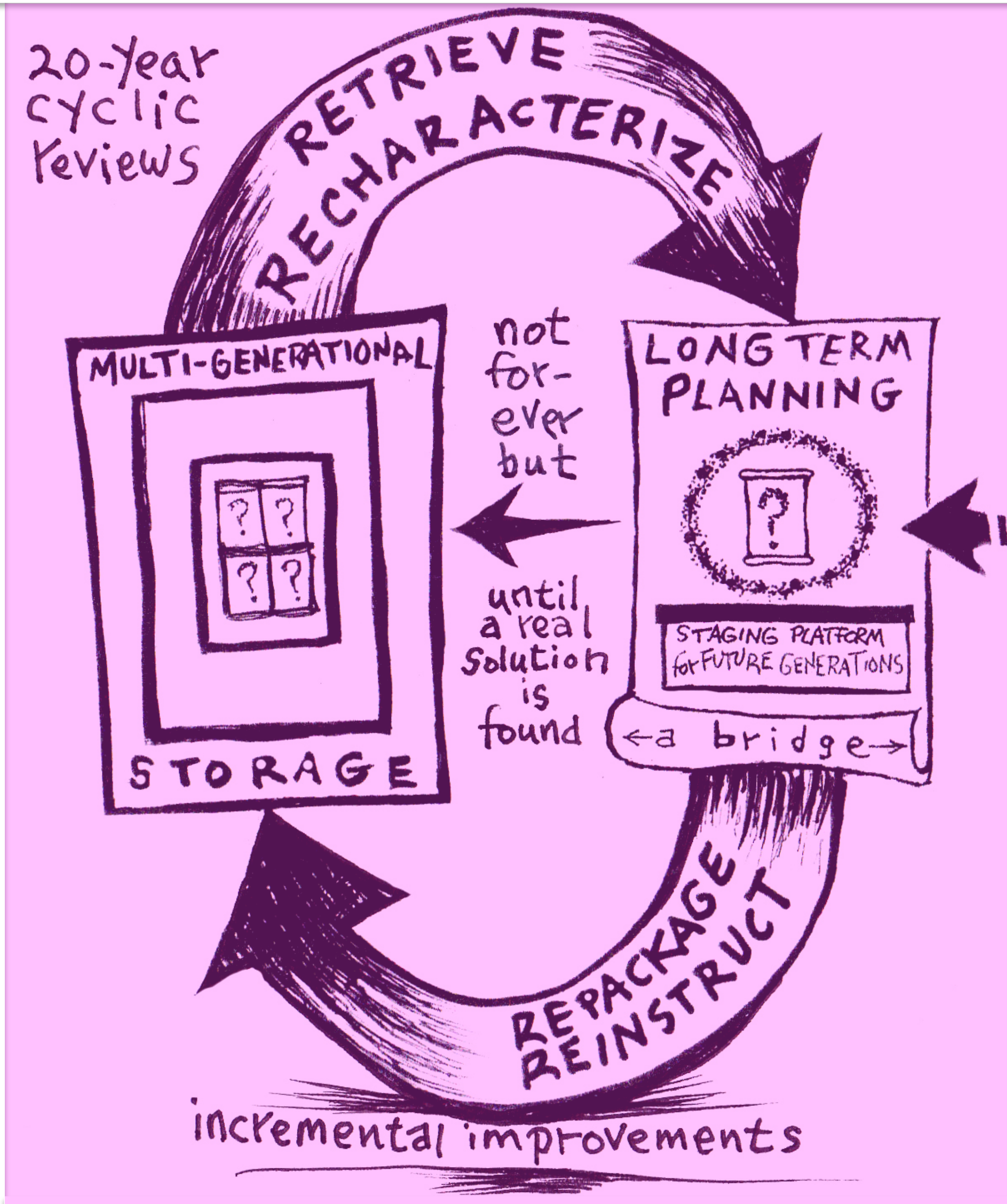
Rolling Stewardship is needed **until a "genuine solution" is found**.

The production of additional wastes can & should be phased out.

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



graphic by Robert Del Tredici

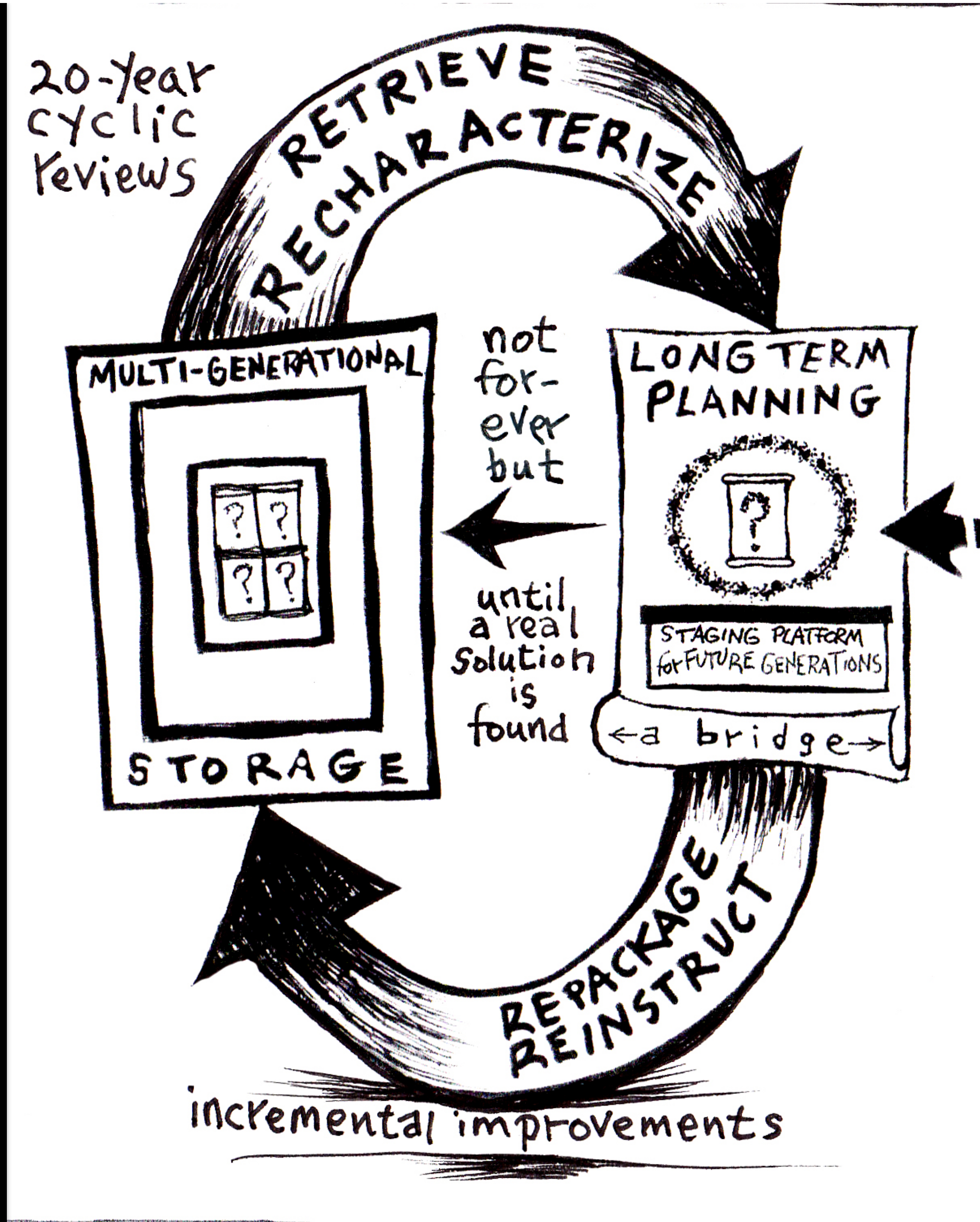


Rolling Stewardship is an
intergenerational
management strategy

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


20-Year cyclic reviews
RETRIEVE
RECHARACTERIZE
MULTI-GENERATIONAL
STORAGE
not forever but
until a real solution is found
LONG TERM PLANNING
STAGING PLATFORM for FUTURE GENERATIONS
a bridge
REPACKAGE
REINSTRUCT
incremental improvements

The End

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