Nuclear Fuel Cycle II

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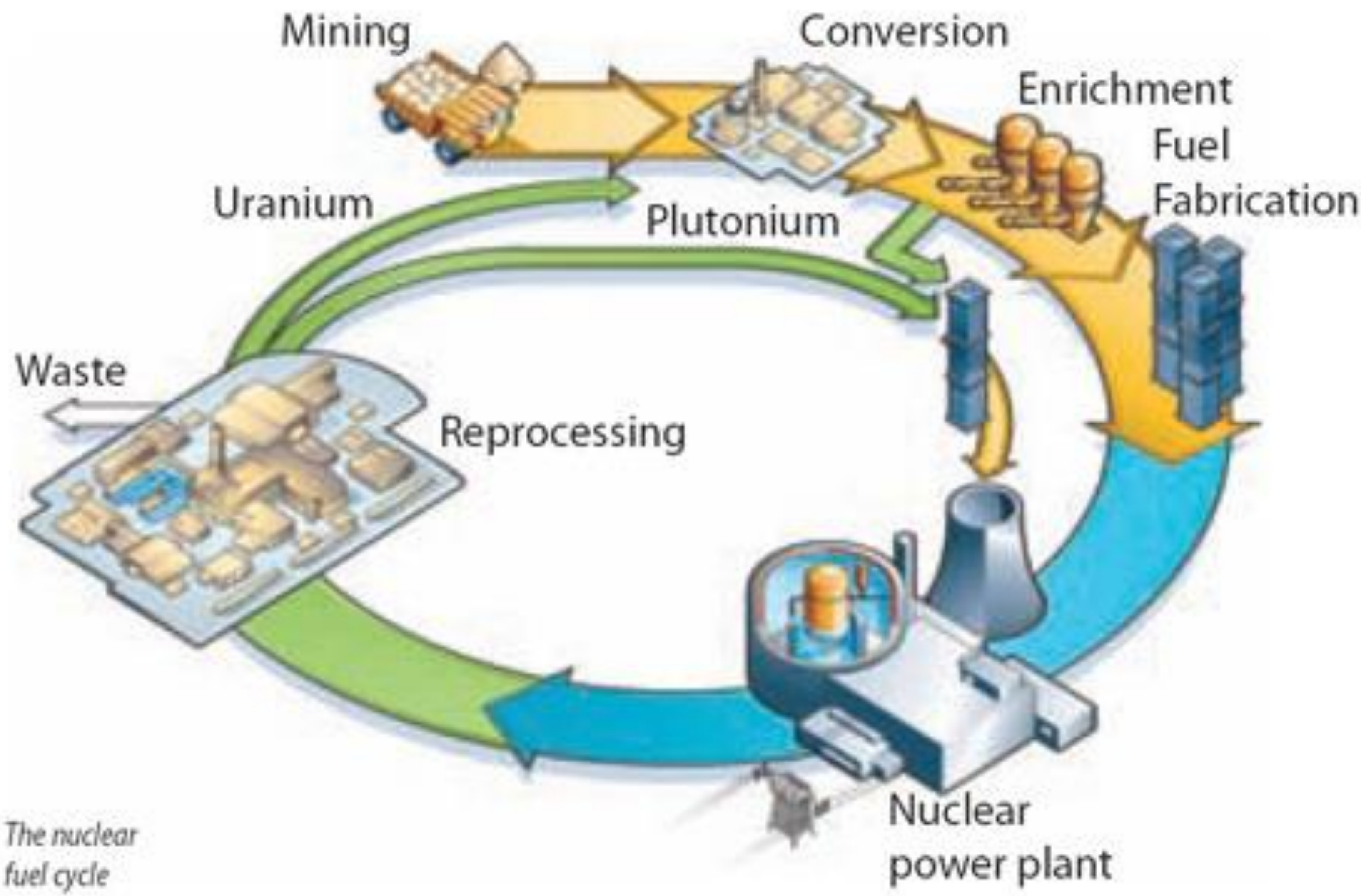
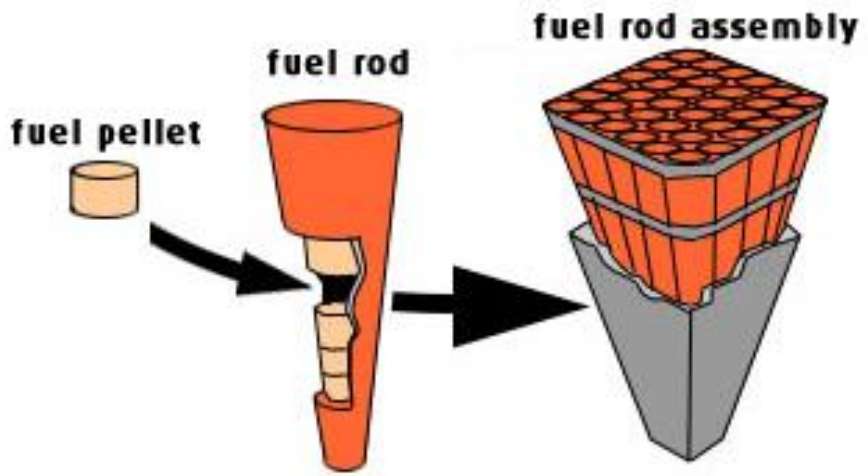
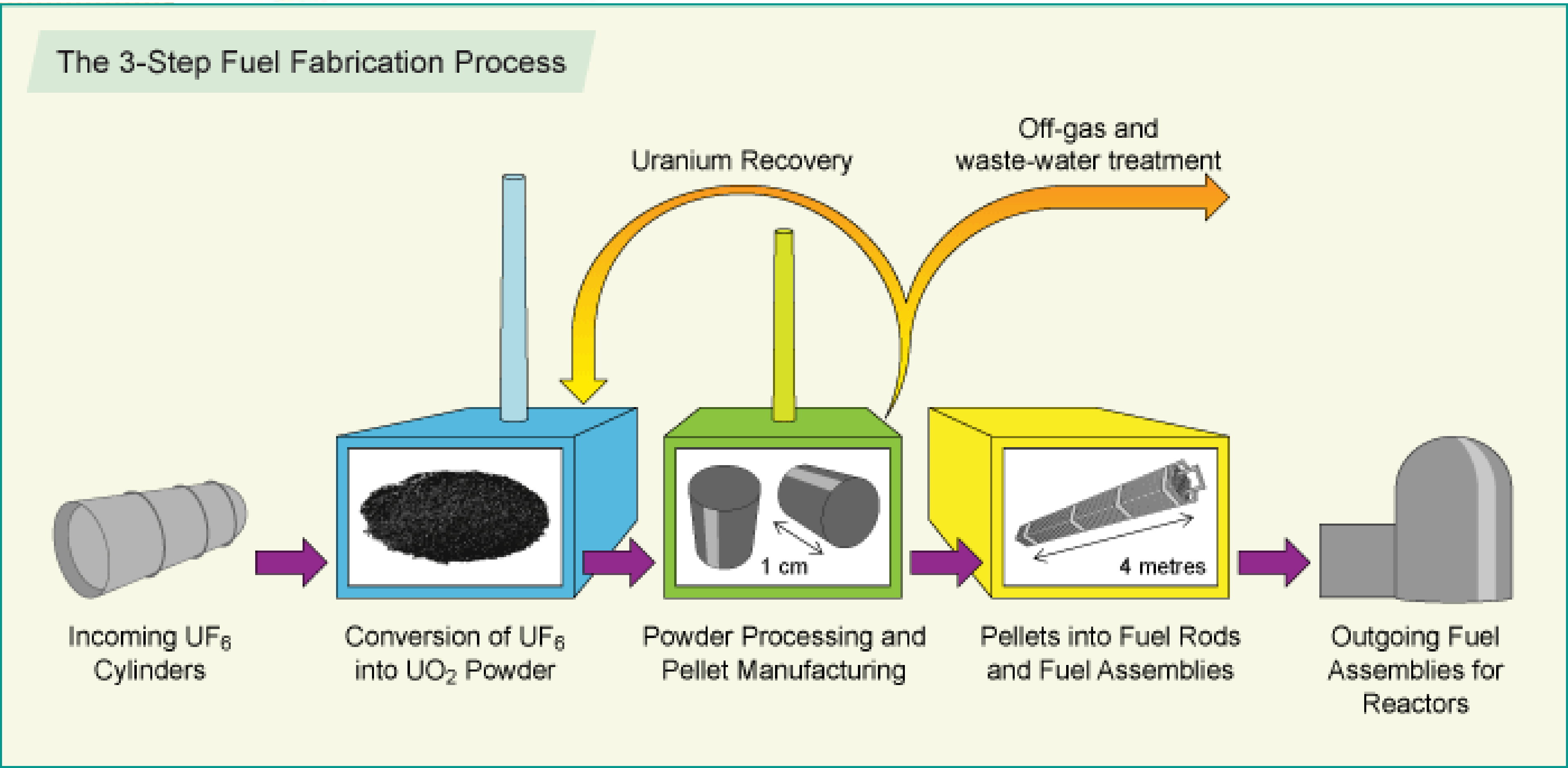
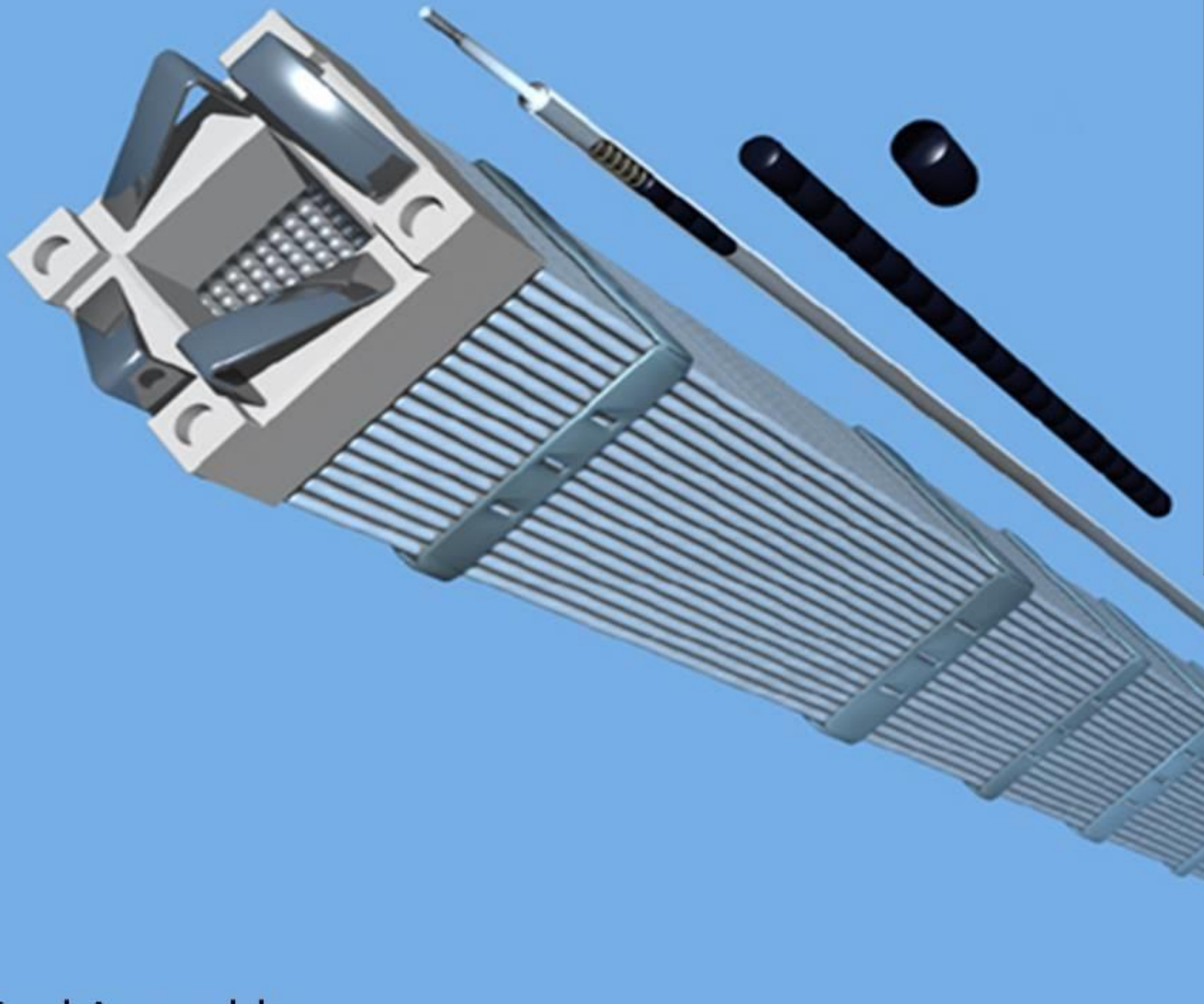
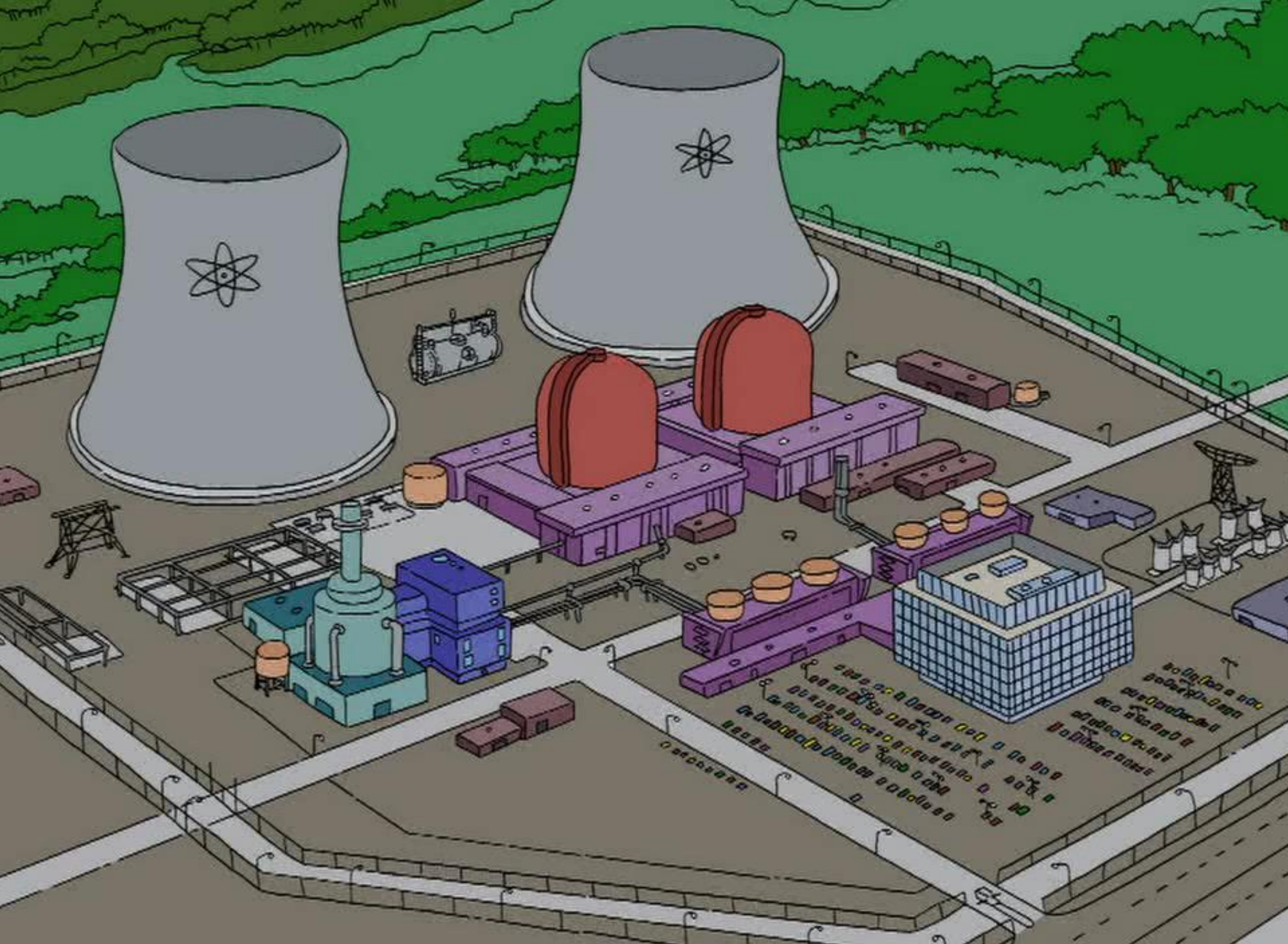
Nuclear Fuel Cycle




fuel rod assembly
fuel rod
fuel pellet


The 3-Step Fuel Fabrication Process
Uranium Recovery
Off-gas and
waste-water treatment
1 cm
4 metres
Incoming UF_6 Cylinders
Conversion of UF_6 into UO_2 Powder
Powder Processing and Pellet Manufacturing
Pellets into Fuel Rods and Fuel Assemblies
Outgoing Fuel Assemblies for Reactors


Fuel Assembly



When and where took the first chain reactions in nuclear reactor place?

When and where was the first nuclear reactor connected to the electricity grid?

When and where took the first chain reactions in nuclear reactor place?

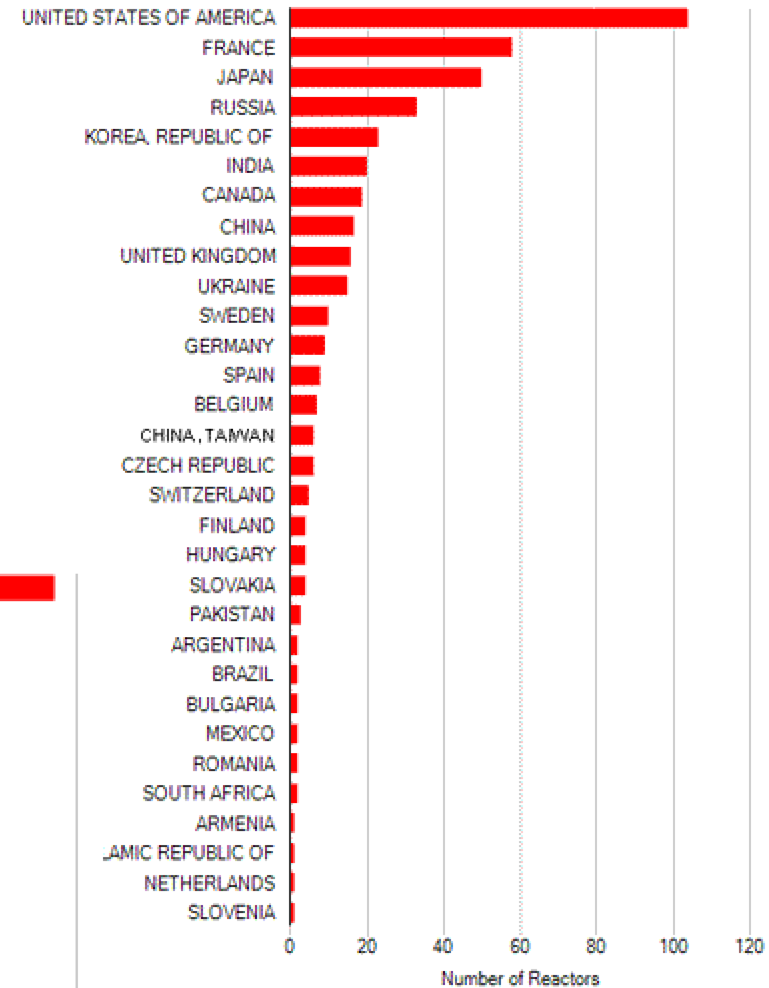
December 20, 1951, at the Experimental Breeder Reactor EBR-I in Arco, Idaho, USA

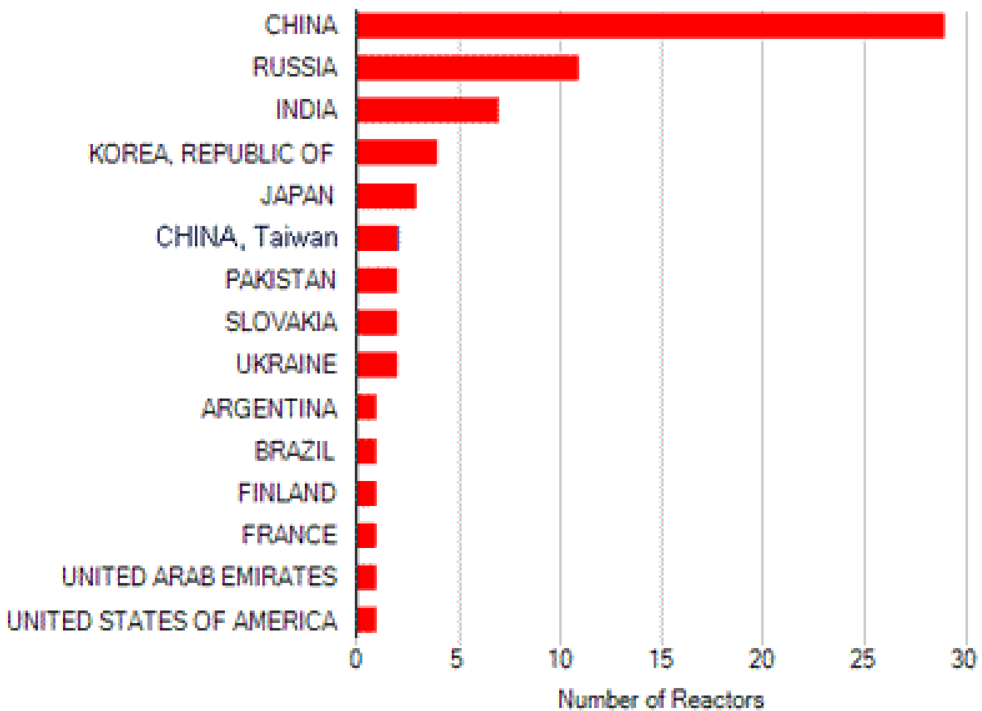
When and where was the first nuclear reactor connected to the electricity grid?

June 26, 1954, at Obninsk, Russia, the nuclear power plant APS-1 with a net electrical output of 5 MW

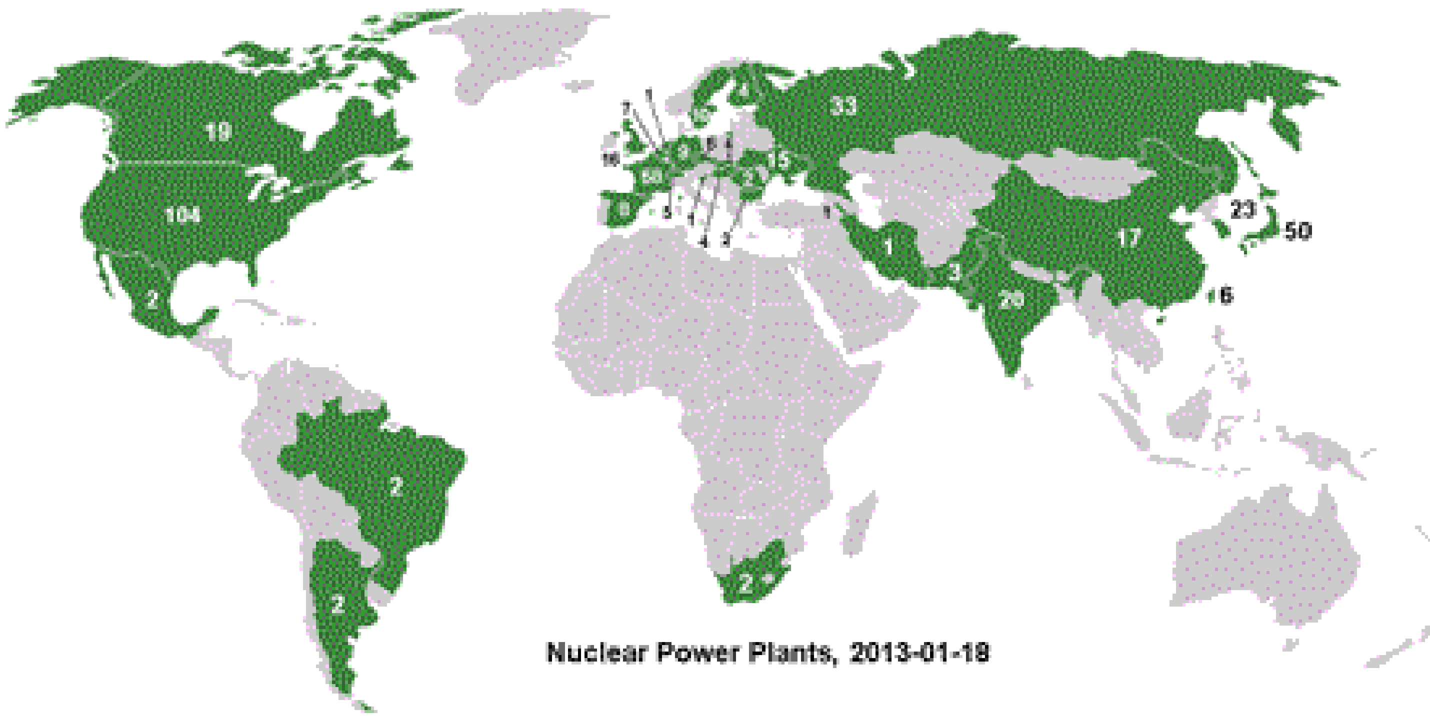
World reactor fleet 2017

- 413 operating reactors
- 31 countries
- 50 under construction
  - 16 in China, 5 in Russia, 7 in India
  - 4 in S. Korea, 4 in UAE



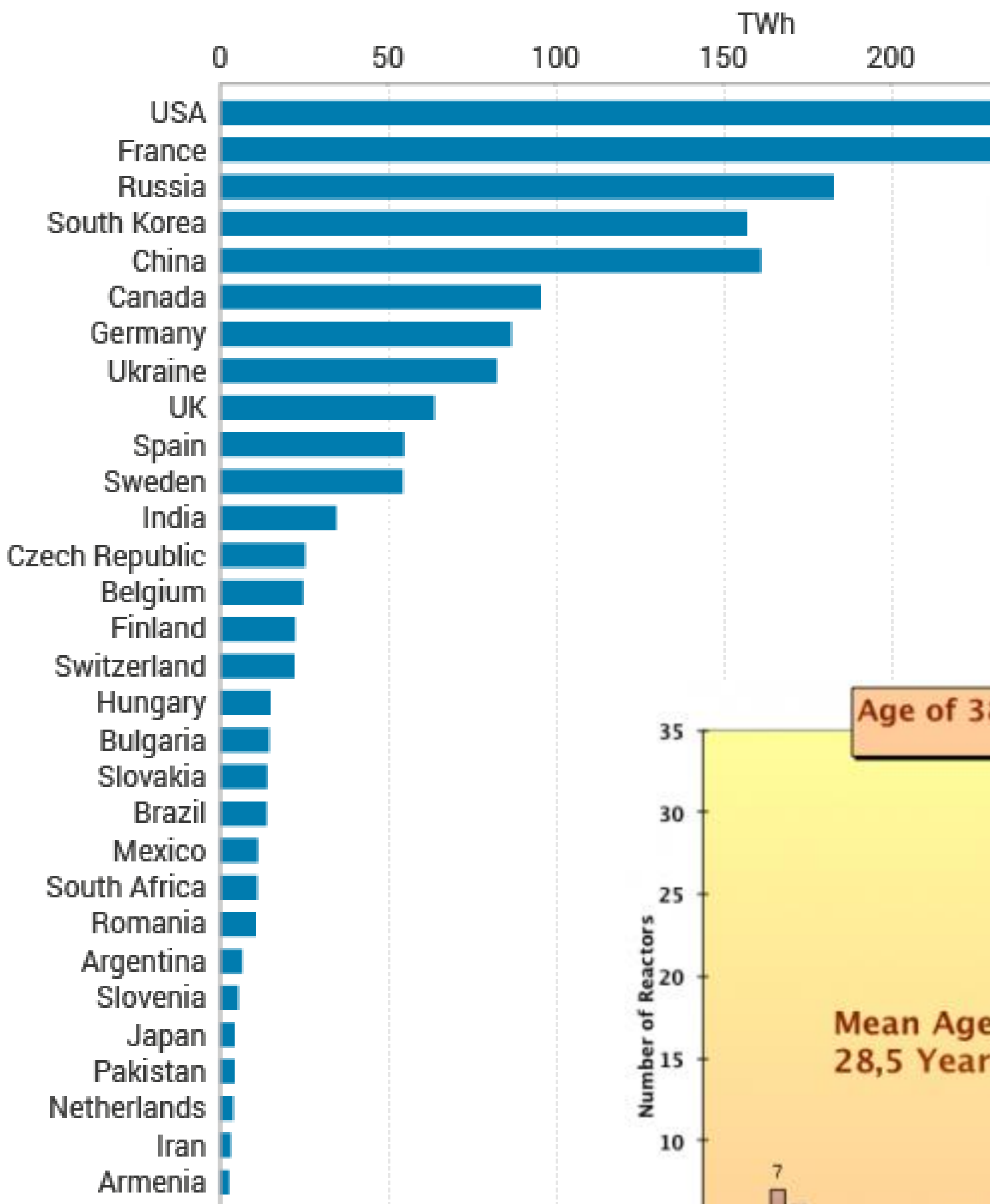


Nuclear power plants



Nuclear Power Plants, 2013-01-18

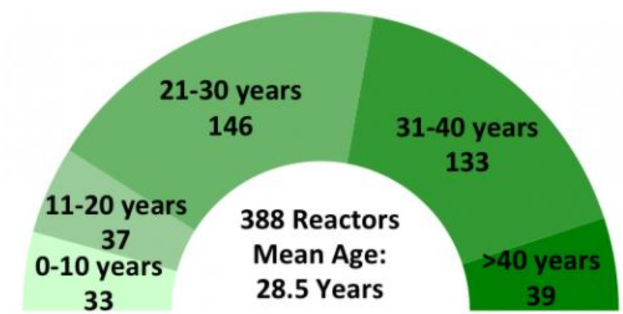
Nuclear Generation by Country 2015

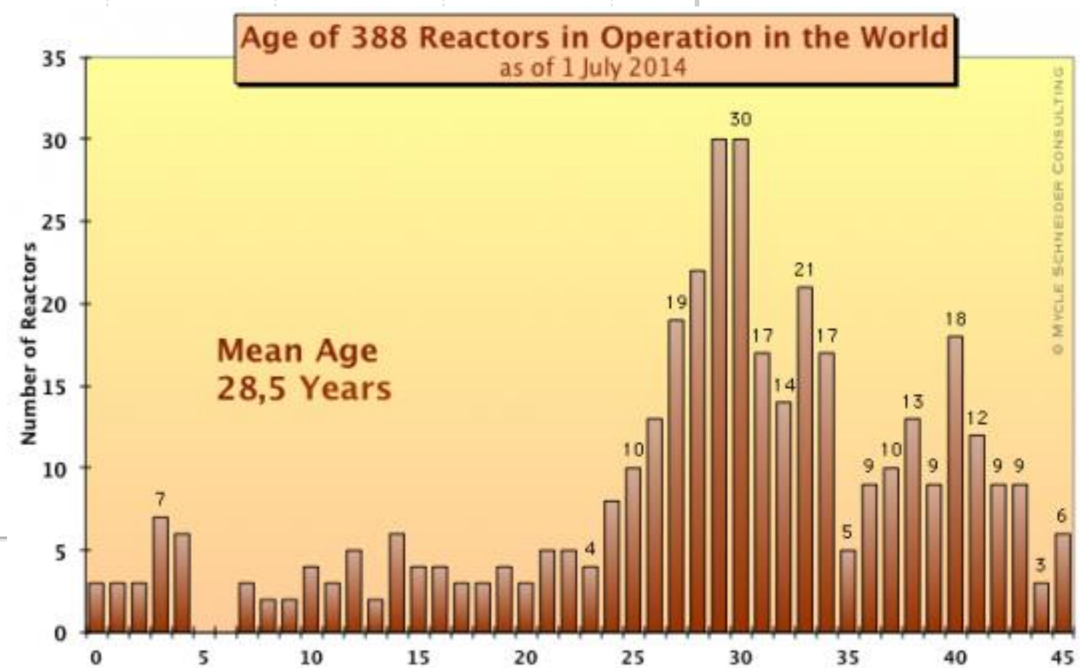


Source: IAEA PRIS Database

Age of World Nuclear Fleet

as of 1 July 2014

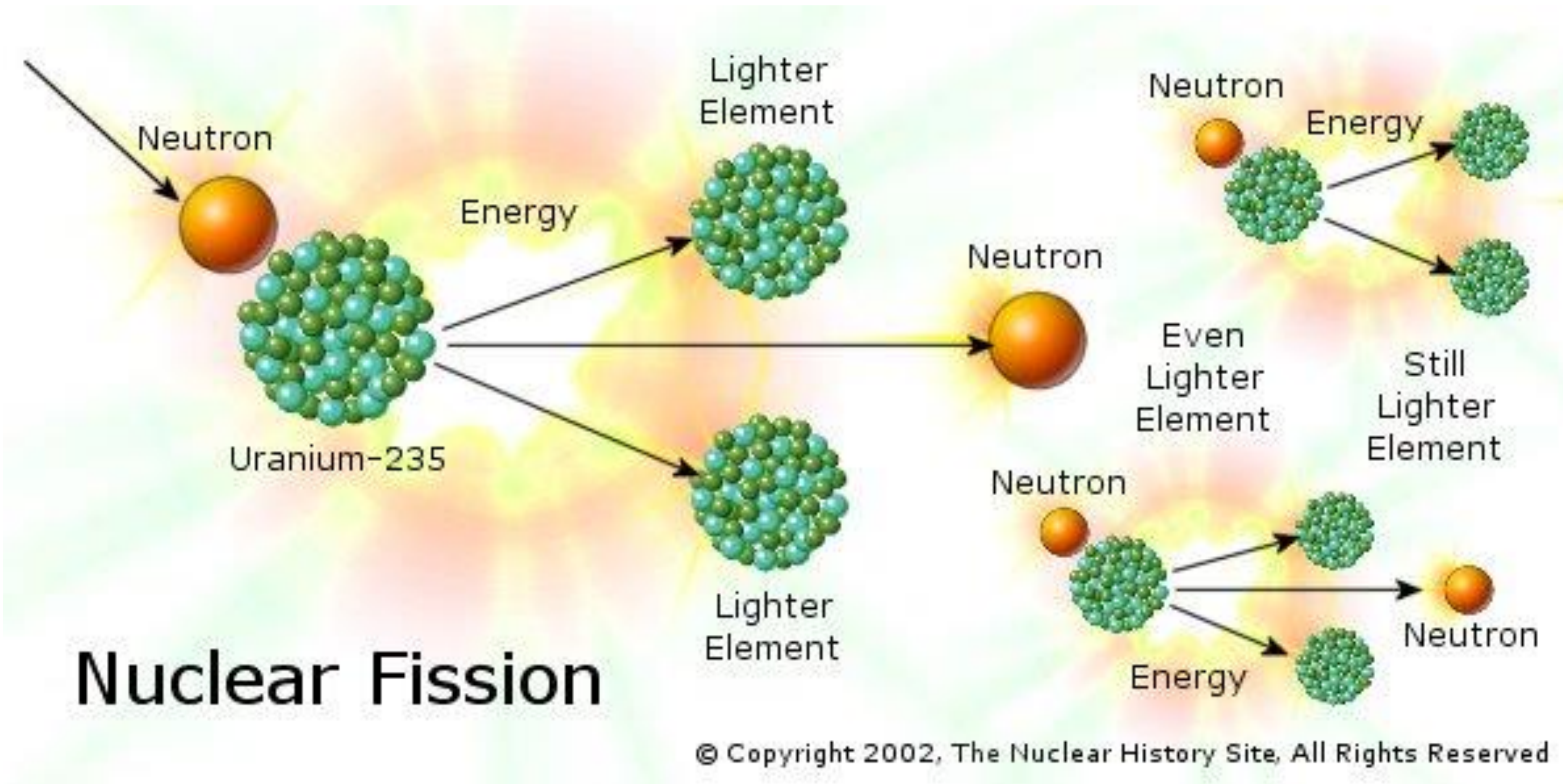




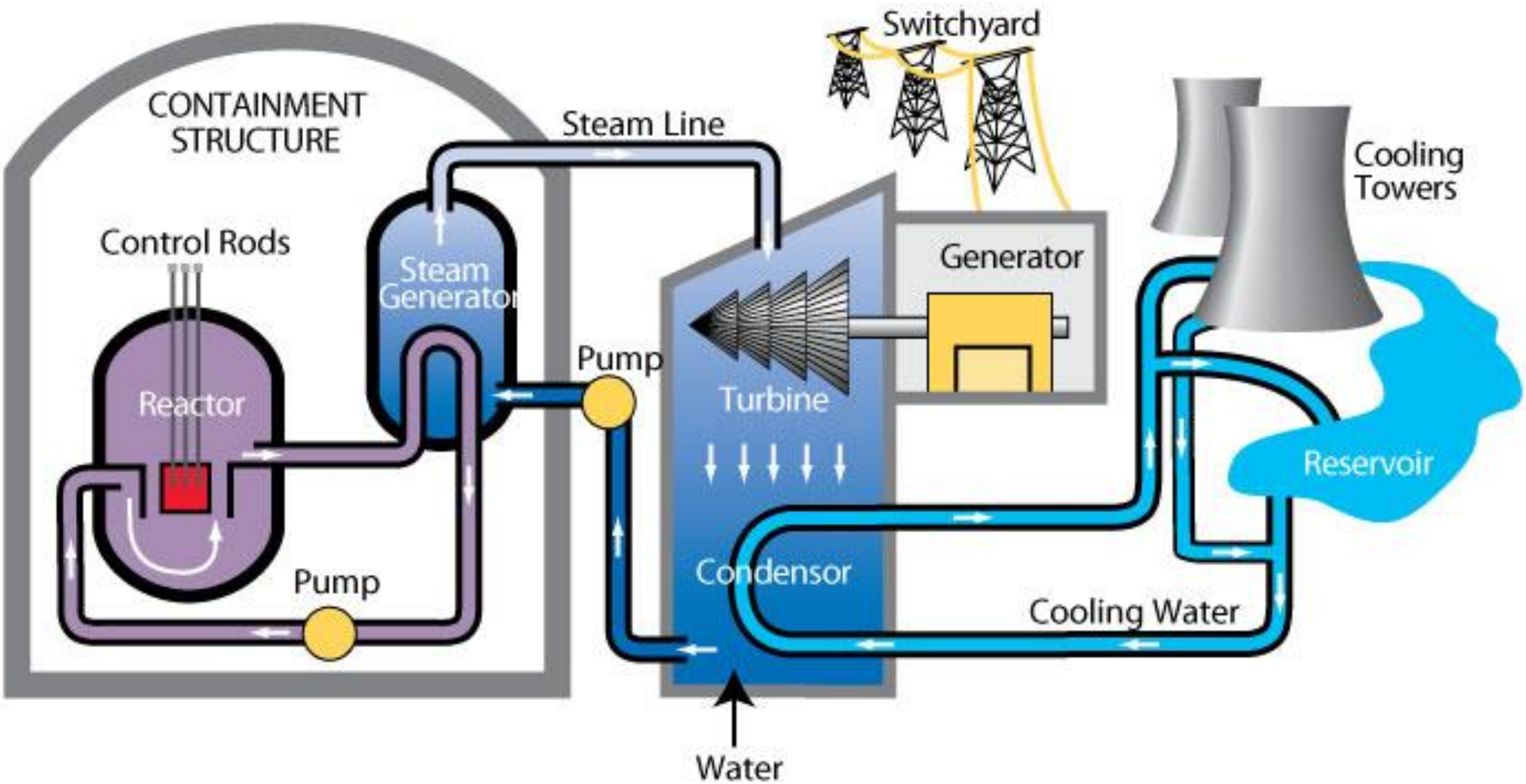
Nuclear power plants in commercial operation

Reactor type	Main Countries	Number	GWe	Fuel	Coolant	Moderator
Pressurised Water Reactor (PWR)	US, France, Japan, Russia, China	271	270.4	enriched UO_2	water	water
Boiling Water Reactor (BWR)	US, Japan, Sweden	84	81.2	enriched UO_2	water	water
Pressurised Heavy Water Reactor 'CANDU' (PHWR)	Canada	48	27.1	natural UO_2	heavy water	heavy water
Gas-cooled Reactor (AGR & Magnox)	UK	17	9.6	natural U (metal), enriched UO_2	CO_2	graphite
Light Water Graphite Reactor (RBMK & EGP)	Russia	11 + 4	10.4	enriched UO_2	water	graphite
Fast Neutron Reactor (FBR)	Russia	1	0.6	PuO_2 and UO_2	liquid sodium	none
	TOTAL	436	399.3			

Nuclear Fission



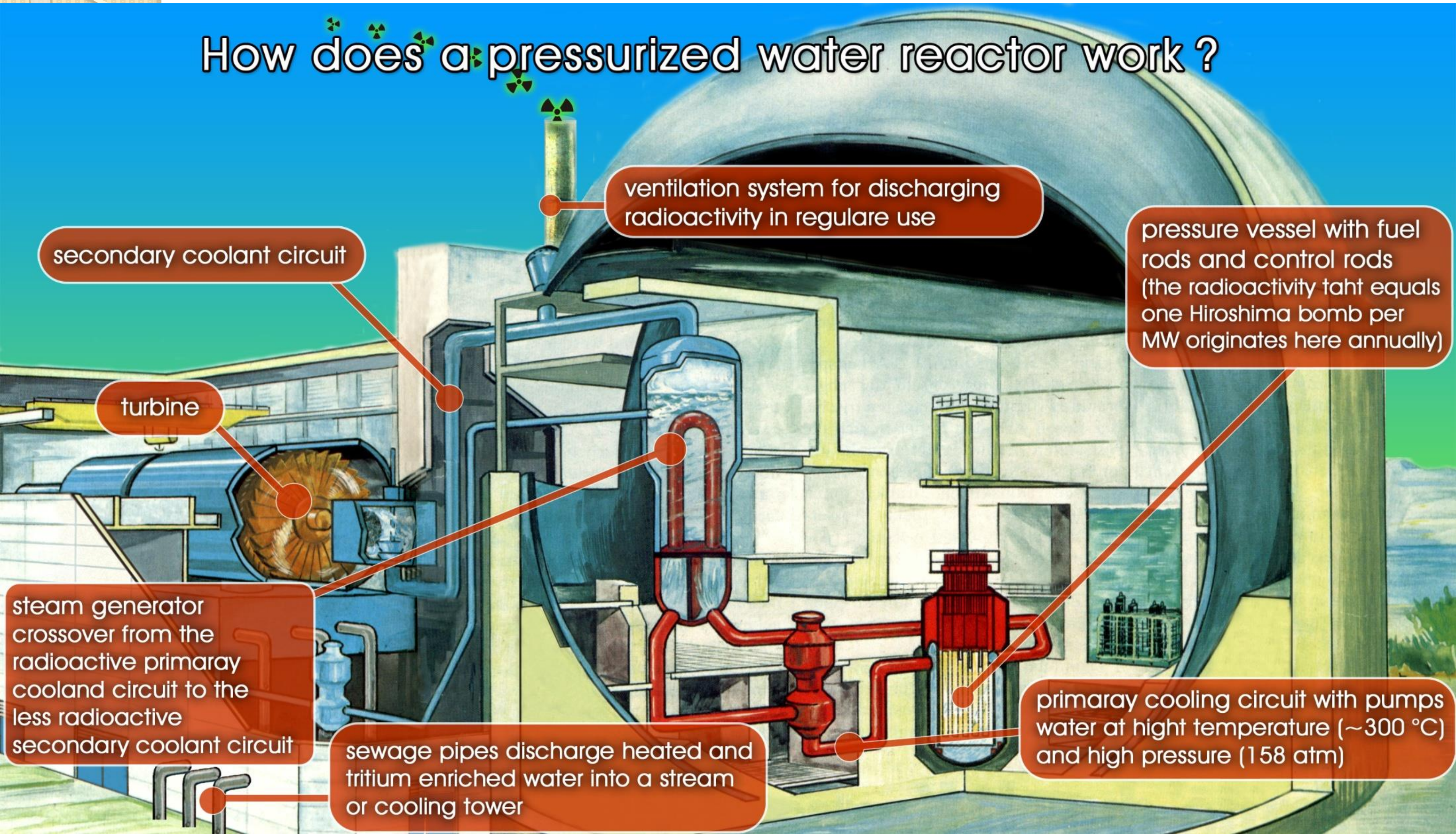
PWR Reactor



Loop = Reactor + Main Circulation Pump + Steam Generator

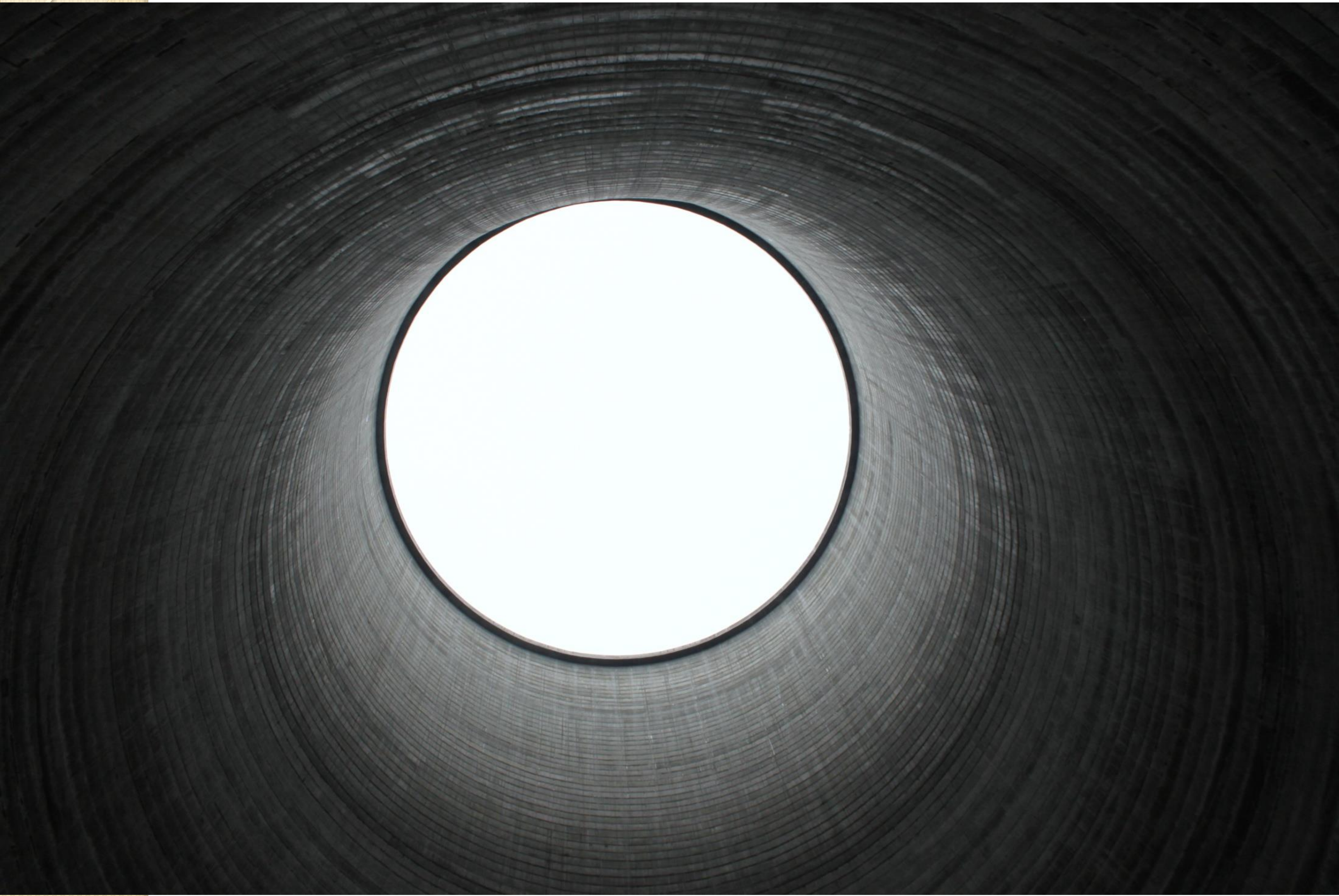
Compensators = electric heaters + water showers

PWR Reactor


How does a pressurized water reactor work ?
ventilation system for discharging radioactivity in regulare use
secondary coolant circuit
pressure vessel with fuel rods and control rods (the radioactivity taht equals one Hiroshima bomb per MW originates here annually)
turbine
steam generator crossover from the radioactive primaray cooland circuit to the less radioactive secondary coolant circuit
primaray cooling circuit with pumps water at hight temperature (~300 °C) and high pressure (158 atm)
sewage pipes discharge heated and tritium enriched water into a stream or cooling tower

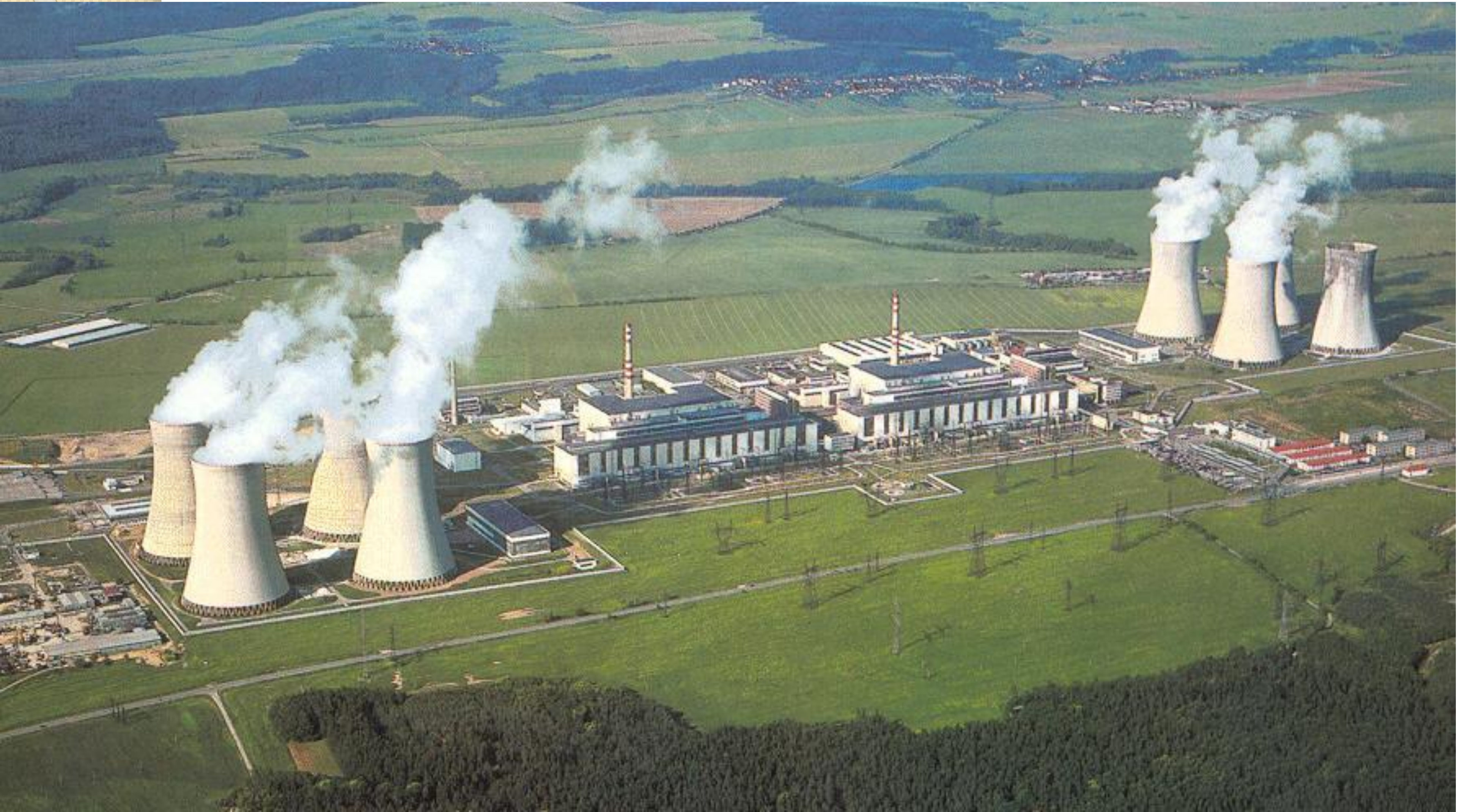

БАЛТКРАН
180(220)/32+220+6,3т
БАЛТКРАН
15т


ТУРБОГЕНЕРАТОР №13



QUIZ

Chernobyl NPP, UKR



Dukovany NPP, CZE

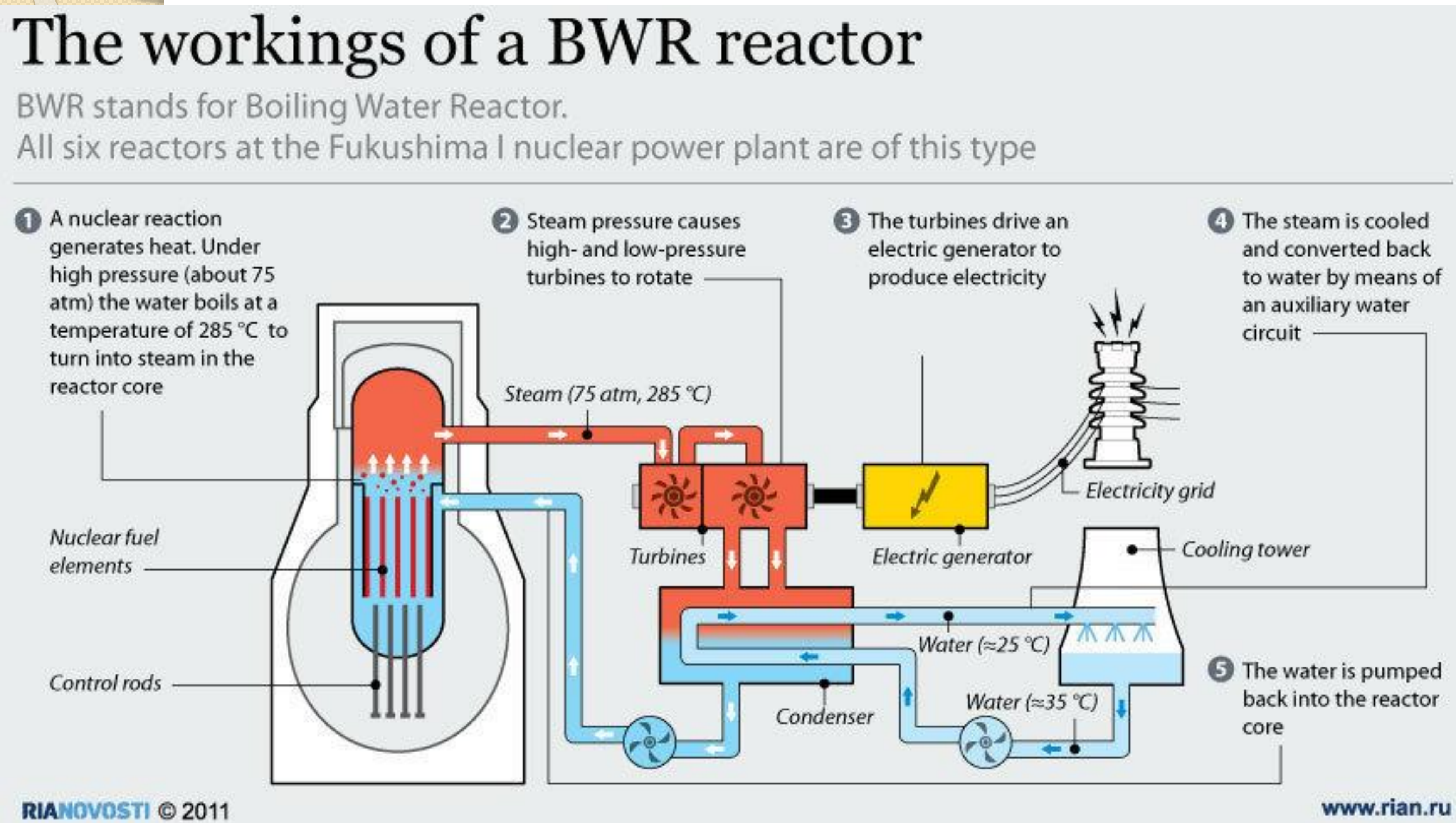
Zwentendorf NPP, AUT


Фото О.Бережковой

Novovoronezh NPP, RF

Obninsk NPP, RF

BWR Reactor


The workings of a BWR reactor
BWR stands for Boiling Water Reactor.
All six reactors at the Fukushima I nuclear power plant are of this type
1 A nuclear reaction generates heat. Under high pressure (about 75 atm) the water boils at a temperature of 285 °C to turn into steam in the reactor core
2 Steam pressure causes high- and low-pressure turbines to rotate
3 The turbines drive an electric generator to produce electricity
4 The steam is cooled and converted back to water by means of an auxiliary water circuit
Steam (75 atm, 285 °C)
Nuclear fuel elements
Turbines
Electric generator
Electricity grid
Cooling tower
Water (≈25 °C)
Control rods
Condenser
Water (≈35 °C)
5 The water is pumped back into the reactor core
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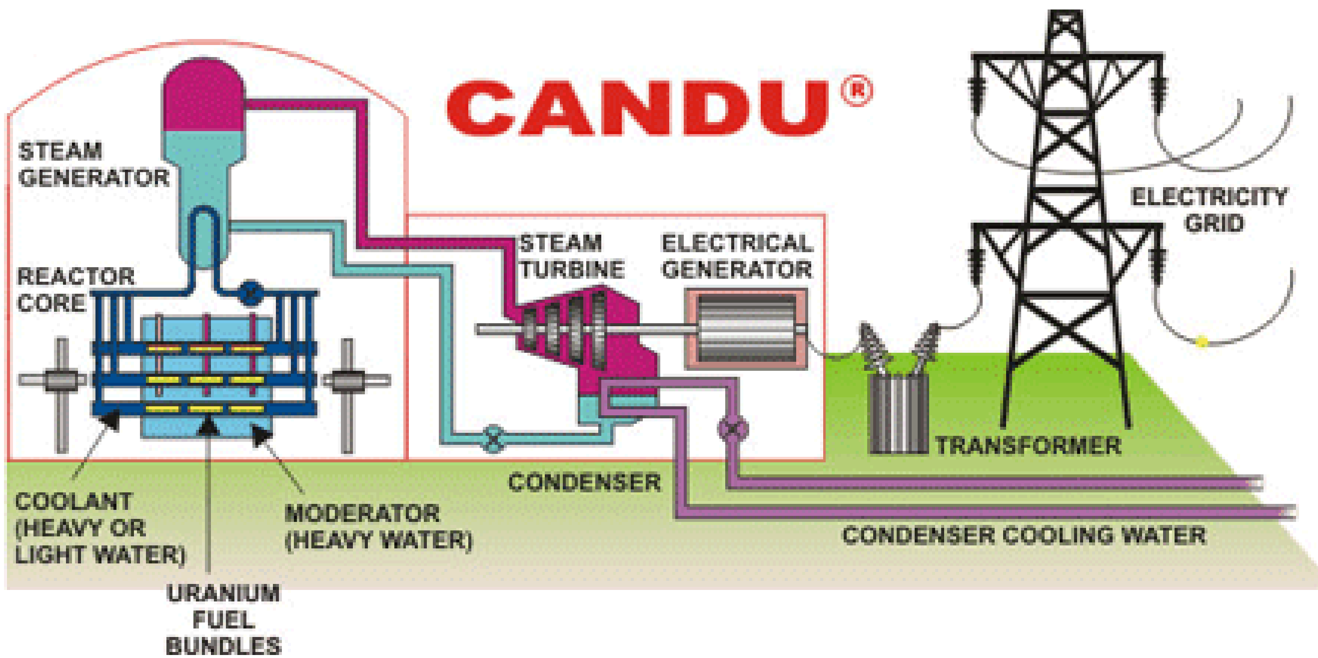
www.rian.ru

PHW Reactor

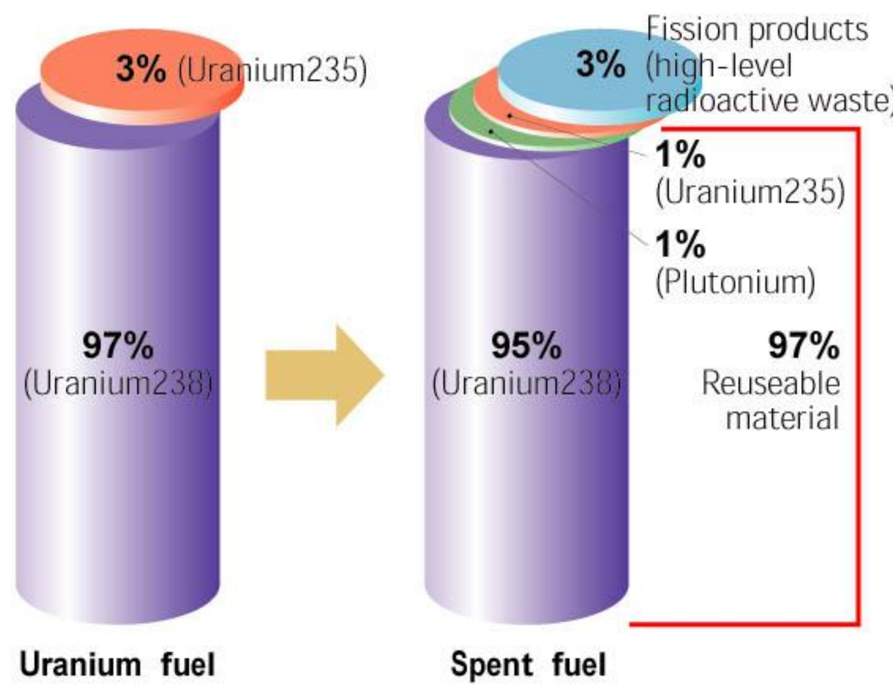
- Generally the same structure as PWR
- Heavy water (nor radioactive) absorbs less neutrons, thus is able both to moderate nuclear reaction and secure criticality = non-enriched fuel can be used



Back End

- Fission chain reaction consumes only uranium isotope 235U.
- Used fuel contains approximately a quarter of the original value of this isotope, thus still remains enriched to about 1% 235U.
- The fuel consists of more

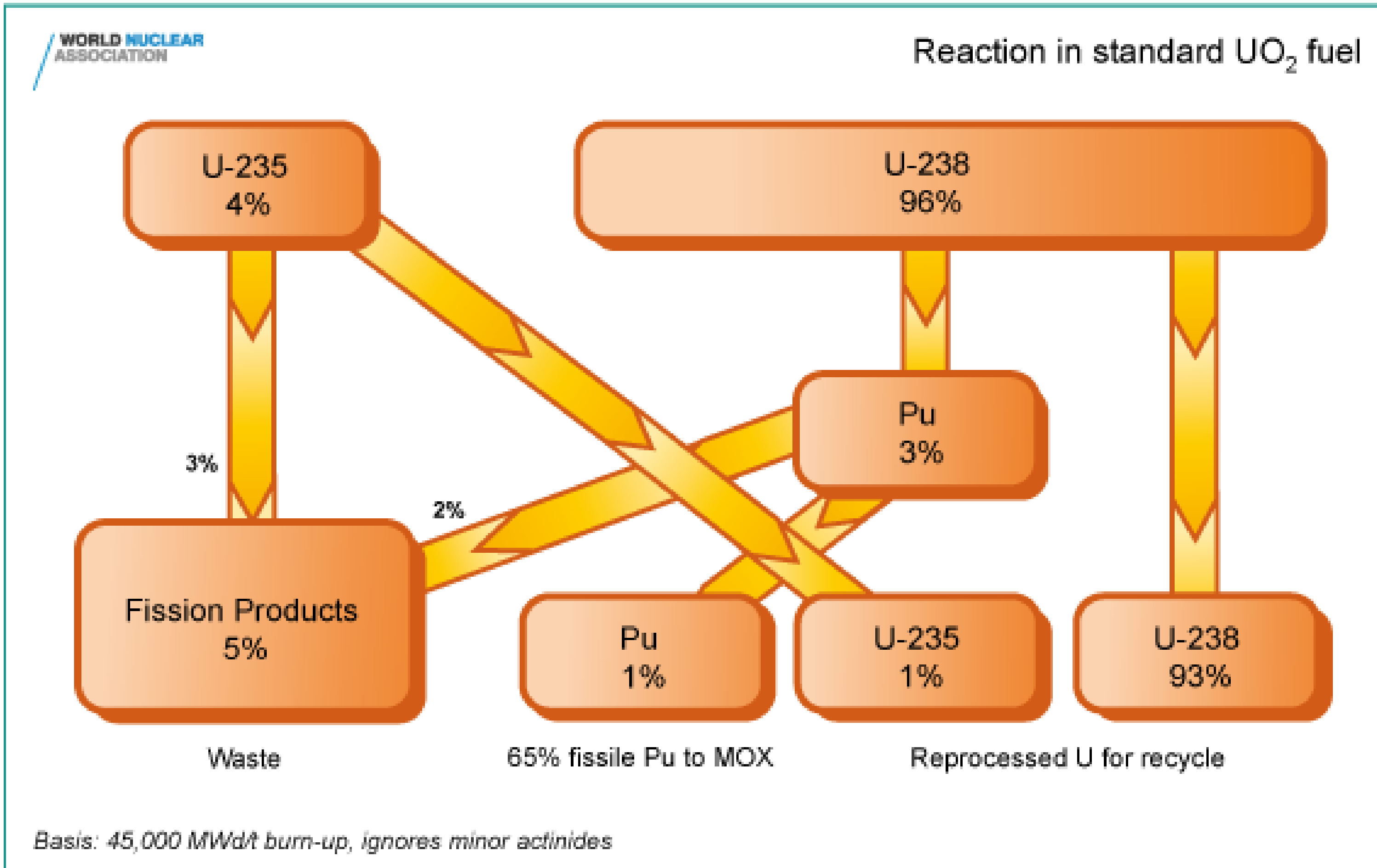
than 96% uranium dioxide (UO2) and newly developed plutonium dioxide (PuO2) in an amount of about 1%, and other compounds (3%), while most of the fission products are radioactive isotopes.



MOX Fuel

- Mixed oxide (MOX) fuel provides almost 5% of the new nuclear fuel used today.
- MOX fuel is manufactured from plutonium recovered from used reactor fuel, mixed with depleted uranium.
- MOX fuel also provides a means of burning weapons-grade plutonium (from military sources) to produce electricity.

MOX Fuel

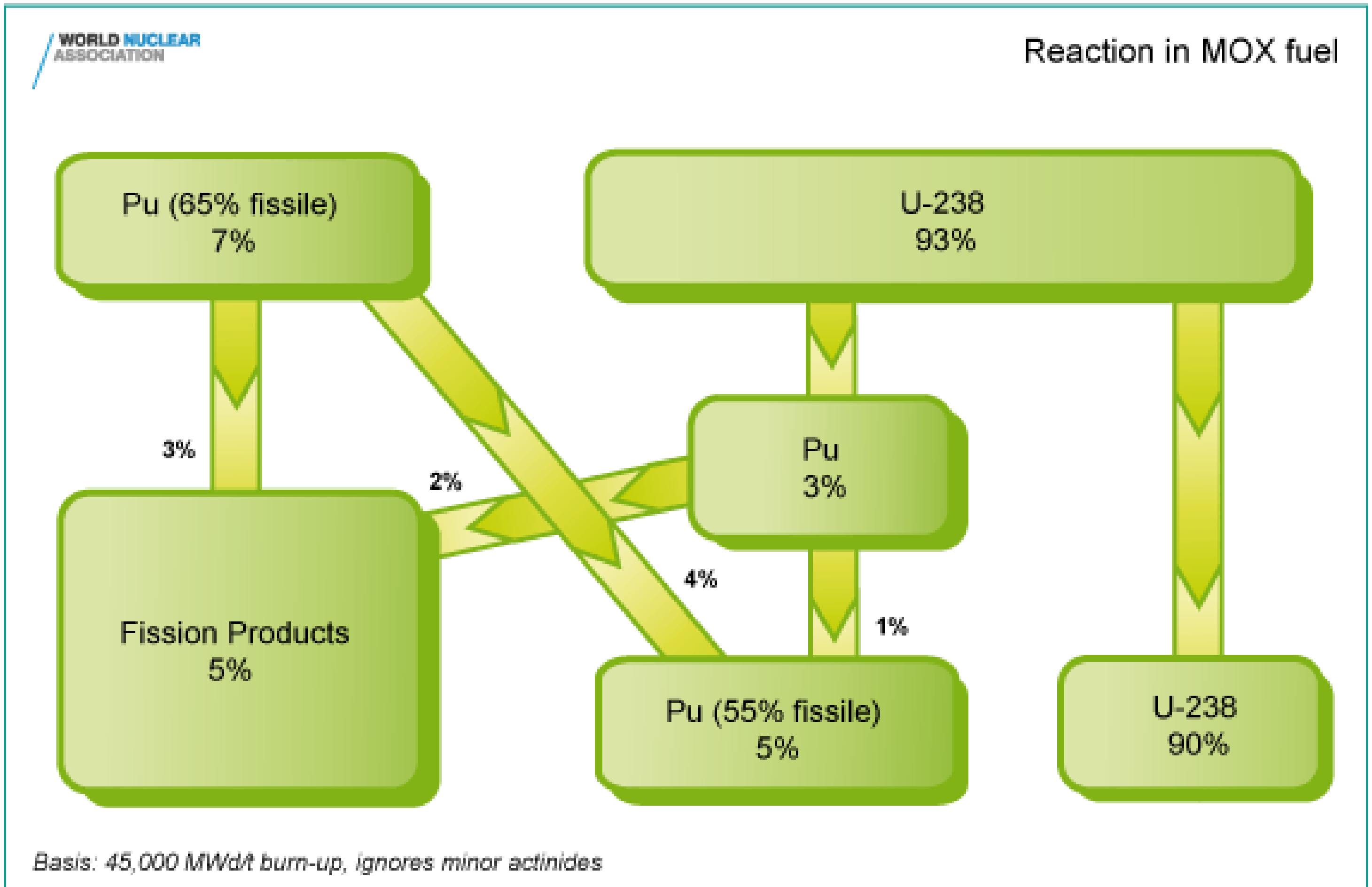


WORLD NUCLEAR ASSOCIATION
Reaction in standard UO_2 fuel
U-235
4%
U-238
96%
Pu
3%
3%
2%
Fission Products
5%
Pu
1%
U-235
1%
U-238
93%
Waste
65% fissile Pu to MOX
Reprocessed U for recycle
Basis: 45,000 MWd/t burn-up, ignores minor actinides

MOX Fuel

World mixed oxide fuel fabrication capacities (t/yr)

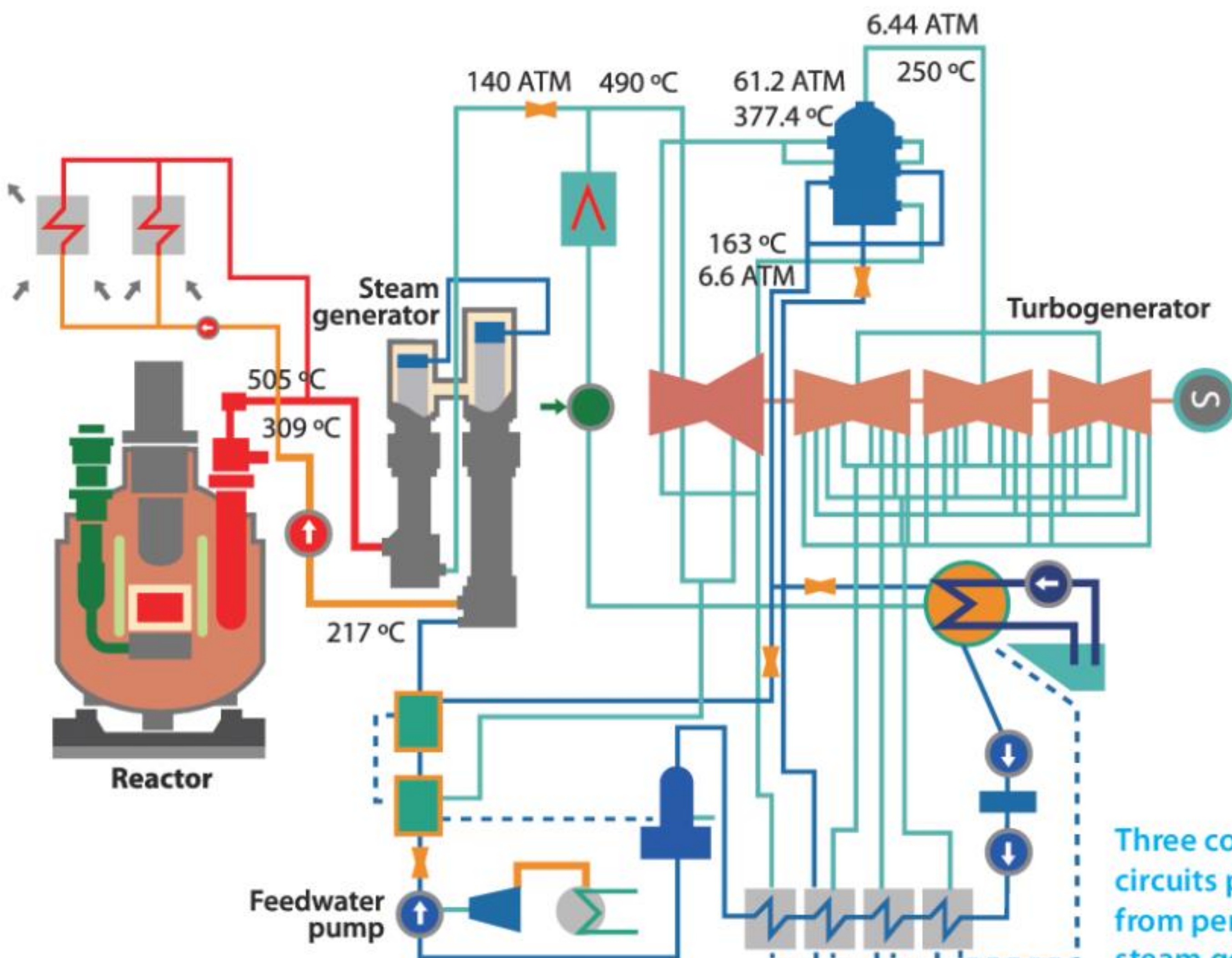
	2009	2020
France, Melox	195	195
Japan, Tokai	10	10
Japan, Rokkasho	0	130
Russia, Mayak, Ozersk	5	5
Russia, Zheleznogorsk	0	60?
UK, Sellafield	40	0
Total for LWR	**250**	**400**



Fast Neutron Reactors

- About 400 reactor-years of operating experience have been accumulated to the end of 2010.
- A fast neutron reactor or simply a fast reactor is a category of nuclear reactor in which the fission chain reaction is sustained by fast neutrons.
- Such a reactor needs no neutron moderator, but must use fuel that is relatively rich in fissile material when compared to that required for a thermal reactor.
- Fuel consists of U-235, Pu-239 (products of fission with higher radiation) that produce more fast neutrons = waste from Gen II and III reactors is used

Fast Neutron Reactors (BN 800)



Three consecutive coolant circuits prevent radioactivity from penetrating into the steam generators

Fast Neutron Reactors

World Fast Neutron Reactor status

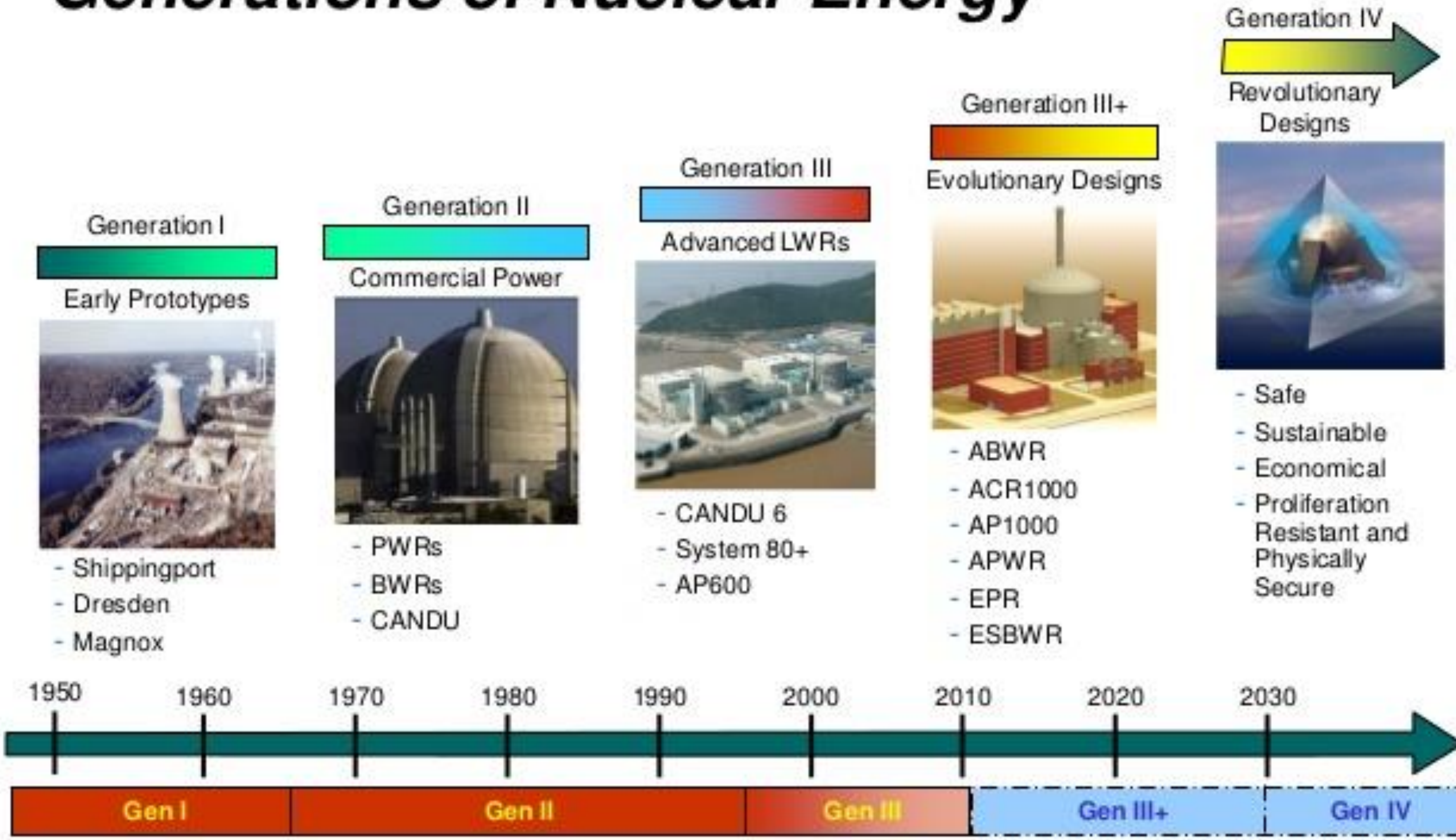
Current FNRs

Reactor	Type, coolant	Power thermal/elect	Fuel (future)	Country	Notes
BOR-60	Experimental, loop, sodium	55/10	oxide	Russia	1969-
BN-600	Demonstration, pool, sodium	1470/600	oxide	Russia	1980-
BN-800	Experimental, pool, sodium	2100/864	oxide	Russia	2014-
FBTR	Experimental, pool, sodium	40/-	oxide & carbide (metal)	India	1985-2030
PFBR	Demonstration, pool, sodium	1250/500	oxide (metal)	India	(2015)
CEFR	Experimental, pool, sodium	65/20	oxide	China	2010-
Joyo	Experimental, loop, sodium	140/-	oxide	Japan	1978-2007, maybe restart 2021
Monju	Prototype, loop, sodium	714/280	oxide	Japan	1994-96, 2010, Decommissioned

FNR designs for near- to mid-term deployment - active development

Reactor	type, coolant	Power thermal/elect	Fuel (future)	country	notes
PRISM	Demonstration, pool, sodium	840/311	metal	USA	From 2020s
Astrid	Demonstration, pool, sodium	1500/600	oxide	France, with Japan	From 2024
Allegro	Experimental, loop?, gas	50-100 MWt	oxide	France	About 2025
MYRRHA	Experimental, Pb-Bi	57/-	oxide?	Belgium, with China	Early 2020s
ALFRED	Prototype, lead	300/120	oxide	Romania, with Italy & EU	From 2025
BN-1200	Commercial, pool, sodium	2800/1220	oxide, nitride	Russia	From mid-2020s
BREST-300	Demonstration, loop, lead	700/300	nitride	Russia	From 2020
SVBR-100	Demonstration, pool, Pb-Bi	280/100	oxide (variety)	Russia	From 2019
MBIR	Experimental, loop, sodium (Pb-Bi, gas)	100-150 MWt	oxide	Russia	From 2020
CDFR-1000	Demonstration, pool, sodium	/1000	oxide	China	From 2023
CDFBR-1200	Commercial, pool, sodium	/1200	metal	China	From 2028
PGSFR	Prototype, pool, sodium	/150	metal	South Korea	From 2028
JSFR	Demonstration, loop, sodium	/500	oxide	Japan	From 2025?
TWR	Prototype, sodium	/600	metal	China, with USA	From 2023?

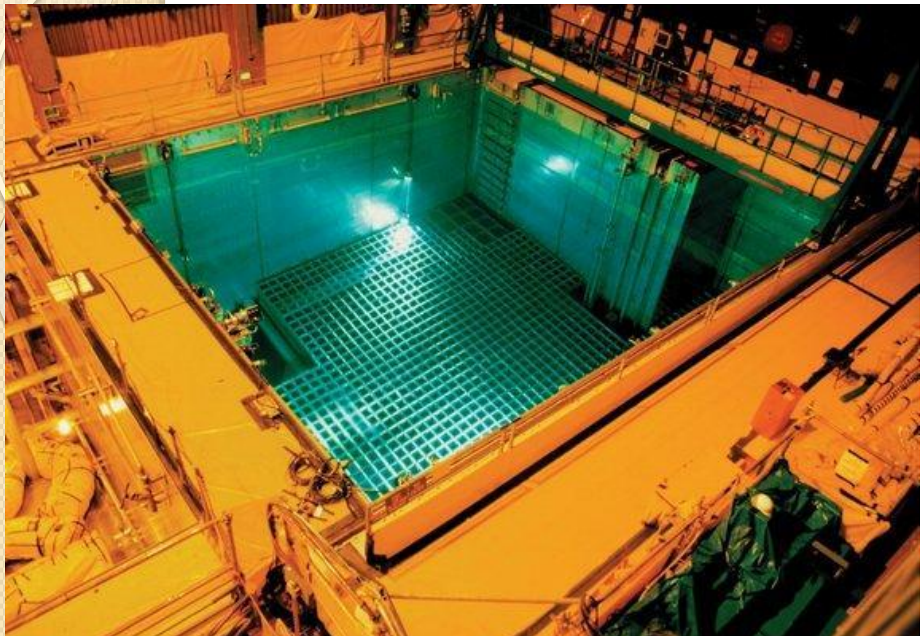
Generations of Nuclear Energy

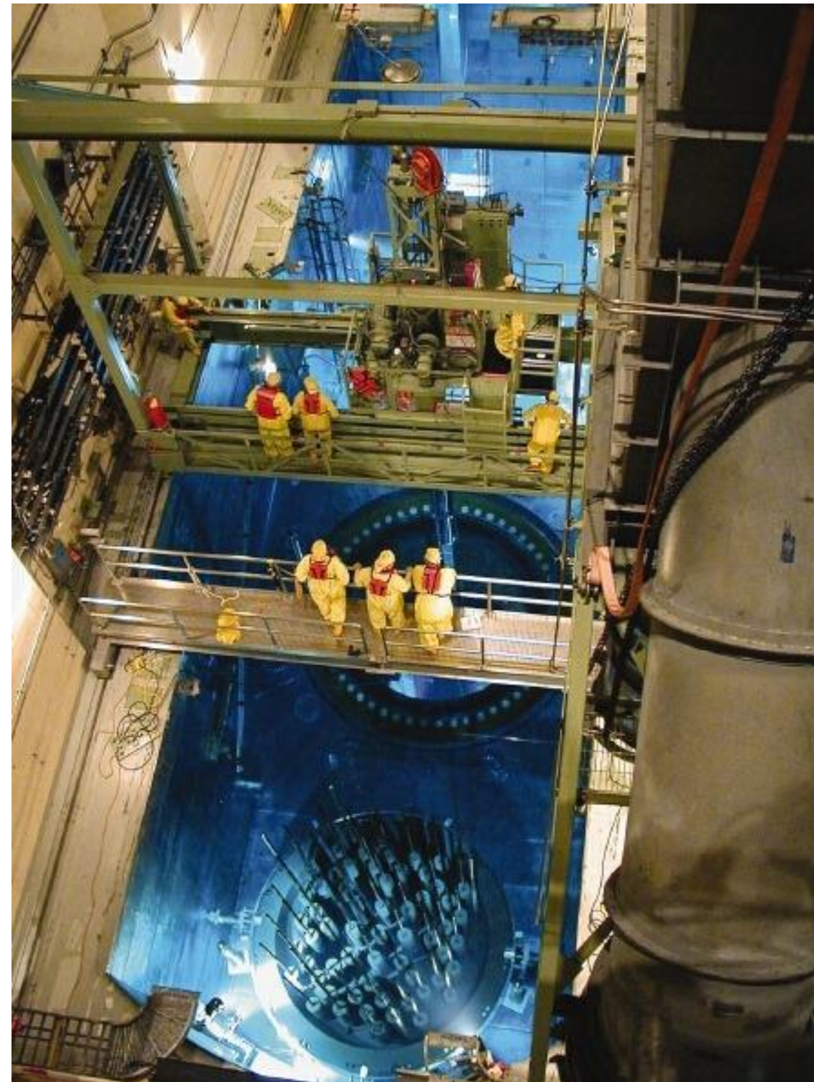


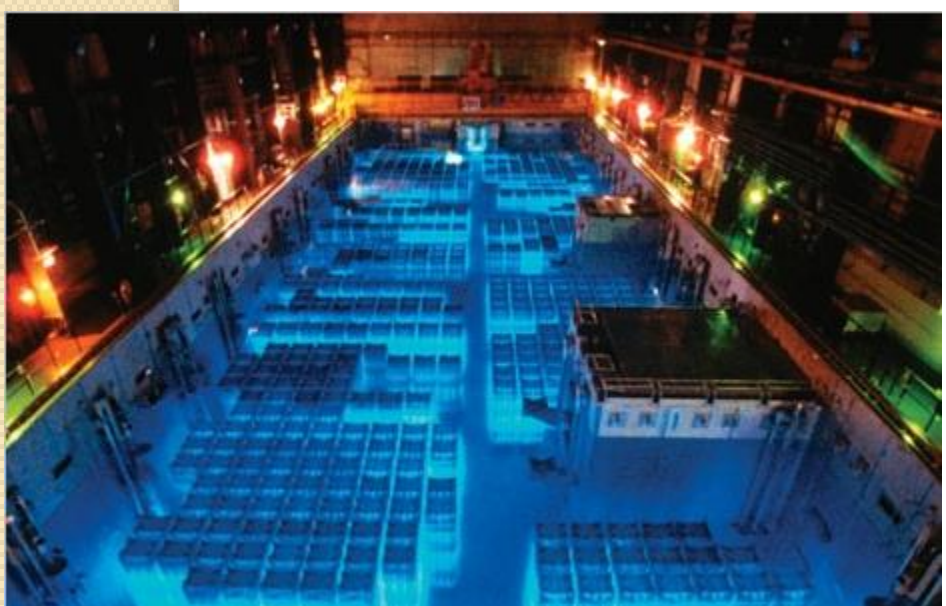
Back-end of Nuclear Fuel Cycle

- In the **first phase**, the fuel is actively cooled in a pool next to the reactor. After five-ten years they are put into dry containers and passively cooled in interim storages.
- Dukovany NPP annually produces less than one container of spent fuel. Temelin NPP annually produces two full containers of used fuel.
- The dry interim storage facility is constructed to store fuel for about 80 years.
- The **second phase**, i.e. transport phase, is/will be provided by rail.
- The **third phase** is the underground geological repository

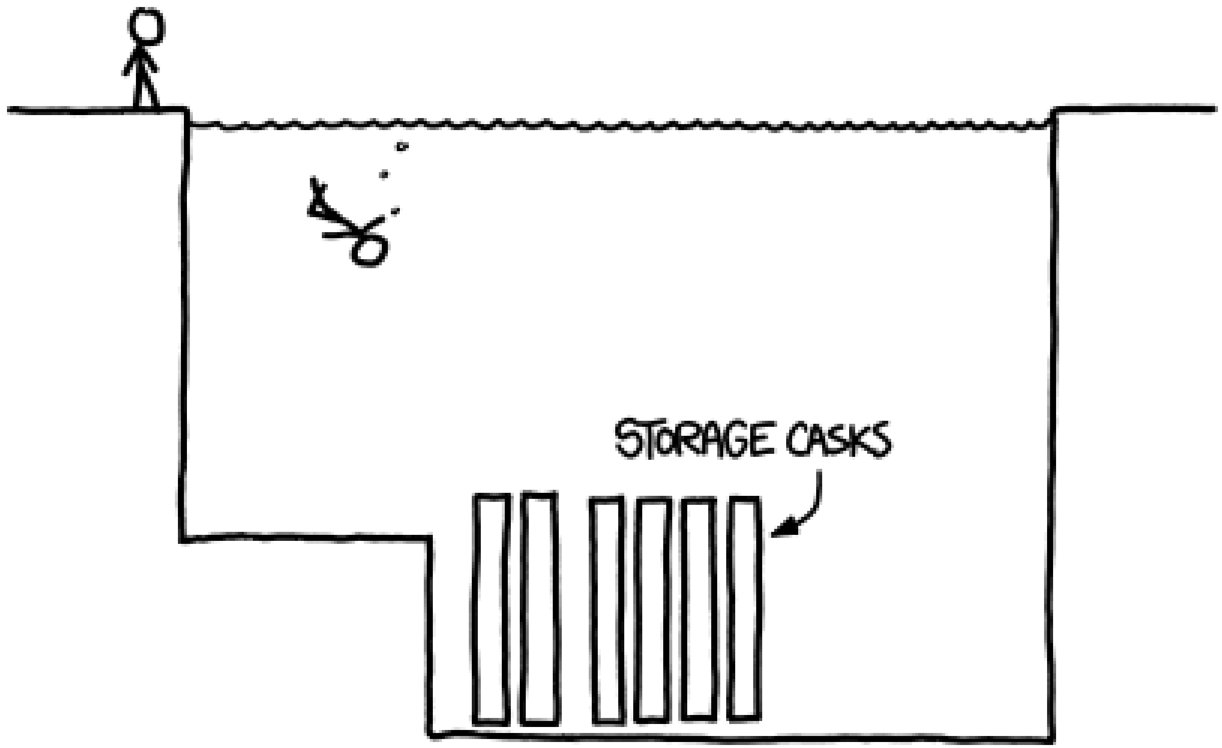
Back-end of Nuclear Fuel Cycle







Is it safe to swim in the spent fuel pool?



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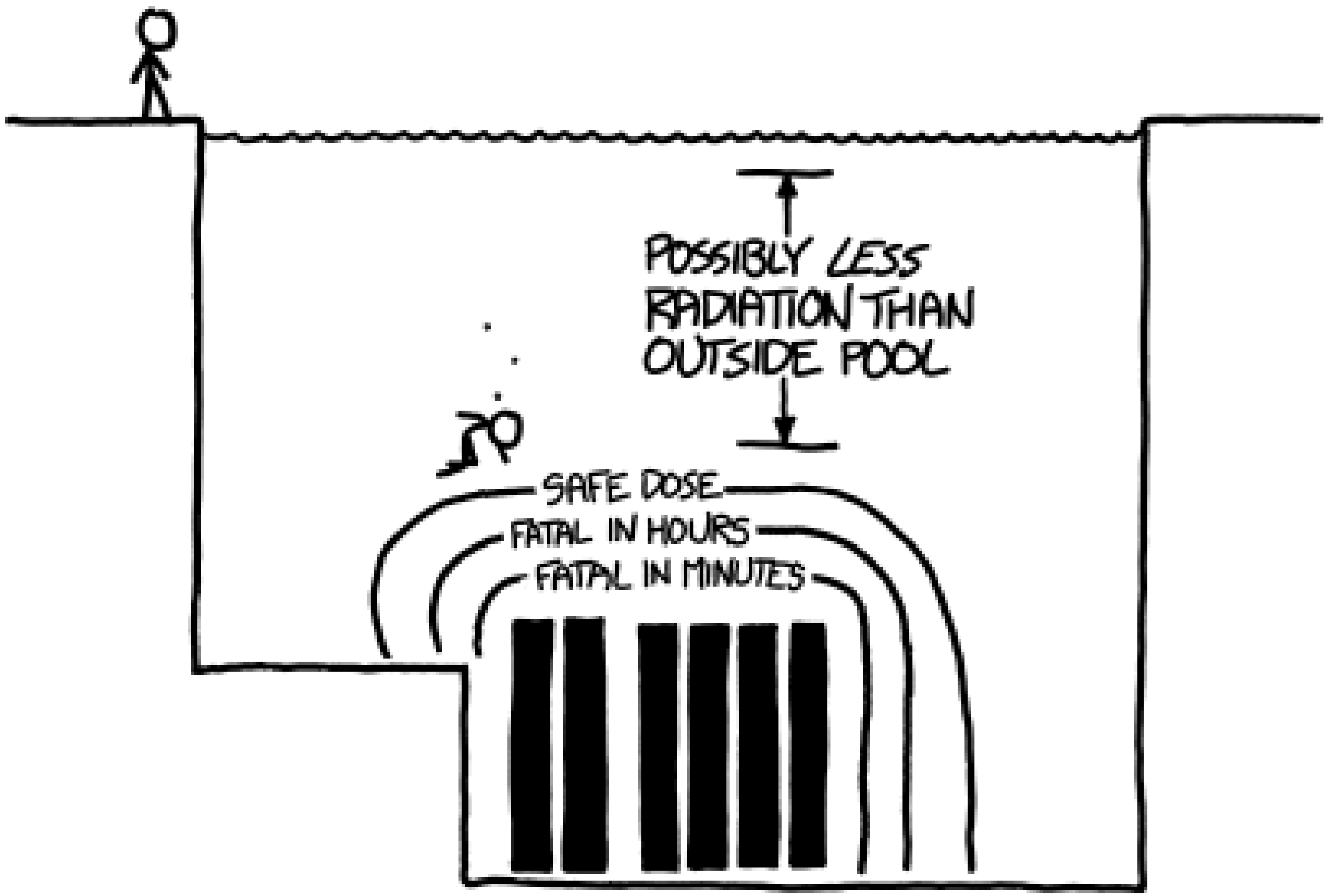
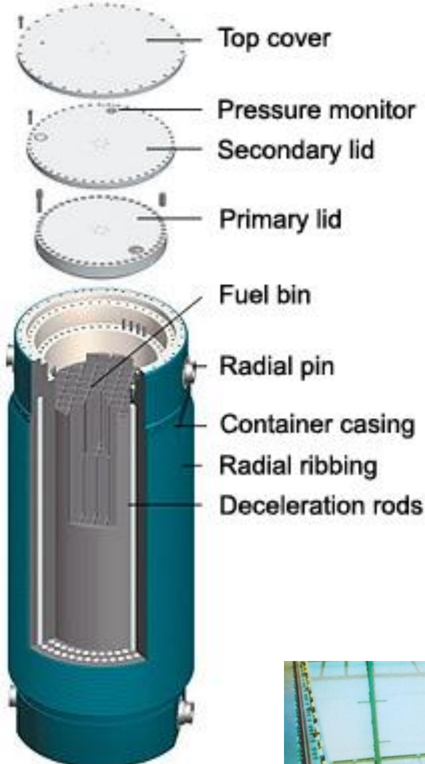


https://what-if.xkcd.com/29/


Top cover
Pressure monitor
Secondary lid
Primary lid
Fuel bin
Radial pin
Container casing
Radial ribbing
Deceleration rods

Open vs. Closed Cycle

Types of waste

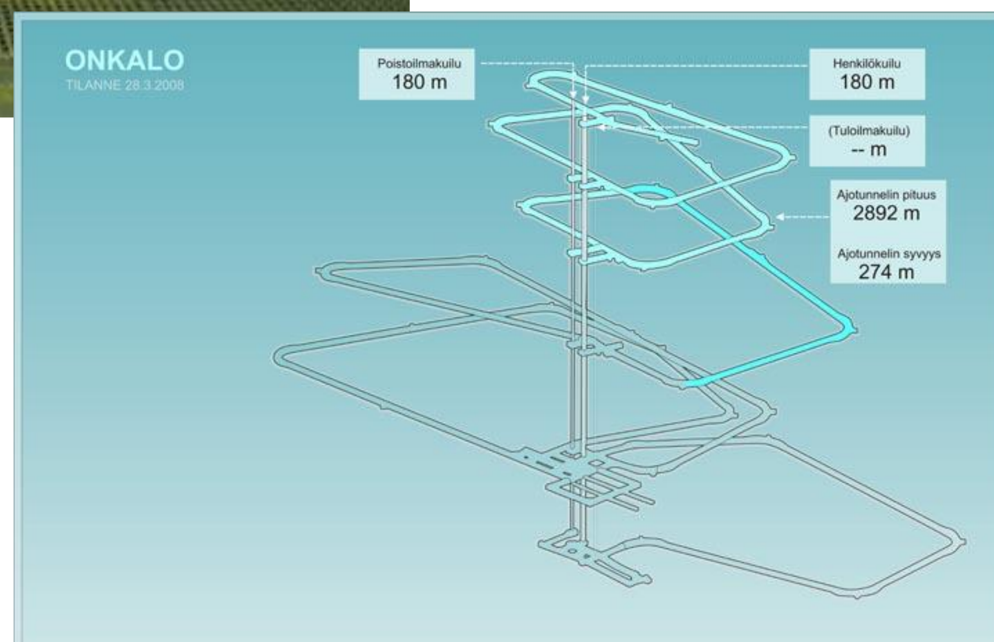
(1) negligibly hazardous waste (not considered a risk to humans or the environment, e.g. material after the demolition of nuclear power plants)
(2) slightly hazardous waste (produced for example in hospitals, pharmacies, some manufacturing processes, and in some parts of the nuclear fuel cycle, this waste does not require casing and can be placed into surface storages)
(3) moderately hazardous wastes (e.g. contaminated material after the demolition of the reactor of the NPP, the waste may require cladding and shielding)
(4) highly hazardous waste (spent fuel, it is essential to shield and cool it)

Surface storage is needed for at least 40-50 years, after which the temperature and the radioactivity drops to a level that is acceptable for underground geological repository with limited or no access of cooling.

Geological surveys and technical plans are fairly advanced in Sweden and Finland, which have a defined location. U.S. repository should be built at Yucca Mountain in Nevada, but the decision was postponed.

Variants of Storage

- Underground
- Space
- Long-term surface storage


ONKALO
TILANNE 28.3.2008
Poistoilmakuilu
180 m
Henkilökuilu
180 m
(Tuloilmakuilu)
-- m
Ajotunnelin pituus
2892 m
Ajotunnelin syvyys
274 m