Nuclear Waste 101:

Introduction and Overview

A Slide Show

prepared for a
Congressional Briefing
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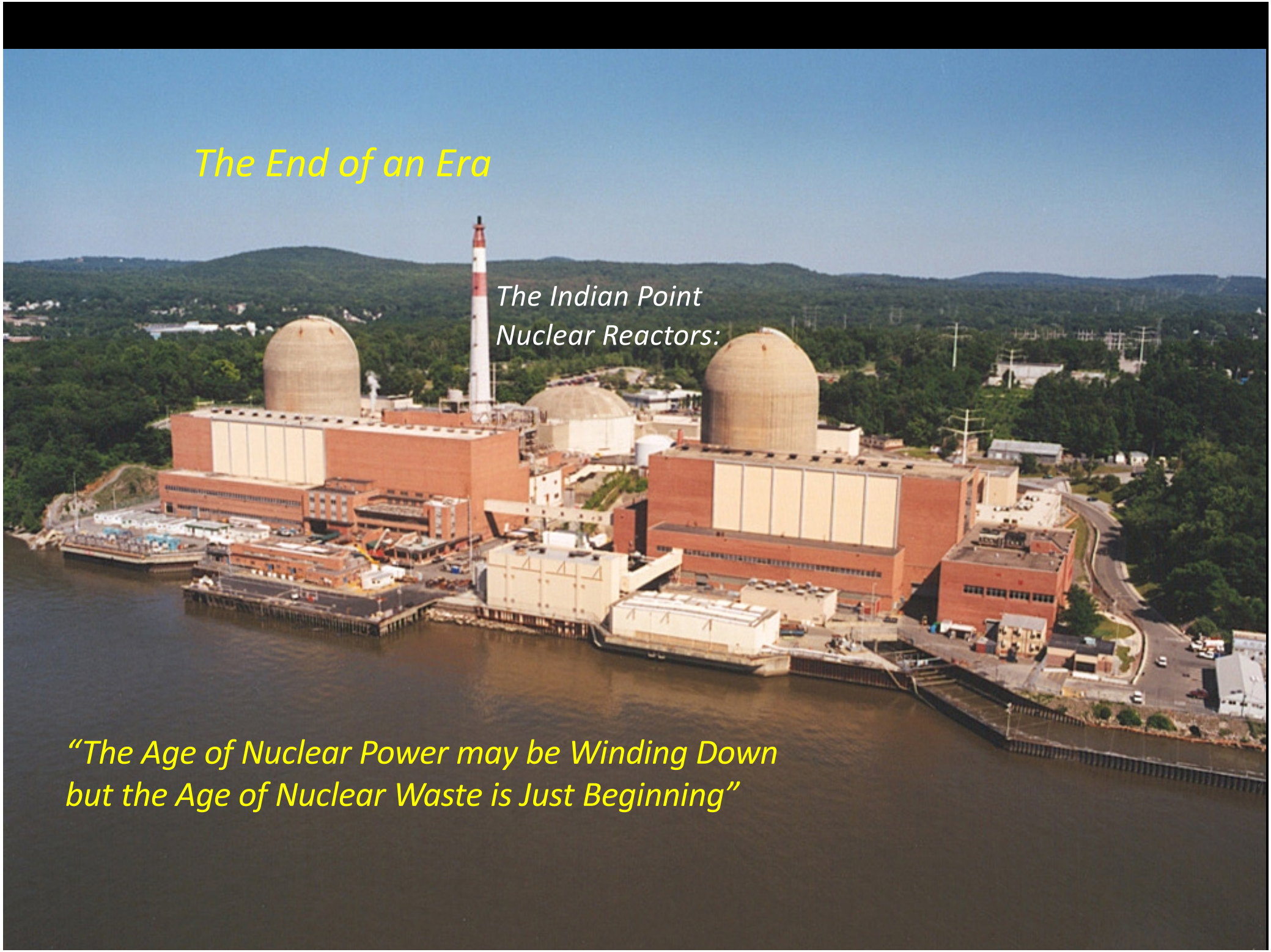

The End of an Era
The Indian Point
Nuclear Reactors:
"The Age of Nuclear Power may be Winding Down
but the Age of Nuclear Waste is Just Beginning"

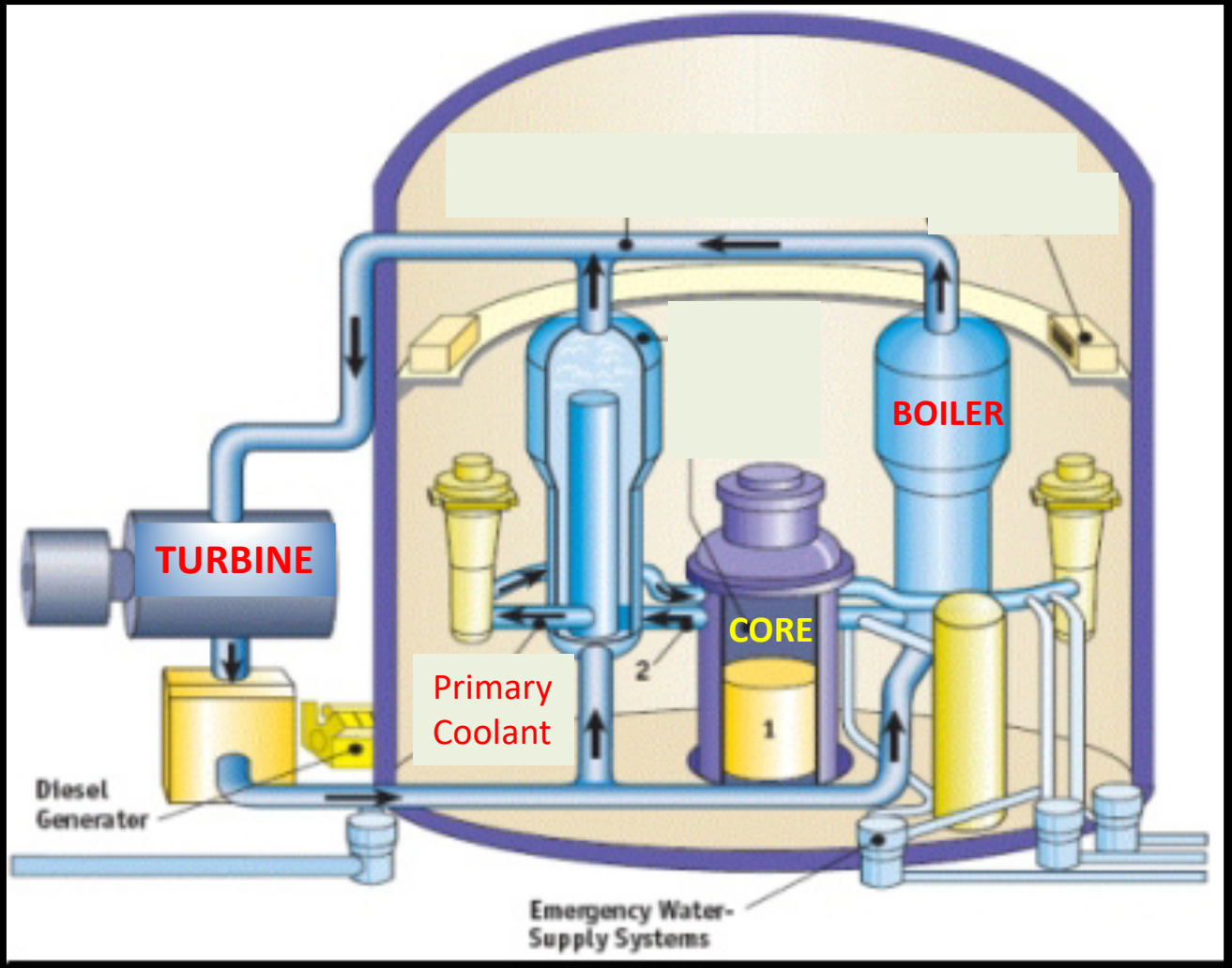
What is Nuclear Energy?

Every atom has a tiny NUCLEUS surrounded by orbiting electrons.

NUCLEAR ENERGY comes directly from the atomic nucleus

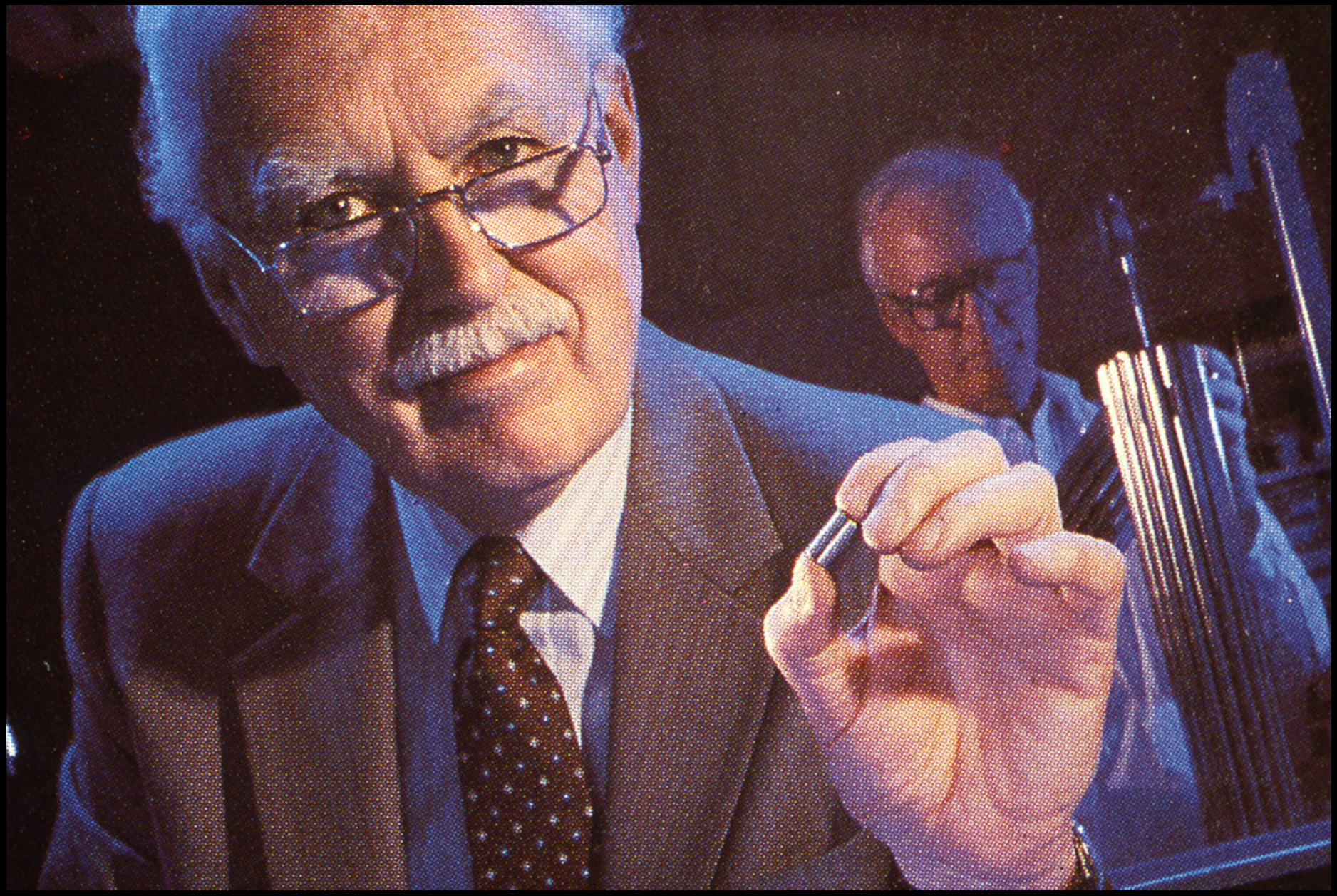
Nuclear power is another way to boil water.

Steam turns a turbine & generates electrcitiy



Radioactive wastes are created in the core

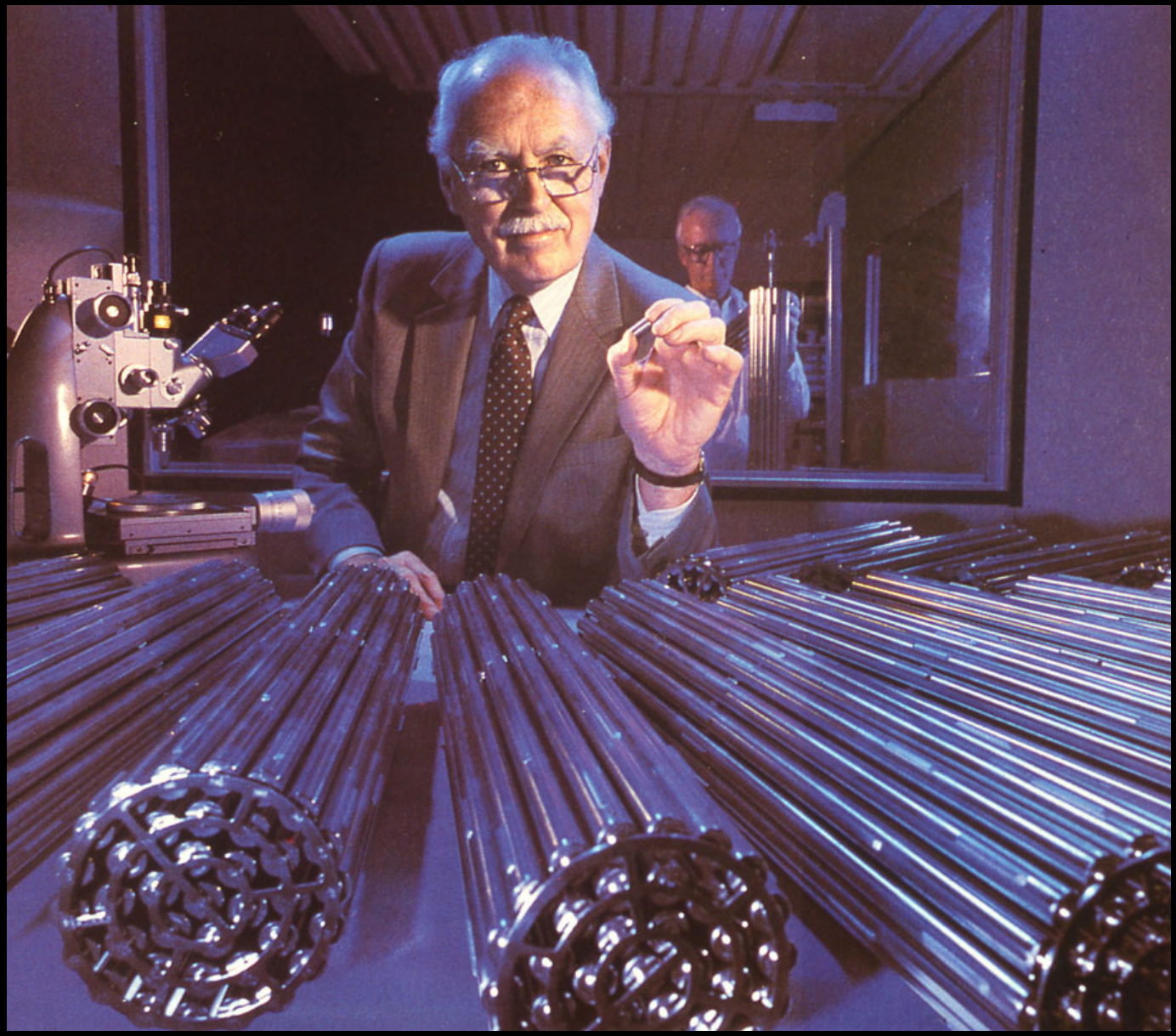
and spread by the primary coolant.



Advantage: one fuel pellet has as much energy as a carload of coal – with no CO_2 emissions

Canadian Nuclear Association ad: 'Small Wonder'

Photo: Robert Del Tredici



Disadvantage: while nuclear fuel rods and pellets can be handled safely before use, once used, the radioactive waste will deliver a lethal blast of radiation in seconds.

"Small Wonder" : Canadian Nuclear Association Ad

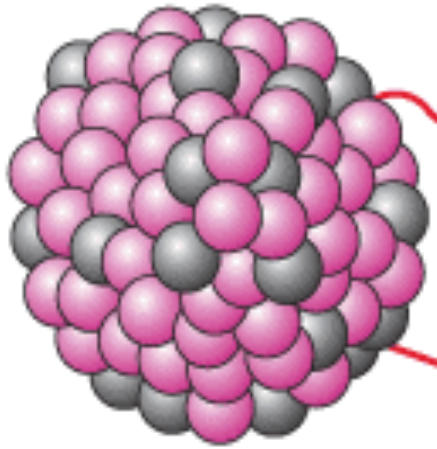
Radioactivity is

a form of nuclear energy

that cannot be shut off.

That's why we have
a nuclear waste problem.

What is Radioactivity?



Radioactive Nucleus

gamma

Energy

alpha or beta

Atomic Radiation

Particle

- ***a radioactive nucleus is like a miniature time bomb***
- ***it will suddenly explode, damaging nearby materials***

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

But in a “cloud chamber” you can see the tracks

RADIOACTIVE MATERIALS

Fission Products are chemical substances which are also radioactive.

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

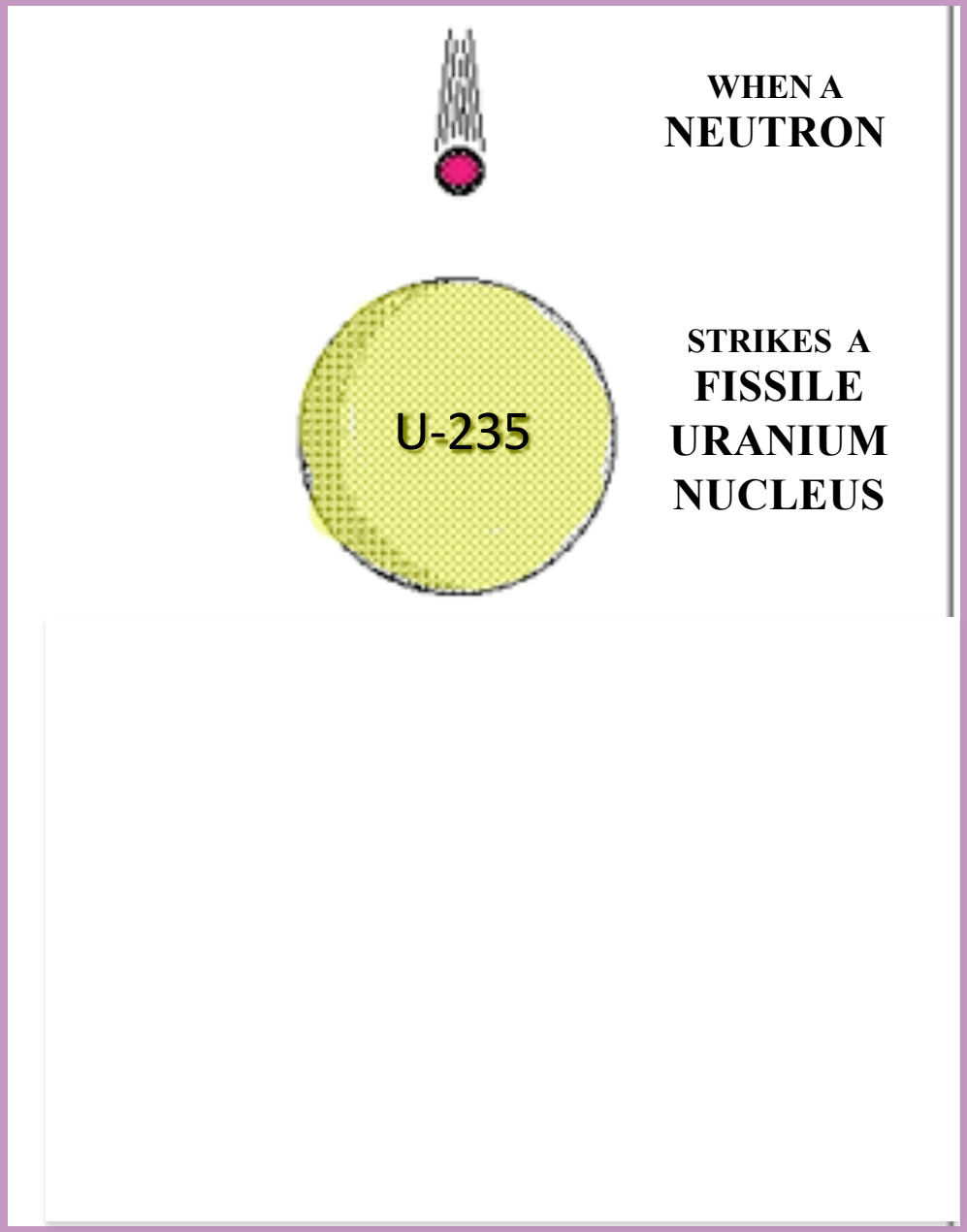
BONE
radium–226
alpha ; 1 620 years
zinc–65
gamma ; 245 days
strontium–90
beta ; 28 years
yttrium–90
beta ; 64 hours
promethium–147
beta ; 2 years
barium–140
beta (gamma) ; 13 days
thorium–234
beta ; 24,1 days
phosphorus–32
beta ; 14 days
carbon–14 (and fat)
beta ; 5 600 years

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 –

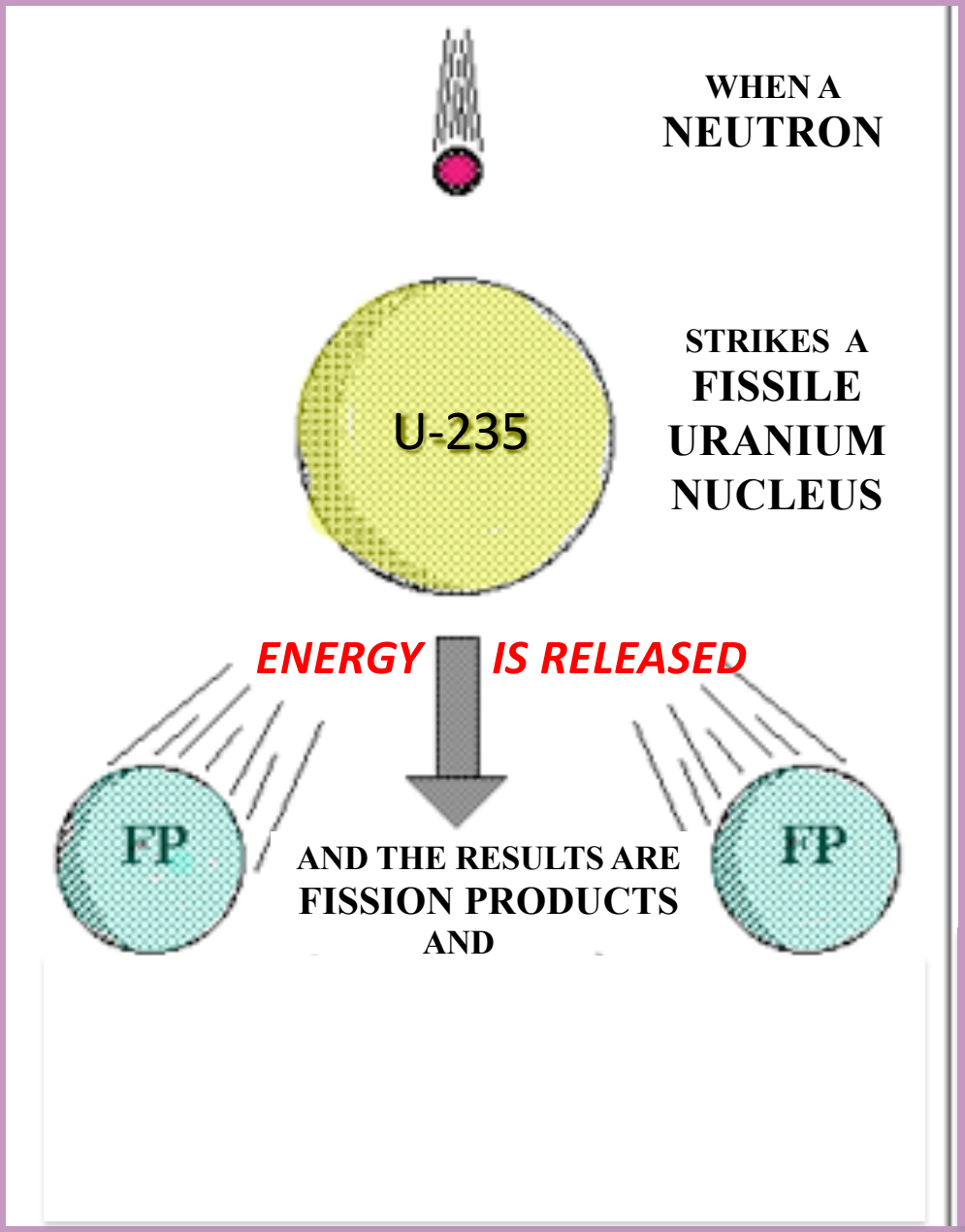
– the onset of disease may occur years or decades after exposure.

How Nuclear Fission Creates Radioactive Wastes



THREE FAMILIES of RADIOACTIVE WASTES created by fission

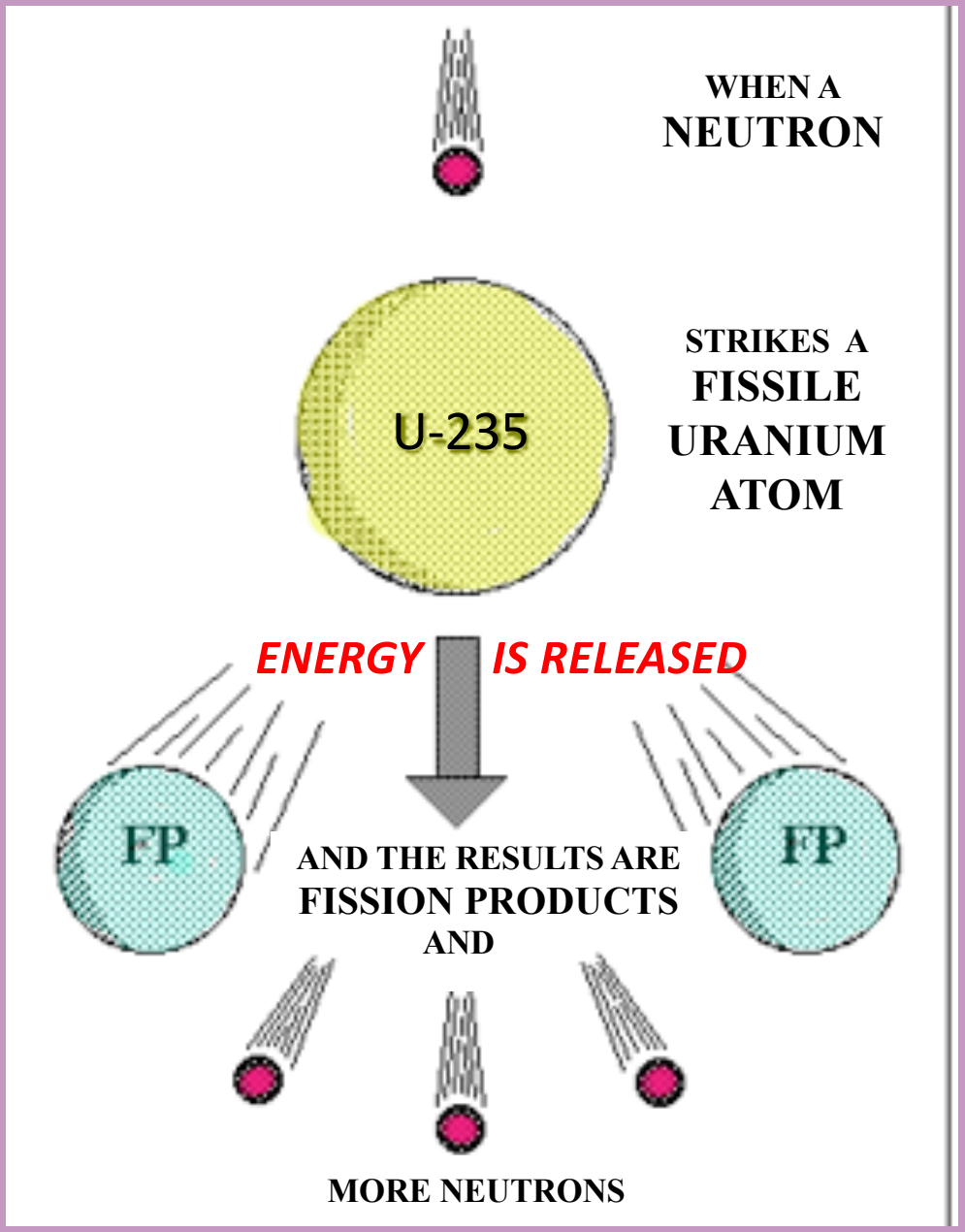
Nuclear Fission



THREE FAMILIES of RADIOACTIVE WASTES created by fission

1. FISSION PRODUCTS broken pieces of uranium atoms

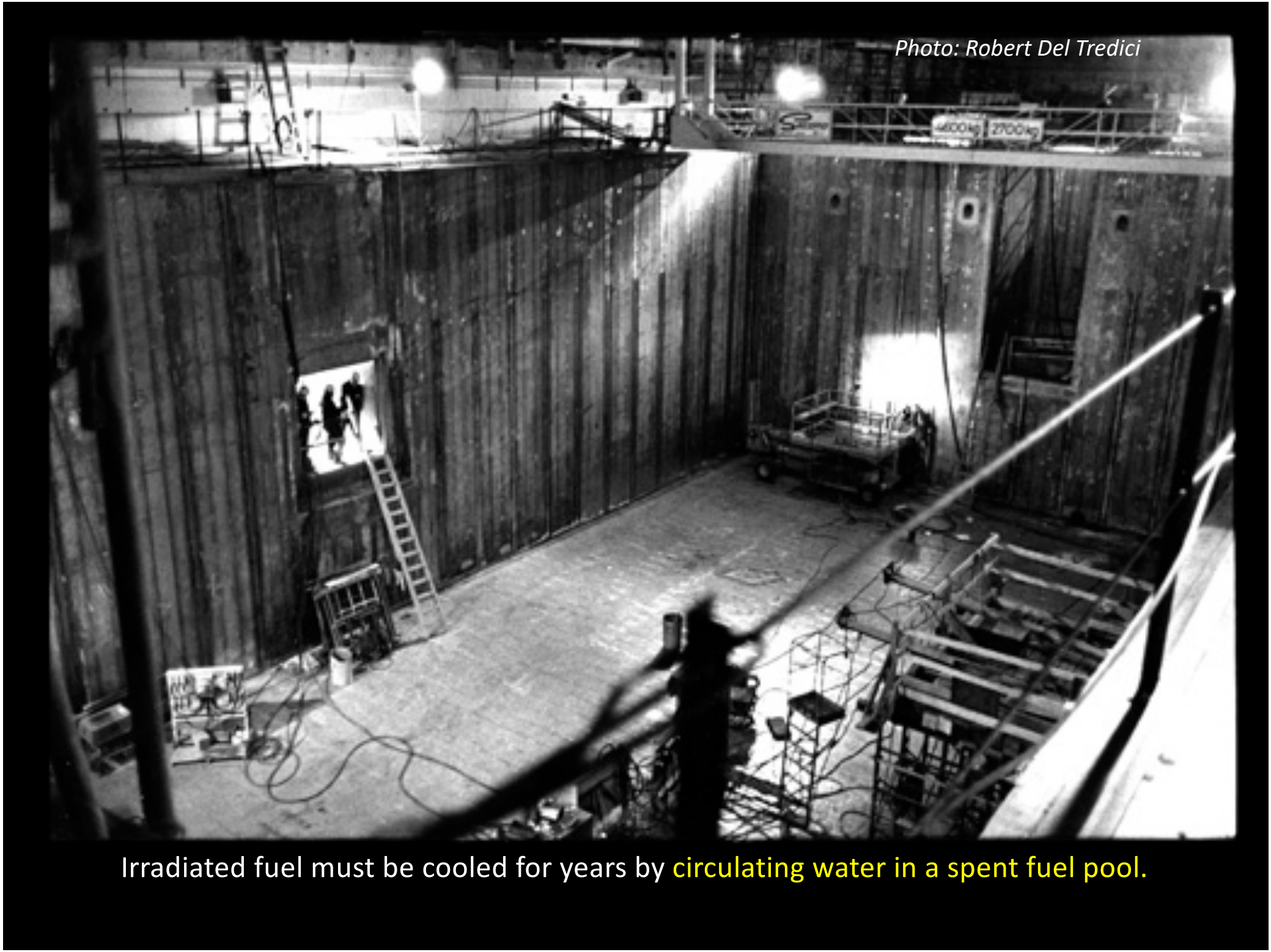
Nuclear Fission



THREE FAMILIES of RADIOACTIVE WASTES created by fission

1. FISSION PRODUCTS broken pieces of uranium atoms

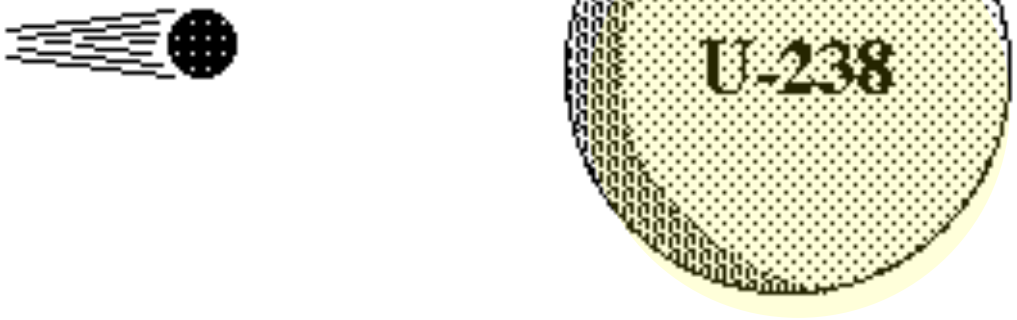
2. PLUTONIUM etc. and
3. ACTIVATION products created by . extra neutrons



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

How is PLUTONIUM created?

when an nucleus of uranium-238 absorbs a neutron . . .

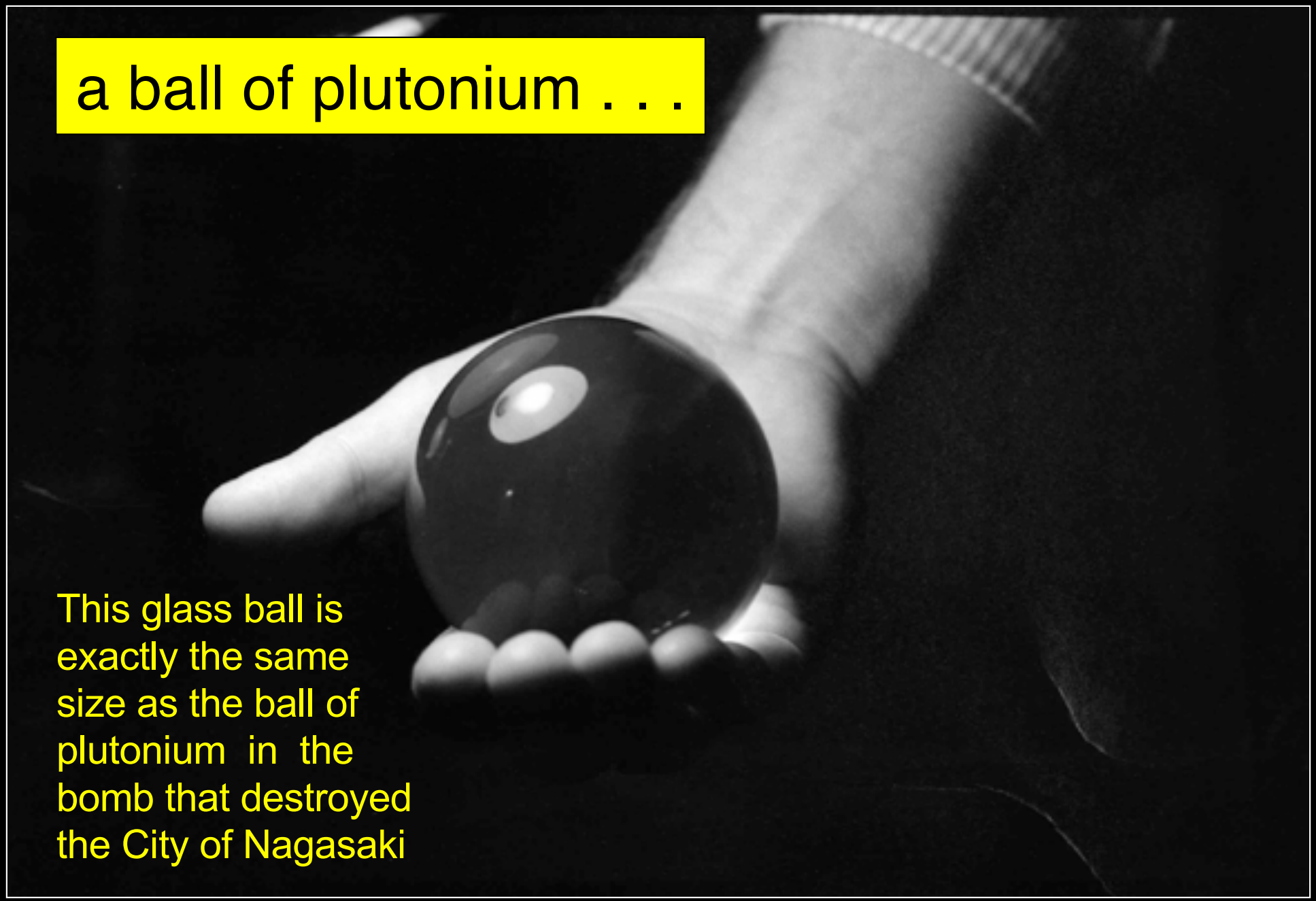


How is PLUTONIUM created?

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

Plutonium can be used for nuclear weapons now or 1000's of years from now

a ball of plutonium . . .



This glass ball is exactly the same size as the ball of plutonium in the bomb that destroyed the City of Nagasaki

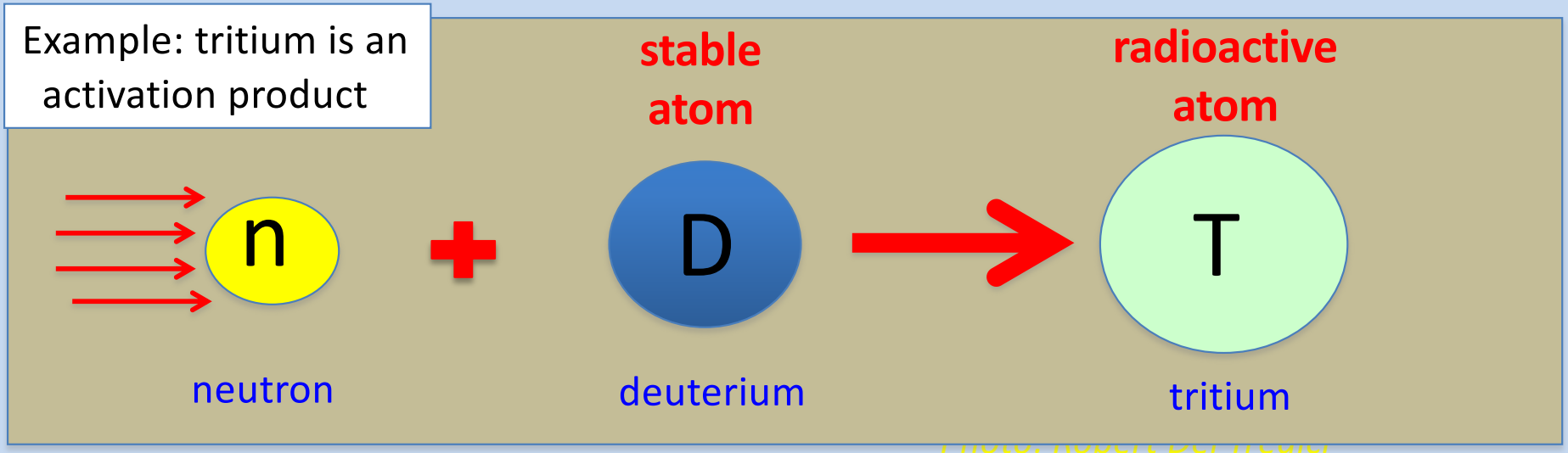
Photo by
Robert Del Tredici

What is an Activation Product?

When a stray neutron is absorbed by a non-radioactive atom

It becomes destabilized – radioactive– an “activation product”.

Example: tritium is an activation product



Example: a non-radioactive atom of deuterium becomes a radioactive atom of tritium when it absorbs a stray neutron.

What gets activated?

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

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

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

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

Nickel-63 – half life of 100 years
Nickel-59 – half-life of 76,000 years

128 steam generators (100-tonne each) from Bruce reactors.

Loaded on a 40-wheel truck; destined to be stored as radioactive waste.

Why are these boilers 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.

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 Ar	Argon Argon	39 42		¥ ¥	¥ ¥	
K K	Potassium Potassium	40 42		¥	 ¥	
Ca Ca	Calcium Calcium	41 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 Fe	Iron Iron	55 59		¥¥¥	¥¥¥ ¥	
Co Co	Cobalt Cobalt	58 60		¥ ¥¥¥	¥ ¥¥¥	
Ni Ni	Nickel Nickel	59 63		¥ ¥¥¥	¥¥¥ ¥¥¥	
Zn	Zinc	65		¥	¥	
Se	Selenium	79	¥¥¥			
Kr Kr	Krypton Krypton	81 85	¥ ¥¥¥			
Rb	Rubidium	87	¥			
Sr Sr	Strontium Strontium	89 90	¥ ¥¥¥	 ¥	¥ ¥	
Y	Yttrium	90	¥¥¥	¥	¥	

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	¥		¥	

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)
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	¥		¥	
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		¥		

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

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				¥

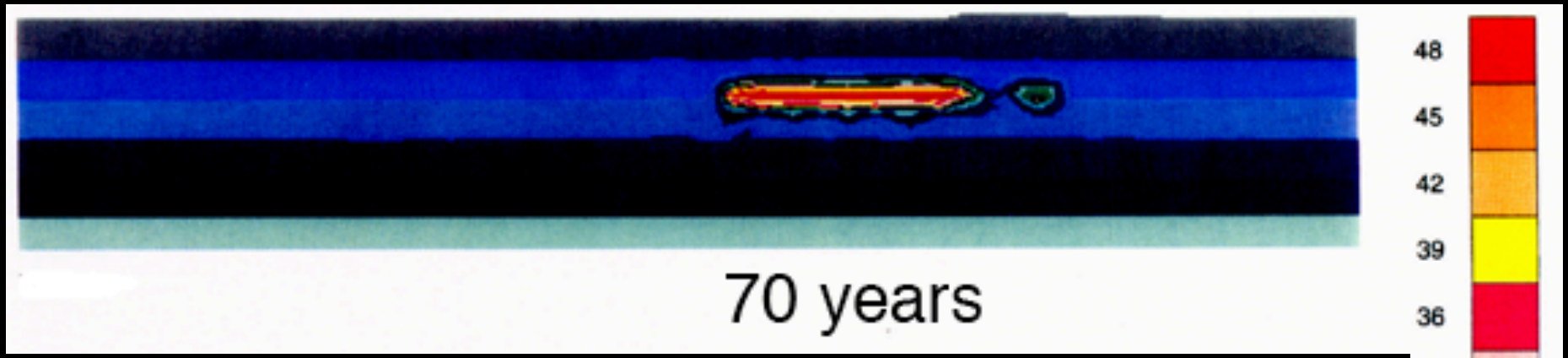
Th	Thorium	234				¥¥¥
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	F.P. Fission Product	F.I.A.P. Activation Product	Z.A.P. Activation Product	Actinide (includes progeny)
Pa	Protactinium	231				¥
Pa	Protactinium	233				¥¥¥
Pa	Protactinium	234				¥
Pa	Protactinium	234m				¥¥¥
U	Uranium	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	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)

¥ 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 man-made radionuclides contained in irradiated nuclear fuel is by no means complete. (AECL)



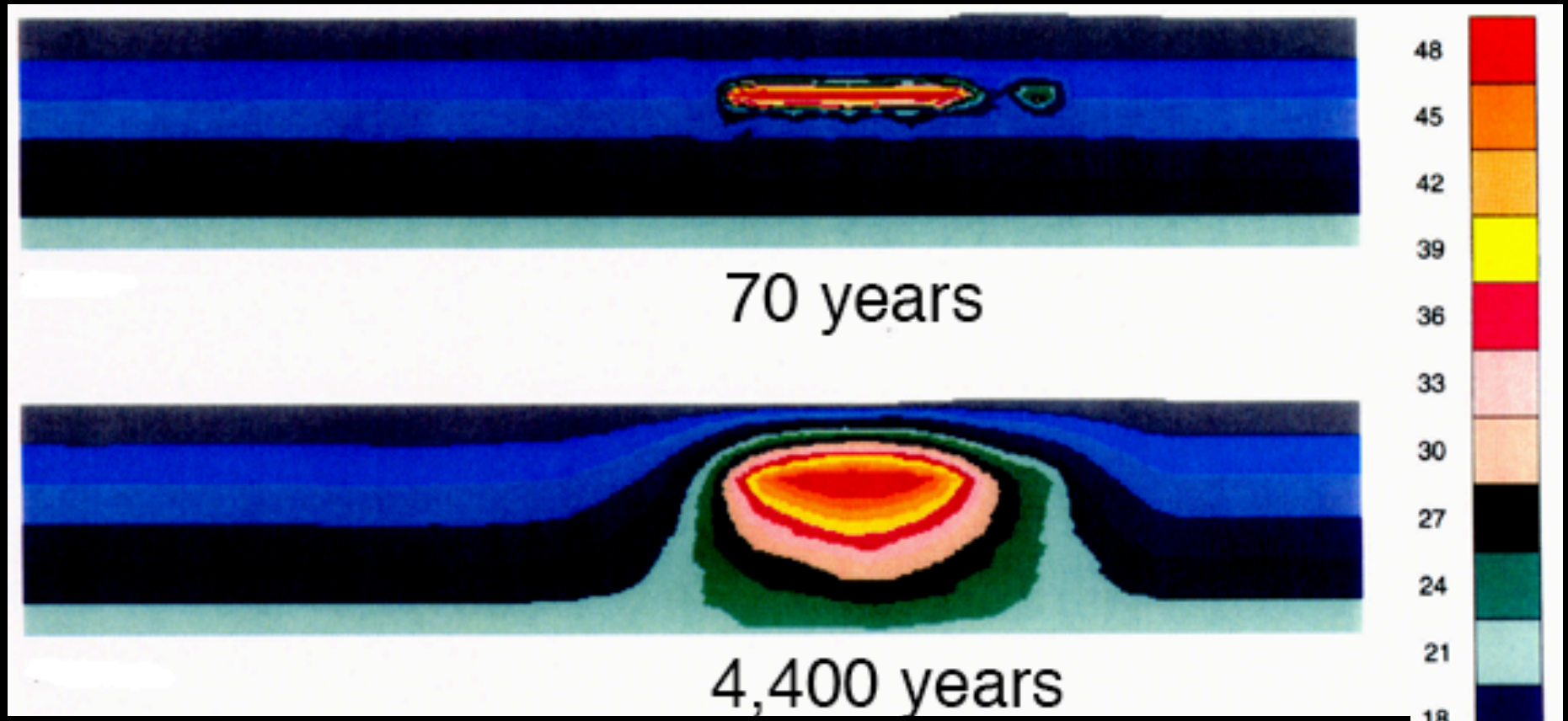
This series of graphics is from AECL's EIS on the DGR Concept.

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.



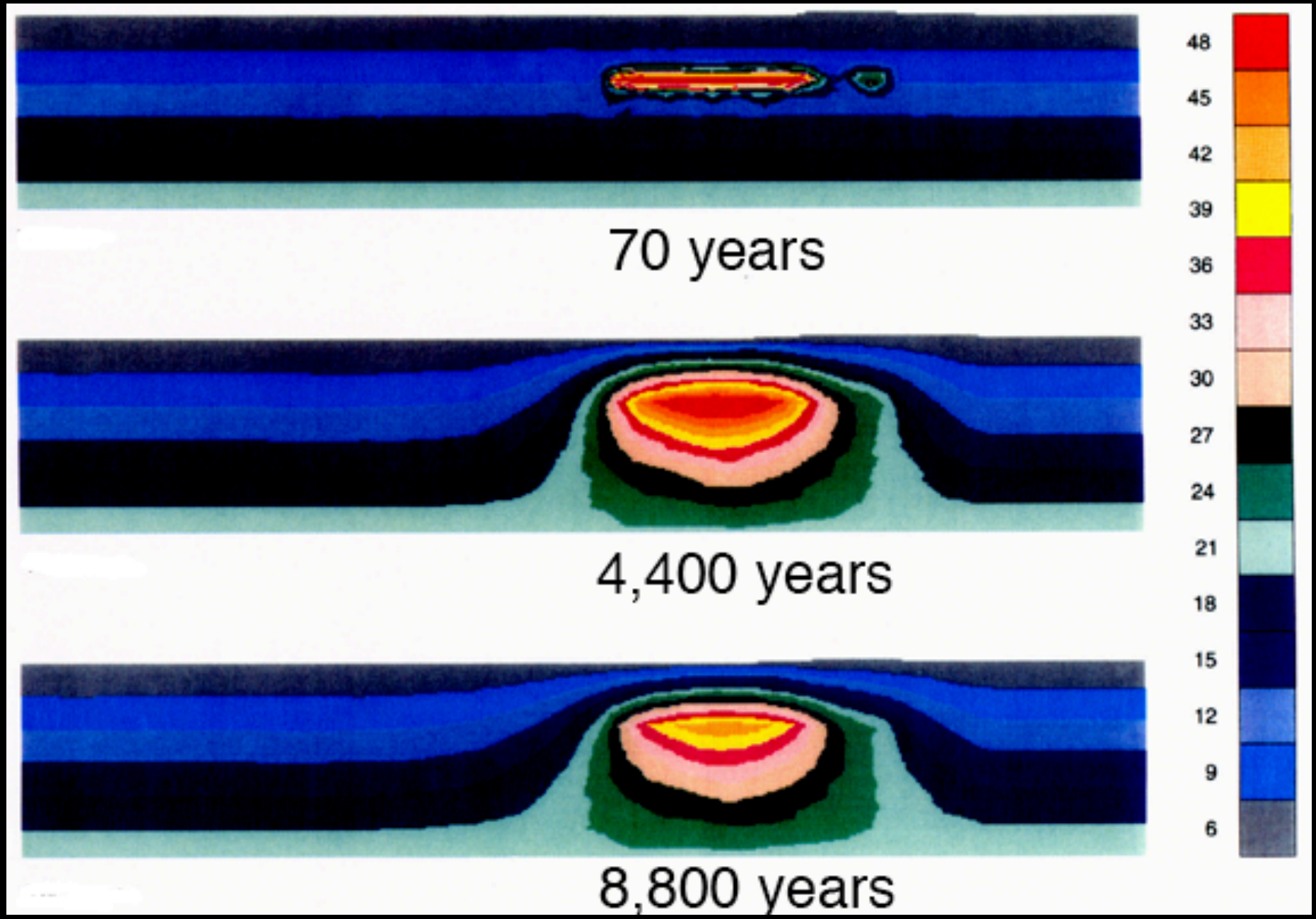
Heat continues to be generated by radioactive disintegration.

This heat goes into the rock, raising the temperature.

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

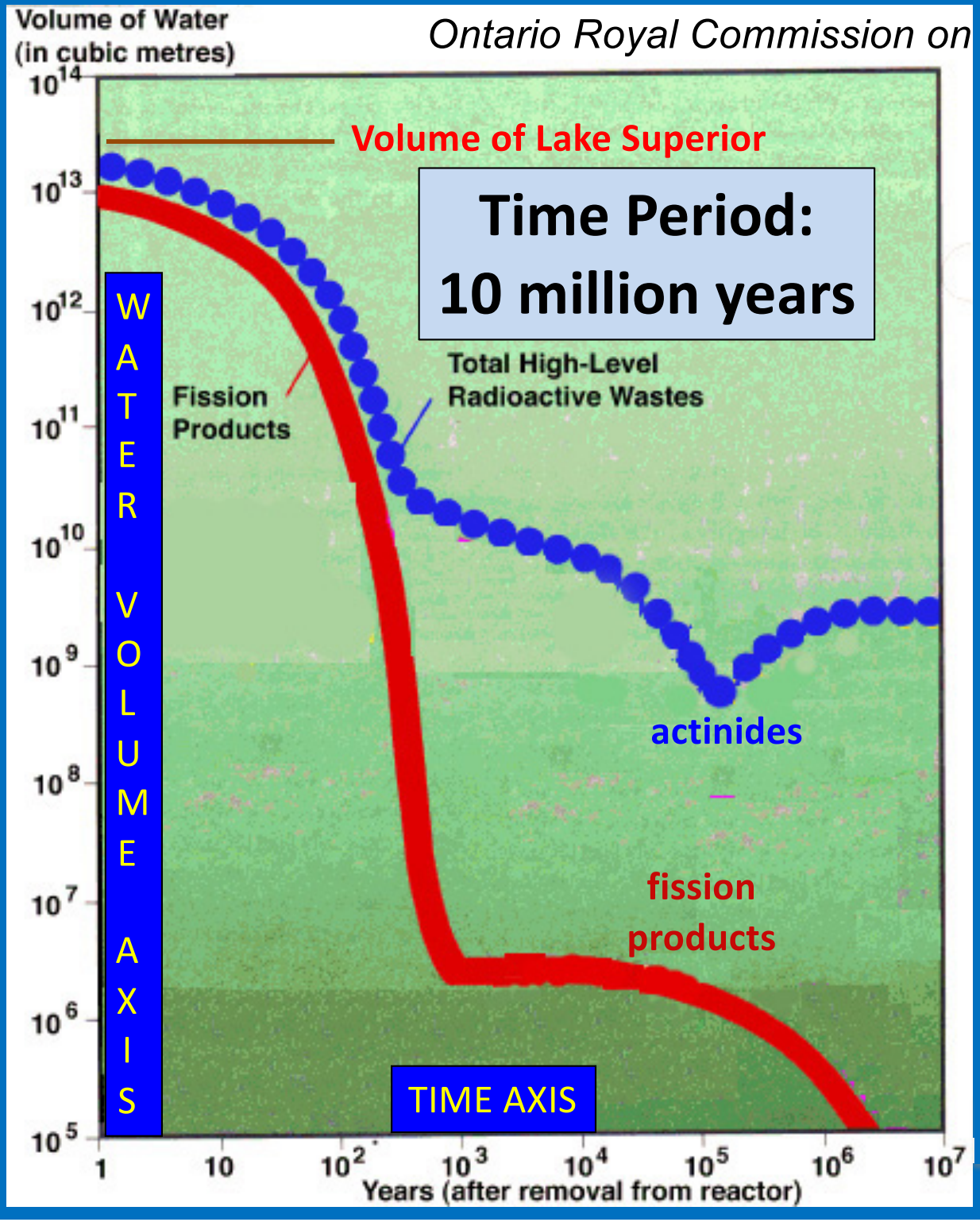
This 50,000 year period is the "thermal pulse" – a small blip in time compared with the multi-million-year persistence of radiotoxicity.

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



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

Ontario Royal Commission on Electric Power Planning (1978)

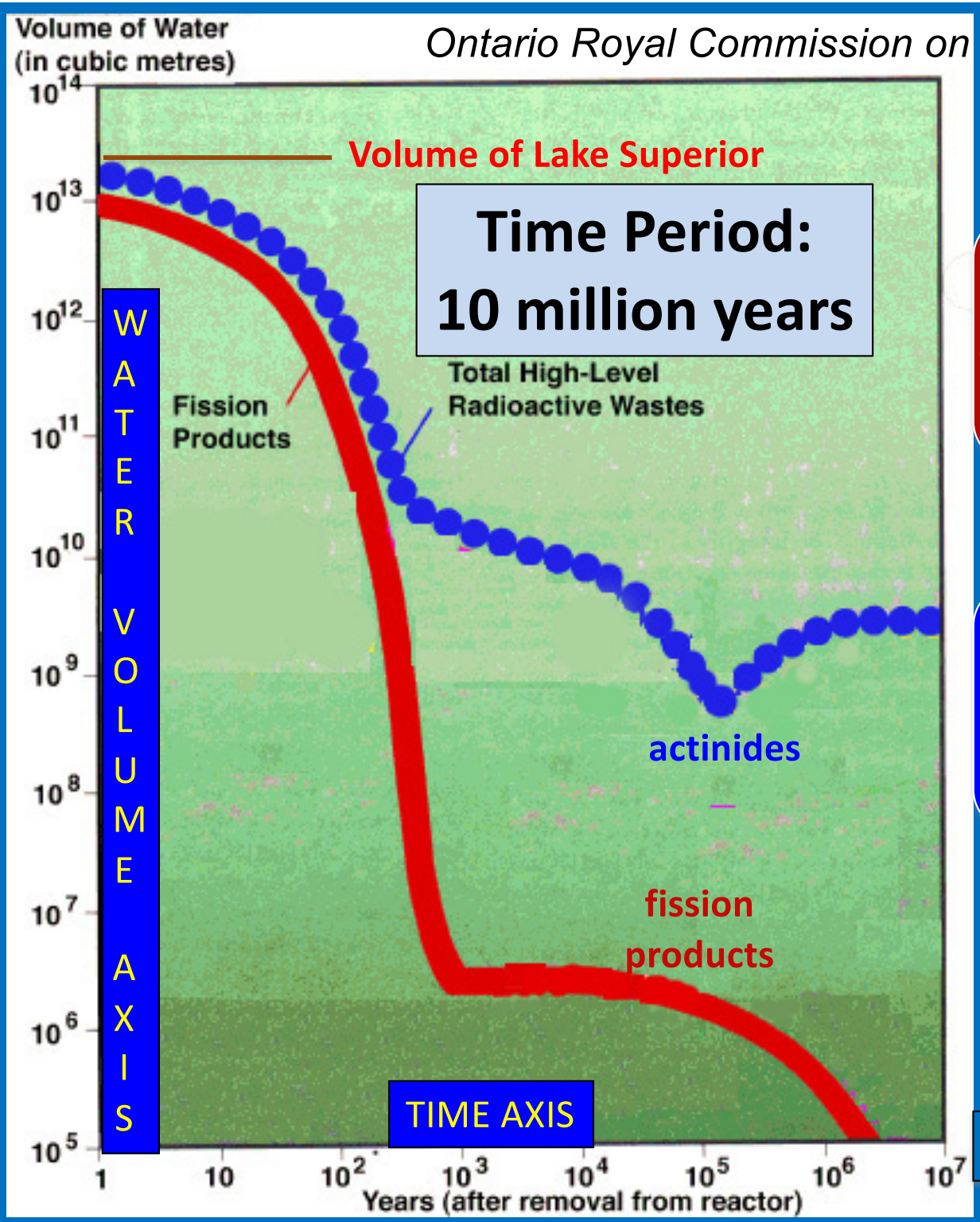


The radiotoxicity of one year's worth of used nuclear fuel from a reactor over ten million years

The amount of water that can be ruined by one year's output of used fuel just out of the reactor is about the volume of Lake Superior.

Royal Commission Report, 1978

Ontario Royal Commission on Electric Power Planning (1978)

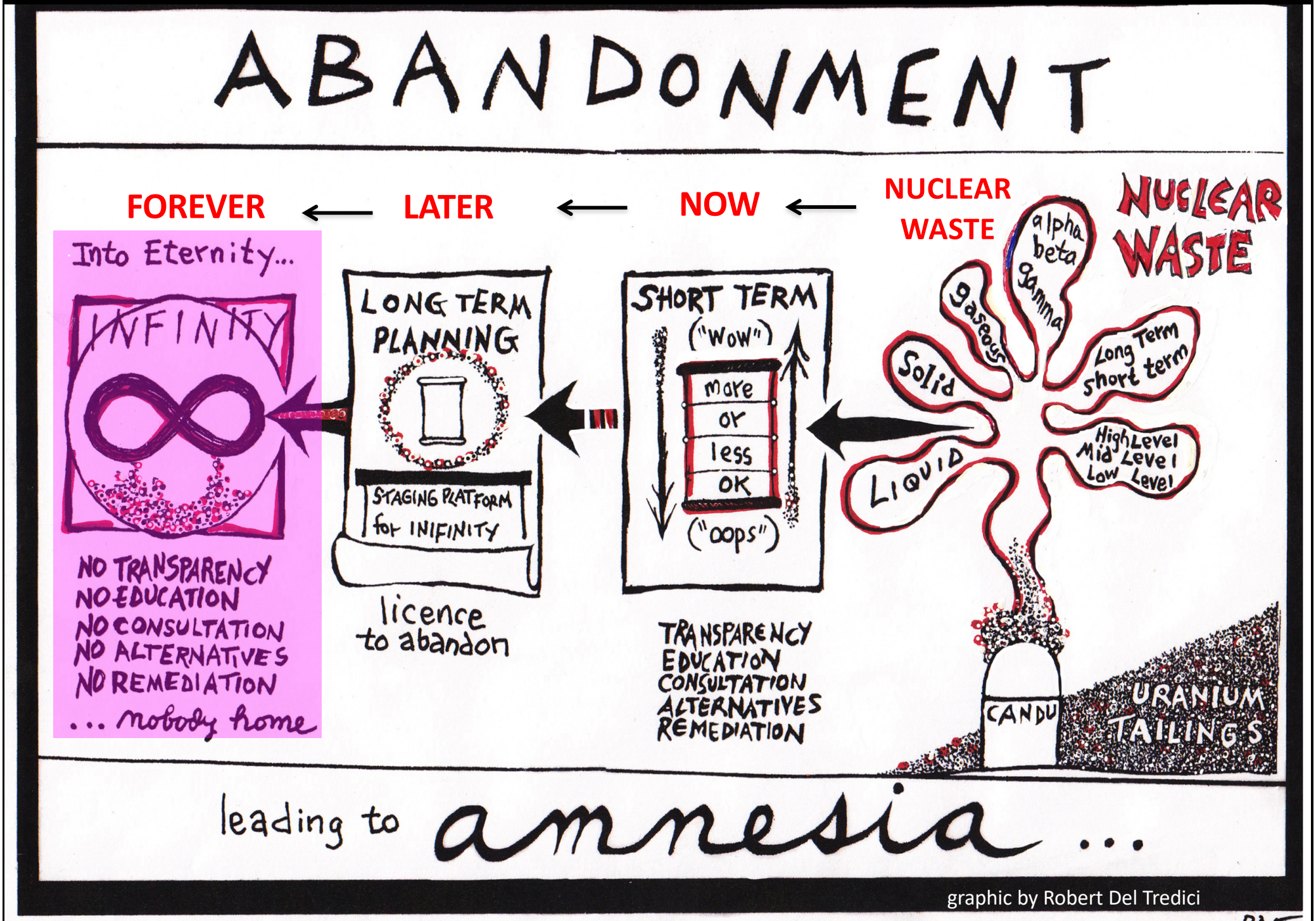


For the first 500 – 1000 years, fission products are the deadliest components of nuclear fuel waste.

After 1000 years, actinides are the deadliest components of nuclear fuel waste.

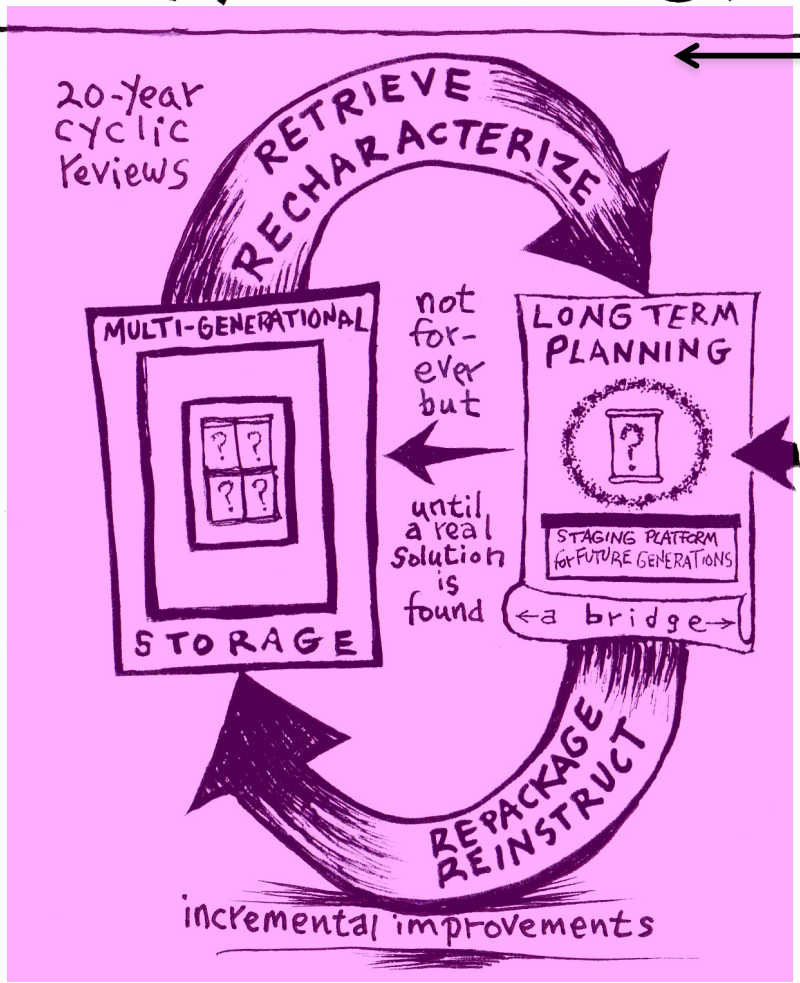
Royal Commission Report, 1978

Abandonment leads to amnesia; no one will know what it is or what to do with it …

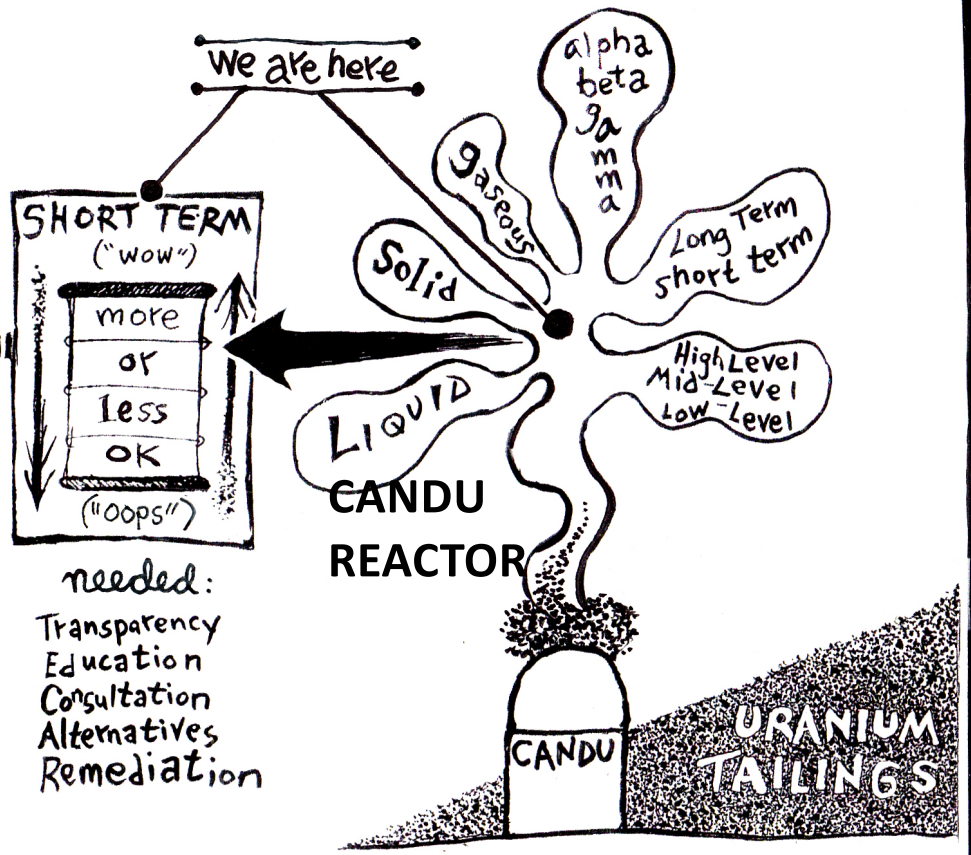


Rolling Stewardship is continuous; it is based on ensuring Persistence of Memory

ROLLING STEWARDSHIP



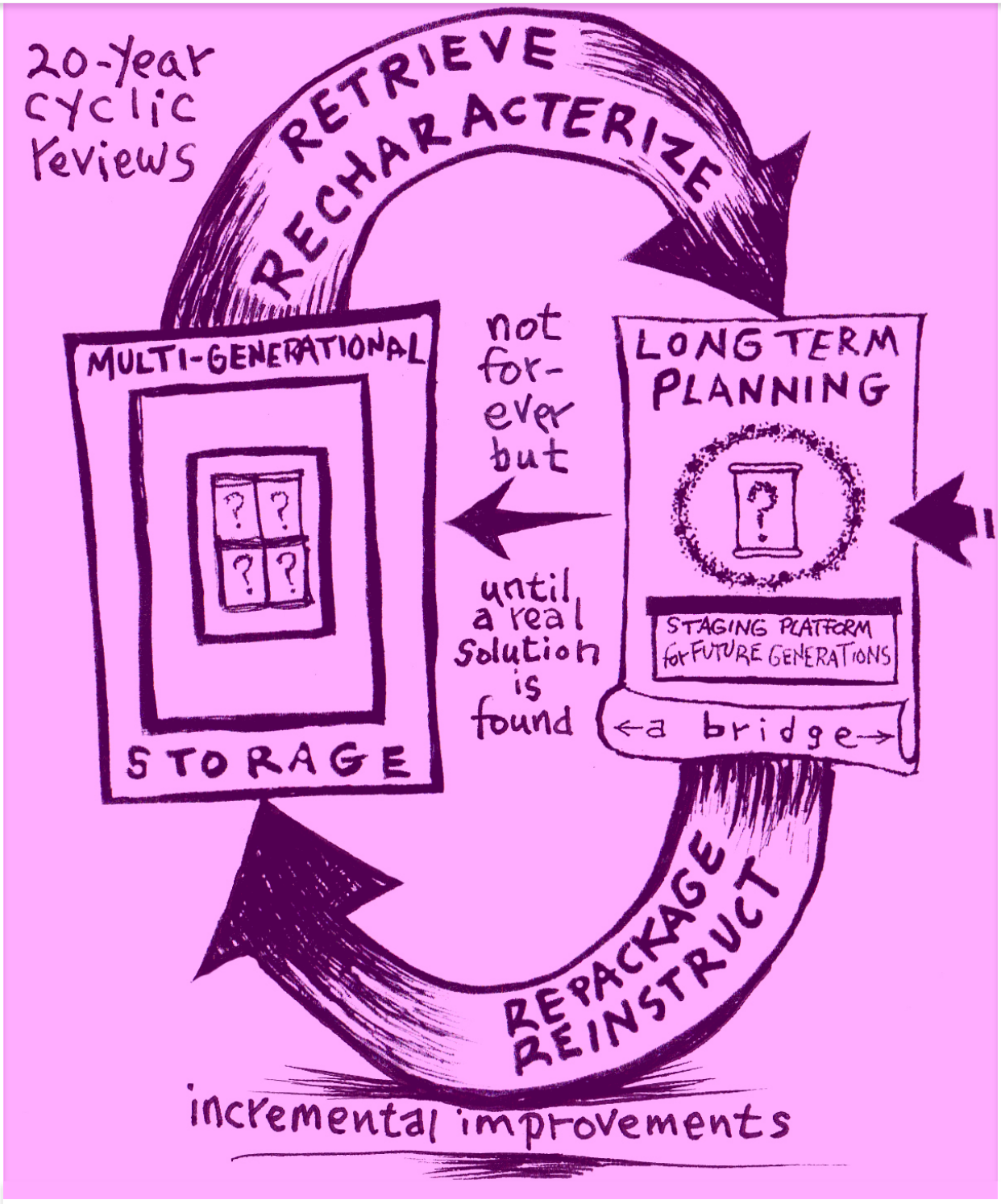
NUCLEAR WASTES



PERSISTENCE of MEMORY

Future generations have an incentive to find a genuine solution

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

The End

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