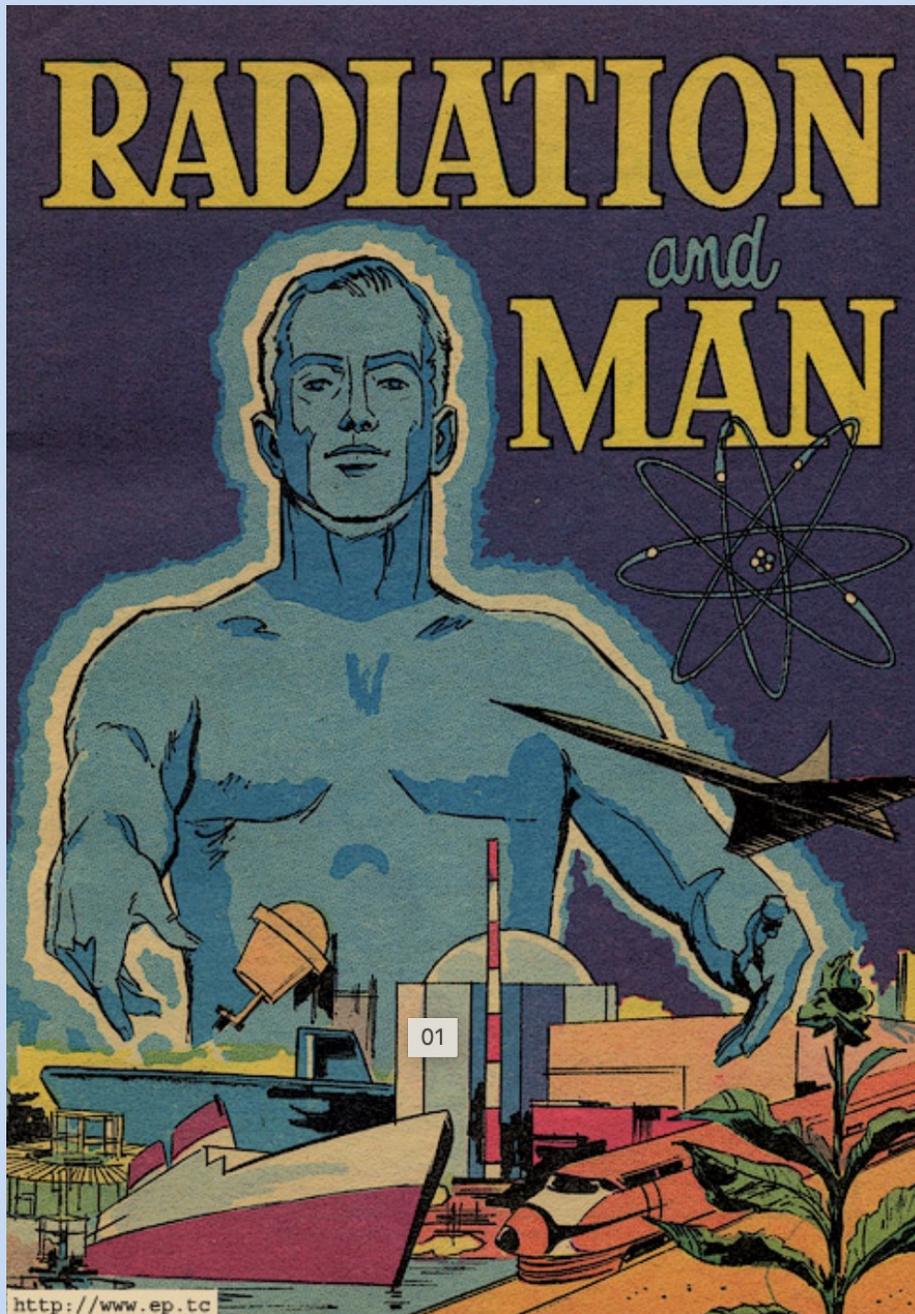


Forums for a Nuclear-Free New York

*Third
in the
Series*

“Debunking Nuclear ‘Hopium’”
with Dr. Gordon Edwards

HOPIUM = BLIND FAITH + ADDICTION (needs a pusher)



NEW BOON TO MANKIND

THE BENEFITS OF NUCLEAR RADIATION THAT WE KNOW TODAY ARE NOTHING WHEN COMPARED TO WHAT WE MAY REASONABLY EXPECT IN THE FUTURE. FOOD MAY BE PRESERVED IN ITS ORIGINAL FRESH CONDITION FOR LONG PERIODS OF TIME; NUCLEAR-POWERED SHIPS MAY PLY THE OCEANS; TRAINS MAY CROSS CONTINENTS MANY TIMES ON ONLY A FEW OUNCES OF NUCLEAR FUEL; POWER REACTORS MAY HELP OPEN UP REMOTE AREAS, SUCH AS CANADA'S NORTH; GREATER AND GREATER USE WILL BE MADE OF RADIOACTIVE MATERIALS IN INDUSTRY, MEDICINE AND RESEARCH. IN TIME IT IS POSSIBLE THAT NUCLEAR POWER MAY LEAD TO TEMPERATURE-CONTROLLED, GERM-FREE CITIES AND A BETTER LIFE FOR ALL MANKIND.



Comic book promoting nuclear power by the Canadian Nuclear Society

Debunking Nuclear Hopium

February 26, 2026

PART ONE

“Small Modular Nuclear Reactors”

S M R

(Spending Money Recklessly)

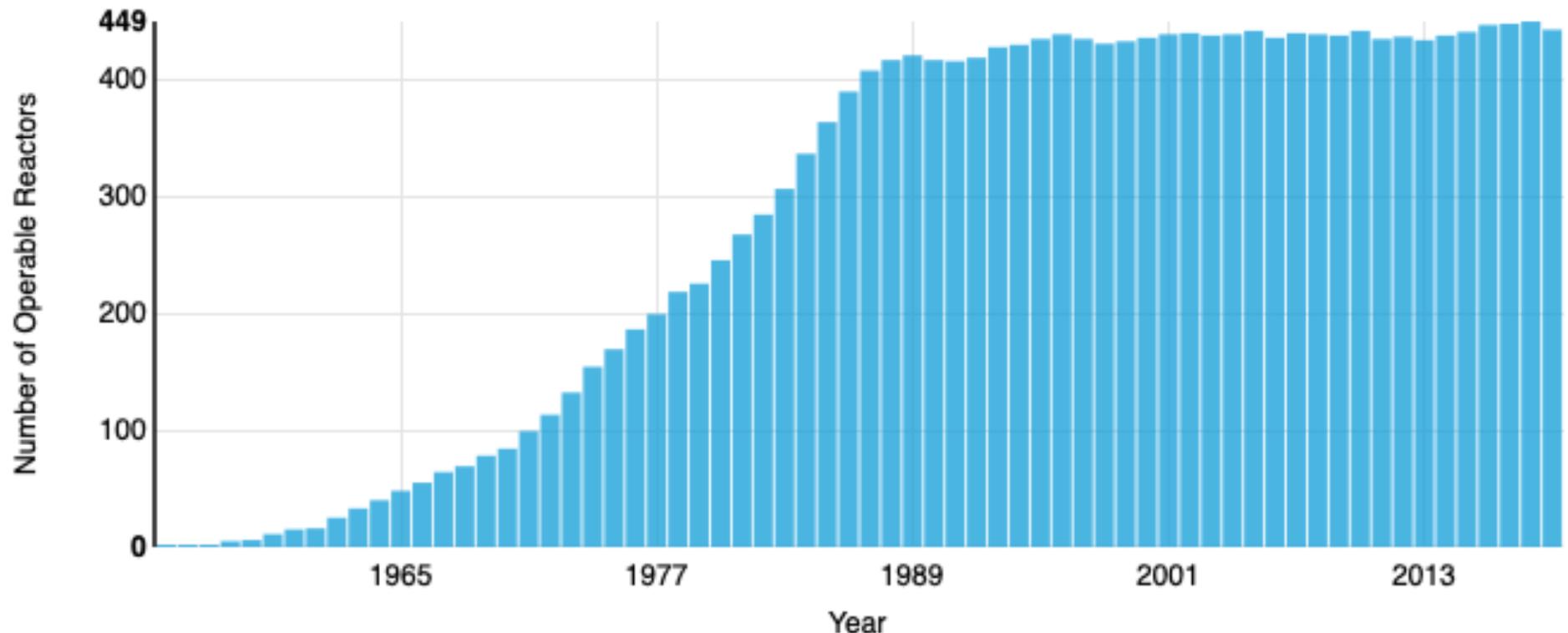
Presenter: Gordon Edwards, Ph.D., President,
Canadian Coalition for Nuclear Responsibility
featuring photographs of Robert Del Tredici

www.ccnr.org

World Nuclear Association Data

2019: The nuclear industry has been stagnant for over 25 years

Number of Operable Reactors Worldwide



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

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

“The State of Affairs [2019]

“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)

The First Nuclear Renaissance (2001):

a litany of failures

Bankruptcy of Westinghouse

Westinghouse Electric filed for bankruptcy in 2017

\$9 billion in losses from new nuclear 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.*

Collapse of French giant Areva

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

Plan: operational in 3 years,
at a cost of 3 billion euros.

Started up - March 2022, 19 years
later, cost 11 billion euros (\$12 billion)

Took 6 times longer to build than
promised and cost 4 times more \$\$.



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 Electricité de France.*

*Nuclear Fission:
the nature of the beast*



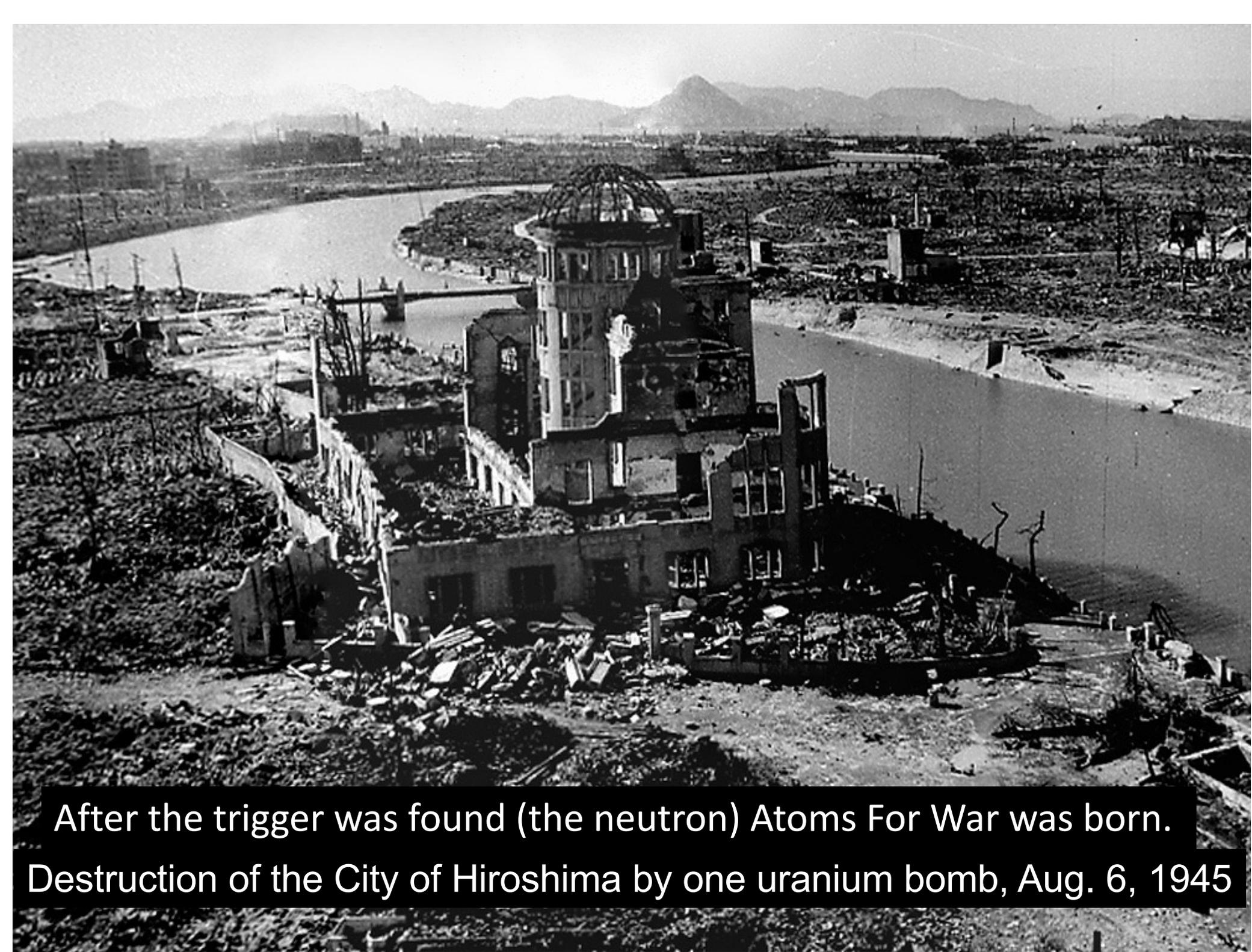
Henri Becquerel 1896

*discovered **radioactivity** of uranium & thorium
~ invisible energy given off ceaselessly ~*



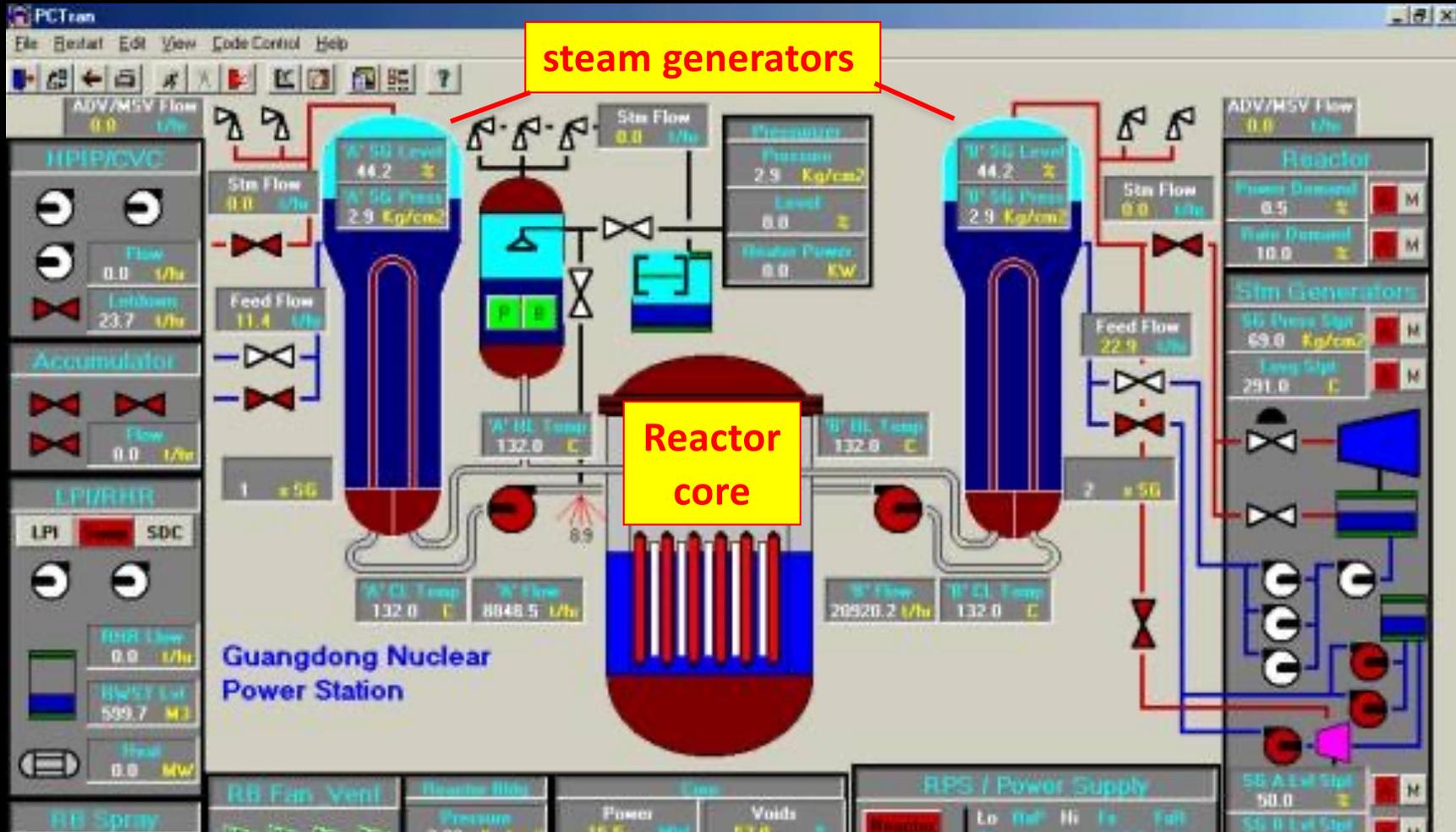
Photo: Robert Del Tredici

In a "cloud chamber" you can see the tracks of radioactive emissions from uranium ore.
Enough energy given off in a few 1000 years to destroy the Earth ~ but no trigger at hand...



After the trigger was found (the neutron) Atoms For War was born.
Destruction of the City of Hiroshima by one uranium bomb, Aug. 6, 1945

“Atoms for Peace” came later – boiling water to make electricity.



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.**

How a nuclear reactor (PWR) works

Model of a Uranium Atom



Uranium is the key element in all nuclear fission technology.

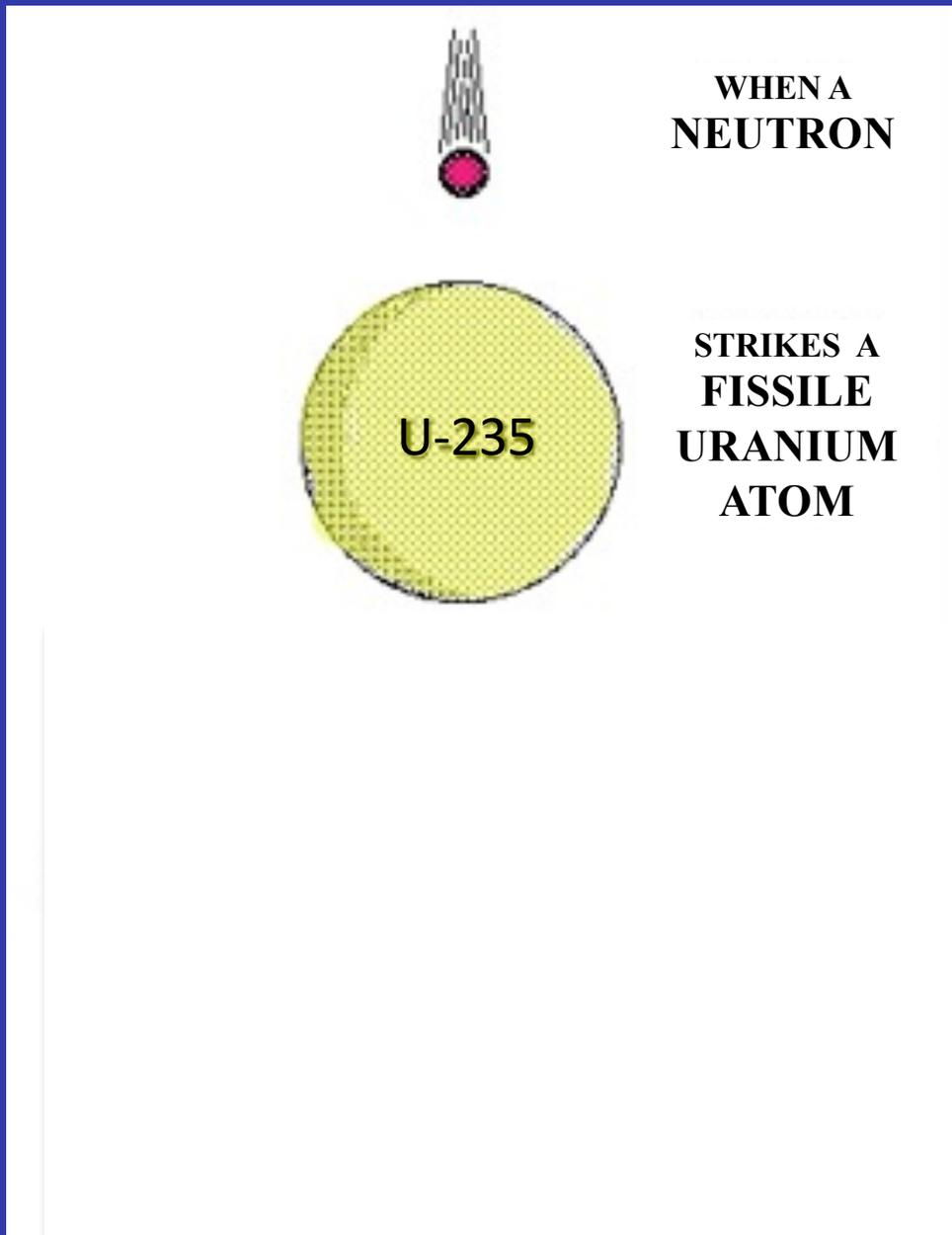
Without it there would be

- 1) NO Nuclear weapons
- 2) NO Nuclear reactors

Photo: Robert Del Tredici

What is Nuclear Fission?

1938-39



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

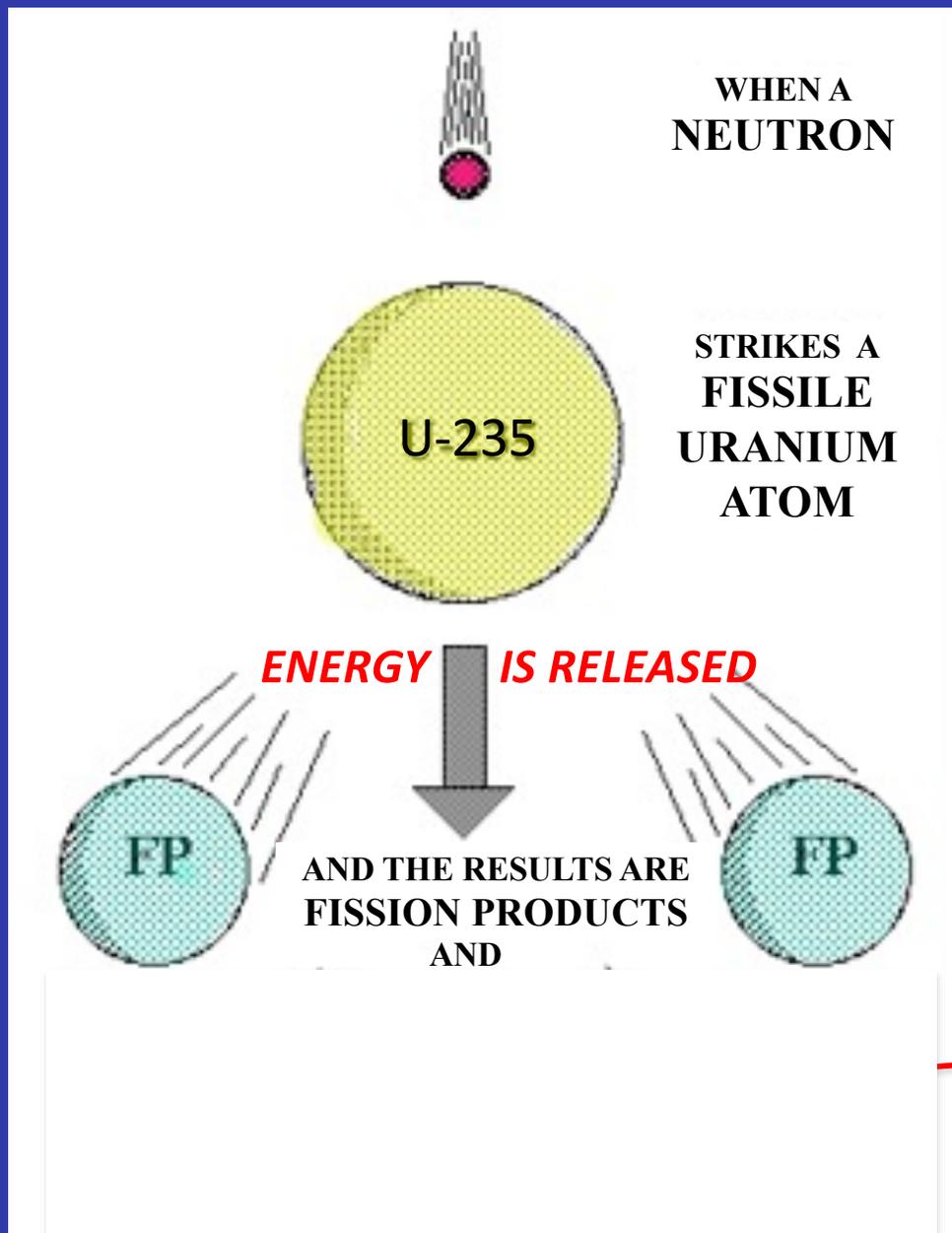
Splitting the Nucleus

1938-39

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

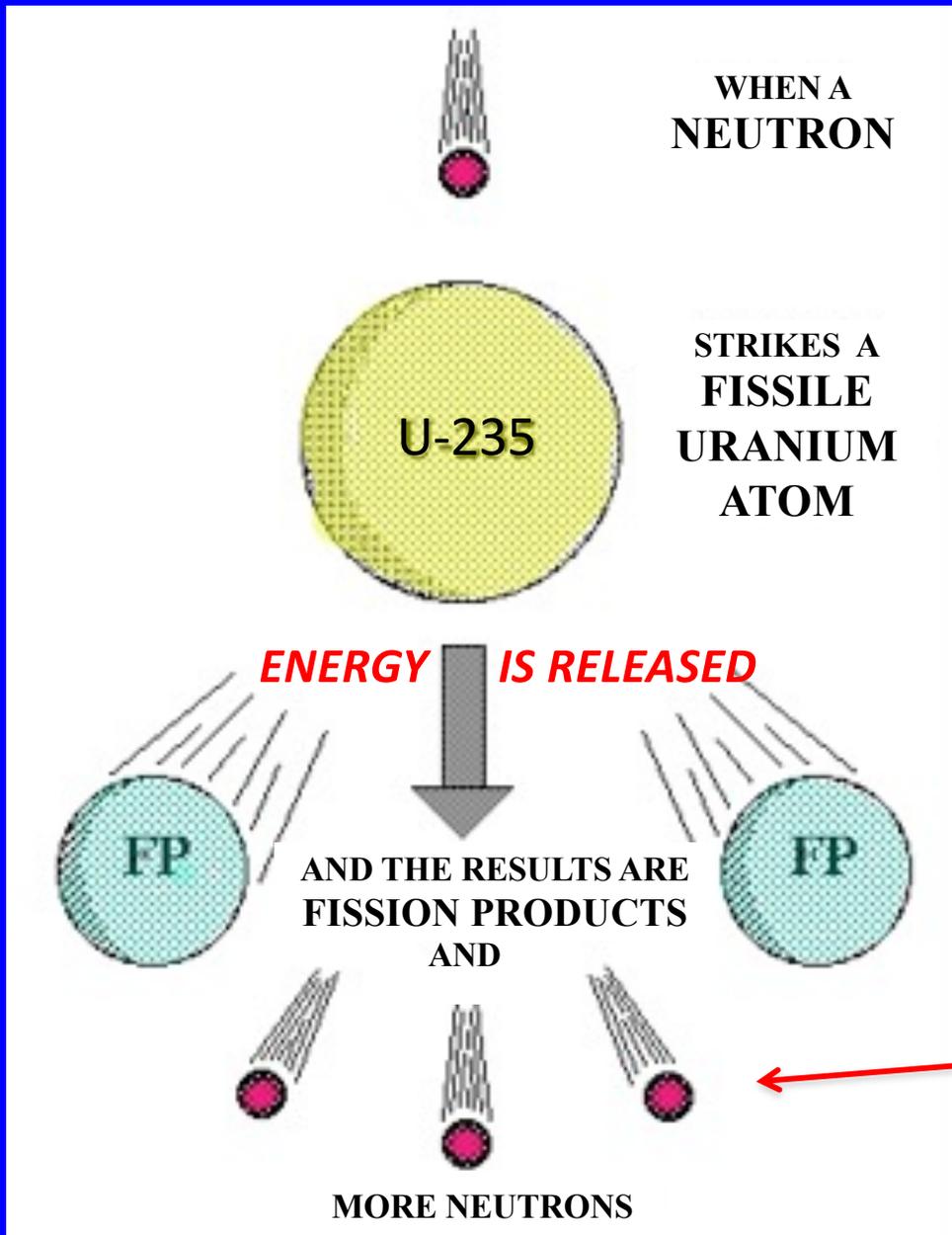
The atom splits into **two smaller atoms** and energy is released – along with **2 or 3 extra neutrons**.

The 2 smaller atoms are **new radioactive materials** called “**fission products**”.



Chain Reaction

1938-39



The atom splits into fragments in hundreds of different ways.

The broken pieces are highly toxic radioactive atoms that constitute the bulk of the waste in the used nuclear fuel.

More neutrons trigger more fissions, and some go on to produce more radioactive byproducts.

What do the extra neutrons do?

- They keep producing fission products*
- They turn some uranium into plutonium*
- They “activate” everything in the core*

What do the extra neutrons do?

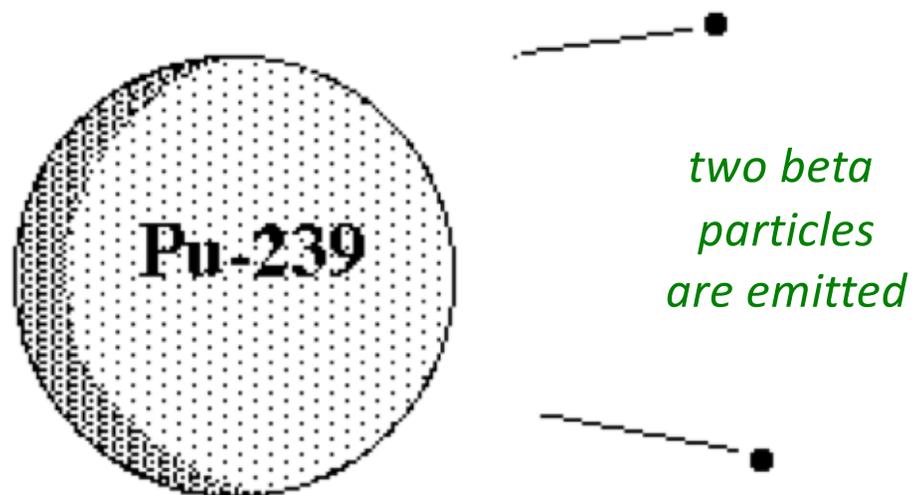
1. Creation of plutonium inside a nuclear reactor ...



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

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

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



The first reactors were built to produce plutonium for bombs.

Other transuranic actinides are produced in a similar way.

This glass paperweight
is the exact size of the
plutonium ball used in
the Nagasaki bomb.

That's how much
plutonium you need
to destroy a city.





Howard Morland with a model of an H-bomb (thermonuclear bomb) showing the plutonium ball (called a “pit”).

This small fission bomb is needed to raise the temperature to 100 million degrees so that nuclear fusion can start.

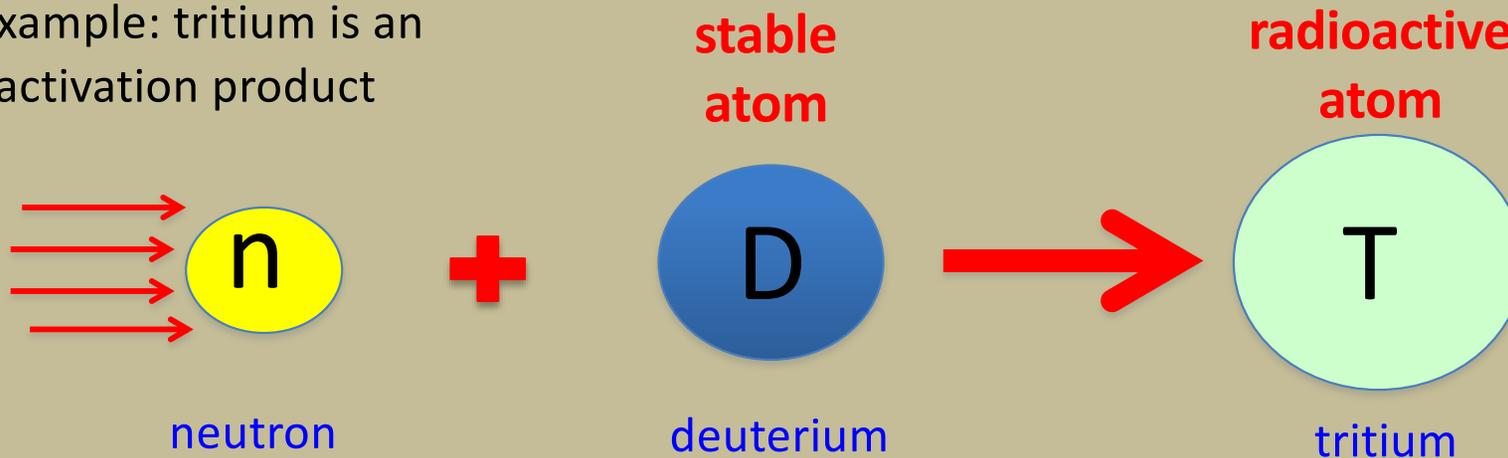
Photo: Robert Del Tredici

What do the extra neutrons do?

2. Creation of “Activation Products”

When a stray neutron is absorbed by a non-radioactive atom the result is often a radioactive atom – an “activation product”.

Example: tritium is an activation product



The diagram shows how a non-radioactive atom of deuterium becomes a radioactive atom of tritium when it absorbs a stray neutron.

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 hydrogen 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.

Longevity of Some Activation Products

Radionuclide	Half-Life	Ten Half-Lives
Nickel-59,	76,000 years	760 thousand years
Nickel-63,	101,000 years	1.01 million years
Niobium-94,	20,300 years	203 thousand years
Technetium-99,	120,000 years	1.2 million years
Iodine-129,	15,700,000 years	157 million years
Chlorine-36,	301,000 years	3.01 million years
Calcium-41,	102,000 years	1.02 million years

The amount of radioactivity decreases by a factor of 1000 after 10 half-lives.

Data from the draft EIS, in-situ decommissioning of the Whiteshell WR-1 Reactor

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	¥		¥	

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

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				YYY
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				Y
Pa	Protactinium	233				YYY
Pa	Protactinium	234				Y
Pa	Protactinium	234m				YYY
U	Uranium	232				Y
U	Uranium	233				Y
U	Uranium	234				YYY
U	Uranium	235				Y
U	Uranium	236				YYY
U	Uranium	237				YYY
U	Uranium	238				YYY
U	Uranium	240				Y
Np	Neptunium	237				YYY
Np	Neptunium	238				Y
Np	Neptunium	239				YYY
Np	Neptunium	240				Y
Np	Neptunium	240m				Y
Pu	Plutonium	236				Y
Pu	Plutonium	238				YYY
Pu	Plutonium	239				YYY
Pu	Plutonium	240				YYY
Pu	Plutonium	241				YYY
Pu	Plutonium	242				YYY
Pu	Plutonium	243				Y
Pu	Plutonium	244				Y
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				YYY
Am	Americium	242				YYY
Am	Americium	242m				YYY
Am	Americium	243				YYY
Am	Americium	245				Y
Cm	Curium	242				YYY
Cm	Curium	243				YYY

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

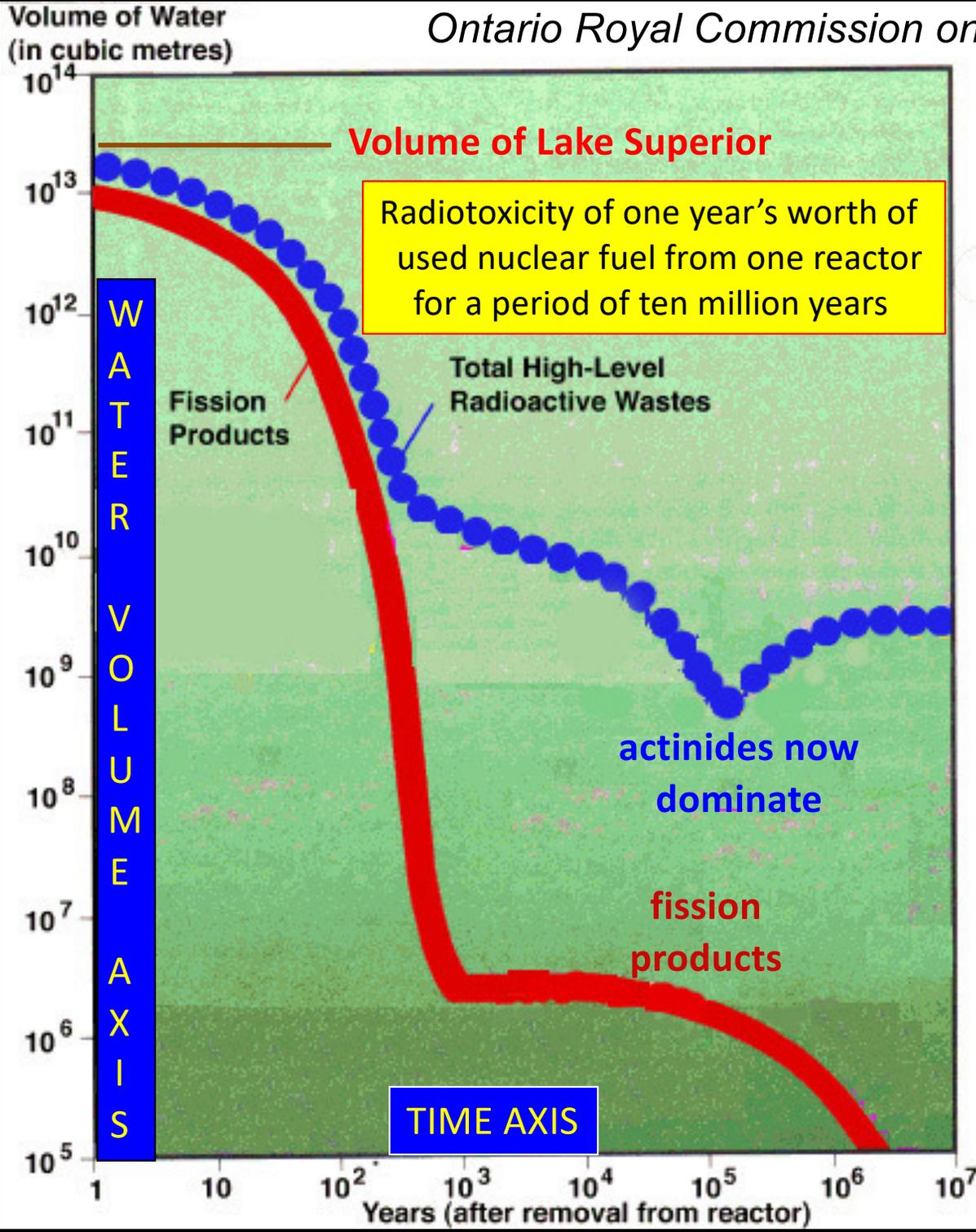
Cm	Curium	244				¥¥¥
Cm	Curium	245				¥
Cm	Curium	246				¥
Cm	Curium	247				¥
Cm	Curium	248				¥
Cm	Curium	250				¥
Bk	Berkelium	249				¥
Bk	Berkelium	250				¥
Cf	Californium	249				¥
Cf	Californium	250				¥
Cf	Californium	251				¥
Cf	Californium	252				¥
Standard Chemical Symbol	Common Name of element	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]

Ontario Royal Commission on Electric Power Planning (1978)



The blue line shows radio-toxicity for a period of 10 million yrs

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.

The Second Nuclear Renaissance (~2018):

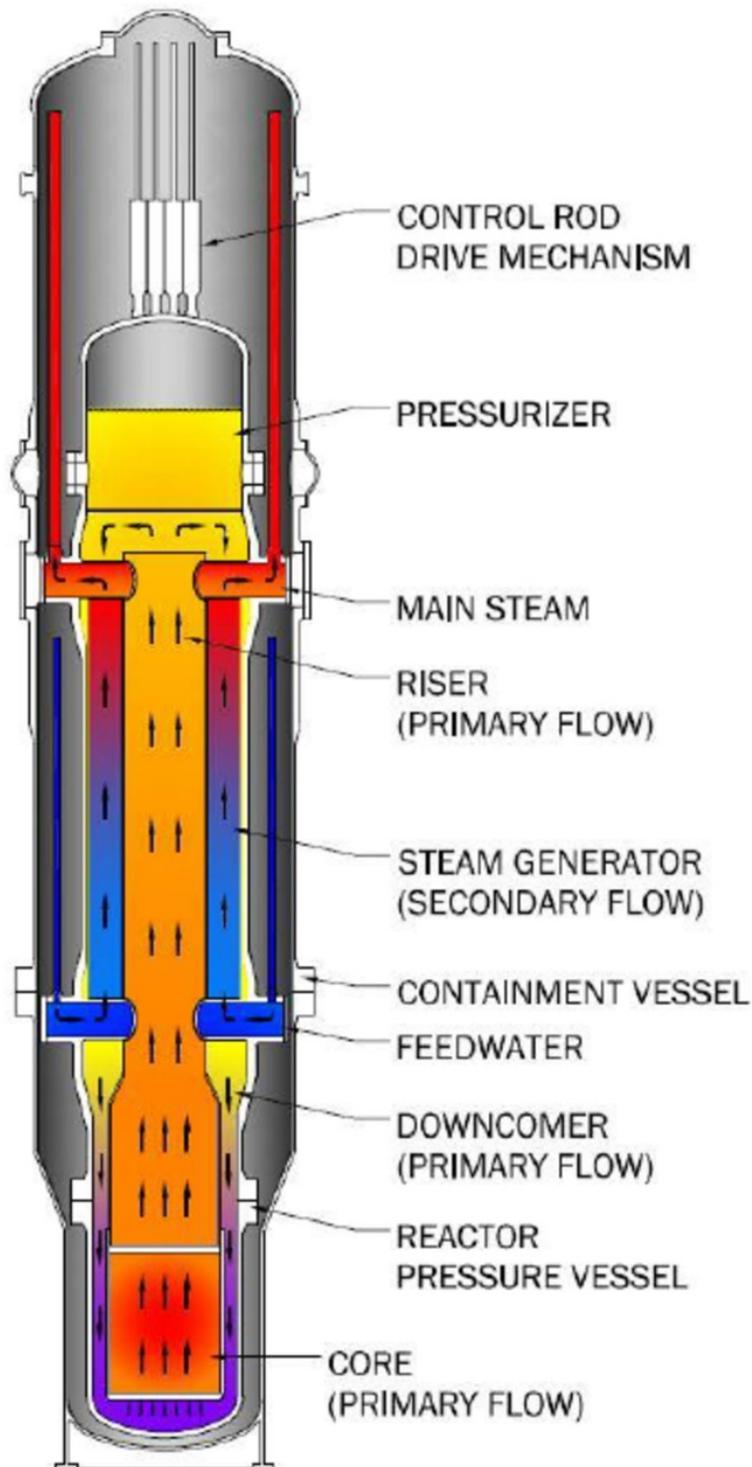
“small modular reactors”

Rationale for Small Modular Nuclear Reactors

- *Large reactors are **too expensive** to finance*
- *Large reactors are **too powerful** for small grids*
- *SMRs can be “modular” for **mass production***
- *SMRs can deliver **heat as well as electricity***
 - *SMRs can **store heat** for flexible usage*
- *SMRS can serve as **backups** for renewables*

Problems for Small Modular Nuclear Reactors

- *Very costly power: mass production needed*
- *More concentrated fission products & activation*
- *Less massive containment: go underground*
- *Over 130 different models: too much competition*
- *Private funding hard to find: public money needed*
 - *Lack of markets and slow deployment*



Schematic of a NuScale power module.

NuScale PWR

The NuScale Power Module is licensed for construction in the USA. But when projected power costs rose sharply, clients backed out.

CANCELLED - 2023

This is a 77 megawatt light-water reactor – PWR – with steam generators (boilers) and passive safety features.

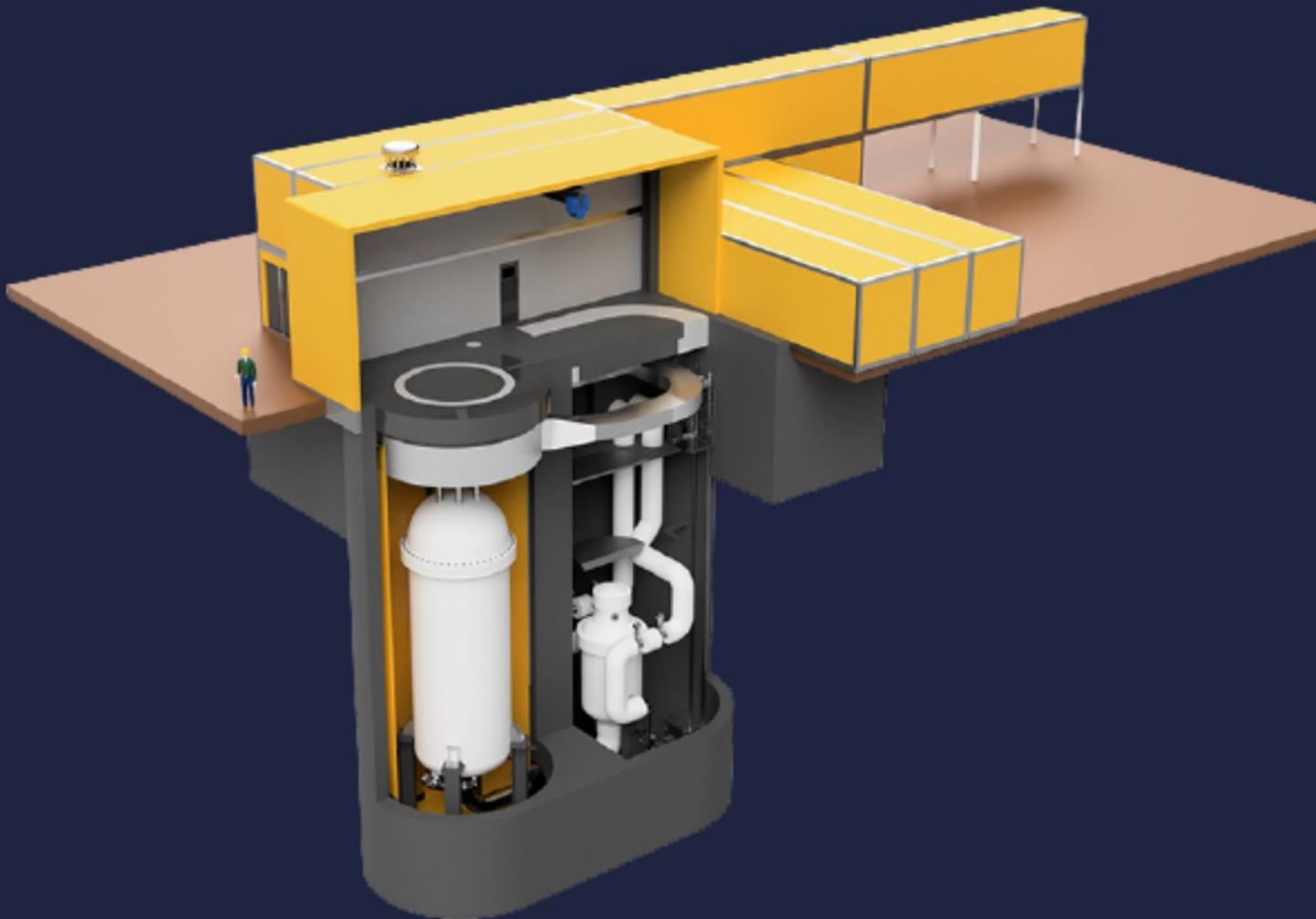
passive = no power required

The Ultrasafe Micro Modular Reactor is a gas-cooled 5 megawatt reactor with a molten salt heat storage system. **Ultrasafe filed for**

bankruptcy in 2024 and so the project is

PAUSED

It is intended for the Chalk River site in Ontario.



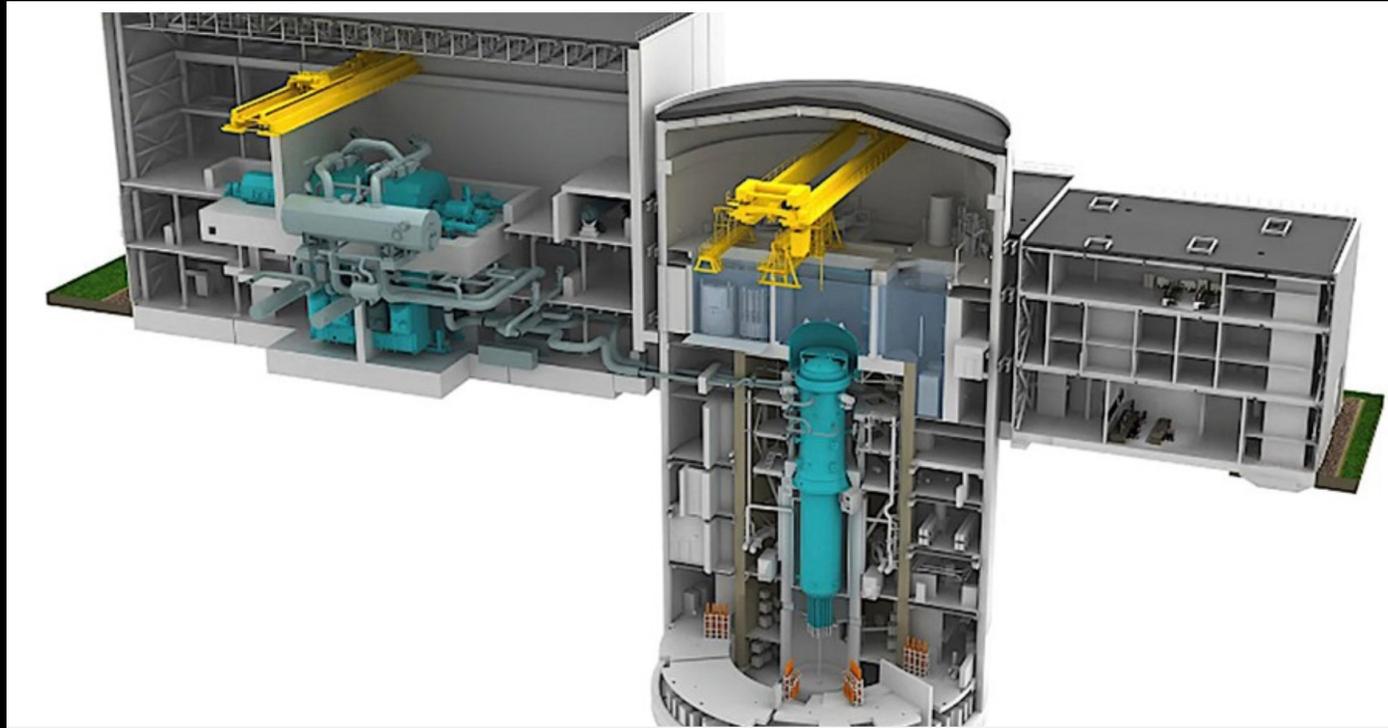
The BWRX-300 is a Boiling Water Reactor (300 megawatts) estimated to cost \$6.5 billion Canadian – equal to the cost per MW of Vogtle.



UNDER CONSTRUCTION

The Canadian regulator CNSC has given a construction licence for the first of four units to be built east of Toronto at Darlington.

A closer look reveals that the BWRX-300 is 21 stories high; 10 stories above-ground and another 11 stories below ground. Not so small.

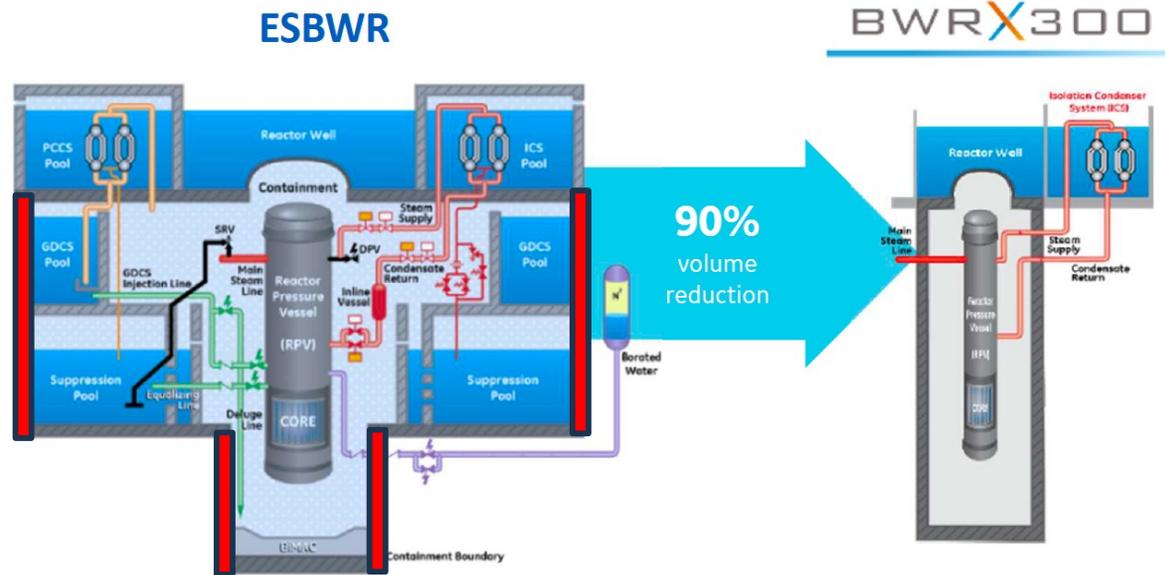


UNDER CONSTRUCTION

And not so modular either. A work force of up to 4000 has been cited by the Prime Minister who has invested federal money in it.

“The BWRX-300 is a 300 MWe water-cooled, natural circulation SMR with passive safety systems that leverages the design and licensing basis of GEH's ESBWR boiling water reactor, certified by the US Nuclear Regulatory Commission.” – World Nuclear News 2021

Simplicity drives cost reduction



Systems/components eliminated:

- Suppression Pool
- GDCS Pool
- Safety Relief Valves & Spargers
- Depressurization Valves
- BiMac (core catcher)

Systems/components simplified:

- Passive Containment Cooling (PCCS)
- Containment (use of SC)
- Boron injection
- Security (built into design)
- Turbine
- Generator (air cooled)

>50% building volume reduction/MW
>50% less concrete/MW

Reduction in size is due in part to elimination of safety systems.

Nuclear Fission Reactors:

Problem #1: Nuclear Wastes

Problem #2: Nuclear Catastrophes

Problem #3: Nuclear Decommissioning

Problem #4: Spreading Nuclear Weapons

None of these problems is eliminated by the use of smaller reactors.

Debunking Nuclear Hopium

February 26, 2026

PART TWO

“Advanced Nuclear Reactors and Fusion”

ANR + F

(Another Nuclear Roller-coaster + Fantasyland)

Presenter: Gordon Edwards, Ph.D., President,
Canadian Coalition for Nuclear Responsibility
featuring photographs of Robert Del Tredici

www.ccnr.org

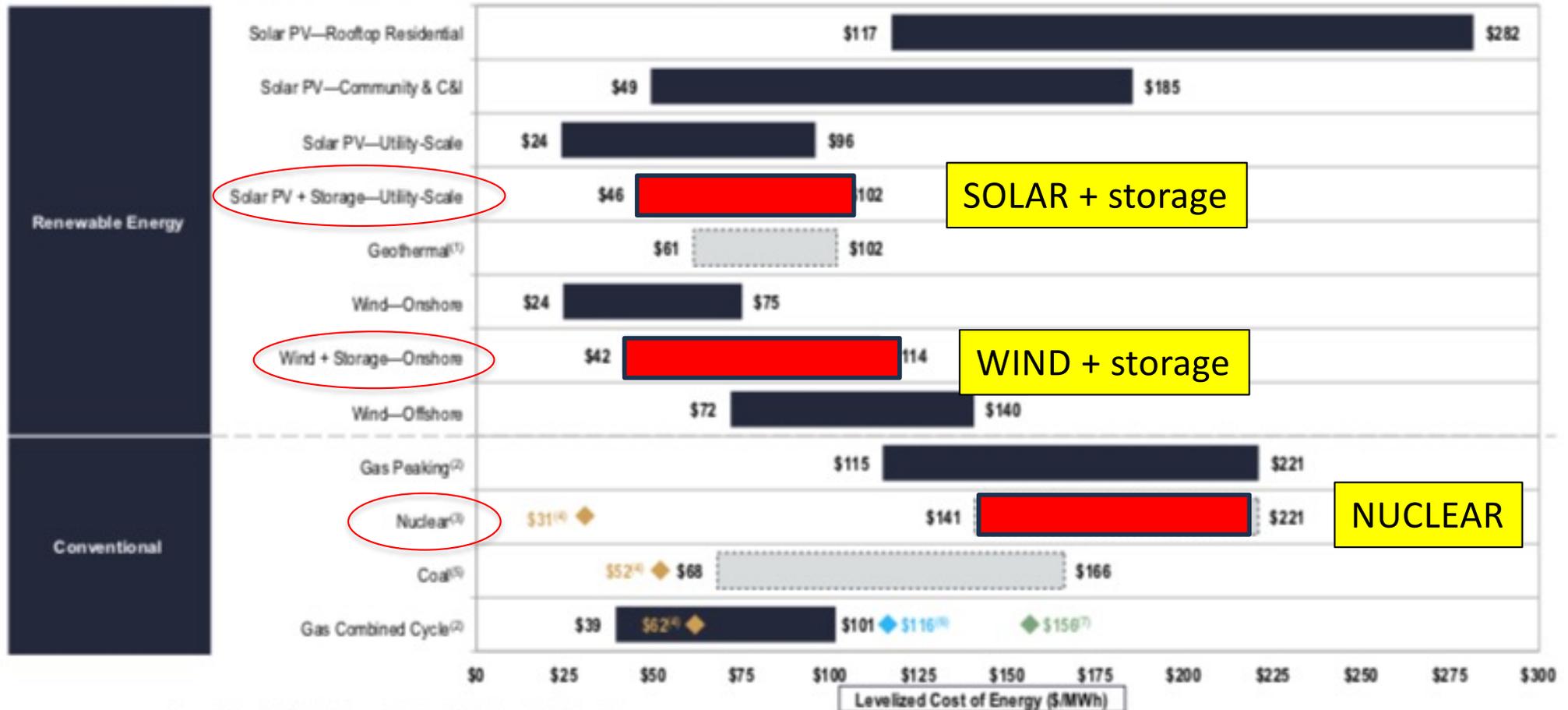
The Competition:

The Status of Renewable Energy

Levelized Cost of Energy Comparison—Unsubsidized Analysis

Lazard. April 2023

Selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances

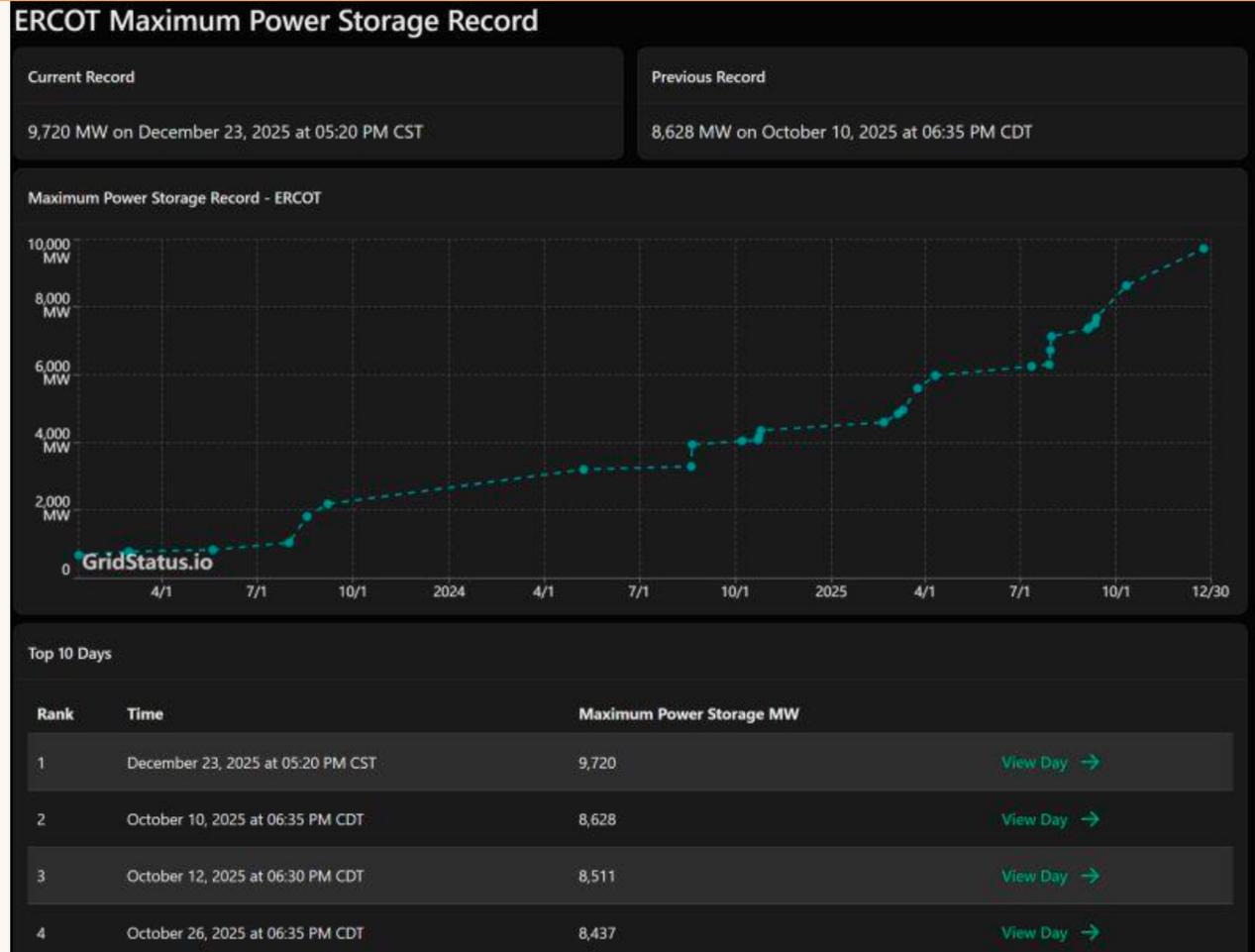


Source: Lazard and Roland Berger estimates and publicly available information

The HIGHEST cost for renewable with storage is far less than the LOWEST cost for nuclear.

Instant Battery Discharge reaches almost 10 GW on ERCOT’s grid in Texas in December 2025:

- then covering a record 18 percent of the load
- then close to twice the operating capacity of the state’s four nuclear reactors’

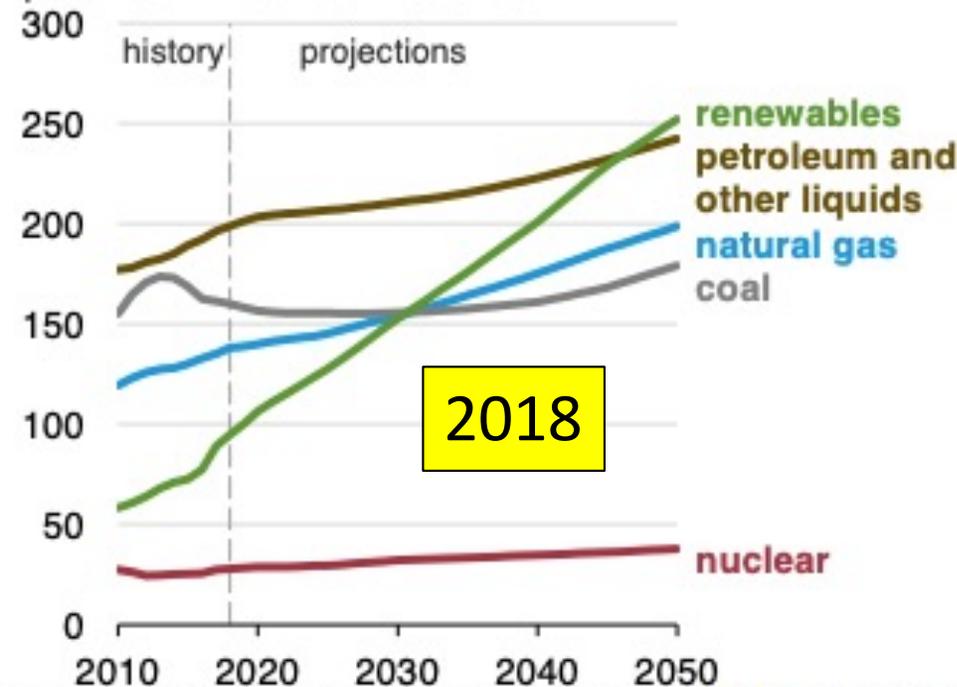


Source: Grid Status 2026, see https://www.linkedin.com/posts/grid-status_last-week-ercot-seta-new-record-for-instantaneous-activity-7411476640809144320-azjb

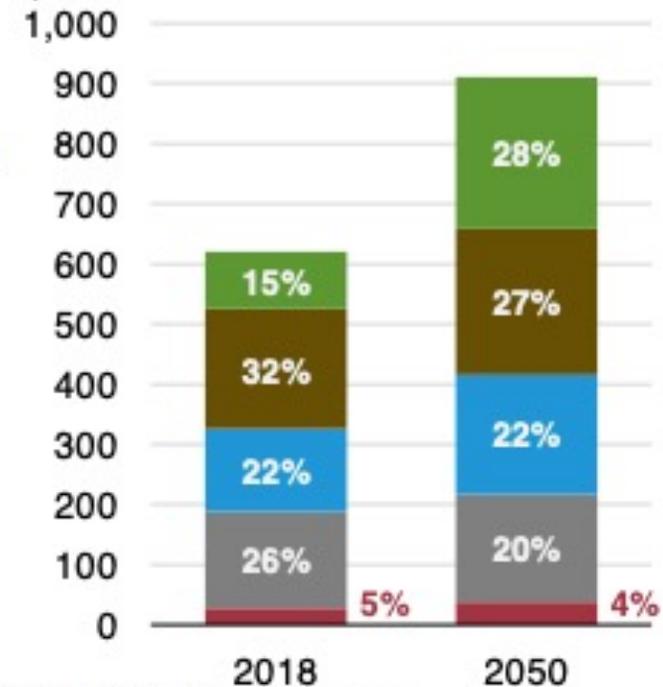
US Energy Information Administration (EIA)

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

quadrillion British thermal units



quadrillion British thermal units



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.

COP 28 (2023):

1. *Triple renewables and double energy efficiency by 2030*
(~200 nations, *official pledge*)
2. *Triple nuclear power by 2050*
(25 nations, *unofficial aspiration* ~ photo-op)

German Greenhouse Gas Emissions

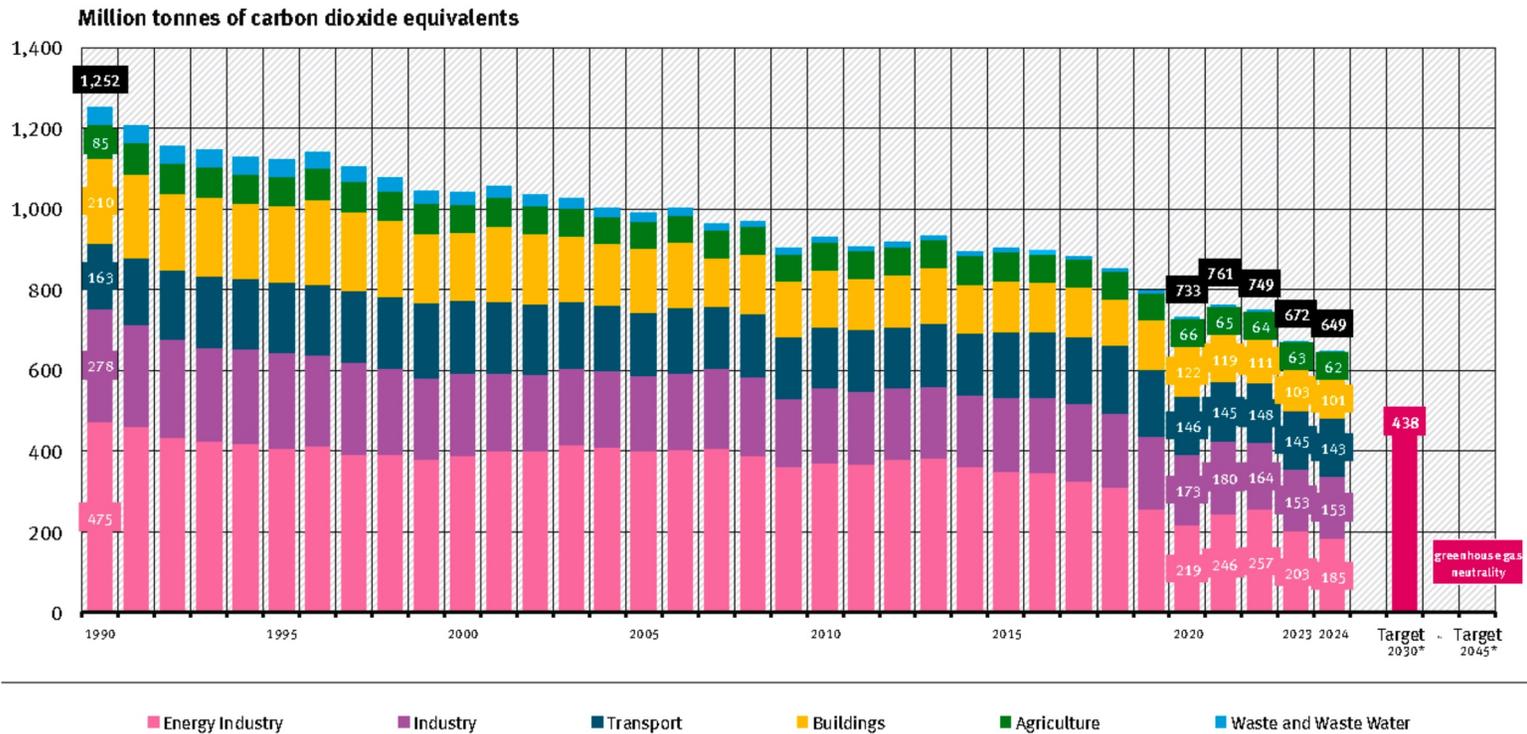
2010–Pre-Nuclear Phaseout Decision:
Total Emissions
 930 million t of CO₂e
 of which
Energy Sector
 373 million t of CO₂e

versus

2024–One year After Last Reactor Closed:
Total Emissions
 649 million t of CO₂e
 of which
Energy Sector
 185 million t of CO₂e

Total Emissions: -30 %
Energy Sector: -50 %

Emission of greenhouse gases covered by the UN Framework Convention on Climate



Emissions by sector of the German Federal Climate Protection Act, excluding land use, land use change and forestry
 *Targets 2030 and 2045: according to the revision of the Federal Climate Protection Act (KSG) as of 12.05.2021

Source: German Environment Agency, National Greenhouse Gas Inventory 1990 to 2023 (as of 03/2025), for 2024 preliminary data (as of 15.03.2025)

Source: German Federal Environment Agency, see <https://www.umweltbundesamt.de/en/data/environmental-indicators/indicator-greenhouse-gas-emissions#at-a-glance>

“Advanced concept”:

Using Molten Salt Coolant

Two abandoned nuclear airplane engines using molten salt.

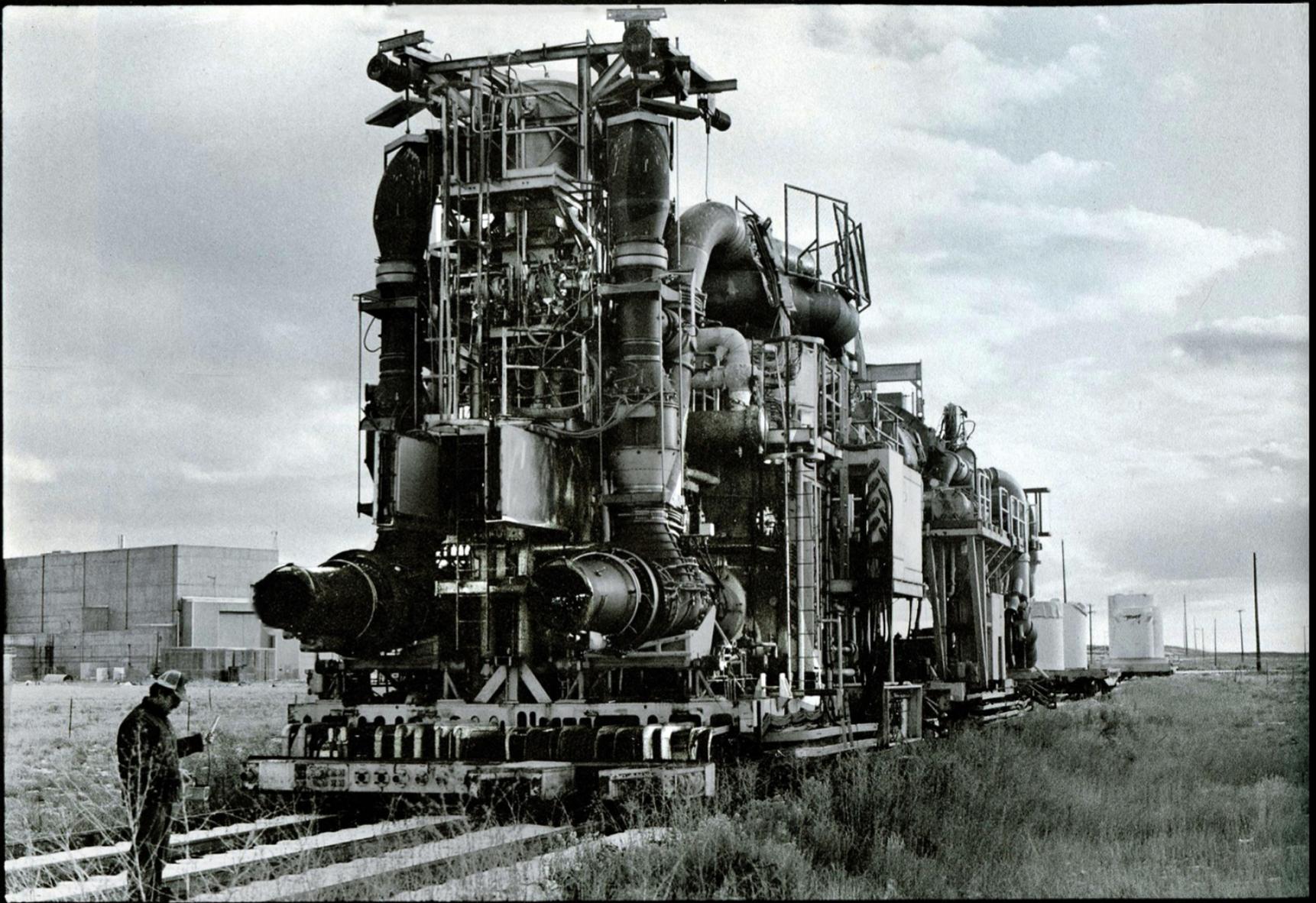


Photo: Robert Del Tredici

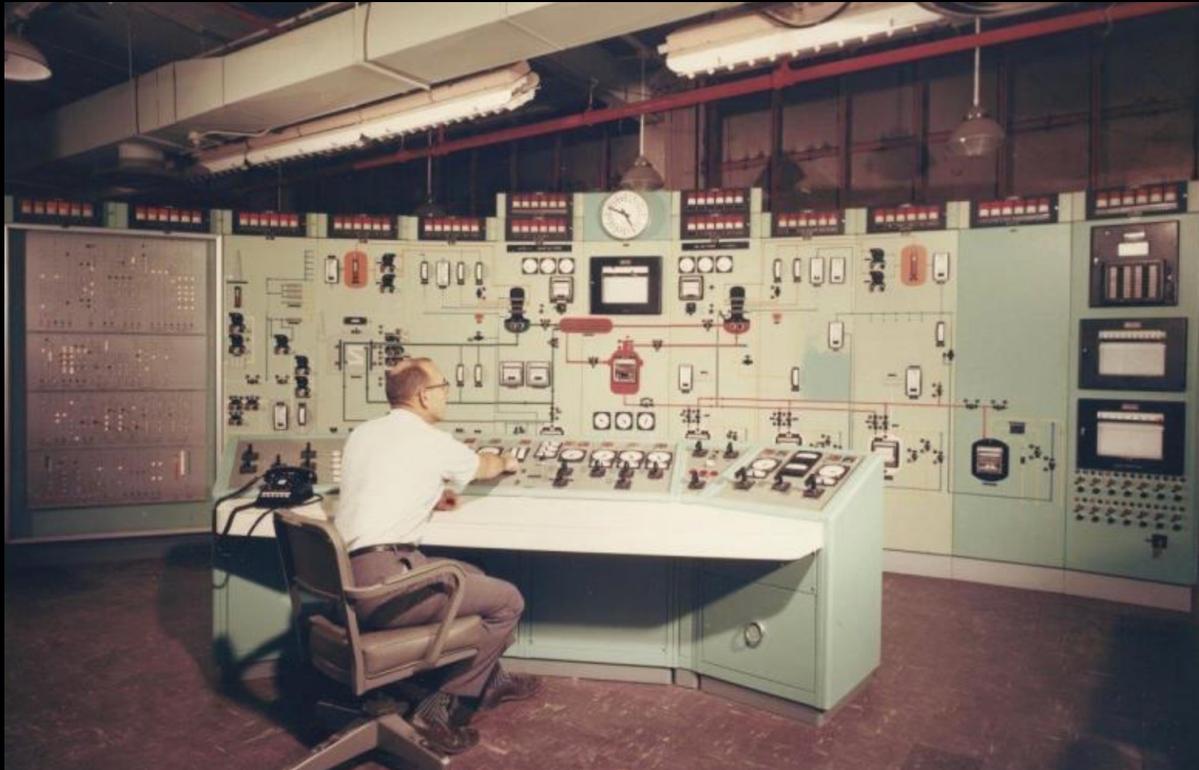
The program was cancelled in 1961 by President Kennedy.



Photo: Robert Del Tredici

Alvin Weinberg ran the Molten Salt Reactor Experiment at Oak Ridge.

The Molten Salt Reactor Experiment, which operated for about five years in the 1960s, used plutonium, bomb-grade uranium and eventually depleted uranium-233 for fuel.



R.I.P.

MSRE
1964-1969

NEWS

Contaminated Molten Salt Reactor Experiment may be entombed in concrete



Brittany Crocker

Knoxville

Updated Dec. 14, 2017, 3:26 p.m. ET

“Advanced concept”:

Using Liquid Sodium Metal Coolant



The Experimental Breeder Reactor II (1964-1994)

A “breeder” is a reactor that makes more fuel than it uses.

- Plutonium
- Thorium

Infused with residual sodium, the EBR2 uranium metal fuel is still very problematic. Sodium reacts violently on contact with water, so fuel cannot be “buried” in a DGR.

USA



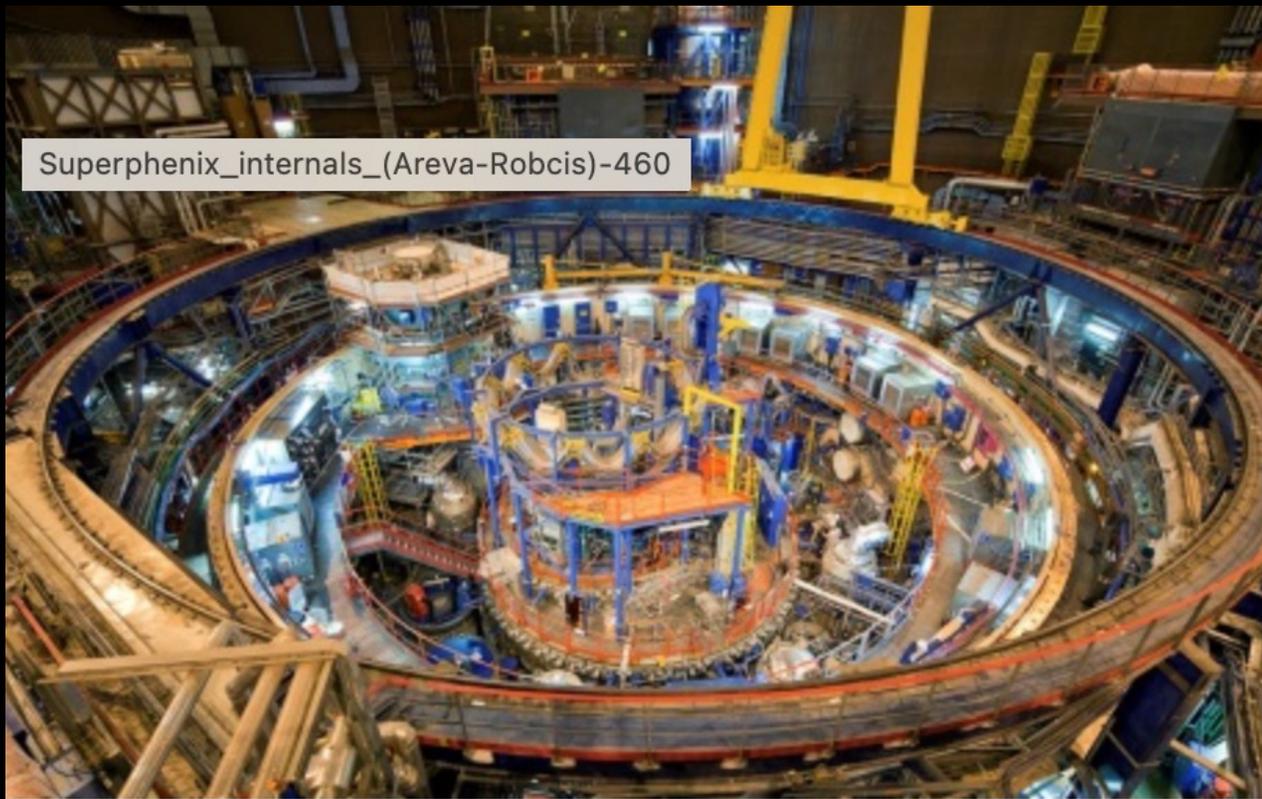
The reactor vessel is moved into the Fermi 1 containment building during construction in the late 1950s. Enrico Fermi Nuclear Generating Station is a nuclear power plant located in Frenchtown Township. *Detroit Edison Company*

Liquid sodium-cooled Fermi-1 reactor outside Detroit : fuel melted.

1966

FRANCE

Superphénix is widely considered a technological and economic failure due to extreme costs (approx. €9 billion), immense political pressure, and poor reliability.



It operated for only a fraction of its life (roughly 12 months in 10 years) due to serious technical issues like sodium Leaks.

France's liquid sodium fast breeder reactor Superphénix. Shut down in 1998 – difficult dismantling to end in 2030.

GERMANY



Germany's Kalkar sodium-cooled breeder reactor was built, but never operated – it was turned into an amusement park,

Construction took place from 1973 – 1985.

It never went online due to intense public protest & safety concerns.



JAPAN

Japan's sodium-cooled Monju breeder reactor only operated for less than a year in three decades.



Scrapping Monju: the curtain falls on Japan's experimental fast breeder reactor

Japan has finally pulled the plug on Monju, an experimental fast breeder nuclear reactor that has been plagued by accidents, cover-ups and cost overruns. But why did Monju fail and is there still a future for fast breeder technology? Molly Lempriere finds out.

Molly | January 3, 2017

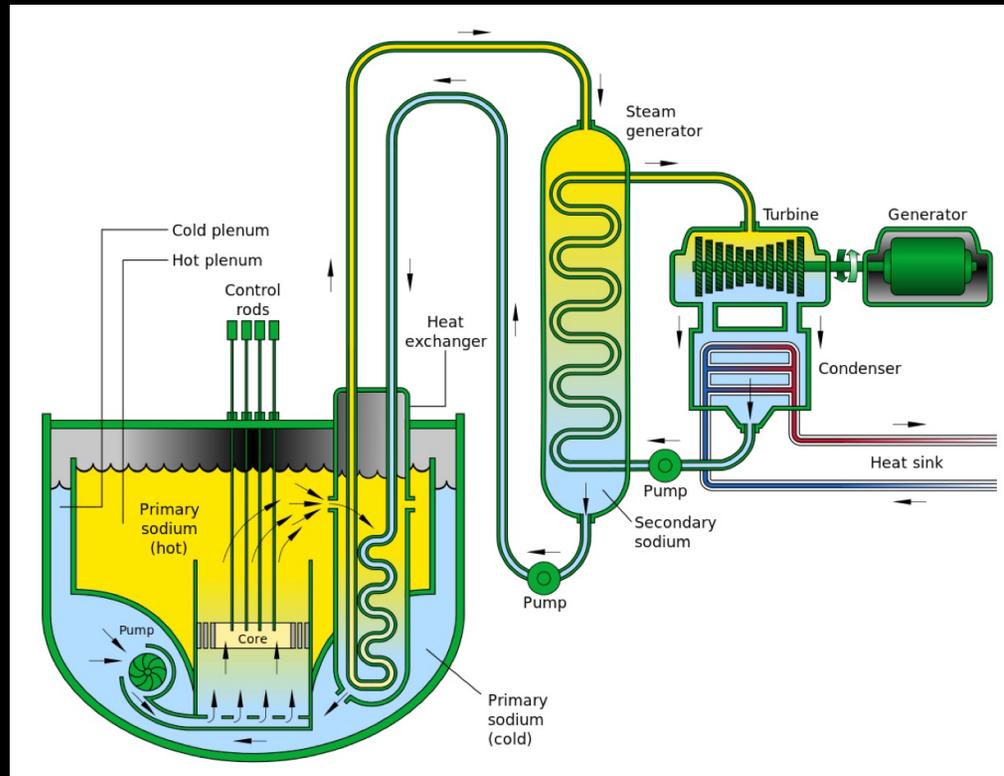
BRITAIN

The Dounreay nuclear breeder, active from the 1950s to 1994, is considered a technical success for pioneering fast reactor technology but an environmental and operational failure due to significant radioactive contamination, safety breaches, and high decommissioning costs. The site's reactors, including the Prototype Fast Reactor (PFR), experienced numerous leaks and released fuel particles onto nearby beaches.



NEW BRUNSWICK (CANADA)

The ARC-100 reactor is a liquid sodium metal-cooled “fast” reactor with HALEU enriched uranium metal fuel at 3 levels of enrichment.



It is currently undergoing a provincial environmental impact assessment.

IN PROCESS

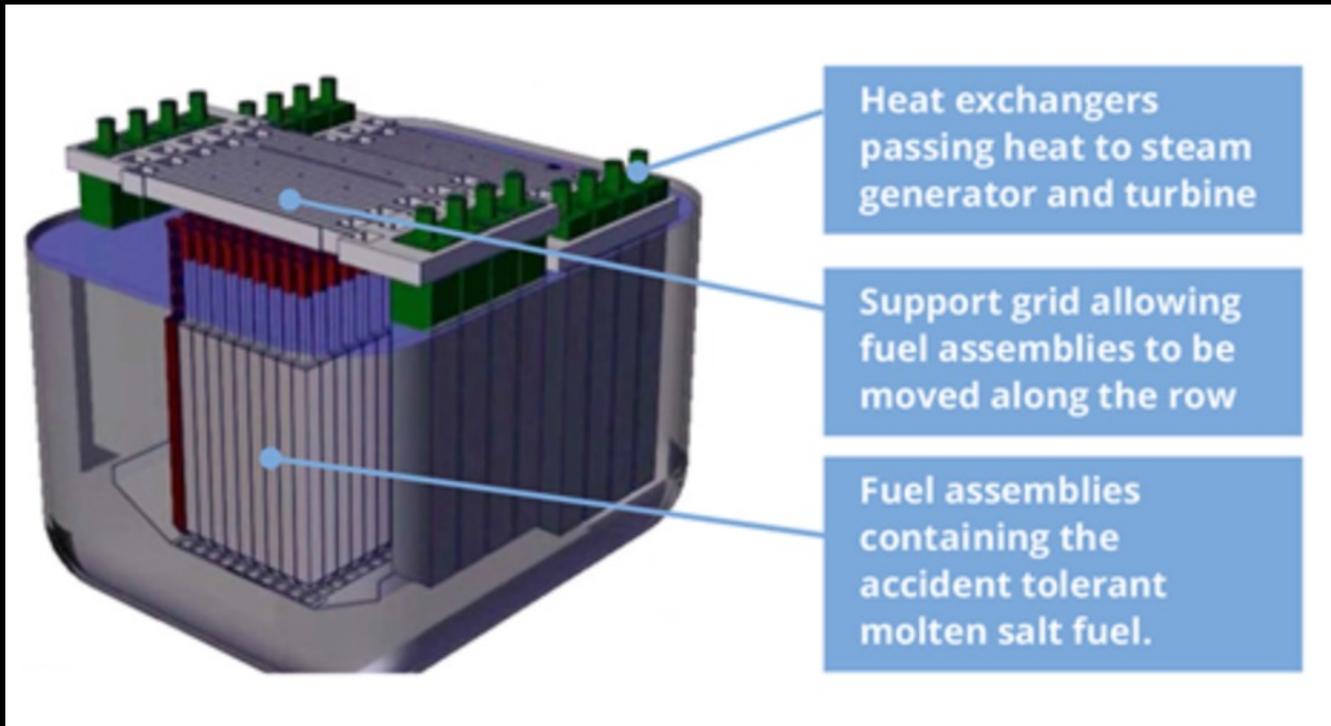
The project is lacking the necessary level of private funding to date.

This reactor may also require a reprocessing facility in order to recover the residual unused enriched uranium and recycle it.

NEW BRUNSWICK

The Moltex “waste-burning” reactor is a molten salt reactor fueled with plutonium and other “actinides” extracted from used fuel

already stored on-site in New Brunswick.



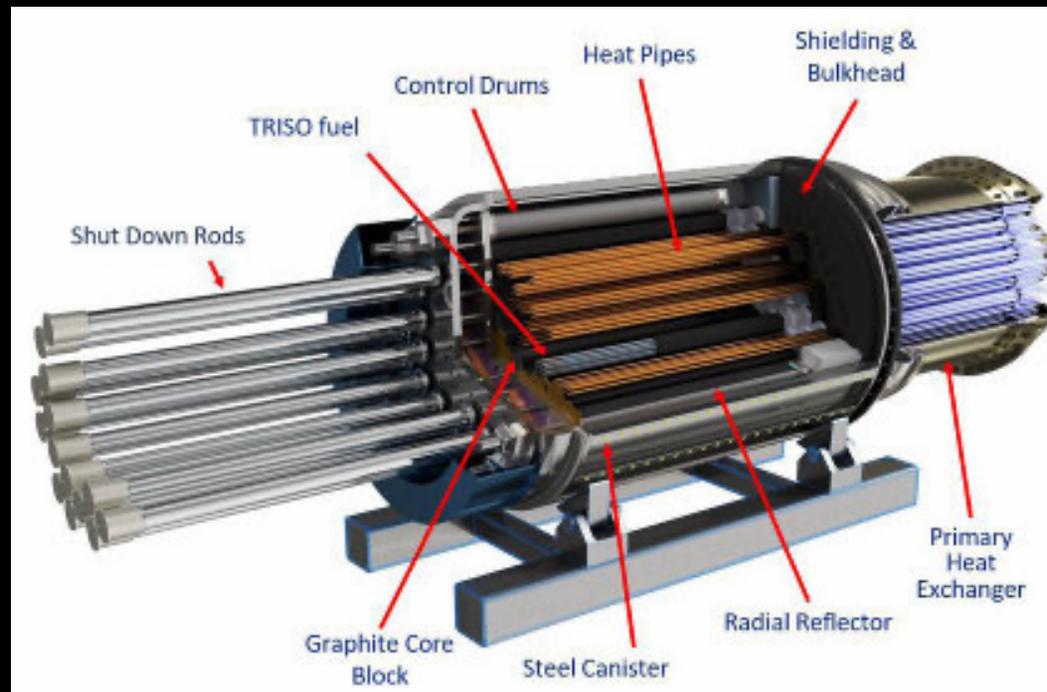
IN LIMBO

It is intended for the Point Lepreau site in New Brunswick.

This reactor would require an electro-metallurgical reprocessing facility in order to extract plutonium from existing used fuel.

SASKATCHEWAN

The Westinghouse eVinci reactor uses uranium at the highest level of enrichment allowed for civilian purposes: 19.76 percent U-235.



UNDER STUDY

The Saskatchewan Research Council has received \$80 million to study this reactor for possible deployment in the province.

To make the Hiroshima bomb, the concentration of U-235 had to be greatly increased.

4. Enrichment of Uranium

(visually)

LEU

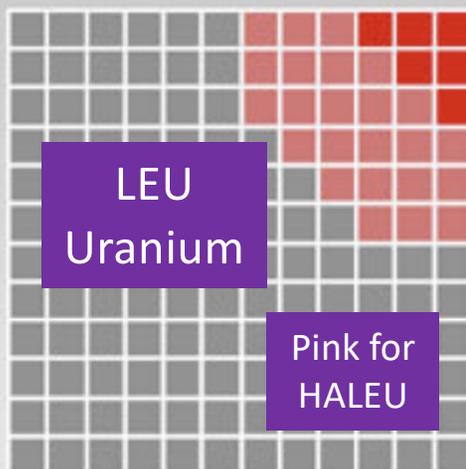
(reactor fuel)

HEU

(weapon-usable)



Natural uranium
0.7% U-235



Low-enriched uranium
typically 3-5%,
but less than 20% U-235



Highly enriched uranium
20% U-235 and above



Weapon-grade uranium
more than 90% U-235

Uranium



Weapons-usable uranium > 20%

Uranium-235 is the "chain-reacting". Variety of uranium

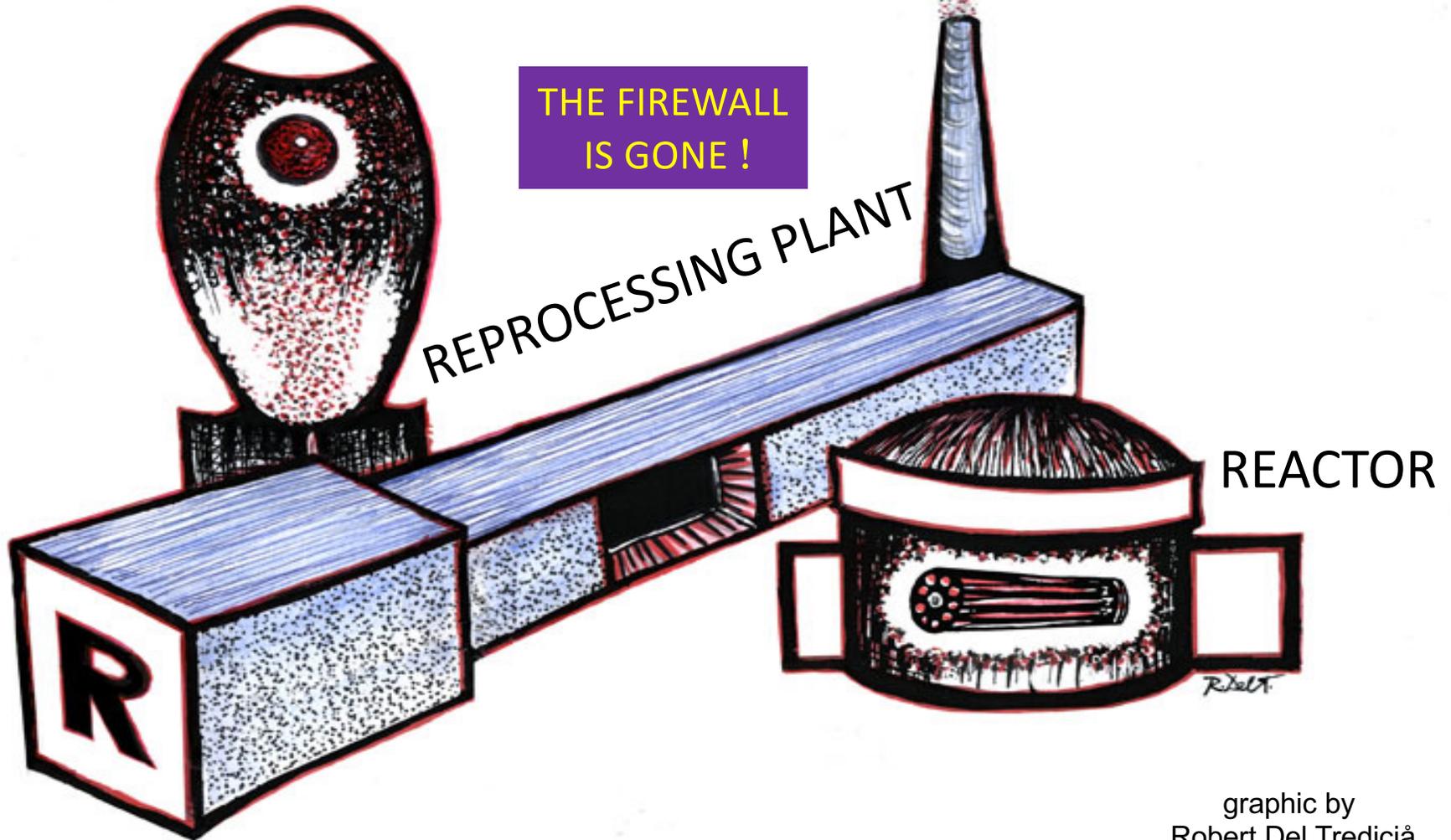
Reprocessing



graphic by
Robert Del Tredicià

There is a radioactive firewall between used reactor fuel and bombs.
Gamma radiation from used nuclear fuel is deadly & easily detectable.

BOMB



graphic by
Robert Del Tredicià

R = Recycling = Reprocessing = Renaissance

A reprocessing plant removes the firewall and makes plutonium more accessible

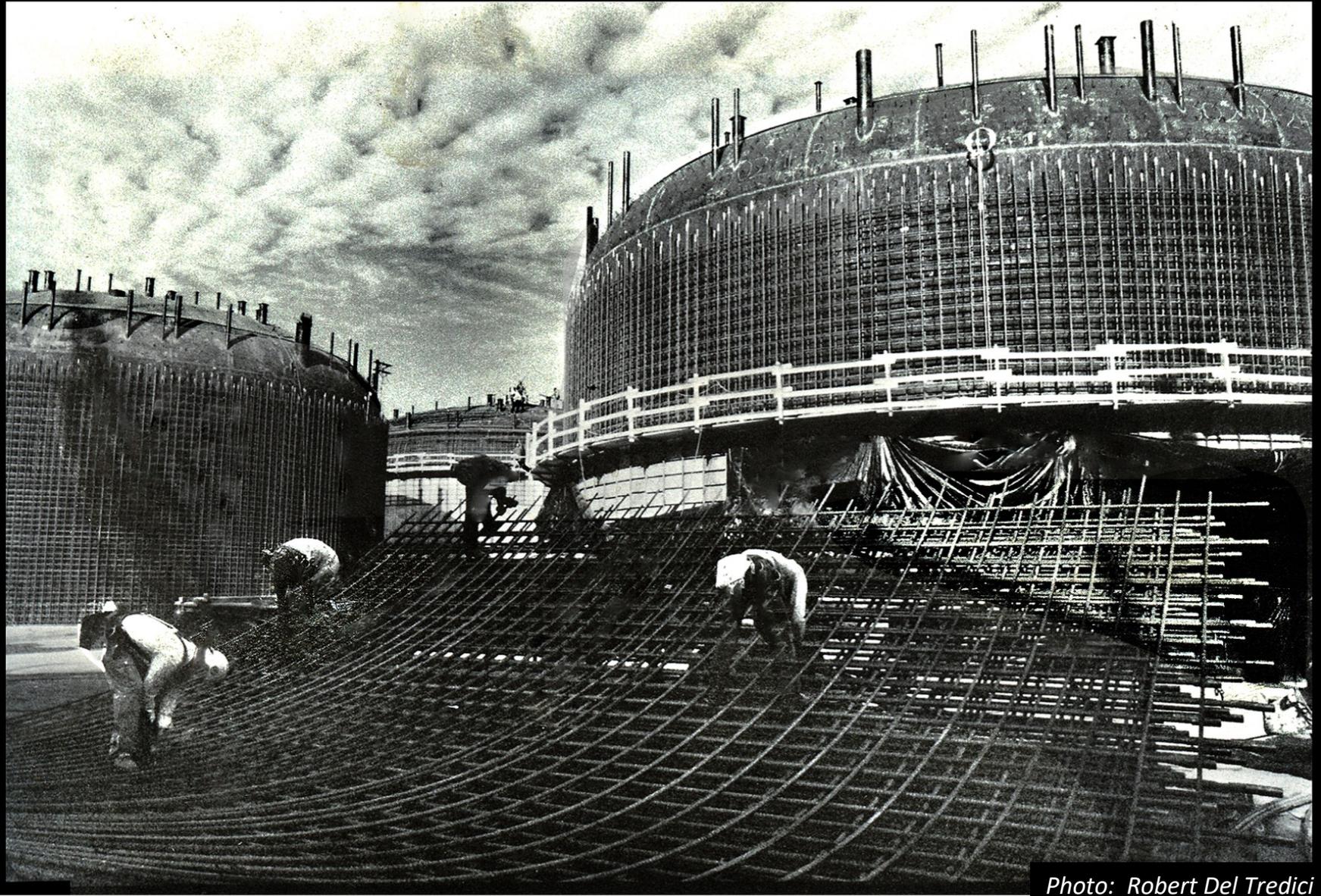


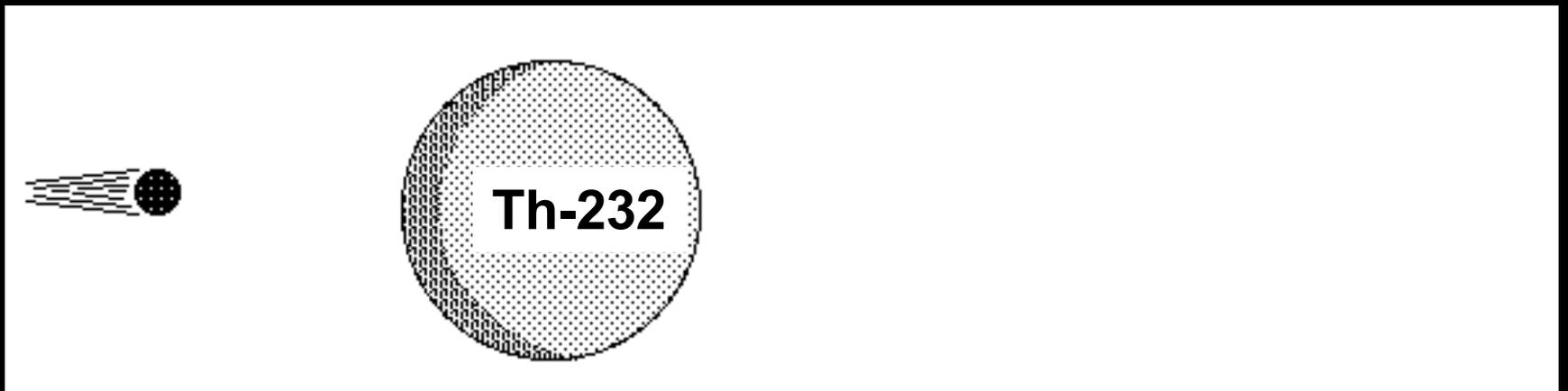
Photo: Robert Del Tredici

Tanks for storing liquid high-level waste from reprocessing.
GAO estimates Hanford "cleanup" between \$300 b & \$640 b.

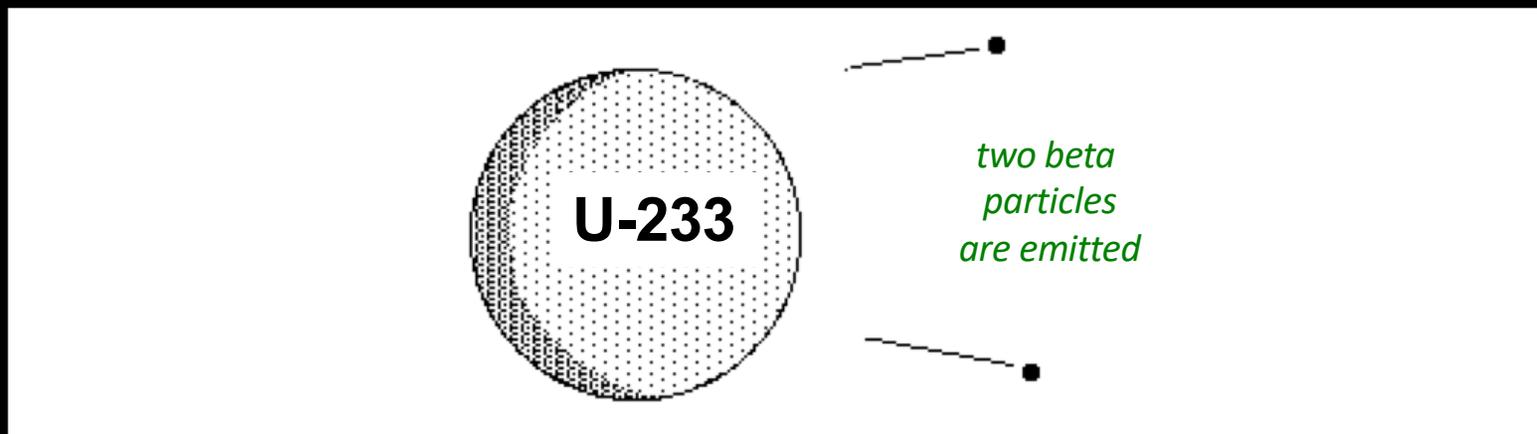
“Advanced concept”:

Using Thorium as a “Fuel”

Creation of uranium-233 inside a nuclear reactor ...



... when an atom of thorium-232 absorbs a neutron



. . . it is transformed into an atom of uranium-233

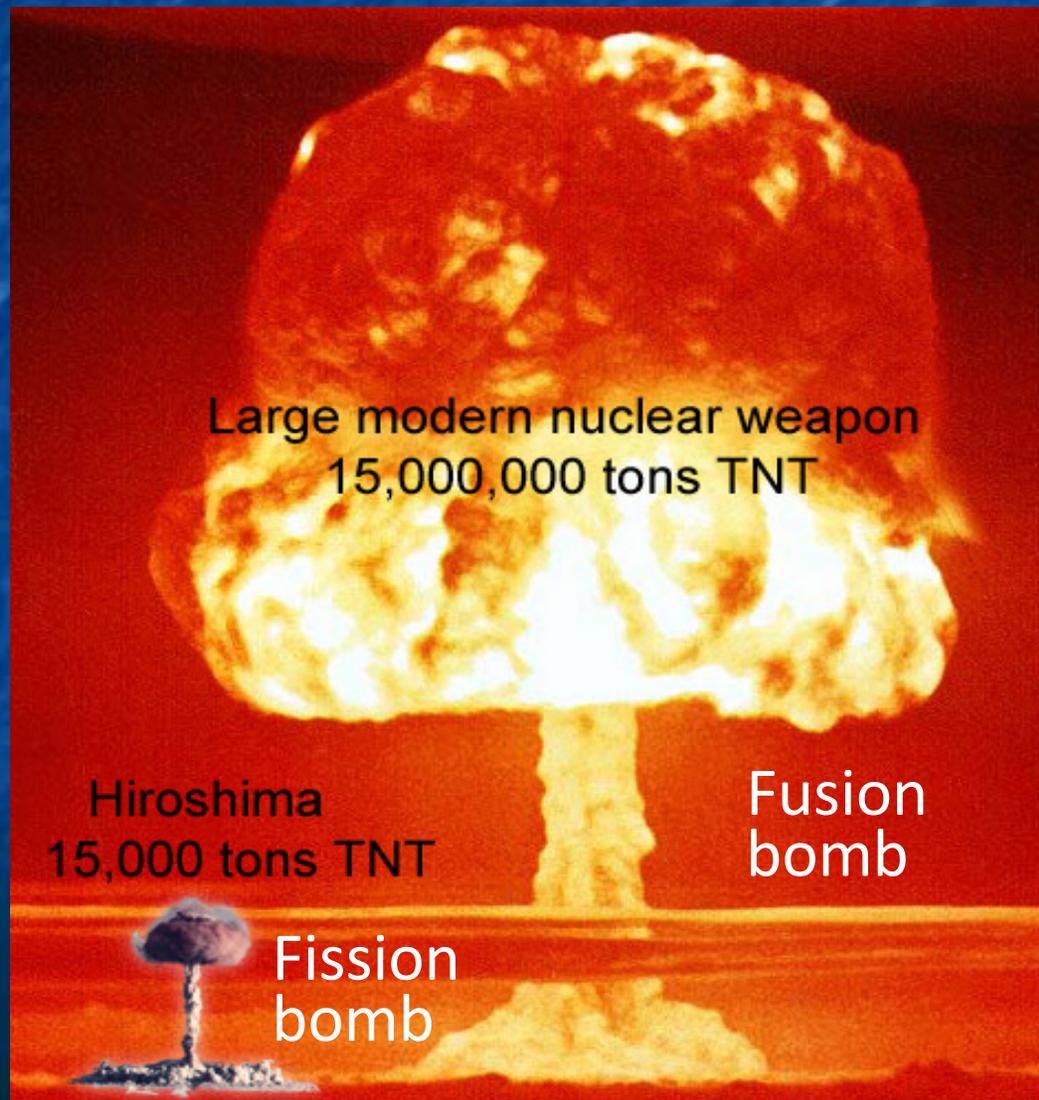
Human-made uranium-233 is a fissile material - excellent for bombs.
Reprocessing used nuclear fuel is unavoidable to recover U-233.

Nuclear Fusion:

The Nature of the Beast

Largest conventional bomb = 44 tons TNT
Hiroshima-size nuclear weapon = 15,000 tons TNT
Smallest strategic nuclear weapon = 100,000 tons TNT
Large U.S. strategic nuclear weapon = 1,300,000 tons TNT
Largest known strategic nuclear weapon = 100,000,000 tons TNT

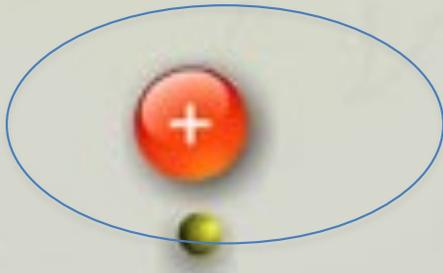
Nuclear fusion
Is much more
powerful
than fission.



H = hydrogen; H-Bomb = hydrogen bomb

There are three different isotopes of hydrogen – they have different masses, but are chemically identical

stable



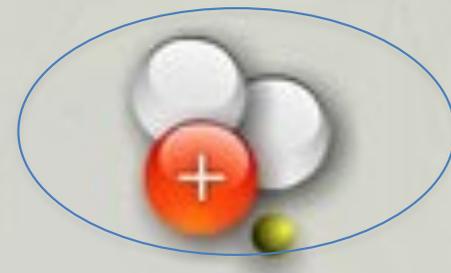
Hydrogen

stable



Deuterium

**unstable
(radioactive)**

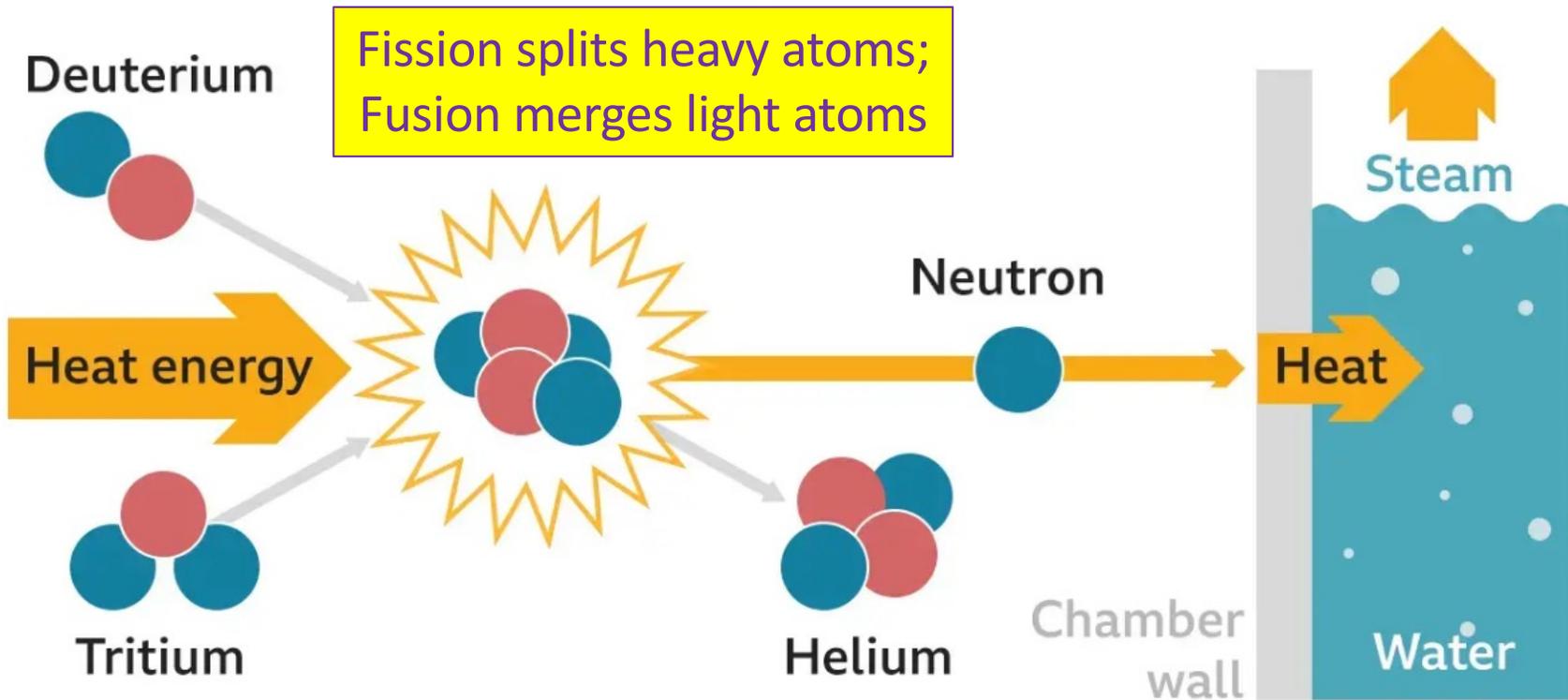


Tritium

an activation product

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

1	2	3	4
Hydrogen atoms are heated	Fusion reaction	Helium, neutron and energy released	Neutron energy heats water



Fusion works on the principle that energy can be released by forcing together atomic nuclei rather than by splitting them, as in the case of the fission reactions that drive existing nuclear power stations. Source: [Major breakthrough on nuclear fusion energy – BBC News](#)

$$E = mc^2$$

E = energy (in joules)

m = mass (in kilograms)

c = speed of light (in metres per second)

$$c^2 = (300,000,000) \times (300,000,000)$$

$$= 90,000,000,000,000,000$$

$$= 90 \text{ quadrillions} = 90 \text{ billion millions}$$

Mass that is lost during fission or fusion is converted into energy according to Einstein's famous equation - first articulated in 1905.

The mass lost in the Hiroshima explosion was the weight of a butterfly's wing.

Facts About Fusion

Temperature has to be over 100 million degrees

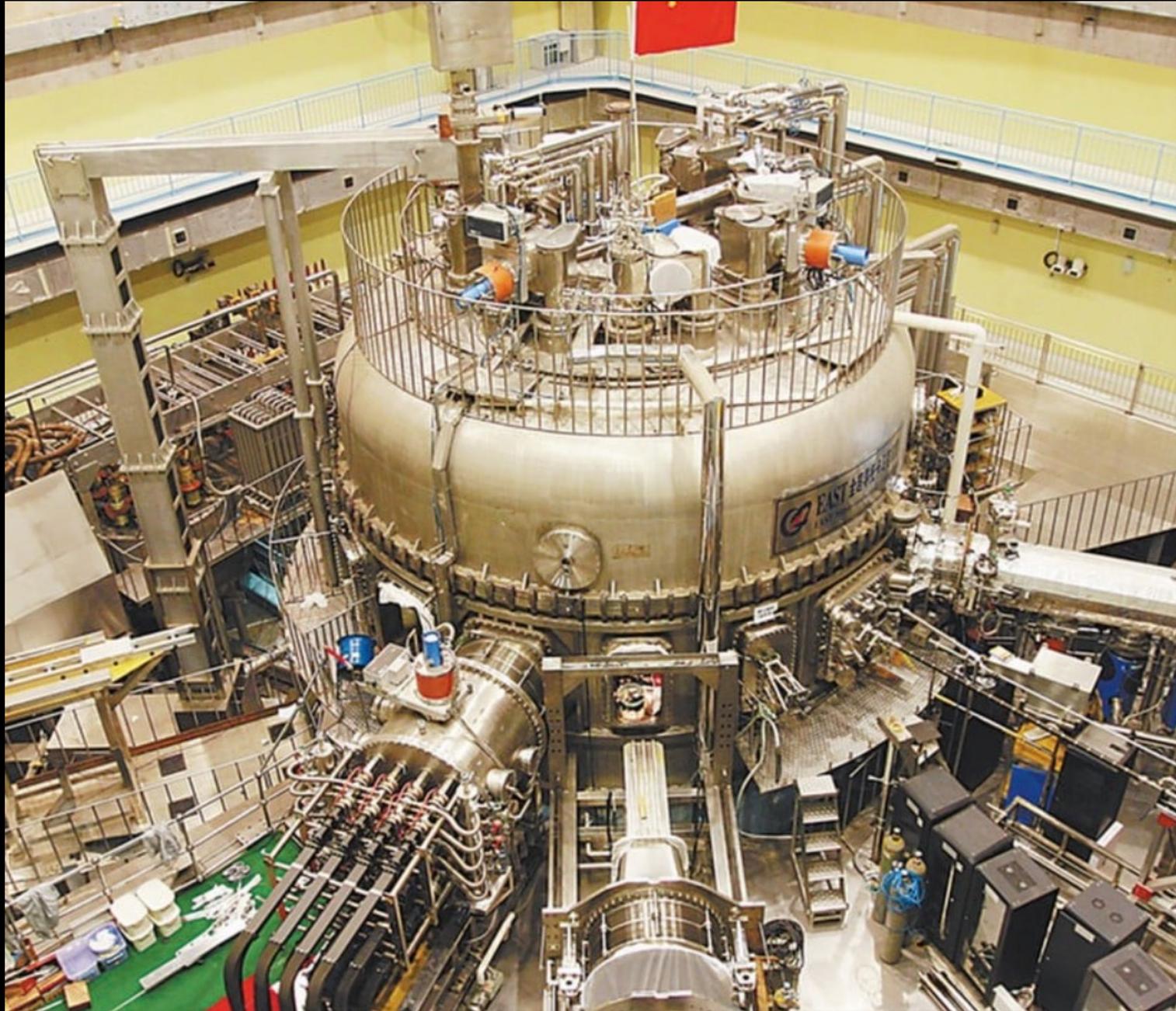
Containment has to be non-material (electromagnetic)

Neutrons are released – more energetic than fission neutrons

Activation and embrittlement are therefore serious limitations

Large amounts of tritium are released to the environment

No fission products; no actinides produced – or are they?



China's EAST Tokamak

Biggest Problem with Fusion

Maintaining the fusion reaction for any length of time.

So far, the record is about 22 minutes – a giant step forward.

WEST (W-Tungsten Environment in Steady-State Tokamak) [FRANCE]

Previous record (2024) was about 17 minutes and 46 seconds.

EAST (Experimental Advanced Superconducting Tokamak) [CHINA]

Before 2024, the record length for fusion was 101 seconds.

Commercial fusion energy will not be here for a long time yet.

Renewable energy potential is often drastically under-estimated.

Current electrical capacity in Michigan:
a bit more than 30,500 MW

Potential for off-shore wind in Michigan:
over 320,000 MW

That's more than **10 times** current capacity in Michigan
and it is about **one-quarter** of total US electrical capacity

Offshore Wind in Michigan - Great Potential & Many Challenges

https://www.mlive.com/green-blawg/2009/12/offshore_wind_in_michigan_-_po.html

The End

ccnr@web.ca