Small Modular Nuclear Reactors

~ The Canadian Context ~

A Slide Show

Montréal Québec.

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

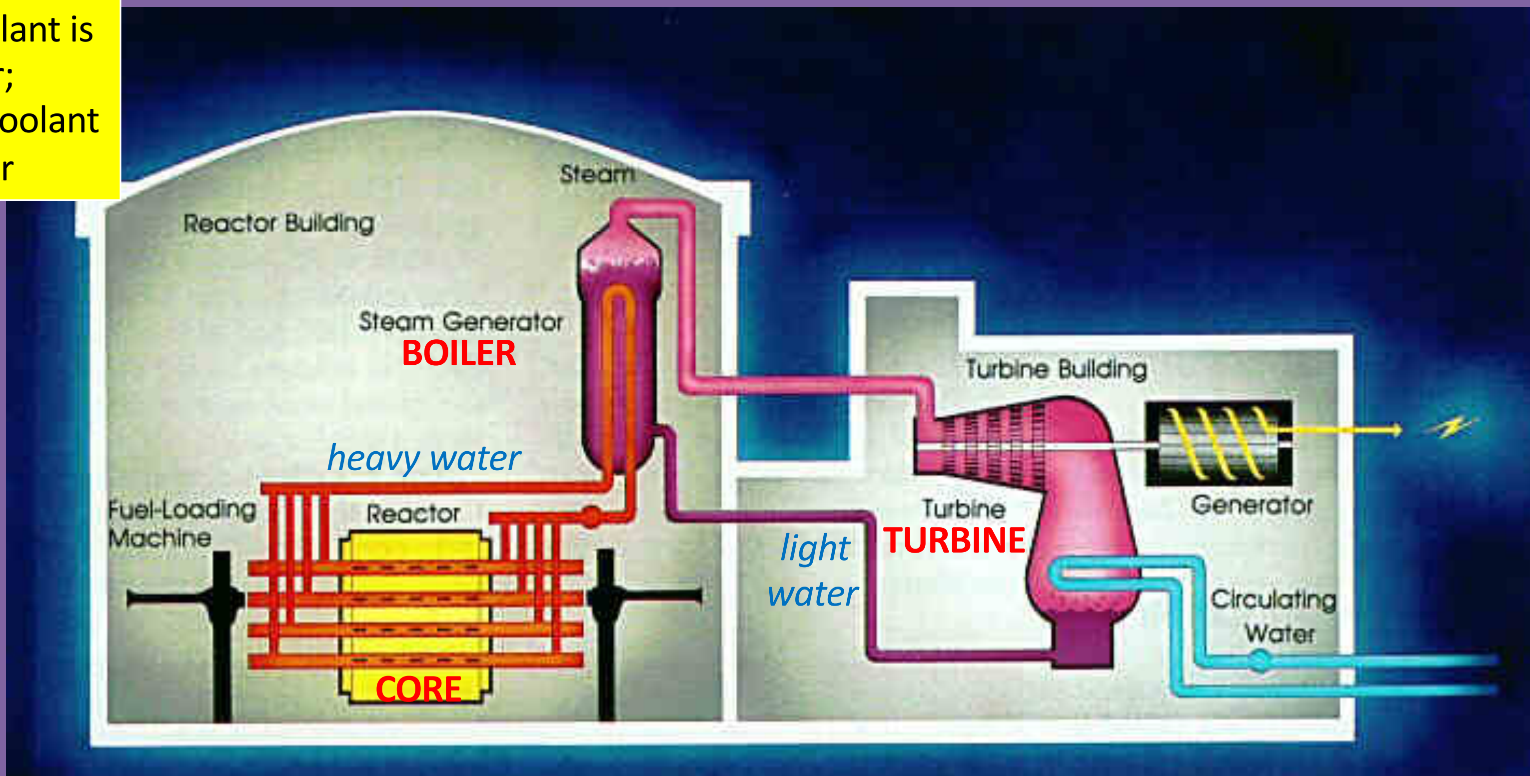
e-mail: ccnr@web.ca

www.ccnr.org

The Point Lepreau Reactor – a CANDU-6 model (about 600 MW electrical)
The fuel is natural (unenriched) uranium; the coolant and moderator are heavy water.

Inside a CANDU reactor

Primary coolant is heavy water; secondary coolant Is light water



Uranium atoms are split in the CORE to heat water.
Hot water is pumped to the BOILER (Steam Generator).
Steam turns the blades of a TURBINE to generate electricity.

Everything in the "primary cooling circuit" (on the left) becomes RADIOACTIVE.

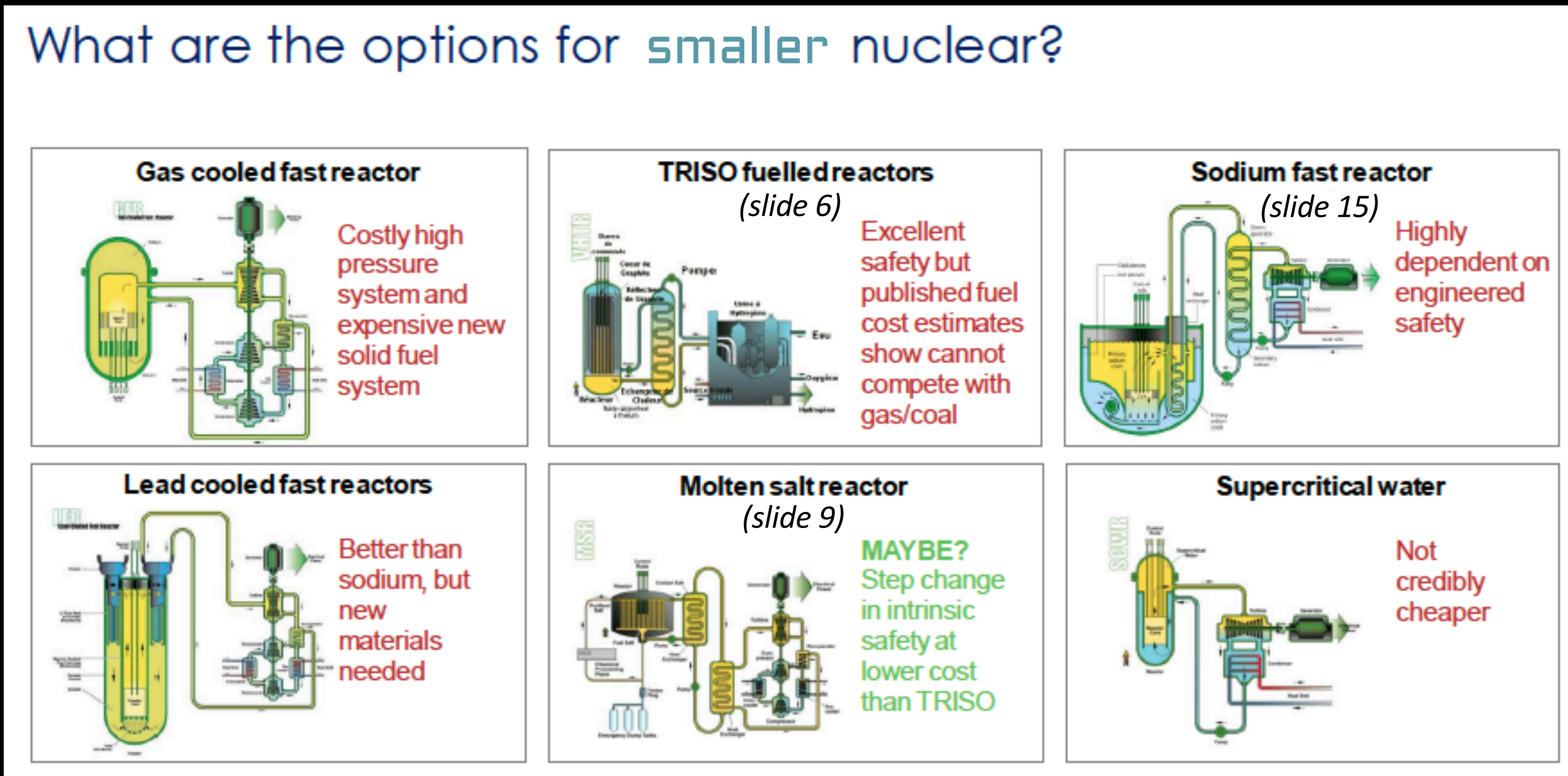
Small Modular Nuclear Reactors being "pre-evaluated" by Canadian Nuclear Safety Commission (CNSC)

VENDOR	SITE	SITE OWNER	BACKER(S)	REACTOR TYPE	DESIGN ACRO	MW	Fuel	Waste "Plan"
ARC Nuclear Canada Inc.	Point Lepreau	NB Power	NB government, NB Power	Sodium cooled fast reactor	ARC-100	100	13.1 % enriched uranium	"removed for recycling"
GE-Hitachi Nuclear Energy	Darlington	OPG	OPG	Boiling water reactor	BWRX-300e	300	3.4 to 4.95 % enriched uranium	'segregated' for "final disposal"
Moltex Energy	Point Lepreau	NB Power	NB government, NB Power	Molten Salt Reactor	SSR-W	300	Reactor grade plutonium	off site "disposal" of fuel waste
NuScale Power, LLC	-	-	Bruce Power, OPG	Pressurized water reactor	NuScale	60	< 4.95 % enriched uranium	wet then dry storage, long term in "national" plan
StarCore Nuclear	Chalk River / Pinawa	AECL	CNL	High-temperature gas cooled reactor	StarCore	10	15 % enriched uranium	off-site waste, entombment on site of reactor
Terrestrial Energy Inc.	Darlington / Chalk River	OPG / AECL	OPG	Molten Salt Reactor	IMSR	200	< 5 % enriched uranium	Liquid Fuel Waste
Ultra Safe Nuclear Corporation	Chalk River	OPG	Global First Power (Proponent), CNL	High-temperature gas cooled reactor	MMR-5 and 10	5-10	19.75 % enriched uranium	Spent fuel in "national" plan
X Energy, LLC	Darlington	OPG	OPG	High-temperature gas cooled reactor	Xe-100	80	15.5 % enriched uranium	Wet then dry storage, long term in "national" plan

Some SMNRs are "fast" reactors, meaning the neutrons are not slowed down by a "moderator". Without a moderator, the fissile material in the nuclear fuel must be much more concentrated.

Source: www.stop-smrs.ca

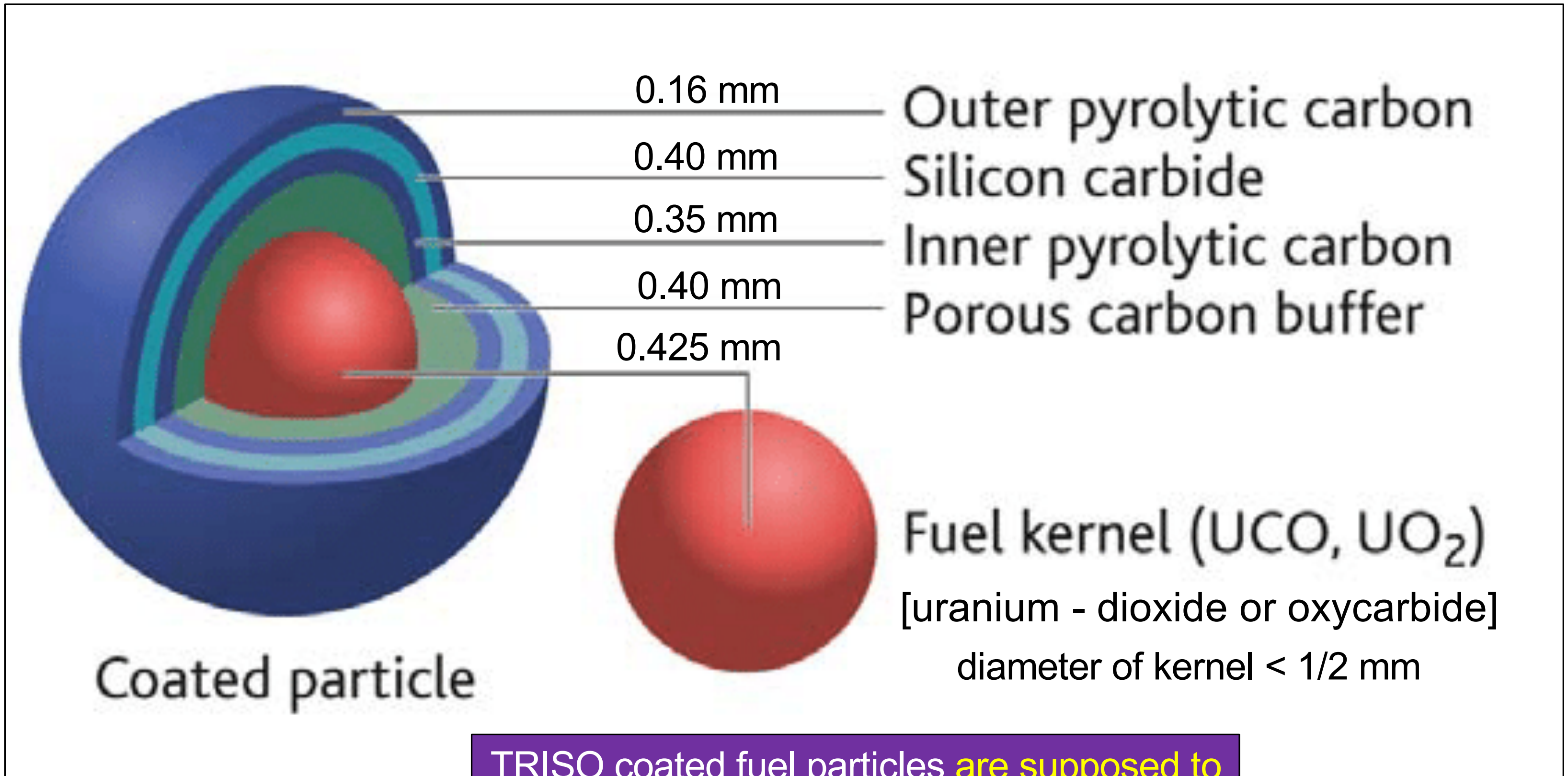
NOTE: This is an industry graphic from Moltex. TRISO fuel (for “slow” reactors) is described in the next slide



Most Small Modular Nuclear Reactors plan to use unorthodox fuels and unusual coolants.
Fuel : Enriched Uranium (HALEU) or plutonium. Coolant: molten salt, liquid metal, or gas.

WHAT IS TRISO FUEL?

Intended for any high temperature gas-cooled reactor that is "moderated" (i.e. uses "slow" neutrons)



TRISO coated fuel particles are supposed to contain all fission products including gases

URANIUM ENRICHMENT and PLUTONIUM

In natural uranium, only 7 atoms out of 1000 are “fissile” (yielding energy). The other 993 atoms are non-fissile, but some “become” plutonium atoms. The earliest reactors, and all CANDU reactors, use natural uranium as fuel.

Plutonium is fissile and usable as a nuclear fuel, but it can only be extracted from used uranium fuel that has been MELTED or DISSOLVED into a LIQUID form.

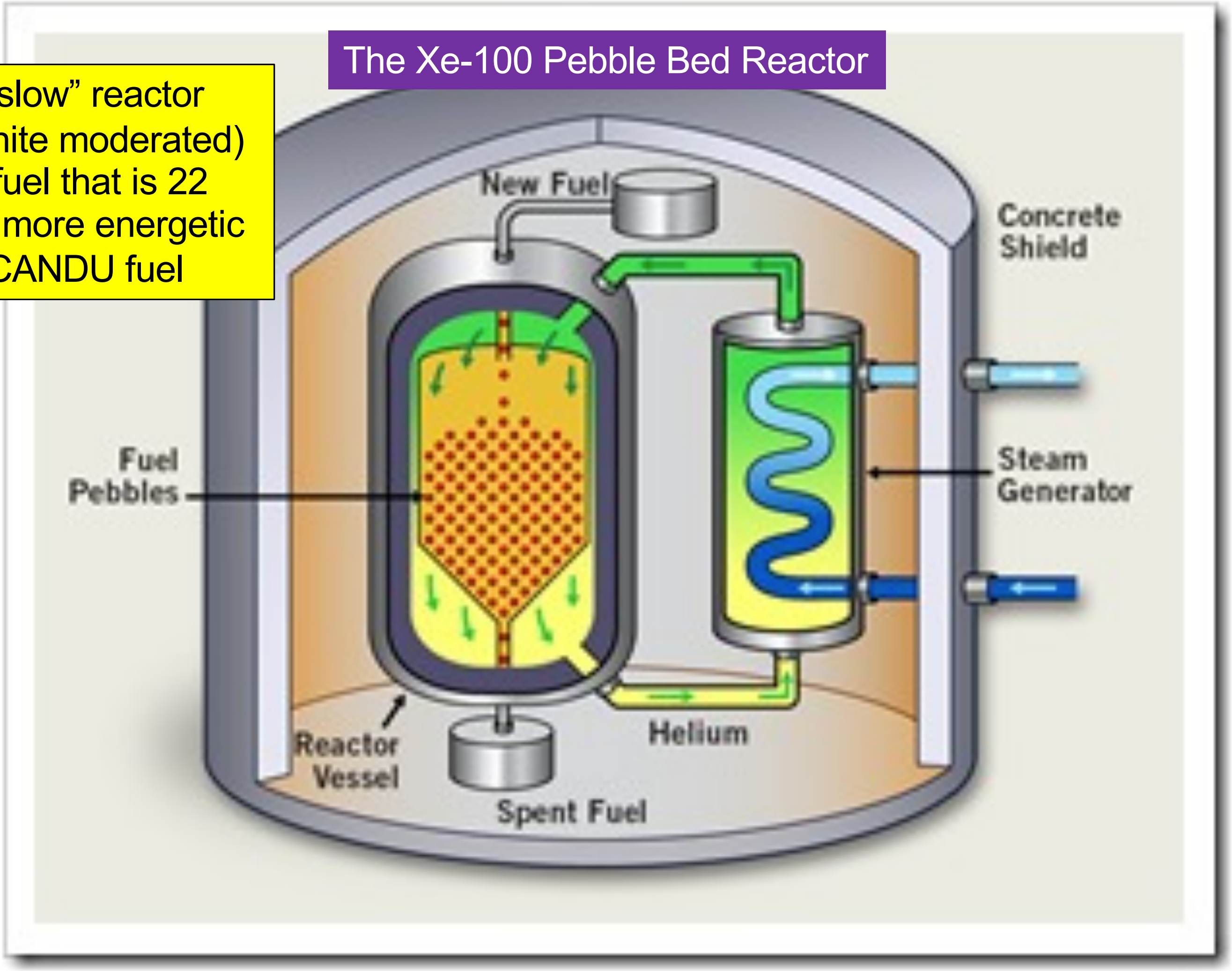
Because all reactor-produced plutonium is usable in nuclear weapons, the “reprocessing” of used uranium fuel to extract plutonium is very controversial.

Most power reactors use Low Enriched Uranium (LEU) in which 30 to 50 atoms out of 1000 are fissile: NON-CANDU reactors use this kind of fuel.

Many proposed SMNRs are planning to use fuel that is High Assay Low Enriched Uranium (HALEU) in which 50 to 200 atoms out of 1000 are fissile.

Highly Enriched Uranium (HEU, with 200-1000 fissile atoms per 1000, is disallowed for commercial use and is also being phased our for research reactors – because HEU is a powerful nuclear explosive material.

With higher enrichment, a smaller mass of uranium fuel is needed per unit of energy output. – and, for a given energy output, the used uranium fuel is more radioactive per kilogram.



This "slow" reactor (graphite moderated) uses fuel that is 22 times more energetic than CANDU fuel

Xe-100 Pebble Bed Reactor – helium-cooled – graphite moderated

NUCLEAR FUEL

Fuel is 15.5 percent enriched uranium

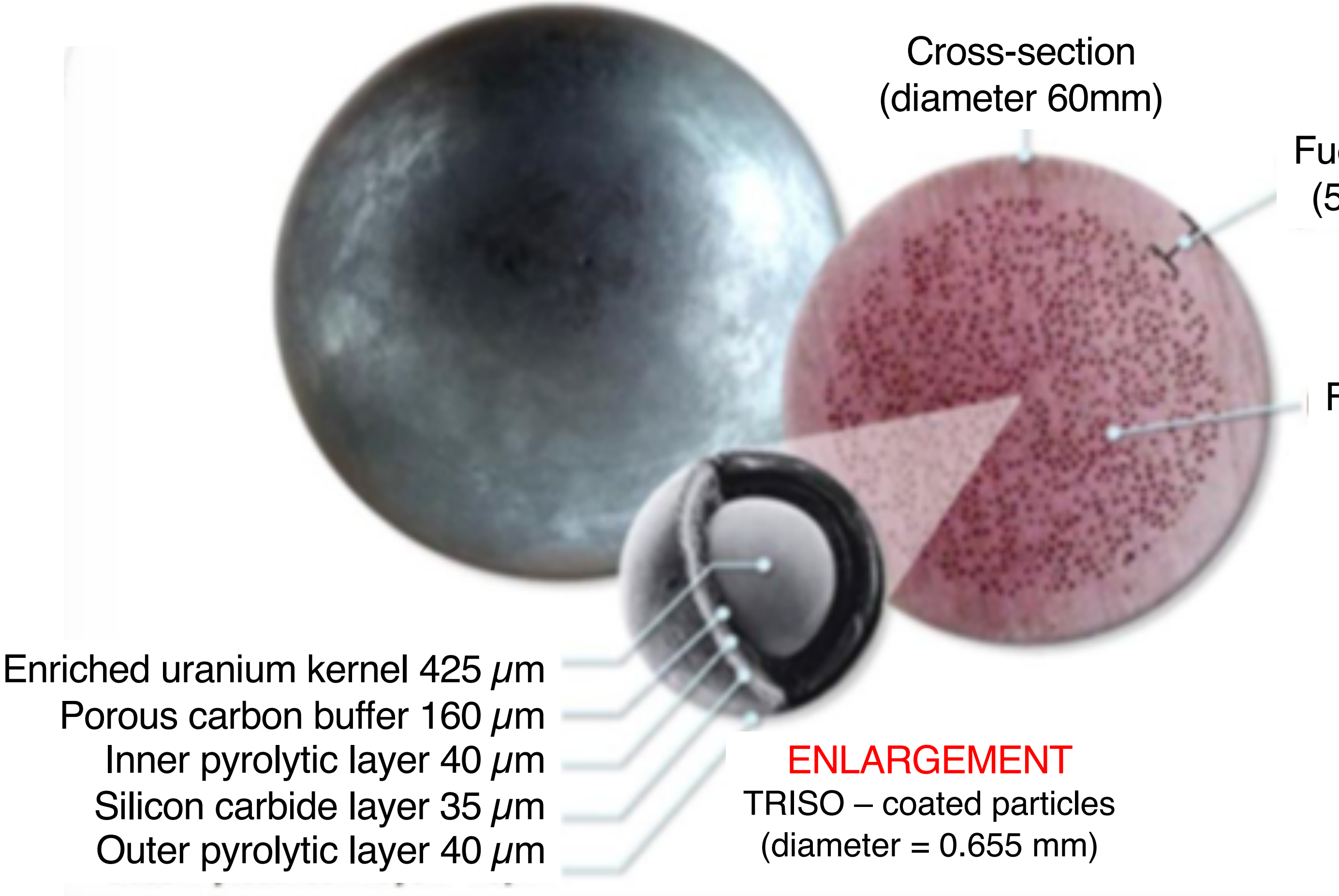
Each graphite "pebble" the size of a billiard ball is filled with thousands of tiny TRISO granules

Pebbles enter from above and exit below, each pellet is re-used up to three times.

PRIMARY COOLANT

High temperature gas reaches temperature of close to 1000 deg C. – greater efficiency of electricity generation

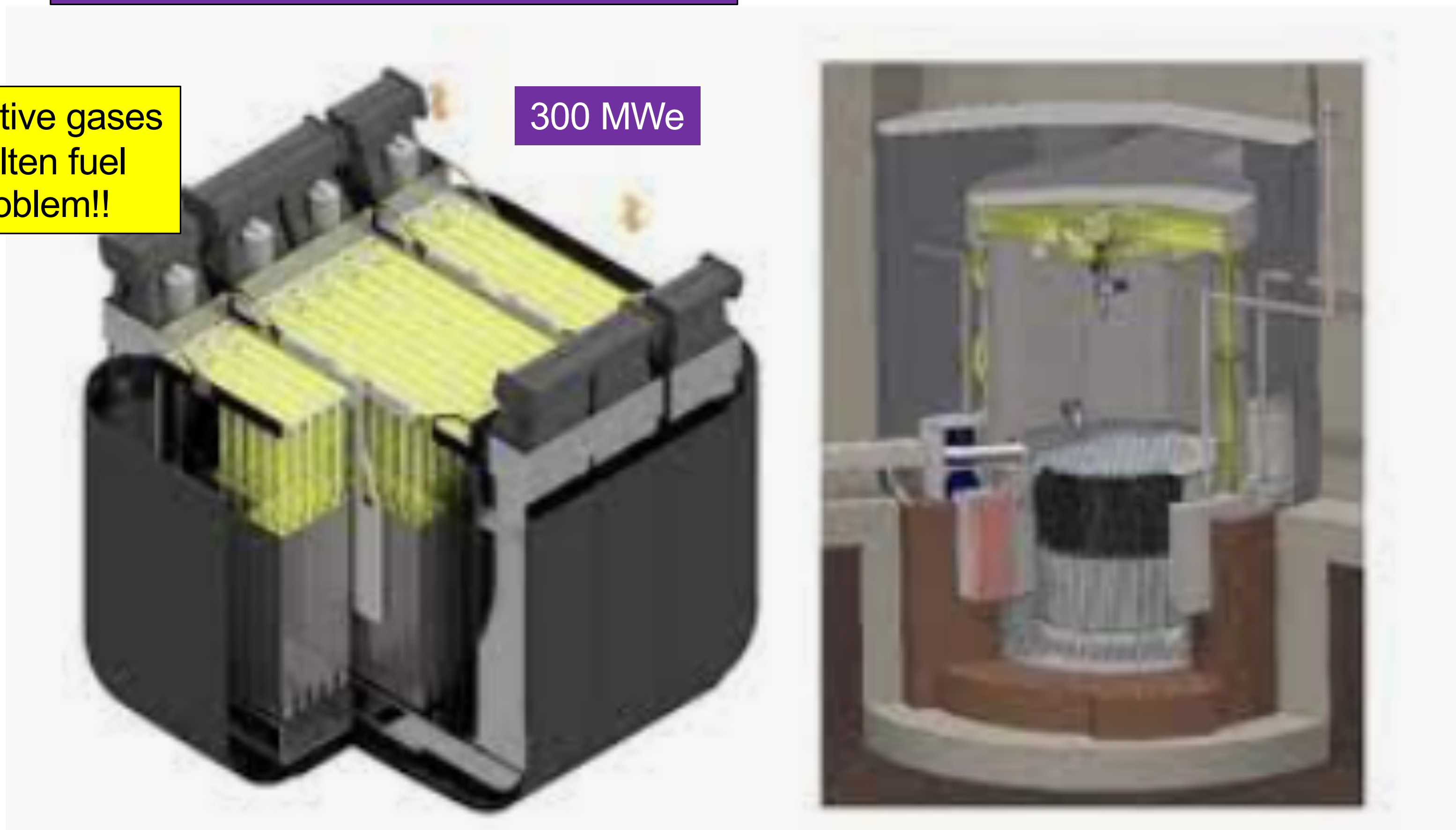
FUEL for The Xe-100 Pebble Bed Reactor



A “fuel pebble” is the size of a billiard ball (seen at your left).

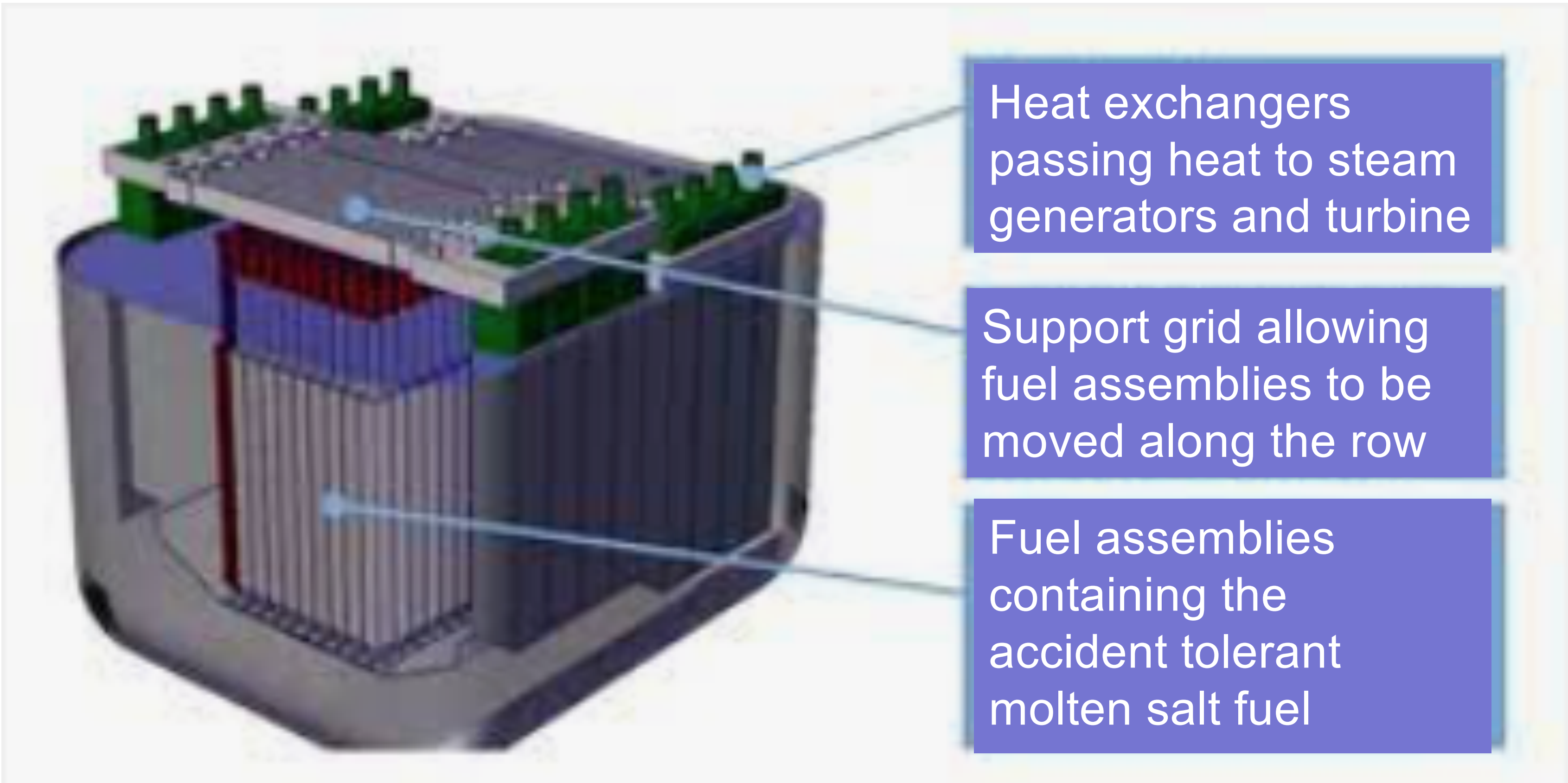
It contains thousands of TRISO particles (see slide 6)

The Moltex Stable Salt Reactor – Wasteburner (SSR-W) is a FAST REACTOR (no moderator)



Each SOLID fuel rod is filled with a LIQUID solution of plutonium and transuranics in molten salt.
The PRIMARY COOLANT is molten salt that carries heat to the SECONDARY COOLANT (water).

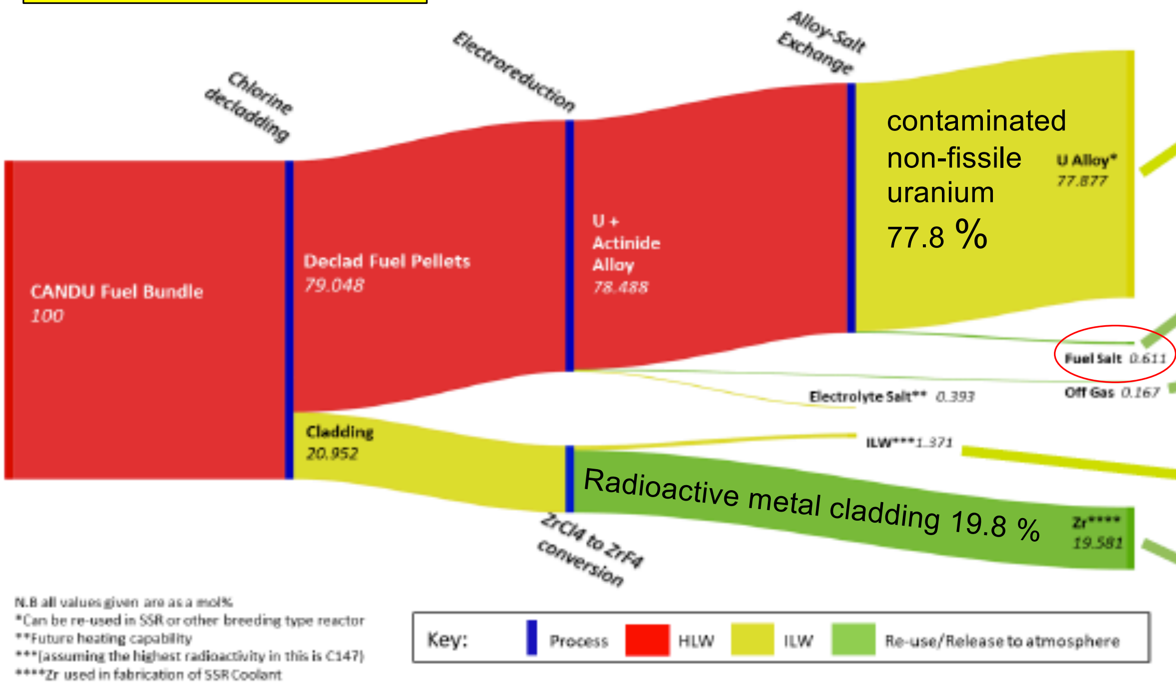
The Moltex Stable Salt Reactor – Wasteburner (SSR-W)



Moltex WATSS = Waste to Stable Salt (pyroprocessing unit) to extract plutonium mix from used CANDU fuel

PYROPROCESSING

To provide fuel for the Moltex SSR-W reactor



Uranium stored for future use or disposed as Intermediate Level Waste

All long lived higher actinide waste reduced down to this stream which is reused as fuel 0.61 % ONLY!!

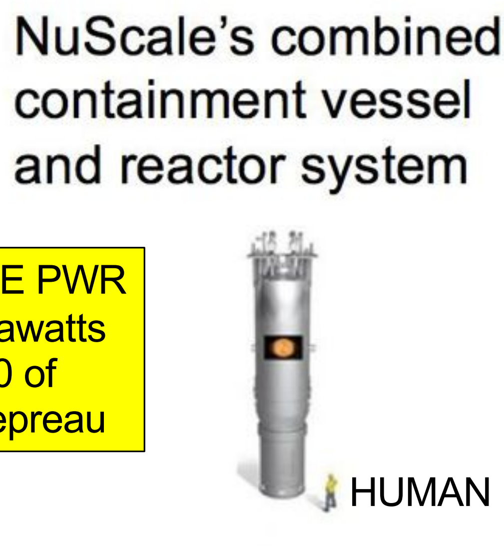
To atmosphere after decay & filtering

Potential energy source but contains Cs & I (HLW for 200-300 years)

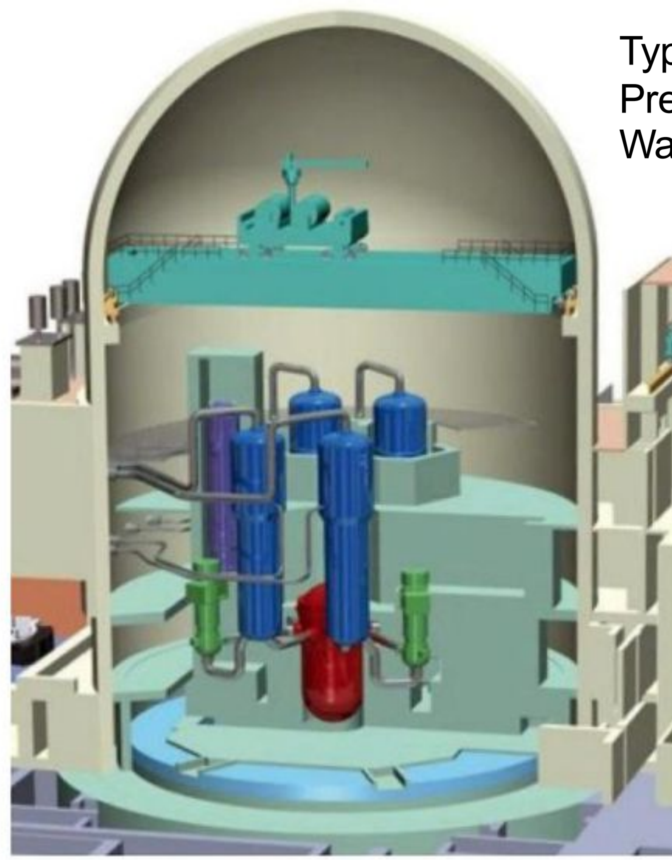
Zirconium from the cladding is reused in the coolant

SSR Fuel = plutonium + other transuranics = 0.61 percent of the total mass of used CANDU fuel. This small fraction is used to fuel the SSR-W reactor. The other 99.39 percent is leftover waste.

NuScale Pressurized Water Reactor



NUSCALE PWR
60 megawatts
= 1/10 of
Point Lepreau



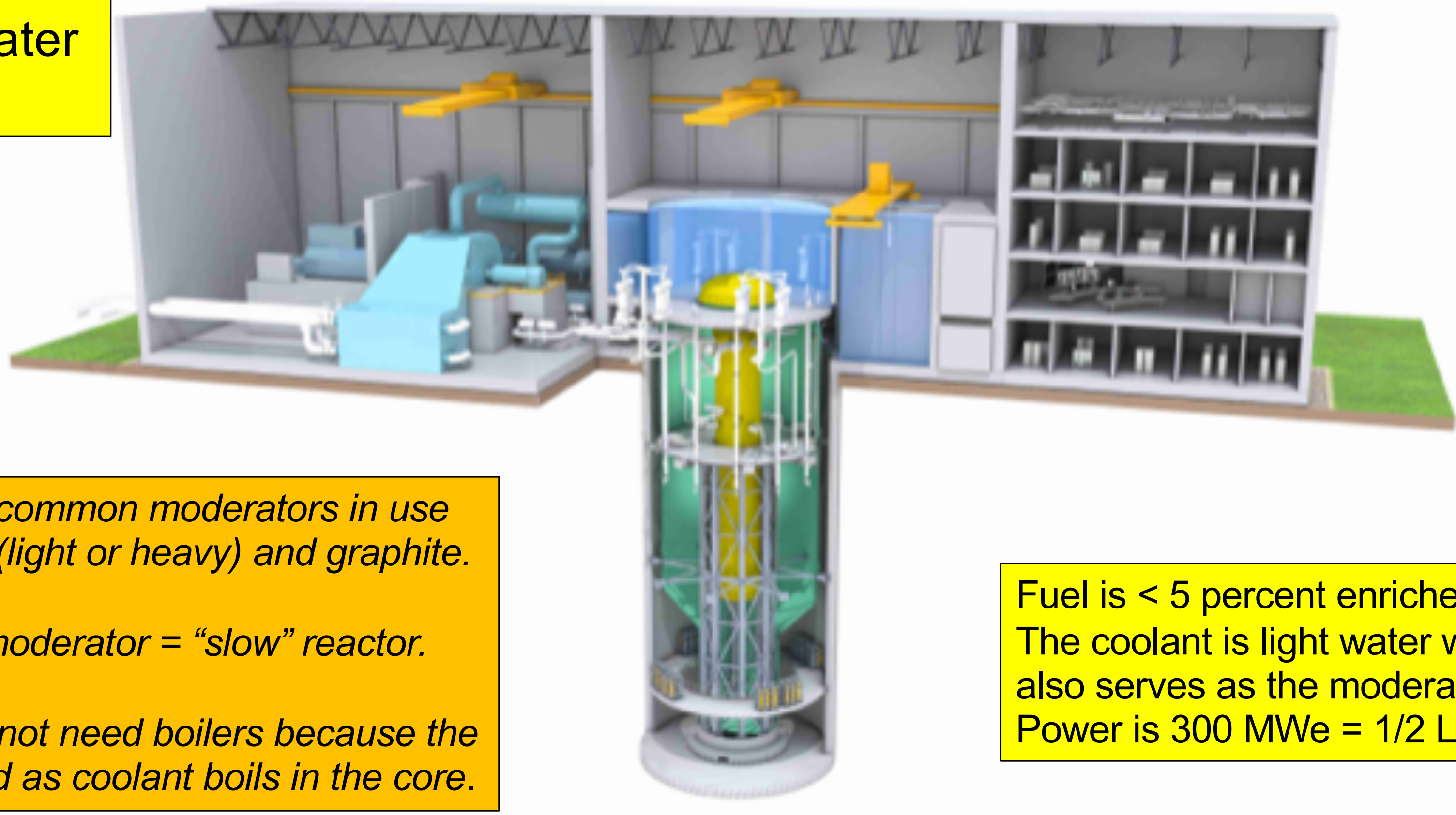
Typical PWR – Pressurized Water Reactor

*Source: NRC

NuScale – pressurized light water reactor, scaled down conventional PWR

BWRX-300 Boiling Water Reactor

BWRS-300
Boiling Water
Reactor



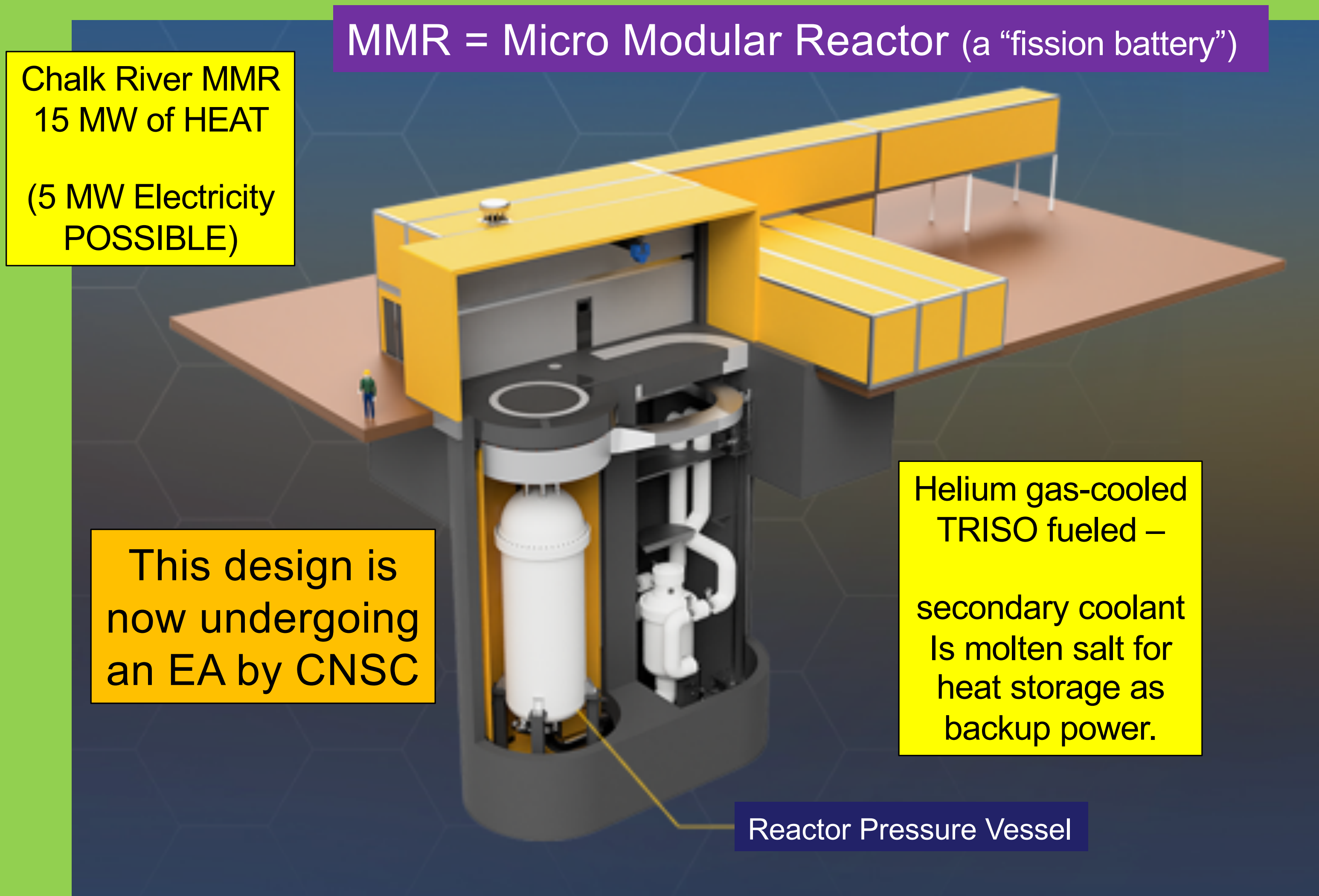
The most common moderators in use are water (light or heavy) and graphite.

Use of a moderator = "slow" reactor.

BWRs do not need boilers because the water used as coolant boils in the core.

Fuel is < 5 percent enriched.
The coolant is light water which also serves as the moderator.
Power is 300 MWe = 1/2 Lepreau

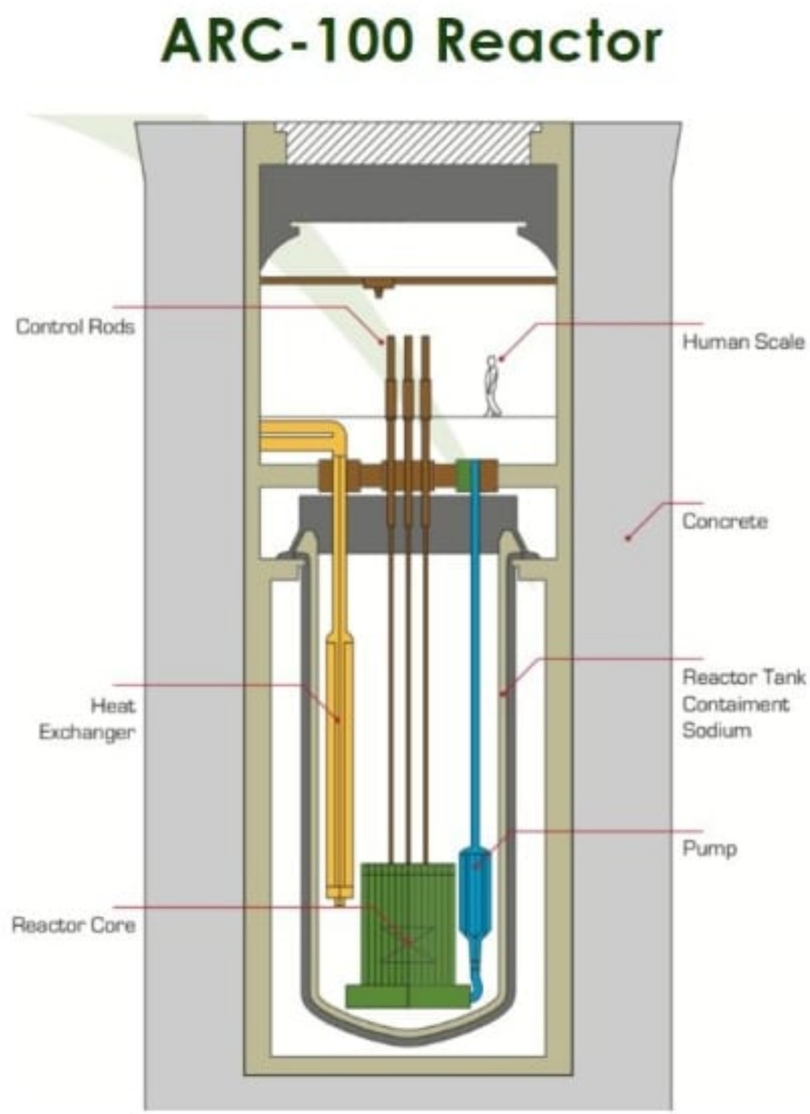
BWRX-300 = scaled down boiling water reactor – GE- Hitachi



Ultrasafe MMR = Micro Modular Reactor – 15 MWth – Helium-cooled – Molten Salt storage

ARC-100
Liquid Metal Cooled
Fast Breeder Reactor

Liquid sodium reacts
violently with air and
on contact with water.



Enriched fuel
(10.1, 12.1, 17.2 %)
Is in METALLIC form
(more compact)

Larger reactors of this type were tried and abandoned in USA, UK, France, Germany

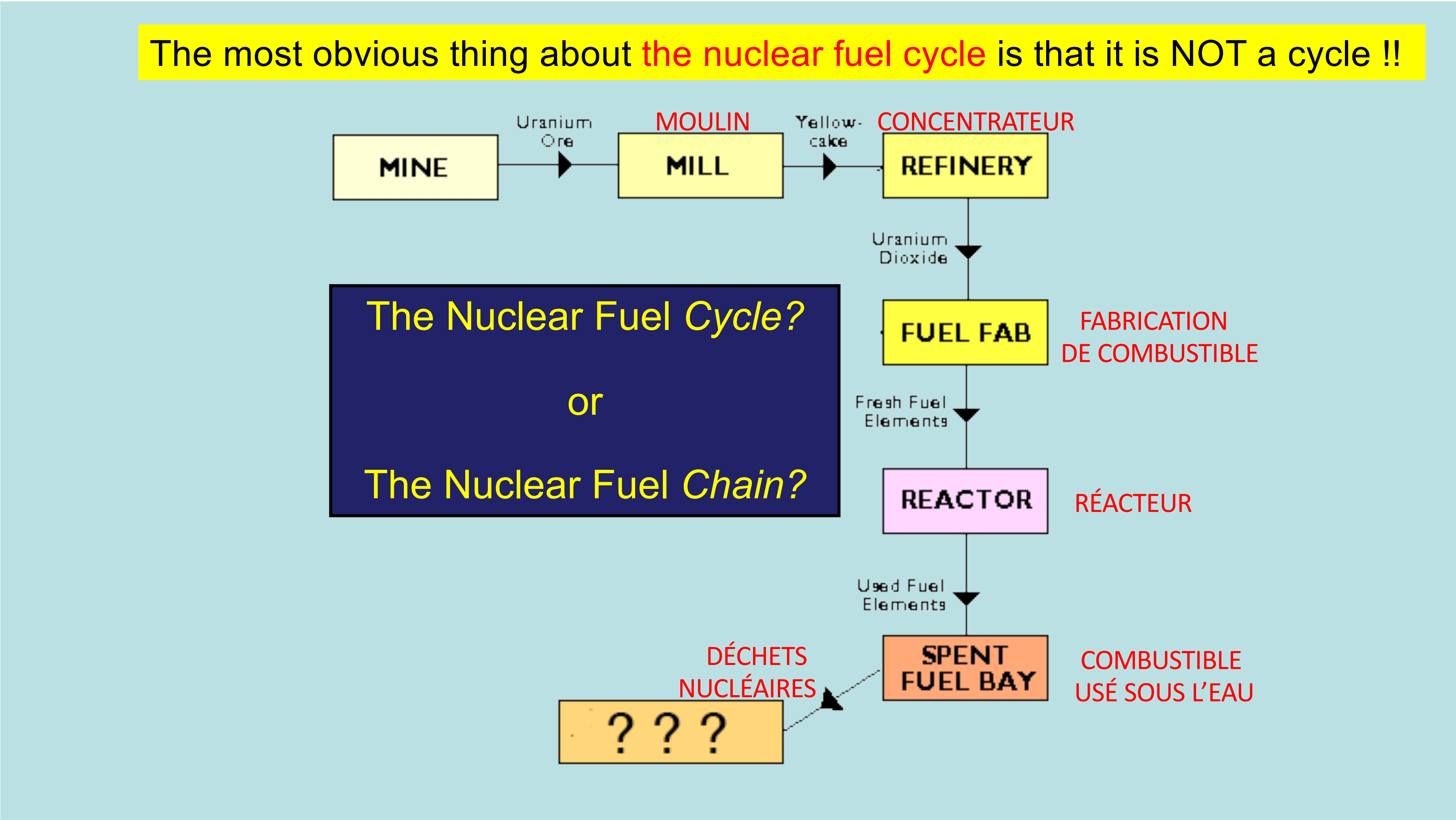
EBR-II – Precursor of the ARC-100 reactor at 1/5 the power

EBR-II
Fast reactor 1964-1994
Liquid Metal Cooled
Experimental
Breeder Reactor

Pyroprocessing was developed to cope with the used EBR-II fuel

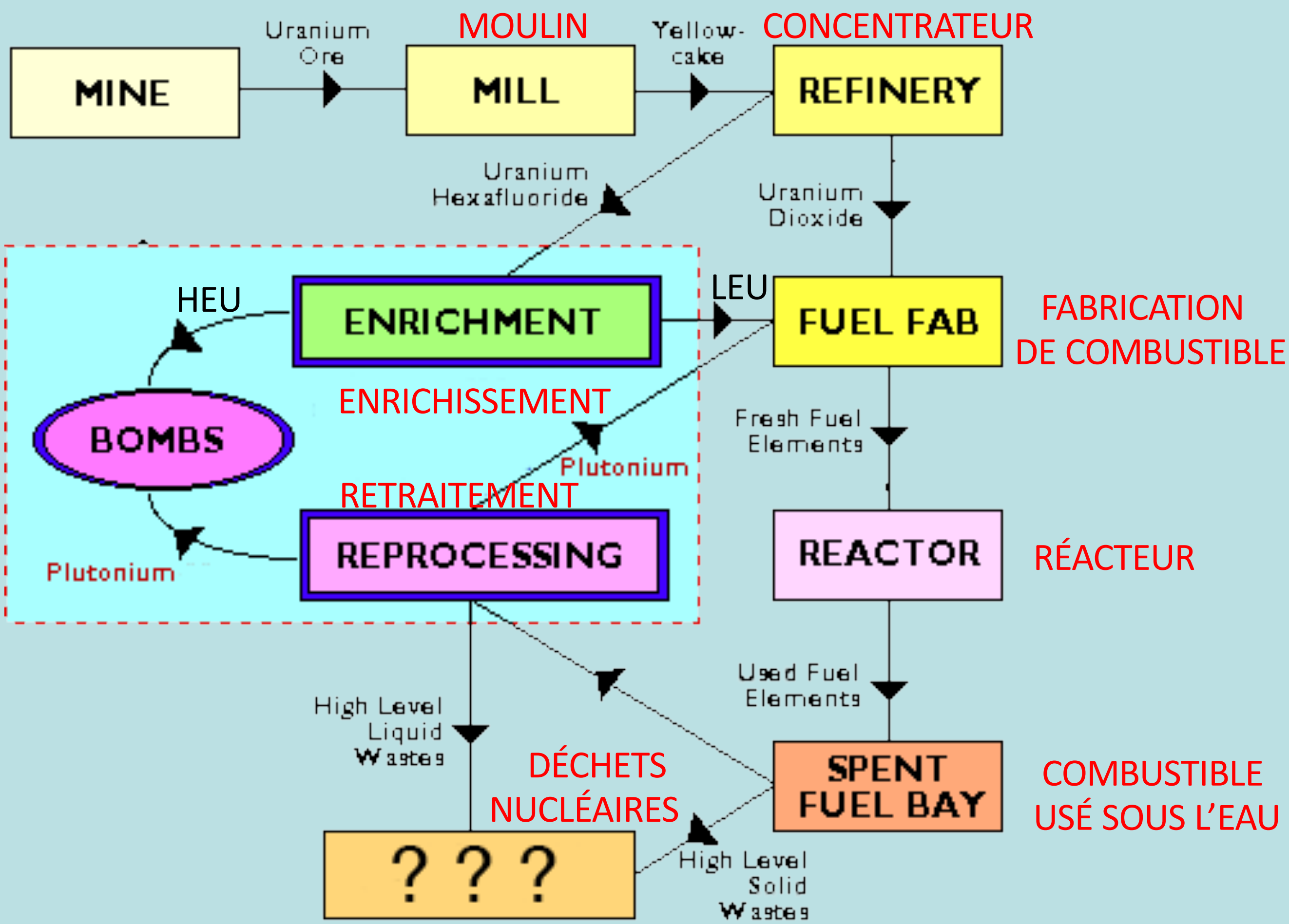
So far, not successfully!!

ARC-100 (100 megawatts) is supposedly modelled on EBR-II (20 megawatts)
EBR-II fuel was 67 % enriched; ARC-100 fuel is 10.1, 12.1, 17.2 % enriched.
A breeder reactor requires continuous reprocessing of the used nuclear fuel.

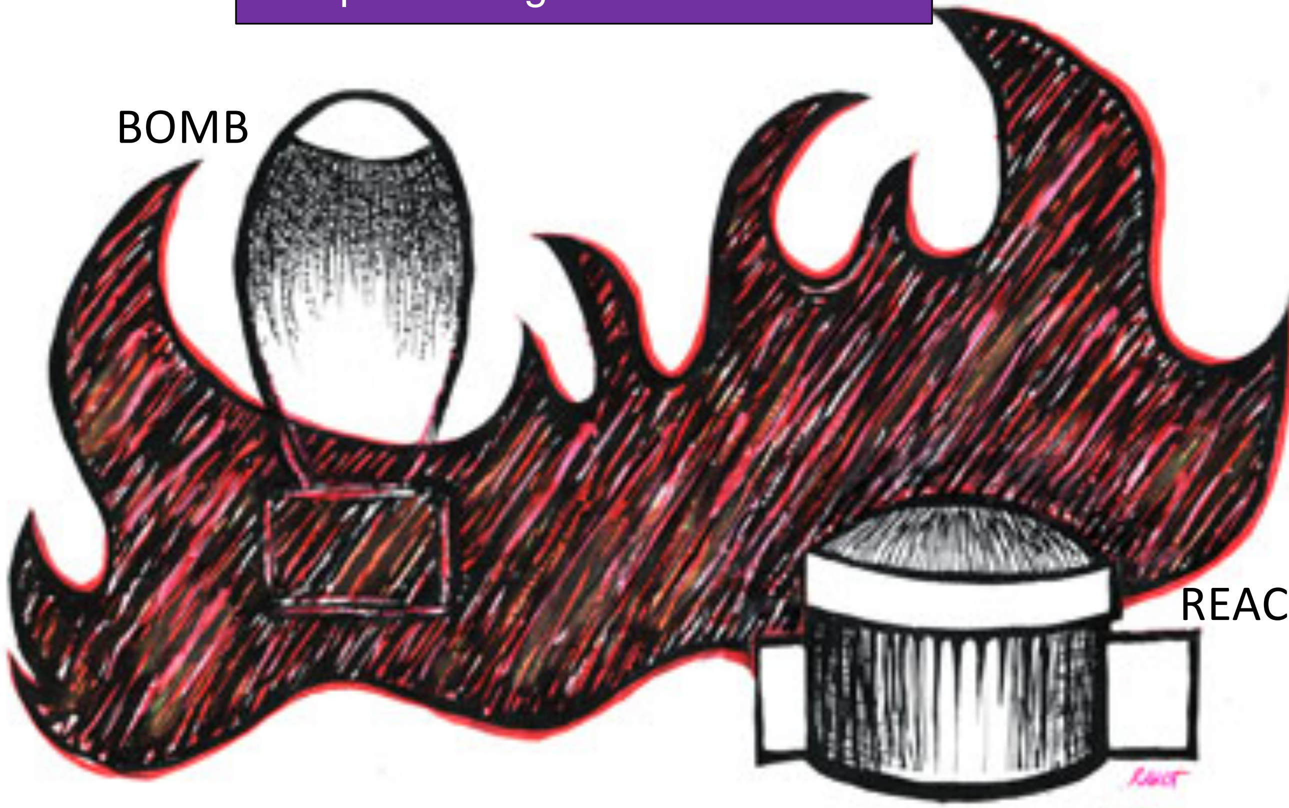


The most obvious thing about the nuclear fuel cycle is that it is NOT a cycle !!
MINE
Uranium Ore
MOULIN
MILL
Yellow-cake
CONCENTRATEUR
REFINERY
Uranium Dioxide
FUEL FAB
FABRICATION DE COMBUSTIBLE
Fresh Fuel Elements
REACTOR
RÉACTEUR
Used Fuel Elements
SPENT FUEL BAY
COMBUSTIBLE USÉ SOUS L'EAU
DÉCHETS NUCLÉAIRES
? ? ?
The Nuclear Fuel Cycle?
or
The Nuclear Fuel Chain?

. . . unless we decide to "recycle" the plutonium, opening Pandora's box!!



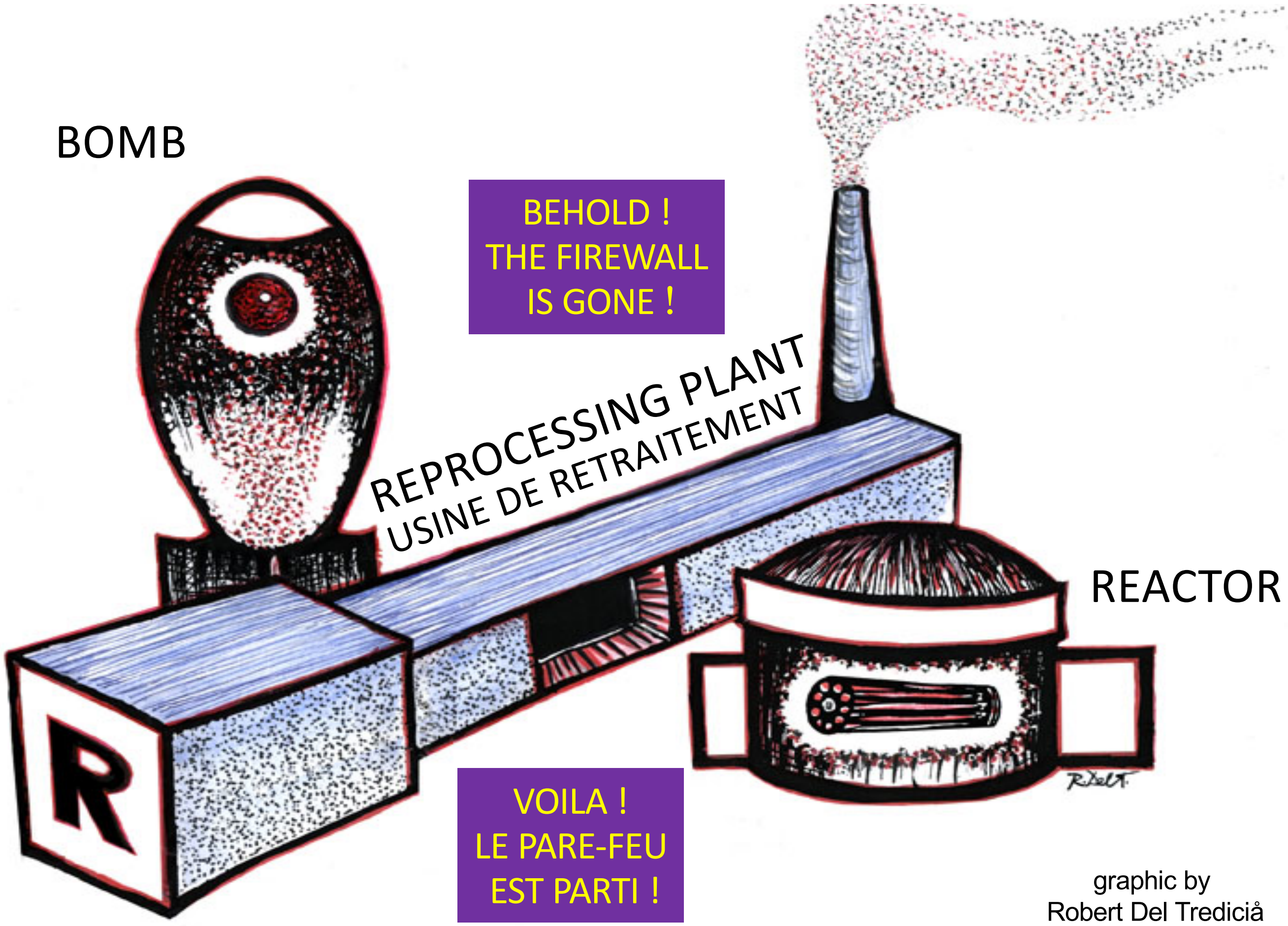
Reprocessing / Retraitement



graphic by
Robert Del Tredicià

There is a radioactive firewall between used reactor fuel and bombs

Il existe un pare-feu radioactif entre le combustible usé des réacteurs et les bombes



R = Recycling = Reprocessing = “Renaissance”

A reprocessing plant removes the firewall and makes plutonium more accessible

Une usine de retraitement supprime le pare-feu et rend le plutonium plus accessible

The End

ccnr@web.ca