Small Modular Nuclear Reactors (SMNRs)

Not Clean,
Not Small,
Not Green,
Not Affordable

New Brunswick
March 12-13, 2020

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

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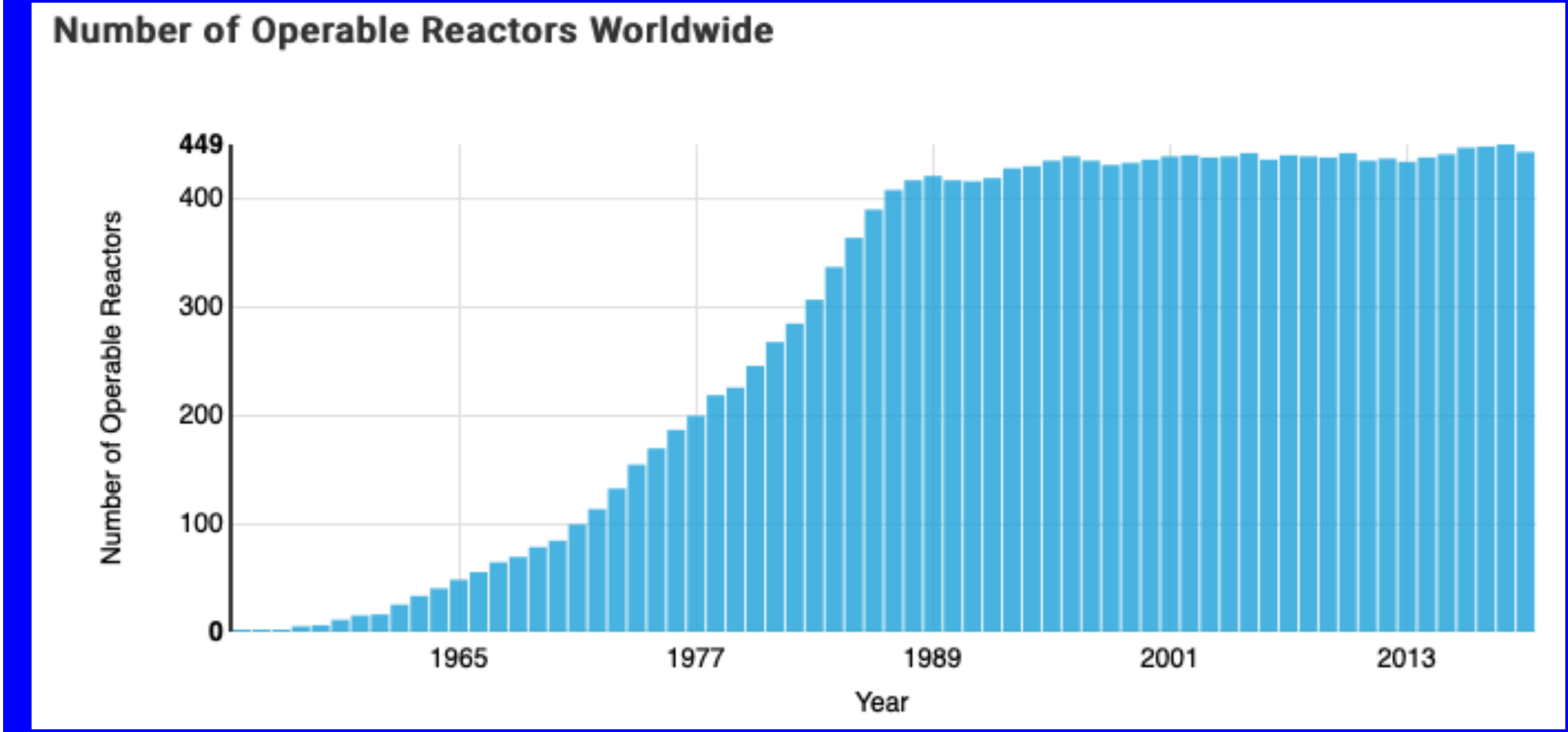
www.ccnr.org

Introduction:

The Status of the Nuclear Industry

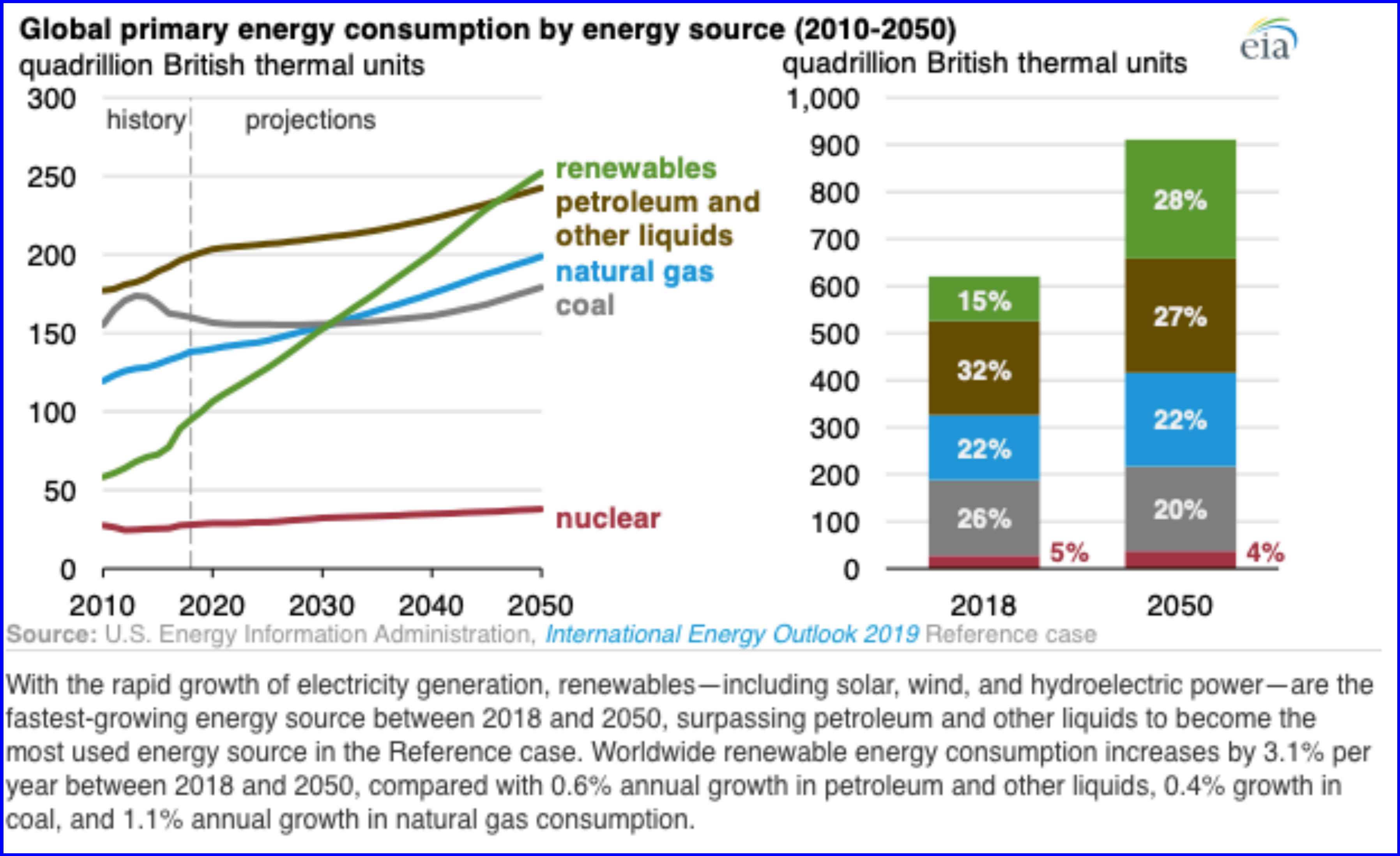
World Nuclear Association Data



1996 – 438 reactors
17% of global electricity
(< 3.3% of global energy)

2019– 442 reactors
10% of global electricity
(< 2% of global energy)

US Energy Information Administration (EIA)



Global primary energy consumption by energy source (2010-2050)

Source: U.S. Energy Information Administration, *International Energy Outlook 2019* Reference case

With the rapid growth of electricity generation, renewables—including solar, wind, and hydroelectric power—are the fastest-growing energy source between 2018 and 2050, surpassing petroleum and other liquids to become the most used energy source in the Reference case. Worldwide renewable energy consumption increases by 3.1% per year between 2018 and 2050, compared with 0.6% annual growth in petroleum and other liquids, 0.4% growth in coal, and 1.1% annual growth in natural gas consumption.

The First Nuclear Renaissance:

a litany of failures

Collapse of French giant Areva

Olkiluoto reactor (1400 Mwe) in Finland – begun in 2005.

It was to be operational by 2009, at a cost of 3 billion euros.

Latest estimate - March 2019, at a cost of at least 8.5 billion euros.

Almost 4 times as long to build as promised, & cost almost 3 times as much money.

Olkiluoto 3 pictured in the summer of 2016 (Image: TVO)

One of the "stars" of the "Nuclear Renaissance"

This "bankrupted" Areva – it was absorbed by Electricté de France.

Bankruptcy of Westinghouse

Westinghouse Electric filed for bankruptcy in 2017

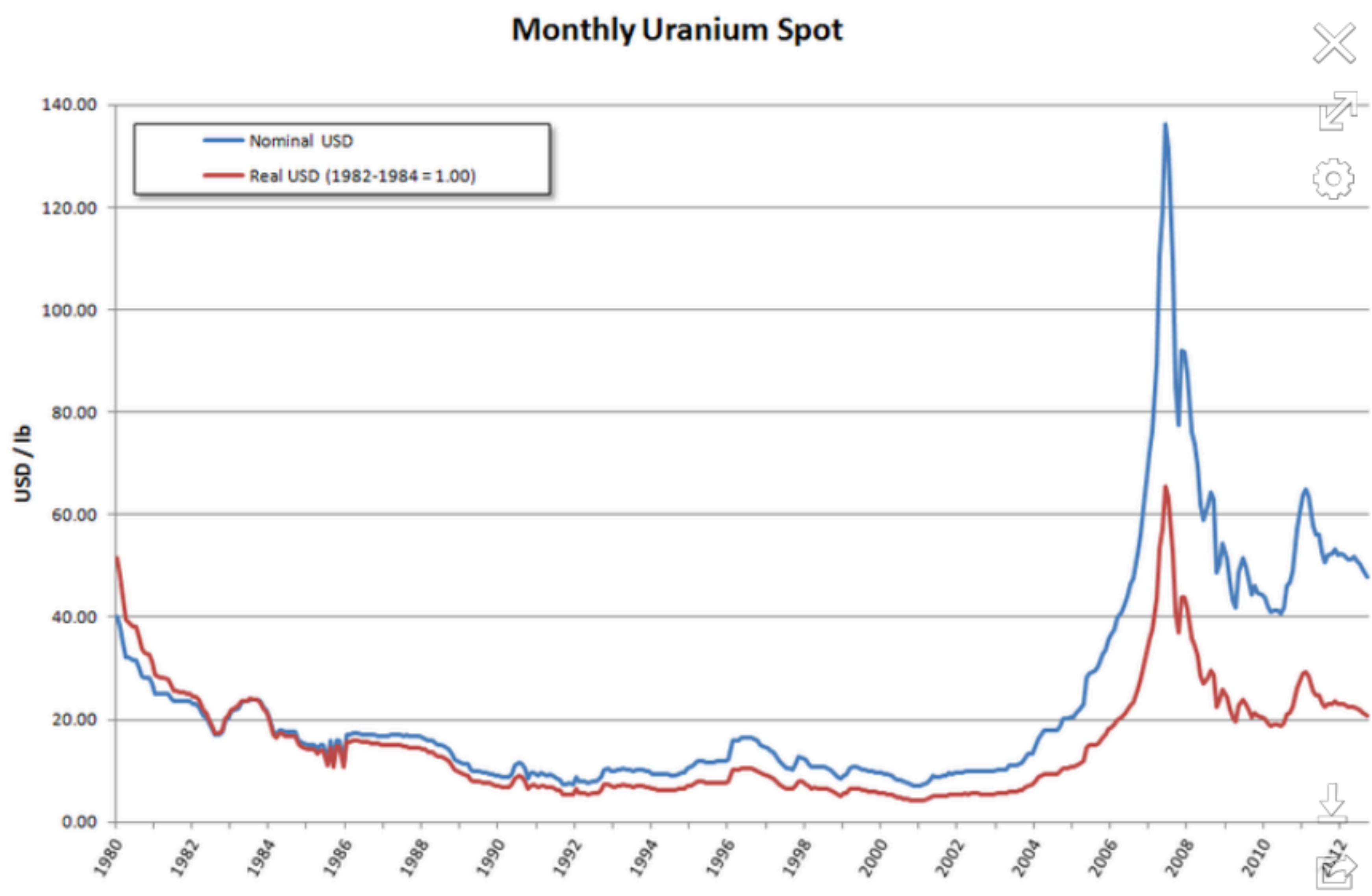
because of $9 billion in losses from nuclear reactor construction projects –

mainly the four AP1000 reactors: Vogtl in Georgia & V C Summer in S Carolina.

S Carolina abandoned the project, Georgia did not.

The US federal government had given $8.3 billion in loan guarantees on the financing of the four reactors.

Bursting the Uranium Bubble



“The State of Affairs

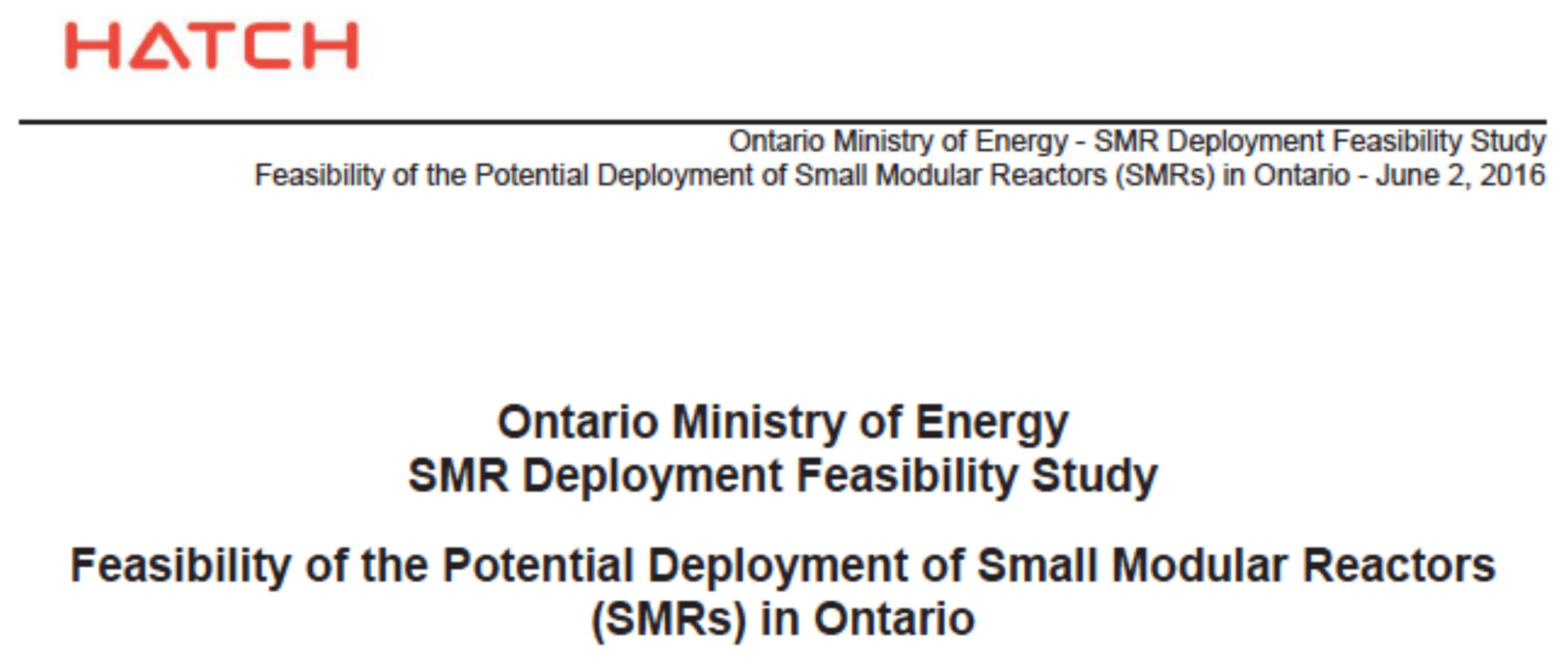
“The International Atomic Energy Agency (IAEA), looking ahead to 2050, sees the most optimistic global electricity market share for nuclear as only about 5 percent, down from 10 percent today . . .

“. . . and in the United States and Europe, it steadily declines to between 3 and 5 percent of the market, constituting a potential for market ‘failure’.”

ASME – The American Society of Mechanical Engineers (Nov 2019)

Second Try at a Nuclear Renaissance

a sense of desperation

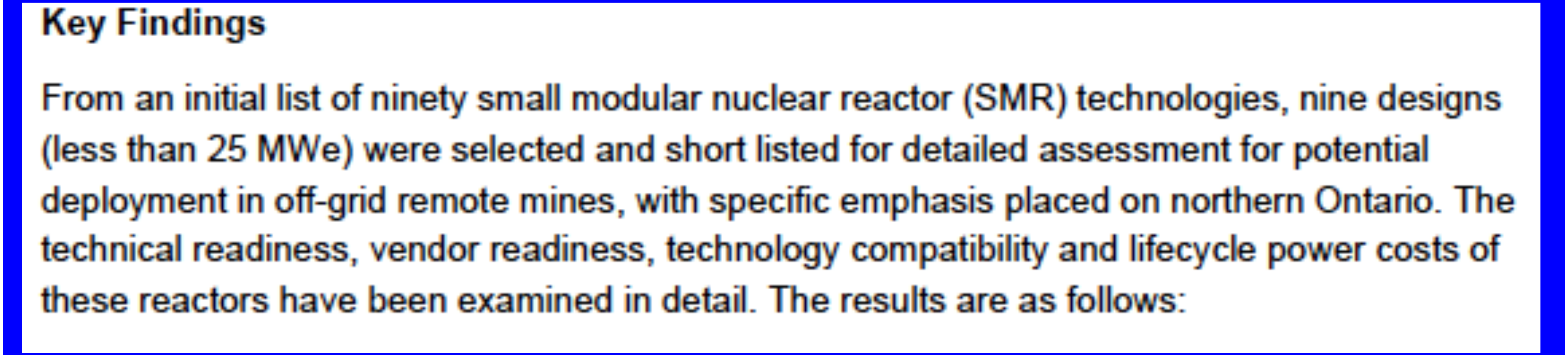


HATCH

Ontario Ministry of Energy - SMR Deployment Feasibility Study
Feasibility of the Potential Deployment of Small Modular Reactors (SMRs) in Ontario - June 2, 2016

Ontario Ministry of Energy
SMR Deployment Feasibility Study

Feasibility of the Potential Deployment of Small Modular Reactors (SMRs) in Ontario



Key Findings

From an initial list of ninety small modular nuclear reactor (SMR) technologies, nine designs (less than 25 MWe) were selected and short listed for detailed assessment for potential deployment in off-grid remote mines, with specific emphasis placed on northern Ontario. The technical readiness, vendor readiness, technology compatibility and lifecycle power costs of these reactors have been examined in detail. The results are as follows:

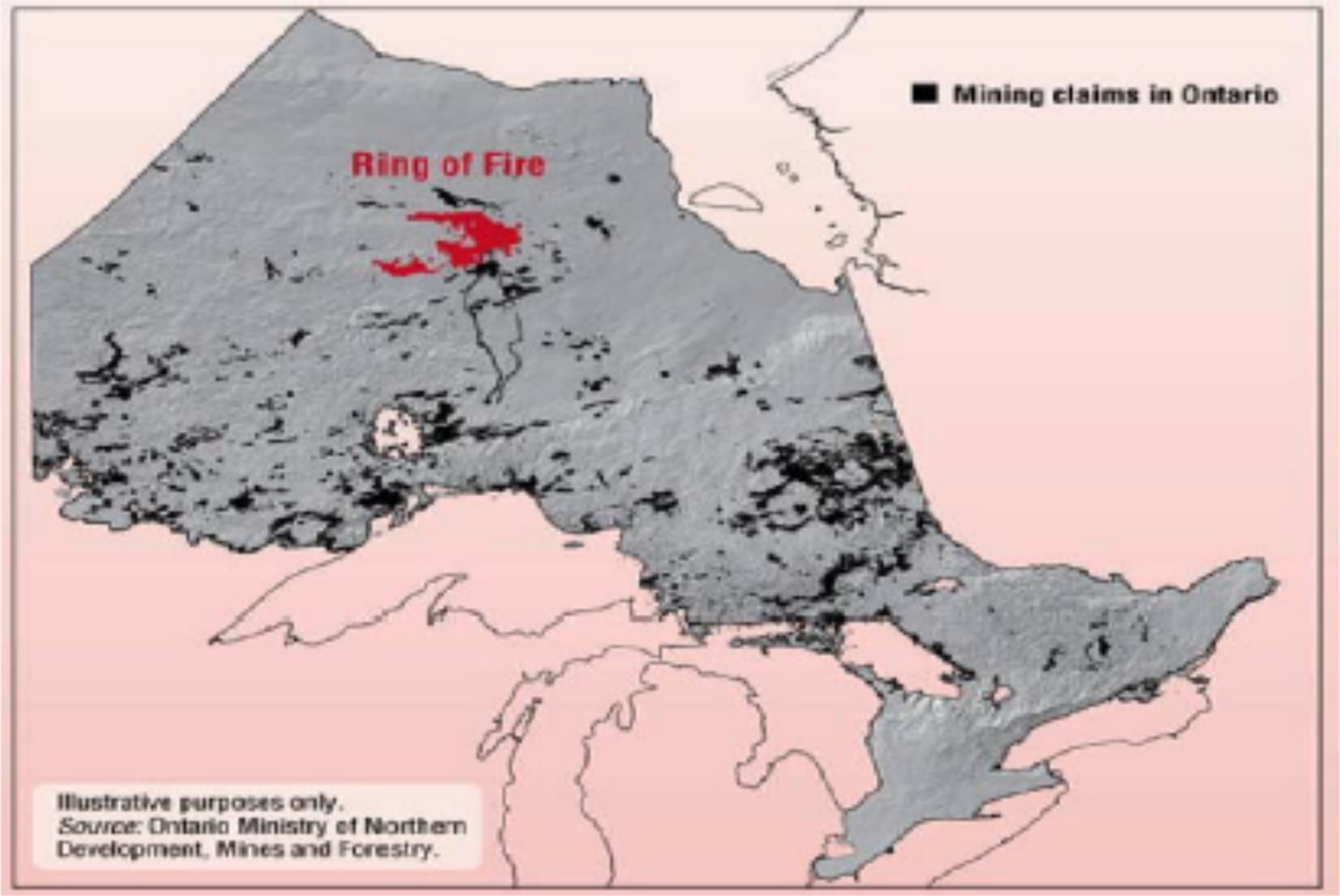


Figure 3-2 - Ring of Fire

Secretariat Office
468 Queen Street East, Suite 400
Toronto, Ontario M5A 1T7
1-877-517-6527
chiefs-of-Ontario.org

CHIEFS OF ONTARIO

Political Office
Taykwa Tagamou Nation
RR#2 Box 3310
Cochrane, Ontario
P0L 1C0

SPECIAL CHIEFS ASSEMBLY
November 20-21-22, 2018
Toronto, Ontario

RESOLUTION 56/18

SUBJECT: **SMALL MODULAR REACTORS**

MOVER: **Chief Duncan Michano Jr., Biigtigong Nishnaabeg**

SECONDER: **Kyle Maclaurin, Proxy, Namaygoosisagagun First Nation**

DECISION: **CARRIED**

WHEREAS:

1. The nuclear industry seeks to build and operate Small Modular Nuclear Reactors (SMR) and to operate these reactors in small communities throughout the north;
2. The nuclear industry is seeking assistance from the Government of Canada to conduct research and build these SMR's;
3. Nuclear reactors, regardless of size, produce products and waste material that are potentially toxic and dangerous to human health for thousands of years;
4. The First Nations of Ontario oppose the construction and operation of these reactors;
5. The First Nations of Ontario have a duty to protect the health of their citizens today and in the future.

THEREFORE BE IT RESOLVED that we, the Chiefs in Assembly:

1. Demand that the Nuclear Industry abandon its plans to operate Small Modular Reactors in Ontario and elsewhere.
2. Demand that the Government of Canada cease funding and support for this program.

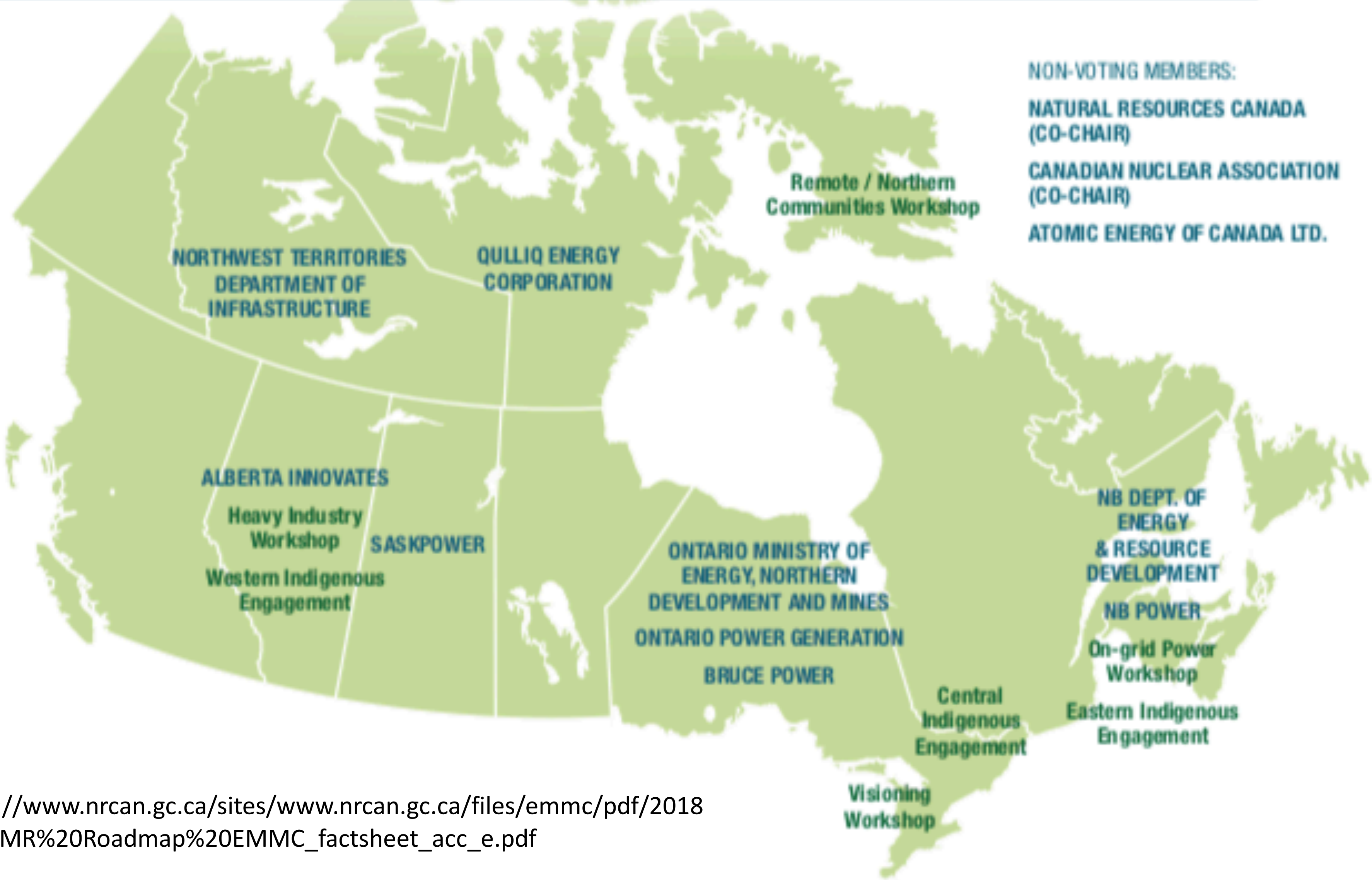
Canadian Small Modular Reactor (SMR) Roadmap

Summary of Key Findings

NRCan

Pan-Canadian Approach

Through the six-month Generation Energy dialogue in 2
would need to work together to realize the potential for
interested provinces, territories and power utilities. Th
industry, as well as potential end-users such as Northe
to explore the potential scope for a national path forwa



https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/2018
/en/SMR%20Roadmap%20EMMC_factsheet_acc_e.pdf

Canadian Small Modular Reactor (SMR) Roadmap

Summary of Key Findings

NRCan November 2017

Small
Modular
~~Nuclear~~
Reactors
(SMNRs)

Small
Modular

Reactors
(SMRs)

Advice to the Industry:

Above all, do NOT mention (except in passing) the very thing that makes nuclear power unacceptable :

RADIOACTIVE WASTE.

Small Modular Nuclear Reactors

No Environmental Assessments

The new Impact Assessment Act will exempt all SMNRs

from any Environmental Assessment whatsoever

- if they produce less than 200 megawatts of heat, or
- if they are located on an existing reactor site regardless of size.

The Elephant in the Room:

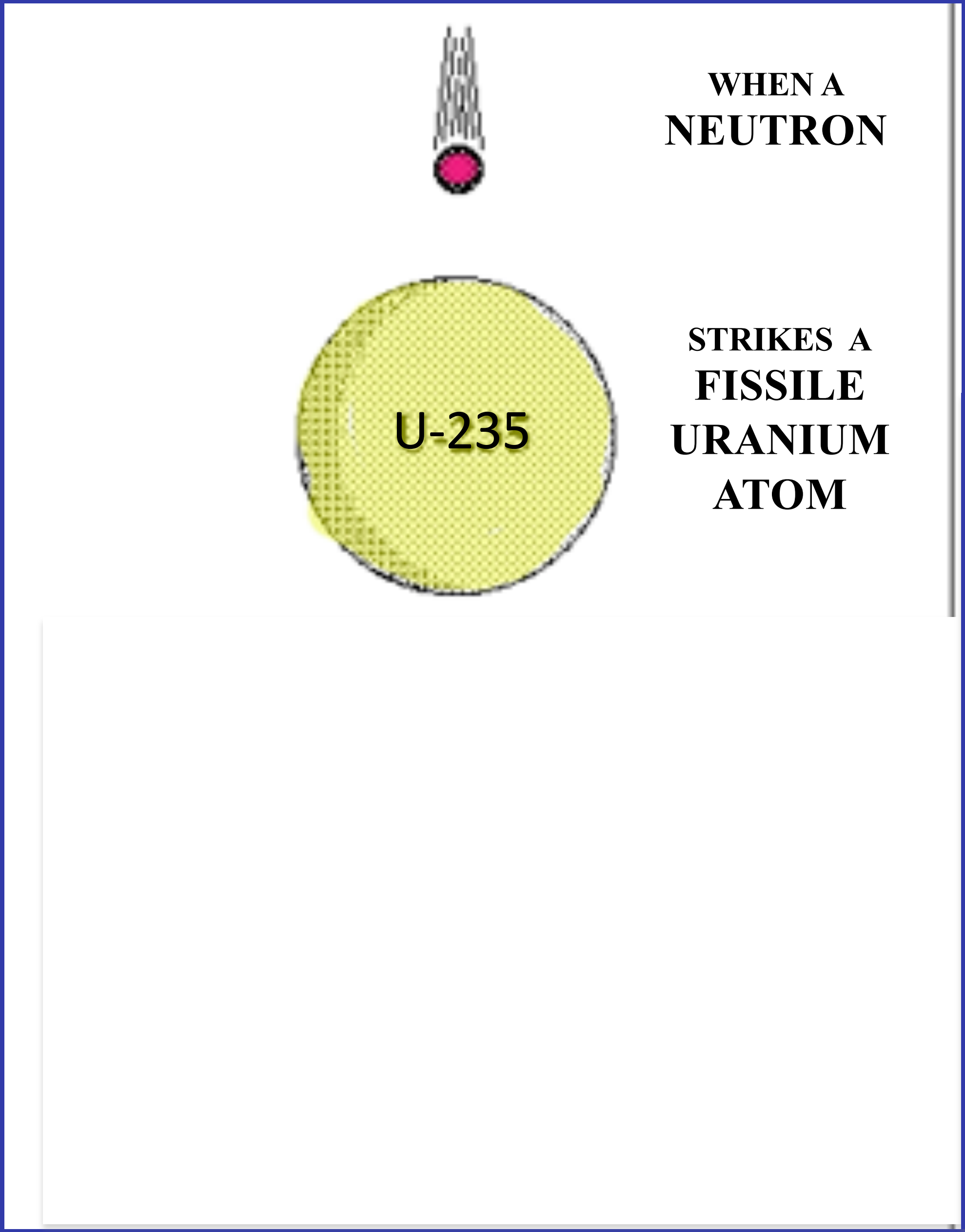
Nuclear Waste - the root of all problems

A Model of the Uranium Atom

Uranium is special. It is the key element behind all nuclear fission technology.

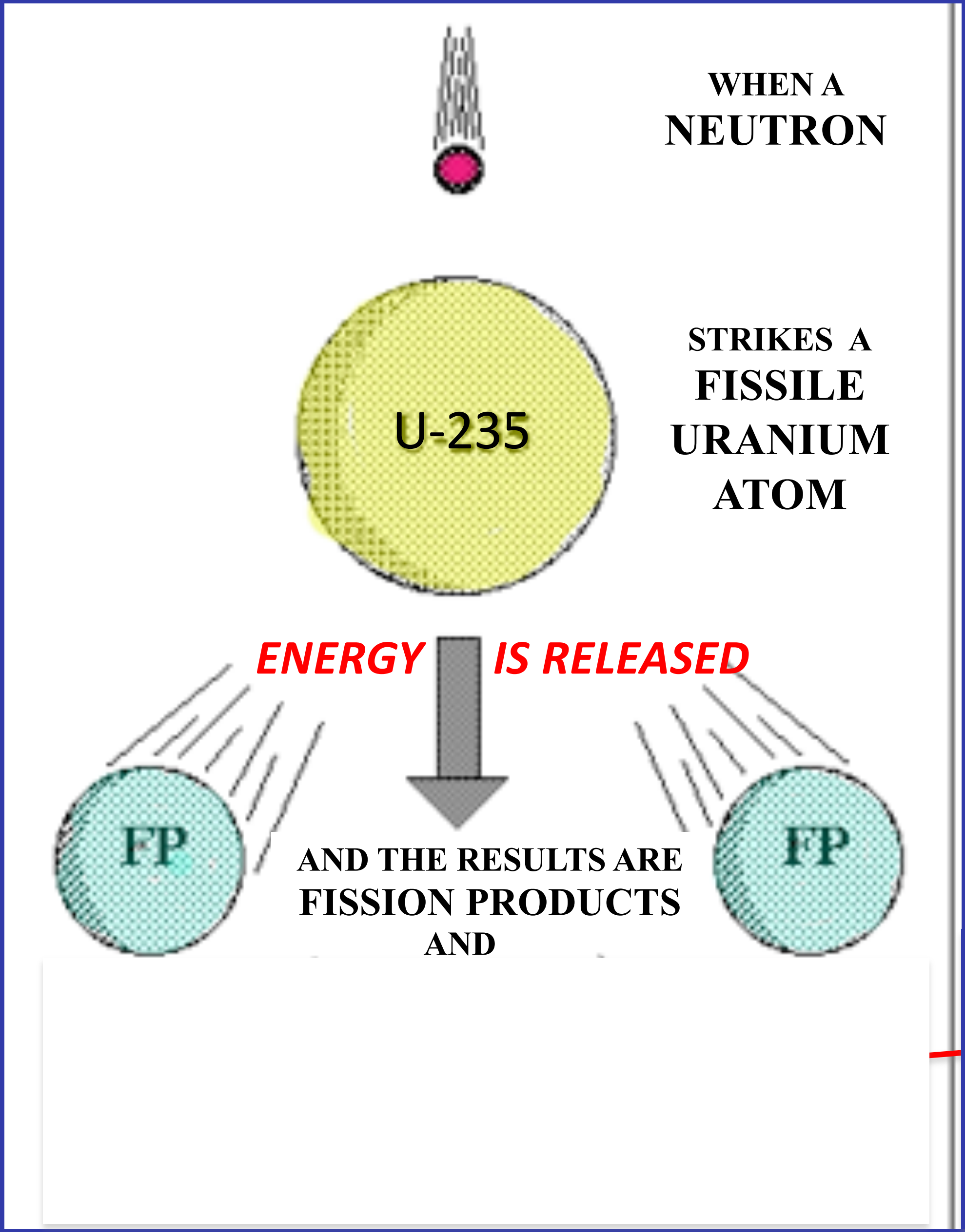
Photo: Robert Del Tredici

What is Nuclear Fission?



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

What is Nuclear Fission?

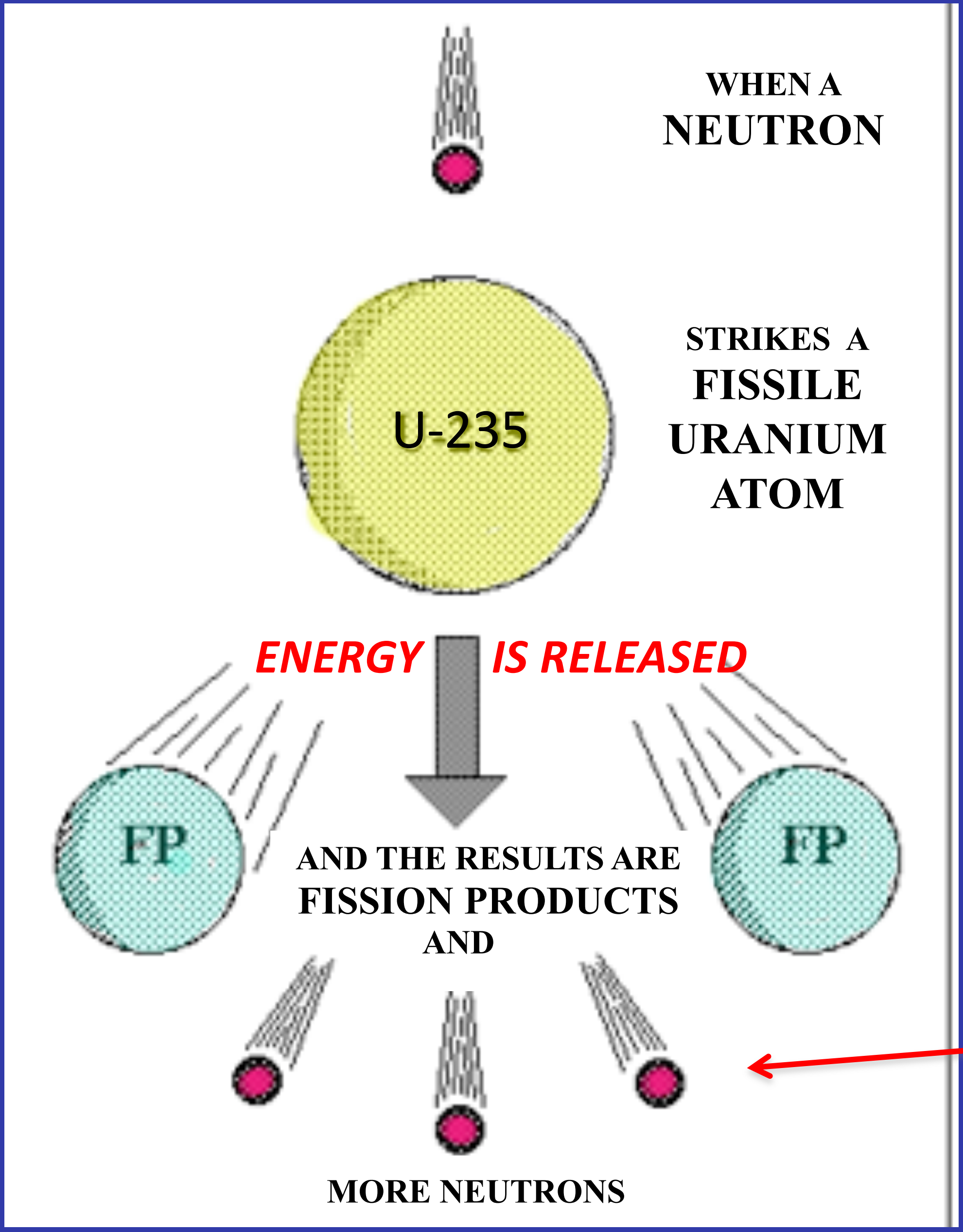


A subatomic projectile called a neutron starts a nuclear chain reaction by splitting a nucleus of "fissile uranium" (U-235).

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".

What is Nuclear Fission?



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More neutrons trigger more fissions and go on to create radioactive materials by 'activation'

What is Radioactivity?

Most atoms are stable, unchanging, eternal.

Radioactive atoms are unstable – they explode (disintegrate).

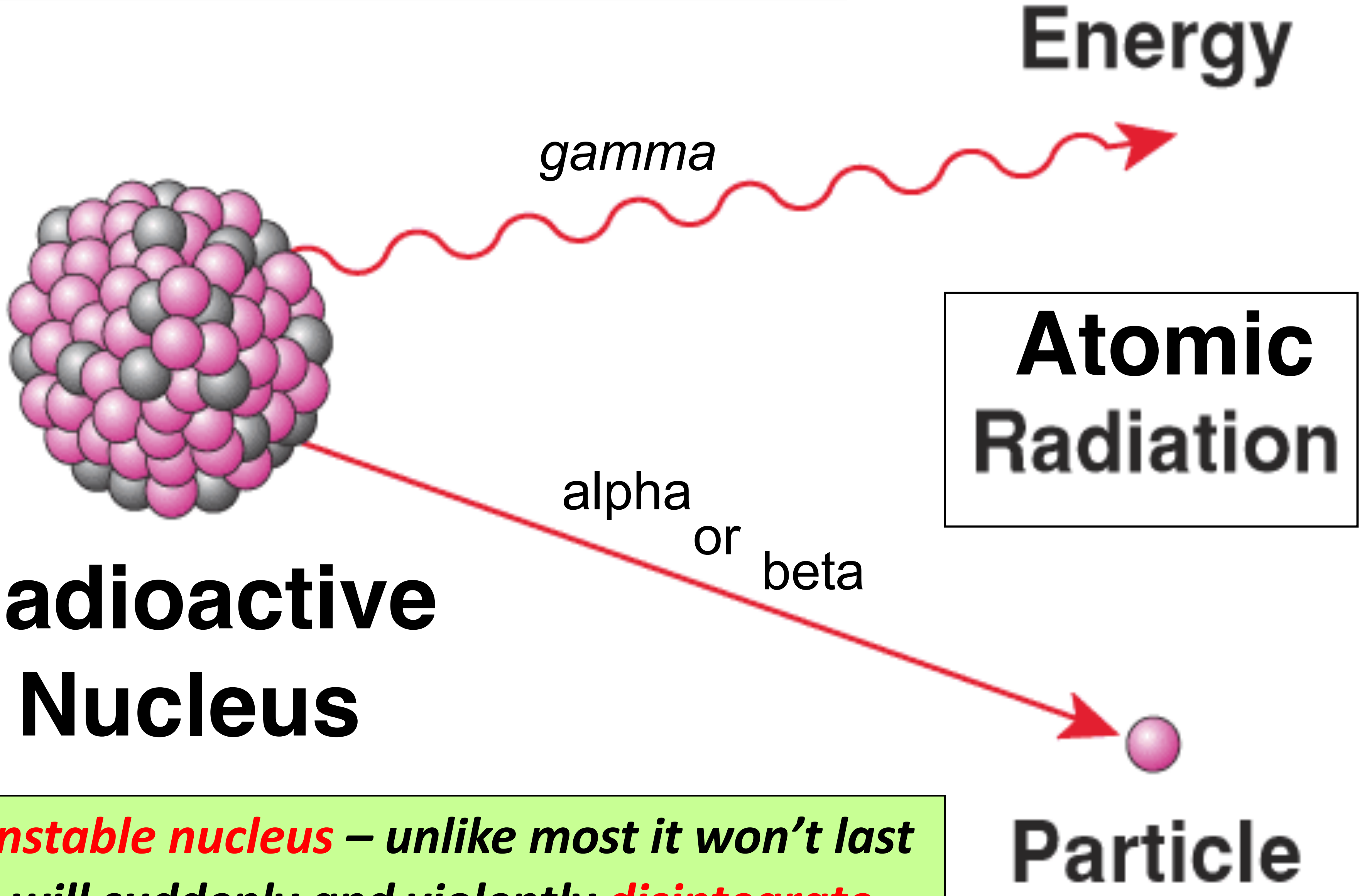
When they disintegrate they damage nearby living cells.

The HALF-LIFE is the time it takes for half the atoms to explode.

There is a small handful of naturally occurring radioactive elements,

but there are many hundreds of human-made radioactive elements.

What is Radioactivity?



Energy

gamma

Atomic Radiation

alpha or beta

Radioactive Nucleus

Particle

- ***unstable nucleus* – *unlike most it won't last***
- ***it will suddenly and violently disintegrate***

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

highly penetrating, easily detectable

A beta particle is like a “sub-atomic bullet”.

moderately penetrating, harder to detect

An alpha particle is like a “sub-atomic cannon ball”.

slightly penetrating, but highly damaging

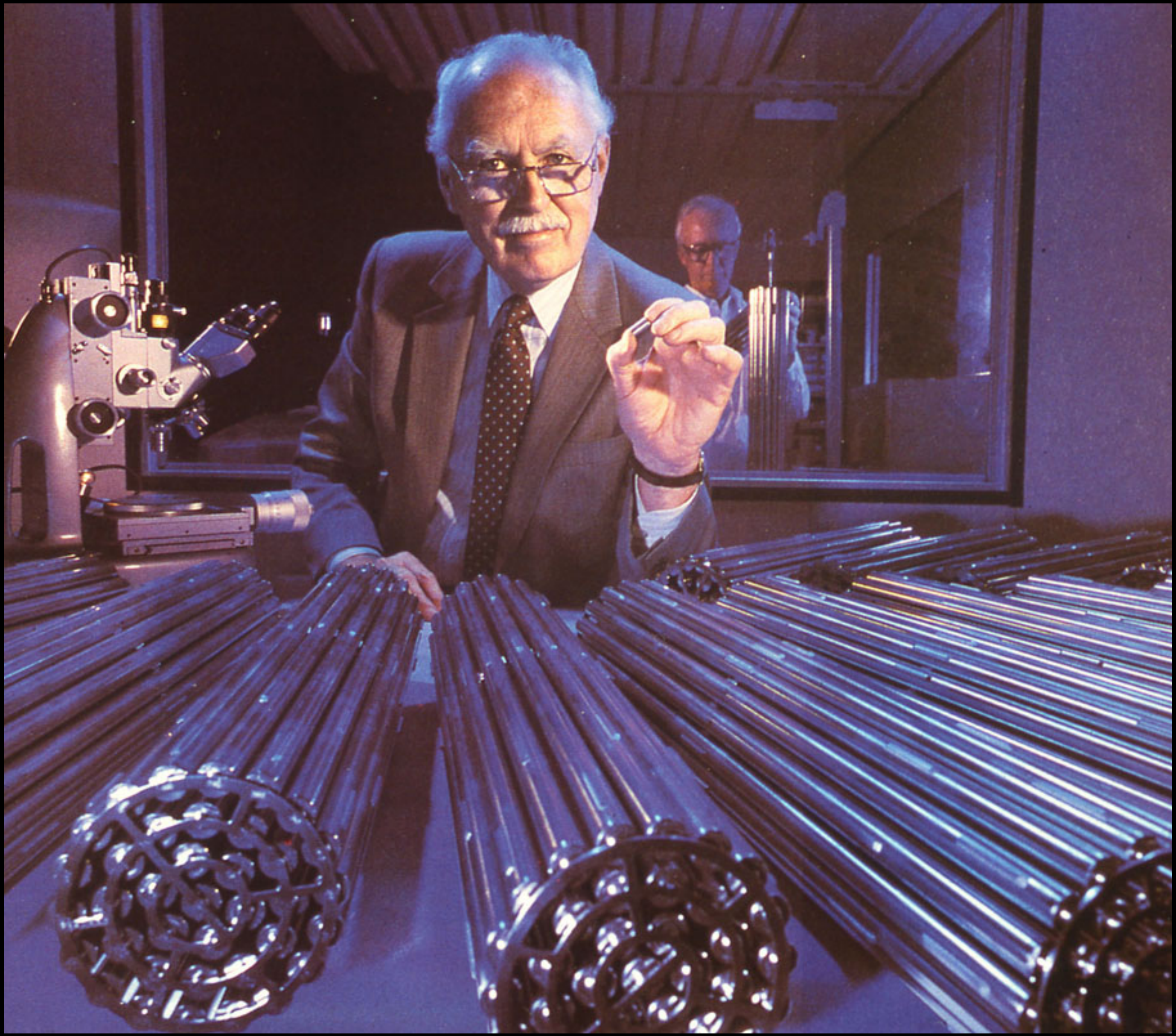
Alpha and Beta emitters are INTERNAL hazards..

Gamma emitters are INTERNAL & EXTERNAL hazards

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

Photo: Robert Del Tredici

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



A CANDU fuel bundle like one of these can be handled safely before it is used, but after use in a reactor it will deliver a lethal radiation dose in a few seconds.

"Small Wonder" : Canadian Nuclear Association Ad

Nuclear Fuel Waste

Three categories of radioactive waste materials:

1. Fission Products (e.g. cesium-137, iodine-131)
   ~ the broken bits of uranium atoms
2. Transuranics (Actinides) (e.g. plutonium, americium)
   ~ heavier-than-uranium elements
3. Activation Products (e.g. cobalt-60, carbon-14)
   ~ “activated” by absorbing stray neutrons

.

A LIST OF SELECTED RADIONUCLIDES IN IRRADIATED NUCLEAR FUEL

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

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

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

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				¥

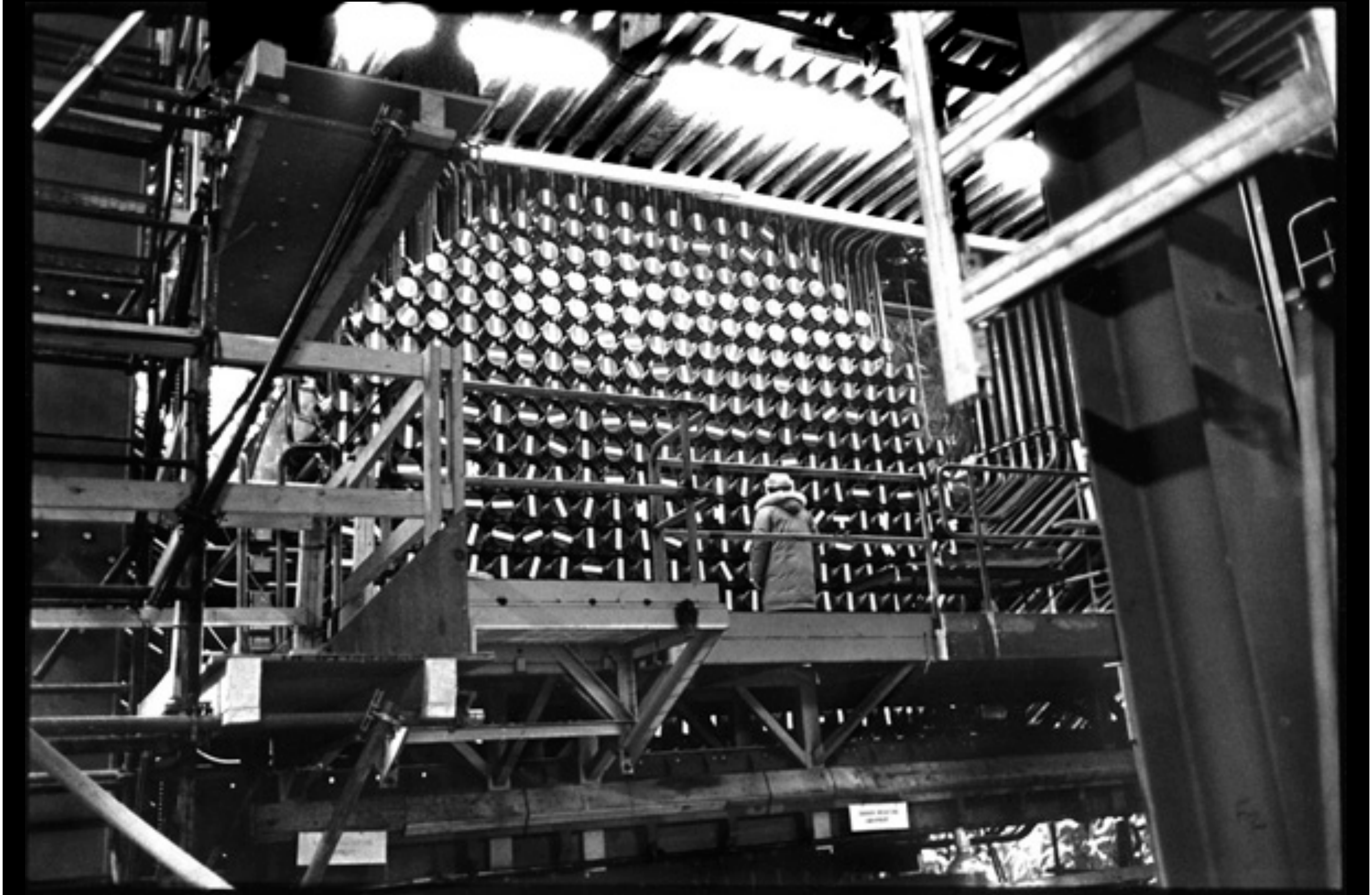
Th	Thorium	234				¥¥¥
Standard Chemical Symbol	Common Name of element	Atomic Mass Number	**F.P.** Fission Product	**F.I.A.P.** Activation Product	**Z.A.P.** Activation Product	**Actinide** (includes progeny)
Pa	Protactinium	231				¥
Pa	Protactinium	233				¥¥¥
Pa	Protactinium	234				¥
Pa	Protactinium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

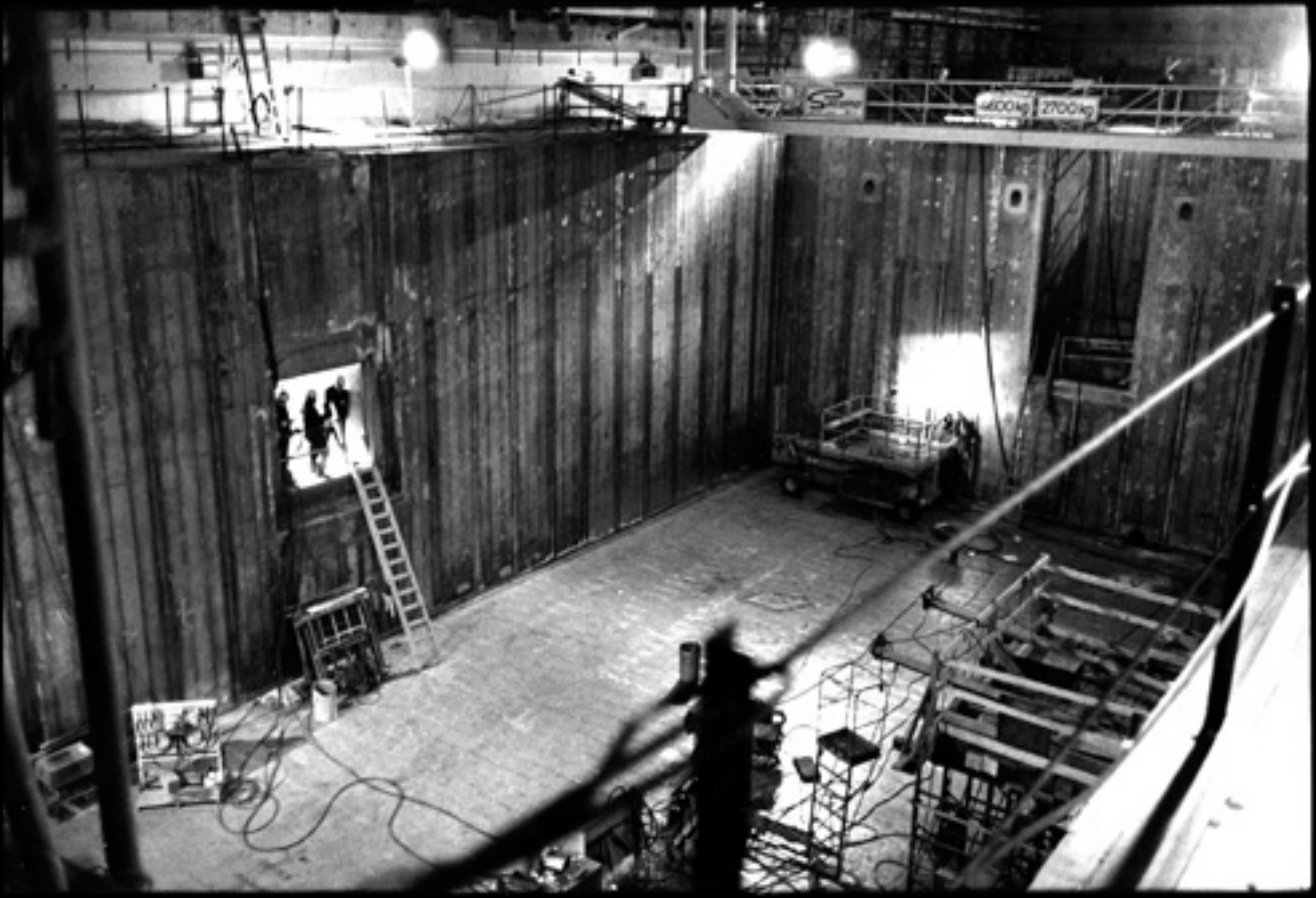
¥¥¥ indicates an activity level of more than a million becquerels per kilogram

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



The face of a CANDU reactor loaded with fresh (unused) fuel bundles

Photo: Robert Del Tredici



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

Photo: Robert Del Tredici

FISSION PRODUCTS

When a uranium (or plutonium) atom FISSIONS, two rather large pieces are left over. These are called “fission products” – dozens of different kinds of radioactive atoms, all lighter than uranium atoms.

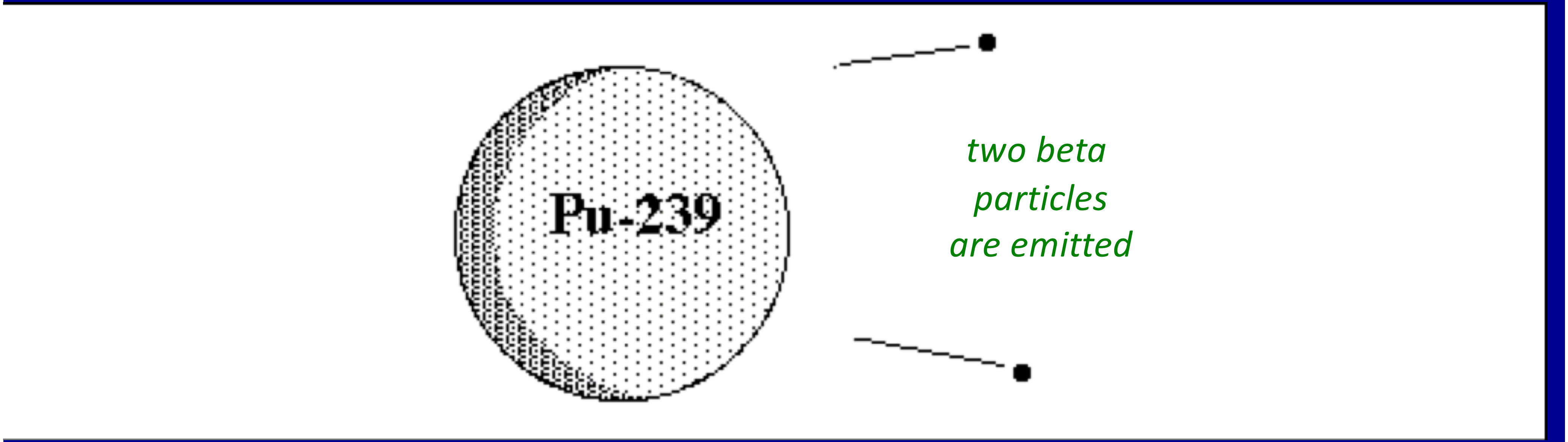
TRANSURANIC ACTINIDES

At the same time, stray neutrons are absorbed by other uranium atoms to make new “heavier than uranium” radioactive atoms called “transuranics”. These so-called “actinides” are all heavier than uranium, and were not found in nature before 1939.

Creation of plutonium inside a nuclear reactor …

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

Absorption of a neutron creates a heavier (“transuranic”) element



*two beta
particles
are emitted*

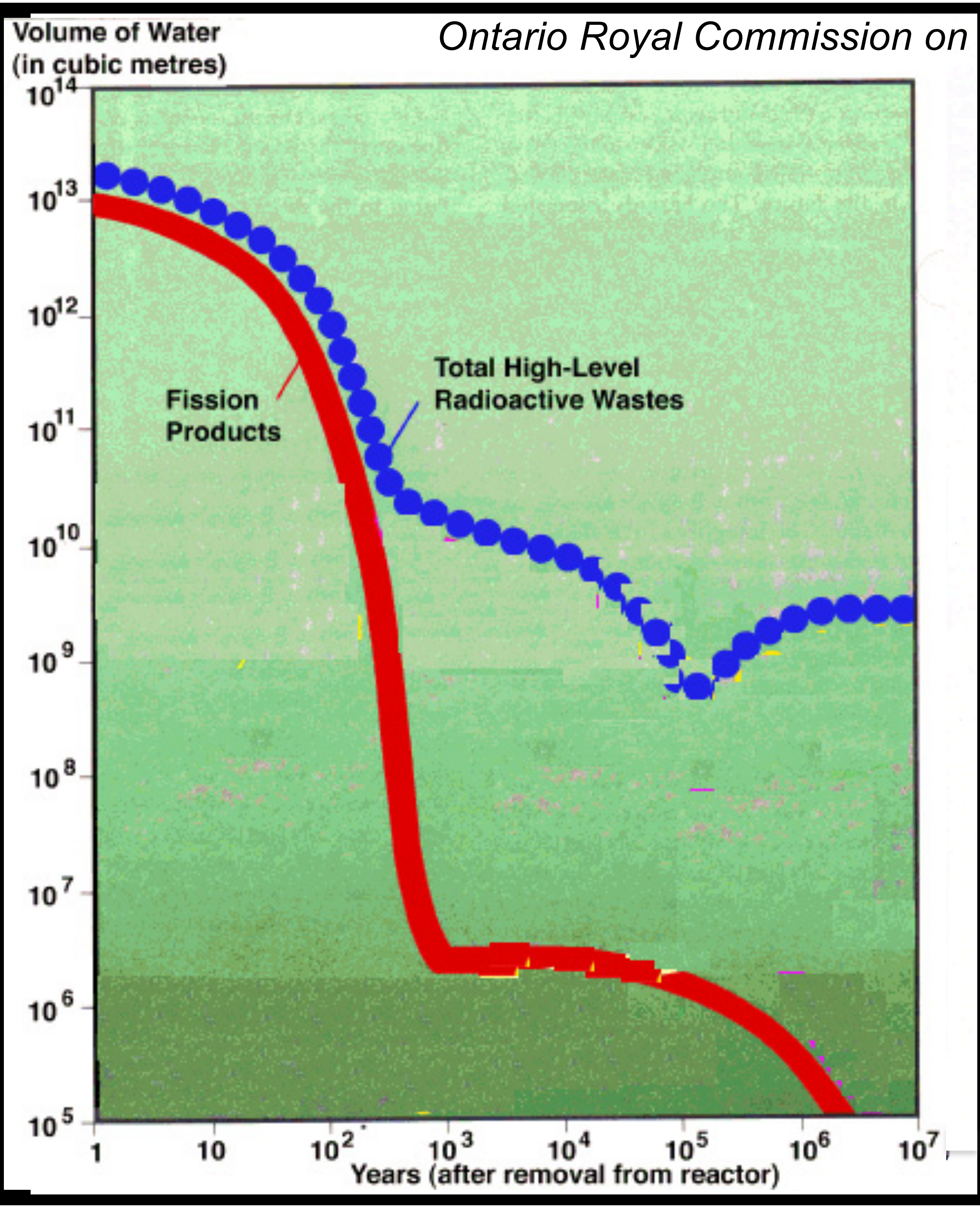
. . . it is transformed into an atom of plutonium-239

Other transuranic actinides are produced in a similar way.

This glass paperweight is the exact size of the plutonium ball that was used as a nuclear explosive in the Nagasaki bomb.

Photo: Robert Del Tredici

Ontario Royal Commission on Electric Power Planning (1978)



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

The minimum amount of water needed to dilute one year of “fresh” spent fuel just out of a CANDU reactor is approximately the size of Lake Superior.

Royal Commission Report, 1978

SMNRs Are Not "Clean"

they produce radioactive wastes of all kinds

Radioactivity is

a form of nuclear energy

that cannot be shut off.

That’s why we have
a nuclear waste problem.

Longevity of SMNR Waste

"… the bulk of the future radiation dose risk *[comes from]* long-lived fission products like selenium-79 and iodine-129 and the activation products carbon-14 and chlorine-36 rather than *[from]* the actinides." (National Research Council 1996)

Here are some very long-lived fission products

FISSION PRODUCT	HALF-LIFE
Selenium-79	327,000years
Technetium-99	210,000 years
Tin-126	230,000 years
Zirconium-93	1,530,000 years
Cesium-135	2,300,000 years
Palladium-107	6,500,000 years
Iodine-129	15,700,000 years

Complications for DGR from SMNR Waste

- SMNR fuel is ALWAYS ENRICHED, unlike CANDU fuel
- Enriched fuel can cause a criticality accident underground
- SMNR fuel can contain corrosive materials like salt
- SMNR fuel can contain dangerous materials like sodium metal that reacts violently on contact with air or water

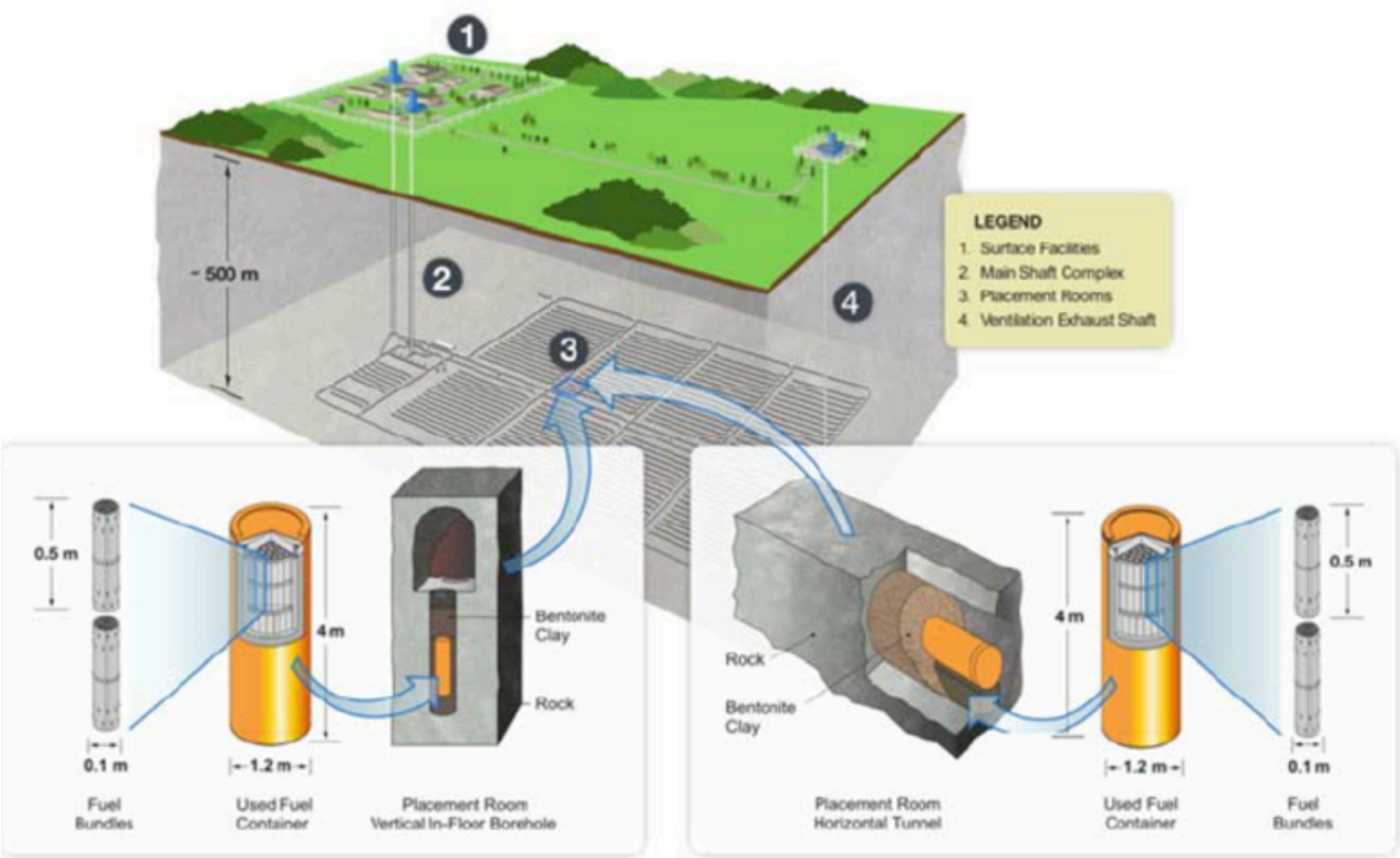
Burning waste or playing with fire?

Waste management considerations for non-traditional reactors

By Lindsay Krall & Allison Macfarlane
Bulletin of the Atomic Scientists 2018

Allison MacFarlane is a geologist, and former Chair of the US NRC

NWMO = Nuclear Waste Management Organization [OPG, HQ, NBP]



NWMO's Reference $23 billion DGR (Deep Geologic Repository)

Reprocessing, Plutonium, Transport

- Both ACR-100 and Moltex SSR plan to re-use spent fuel
- Re-using spent fuel means accessing the plutonium inside
- “Reprocessing” of any kind raises security risks worldwide
- “Proliferation-resistant reprocessing” is an oxymoron
- Reprocessing also requires more transport of spent fuel

Reprocessing Revisited – Arms Control Today

The Source on Non-proliferation and Global Security

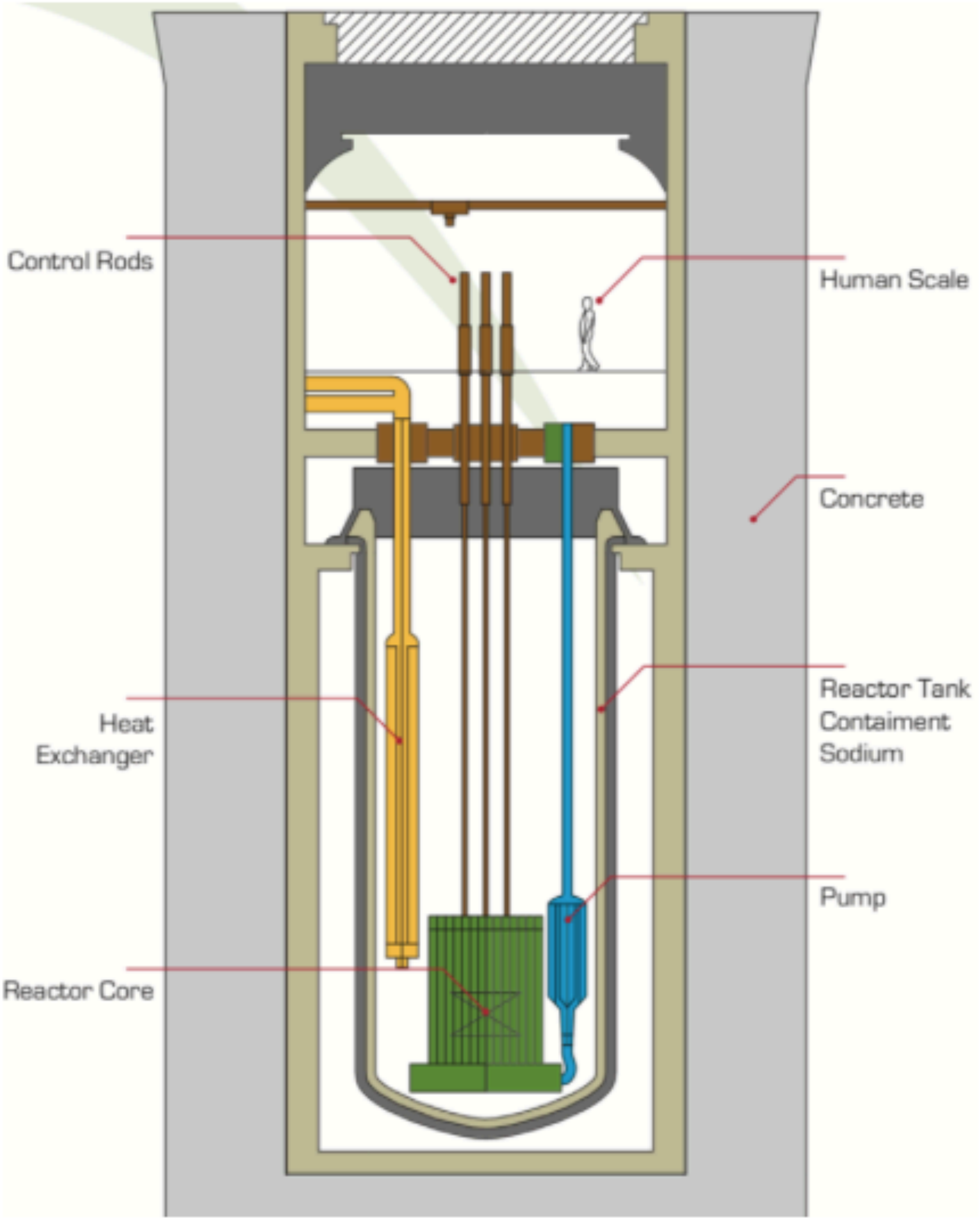
By Edwin Lyman & Frank von Hippel

2008

See section entitled “Proliferation-resistant reprocessing?”

SMNRs Are Not “Small”

there is always a large inventory of radioactivity



AEC-100 Reactor Design

EBR-II produced 62.5 megawatts of heat and 20 megawatts of electricity
It operated from 1964 to 1994.

EBR-I produced 1.4 megawatts of heat and 0.2 megawatts of electricity.
It operated from 1951 to 1964 – partial meltdown in 1955.

Prototype Fast Breeder Reactor Fermi-1 : 69 megawatts of electrciity

partial meltdown in 1966 – as told in “We Almost Lost Detroit”.

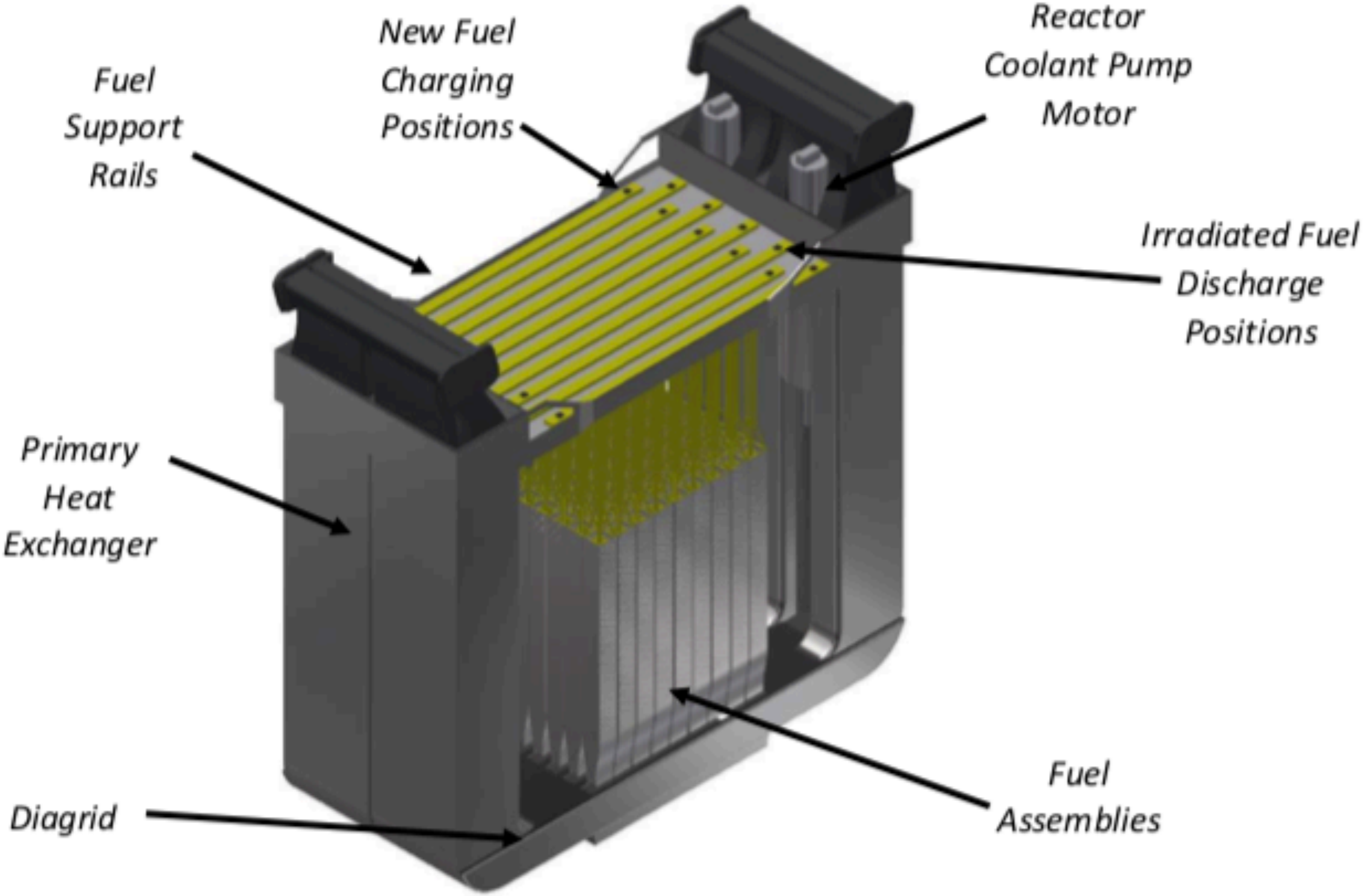
Sodium leaks and breeder fiascos

- sodium reacts violently on contact with air or water
- sodium leaks and fires have plagued breeder reactors
- Clinch River breeder reactor cancelled by President Carter
- Superphénix breeder reactor cancelled by France
- long-standing concerns about the “plutonium economy”

Breeder Reactors – a possible connection between metal corrosion and sodium leaks

By S Rajendram Pillai and M V Ramana, Bulletin of Atomic Scientists

2008



Moltex “Stable Salt Reactor” core module

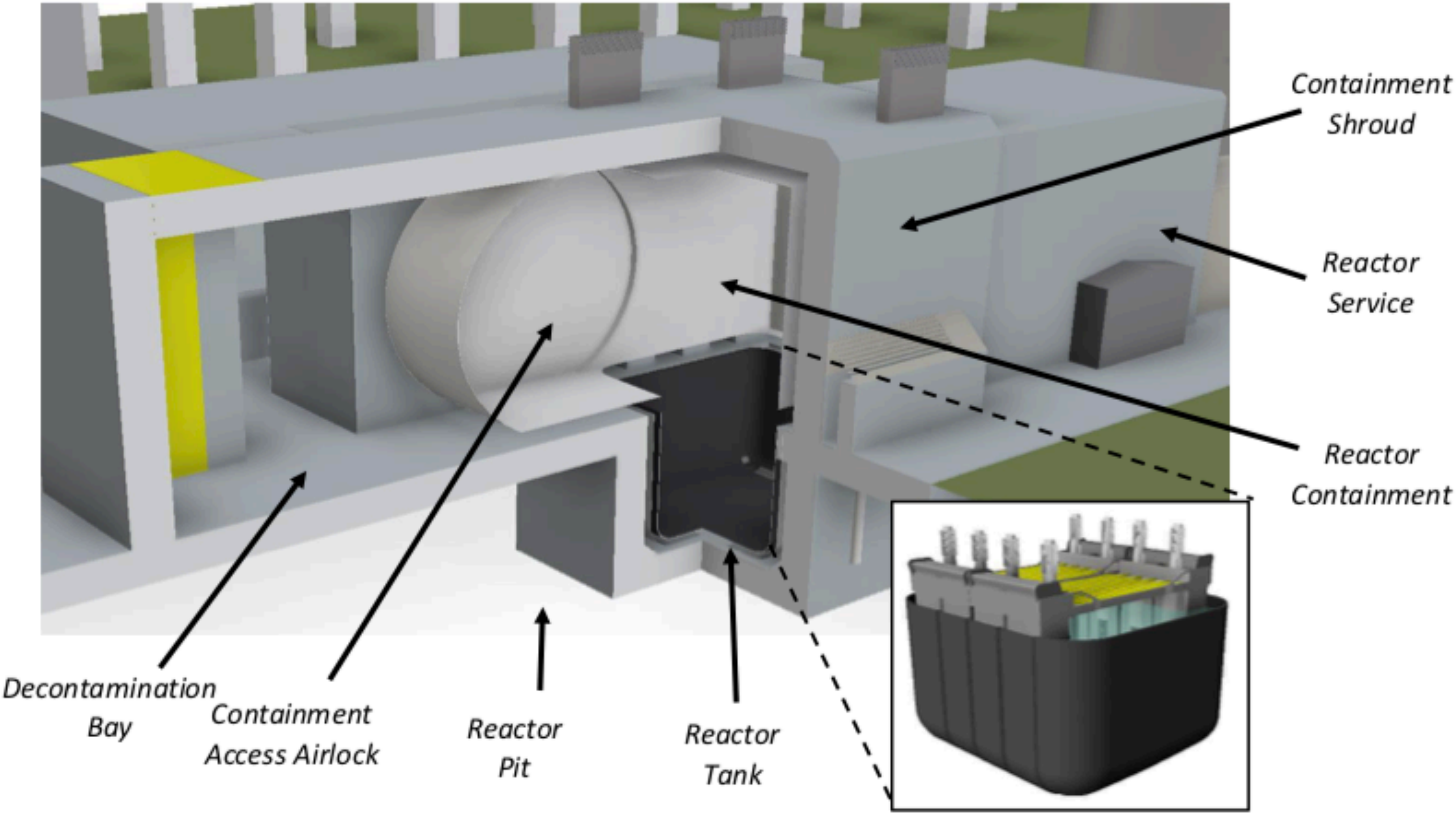


Figure 4: Overview of SSR-W Reactor Facility

SMNRs Are Not “Green”

too costly, too slow – delays climate action now

CLIMATE ACTION IS NEEDED NOW, not 10 years from now

- UK House of Lords reported in 2017 that one could not expect a prototype to be operational before 2030;
- Another decade or so would be needed to achieve a fully commercialized version;
- with higher unit costs per unit of electricity mass production is needed (hence “modular”), but there are too many competitors;
- before operation more Greenhouse Gases are emitted and no carbon relief is available.

ENERGY EFFICIENCY AND RENEWABLES ARE FASTER AND CHEAPER ENERGY POLICY OPTIONS

Germany more than doubled its offshore wind power capacity in 2014

2,300 megawatts

SMNRs Are Not “Affordable”

opportunity costs before, during, and after

radwaste from dismantling old nuclear reactors

Radiation Fields from CANDU Reactor Components

Item	Dose Rate	Lethal Dose (LD50 = 400 rems)
Thermal Shield	260,000 rems/hr	death in 5.5 seconds
Calandria Shell	49,000 rems/hr	death in 29 seconds
Dump Tank	12,000 rems/hr	death in 2 minutes
Pressure Tube	850 rems/hr	death in 28 minutes

Source: Pickering Preliminary Nuclear Decommissioning Cost Study

Radionuclide	Half-Life	
Hydrogen-3 (Tritium),	12.3 years	
Carbon-14,		5 730 years
Chlorine-36,		301 thousand years
Calcium-41,		102 thousand years
Nickel-59,		76 thousand years
Nickel-63,		100 years
Cobalt-60,	5.26 years	
Selenium-79		295 thousand years
Strontium-90,	28.8 years	
Niobium-93m	16.1 years	
Niobium-94		20 thousand years
Zirconium-93		1 530 thousand years
Technetium-99,		211 thousand years
Silver-108m		418 years
Tin-121m	43.9 years	
Tin-126		230 thousand years
Antimony-125,	2.76 years	
Iodine-129,		15 700 thousand years
Cesium-135		2 300 thousand years
Cesium-137,	30.2 years	
Samarium-151	90.0 years	
Europium-152,	13.5 years	
Uranium-234		246 thousand years
Uranium-235		704 thousand years
Uranium-236		23 400 thousand years
Uranium-238		4 470 million years
Neptunium-237		2 140 thousand years
Plutonium-239,		24 thousand years
Plutonium-240,		6 560 years
Plutonium-241,	14.4 years	
Plutonium-242		375 thousand years
Americium-241,		432 years
Curium-243,	29.1 years	
Curium-244,	18.1 years	

Of the 34 radionuclides indicated in Table 4.4-1, twenty-two of them have half-lives over 100 years, eighteen of them have half-lives over 5 thousand years, fourteen of them half half-lives over 100 thousand years, five of them have half-lives over one million years, and one of them has a half-life over one billion years.

Radionuclide	Ten Half-Lives	Remaining Activity
Chlorine-36,	3 million years	40 million becquerels
Calcium-41,	1 million years	7.6 million becquerels
Nickel-59,	760 thousand years	48 million becquerels
Zirconium-93	15 million years	20 million becquerels
Niobium-94,	203 thousand years	70 thousand becquerels
Technetium-99,	1.2 million years	18.9 thousand becquerels
Plutonium-239,	240 thousand years	507 thousand becquerels
Plutonium-242,	3.75 million years	1 thousand becquerels

The longevity of these radioactive materials is measured not just in hundreds of thousands of years, but in millions of years.

The End

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