Pressurized Water Reactors

Illustrations and information from http://en.wikipedia.org/wiki/Pressurized_water_reactor

The Ikata Nuclear Power Plant is located on Shikoku island at Ikata-cho.

- Pressurised Water Reactor (PWR)
- Boiling Water Reactor (BWR)
- Pressurised Heavy Water Reactor (PHWR)
- Light Water Graphite-moderated Reactor (LWGR)
- Gas-cooled Reactor (GCR)
- Fast-neutron Breeder Reactor (FBR)

Heavy vs. Light Water

Regular water is known as light water

$${}^{1}_{1}H + {}^{1}_{1}H + {}^{16}_{8}O = 18\text{g/mole}$$

Heavy water is made of deuterium, hydrogen-2

$${}^{2}_{1}H + {}^{2}_{1}H + {}^{16}_{8}O = 20\text{ g/mole}$$

(PHWR)

- A **pressurized heavy water reactor** (PHWR) is a nuclear power reactor that uses (cheaper unenriched natural uranium (1% U-235) as its fuel and heavy water (expensive) as a moderator (deuterium oxide D2O).
- Heavy water is expensive, but the reactor can operate without expensive fuel enrichment facilities so the cost balances out.

Note Check

Nuclear fuel (in the form of pellets inside a long fuel assembly tube) contains either

A. Natural uranium

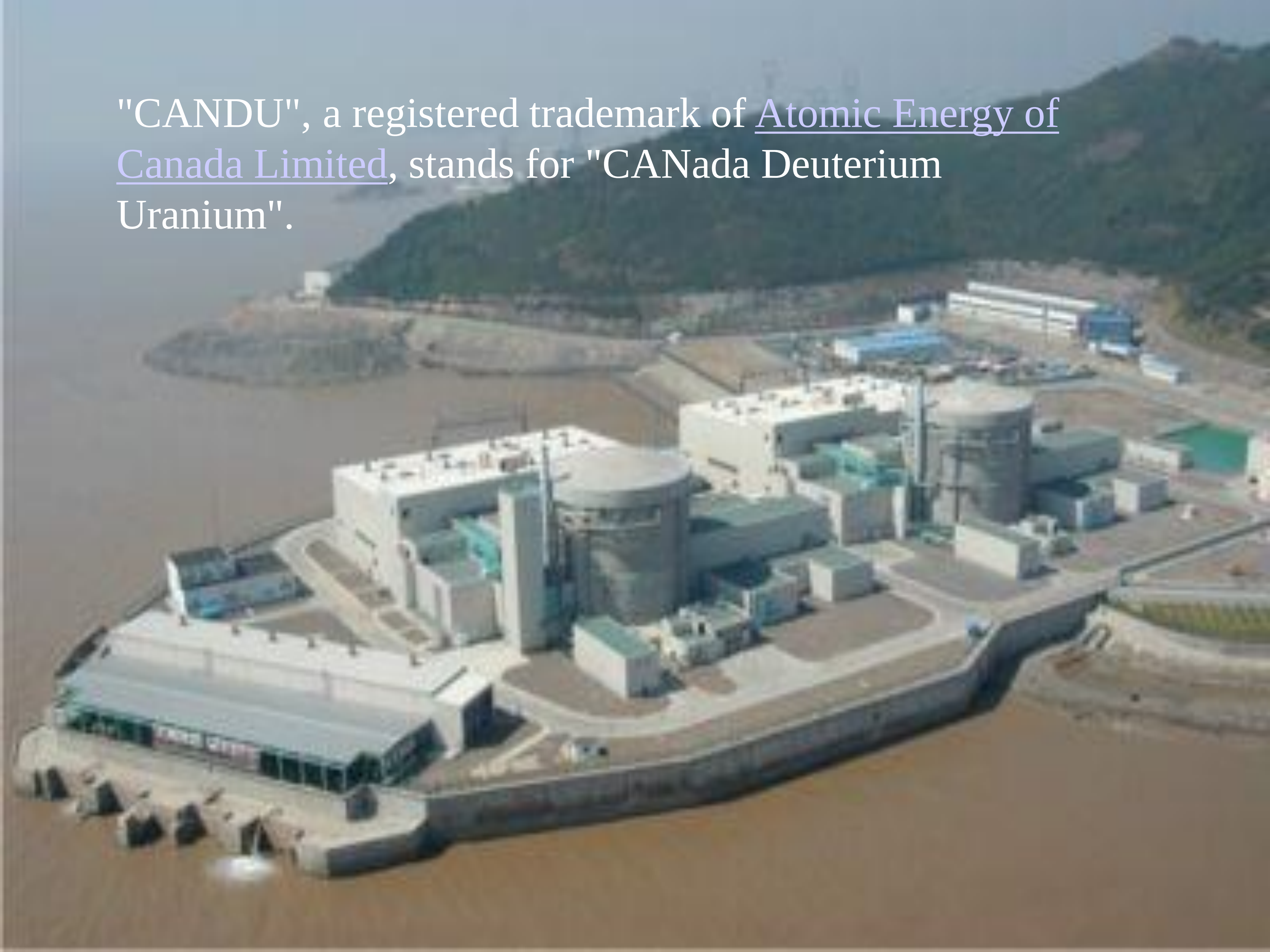
(Less than 1% U-235) used in

heavy / light   water reactors

B. Enriched uranium (2-3% U-235)

Used in heavy / light   water reactors.

"CANDU", a registered trademark of Atomic Energy of Canada Limited, stands for "CANada Deuterium Uranium".



Relative Abundance of Uranium Isotopes

Isotope	U-238	U-235	U-234
Natural Abundance (%)	99.27	0.72	0.0055
Half-life (years)	4.47 billion	700 million	246,000

Natural Uranium vs. Enriched

- 0.7 % uranium-235
- 99.3 % uranium-238
- a trace of uranium-234 by weight.
- Used in heavy water reactors (HWR)

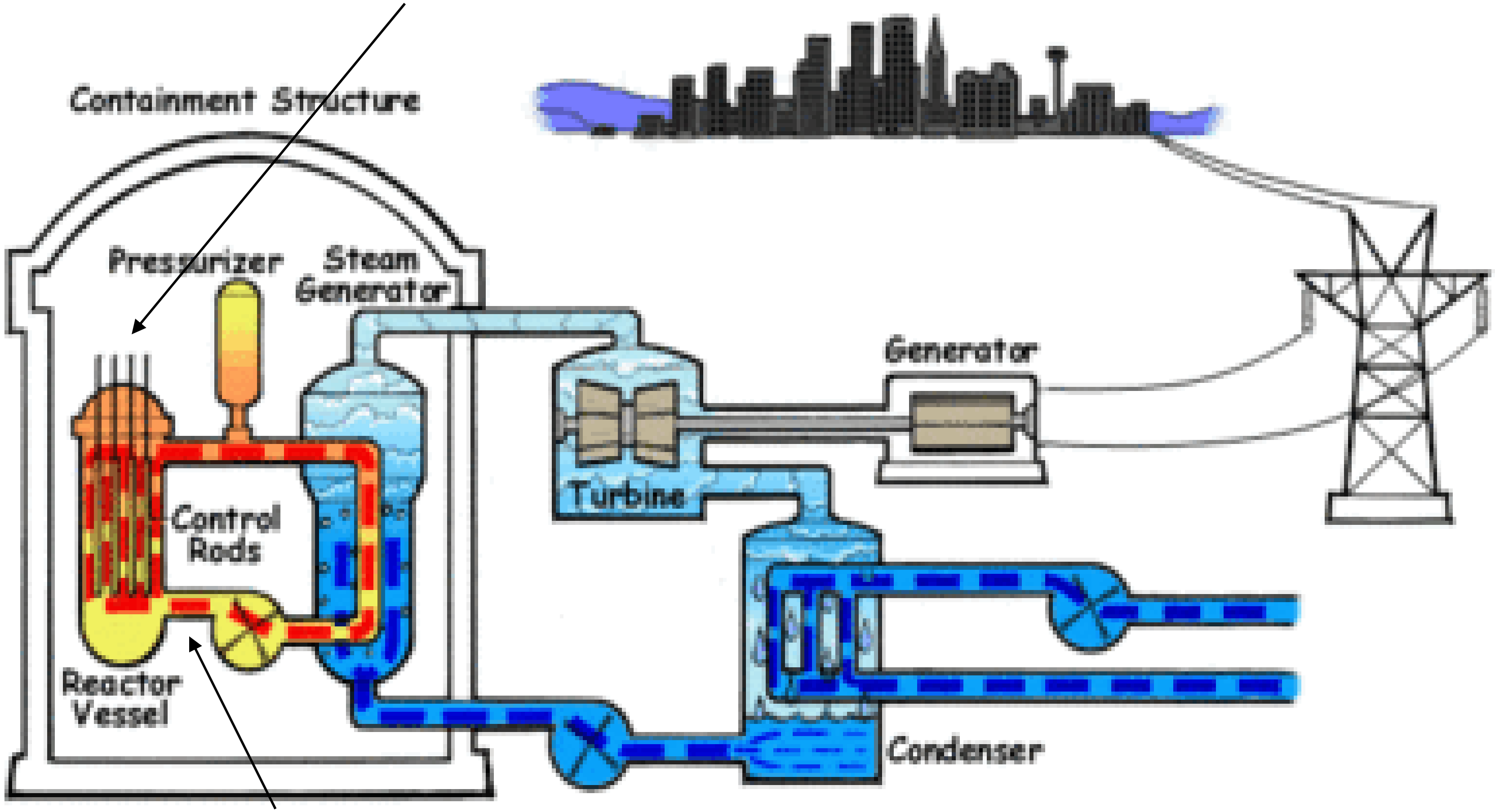
- lower than 20% U-235.
- LWR = 3 to 5 % U-235.
- Used in light water reactors (LWR)
- **Weapons grade is 90+ % enriched**

Note Check

Sustainable Fission (needed for bombs + power plants)

- Since U-235 naturally begins fission it will not be sustainable unless there is a “critical mass” or enough to sustain chain reaction. In a nuclear power plant enough U-235 is present when control rods are removed.
- Weapons grade = 90% and higher achieved with centrifuging equipment

1. Control rods are removed gradually to initiate chain reaction in the reactor vessel.



2. The chain reaction heats up the reactor vessel. Light water in the primary coolant loop heats up.

Note Check

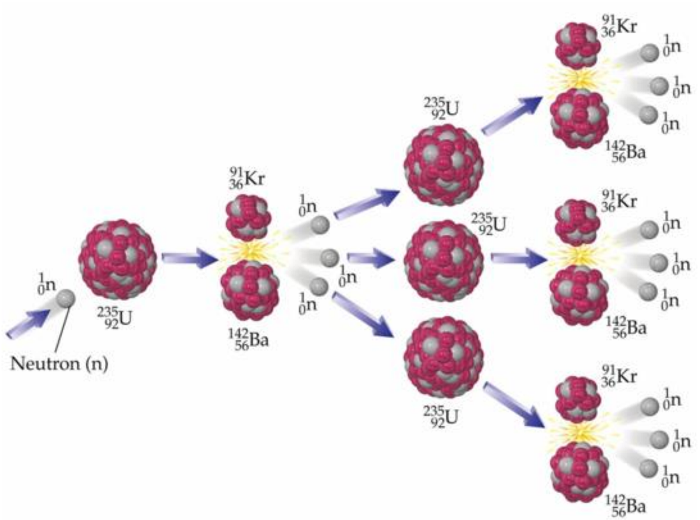
control rods

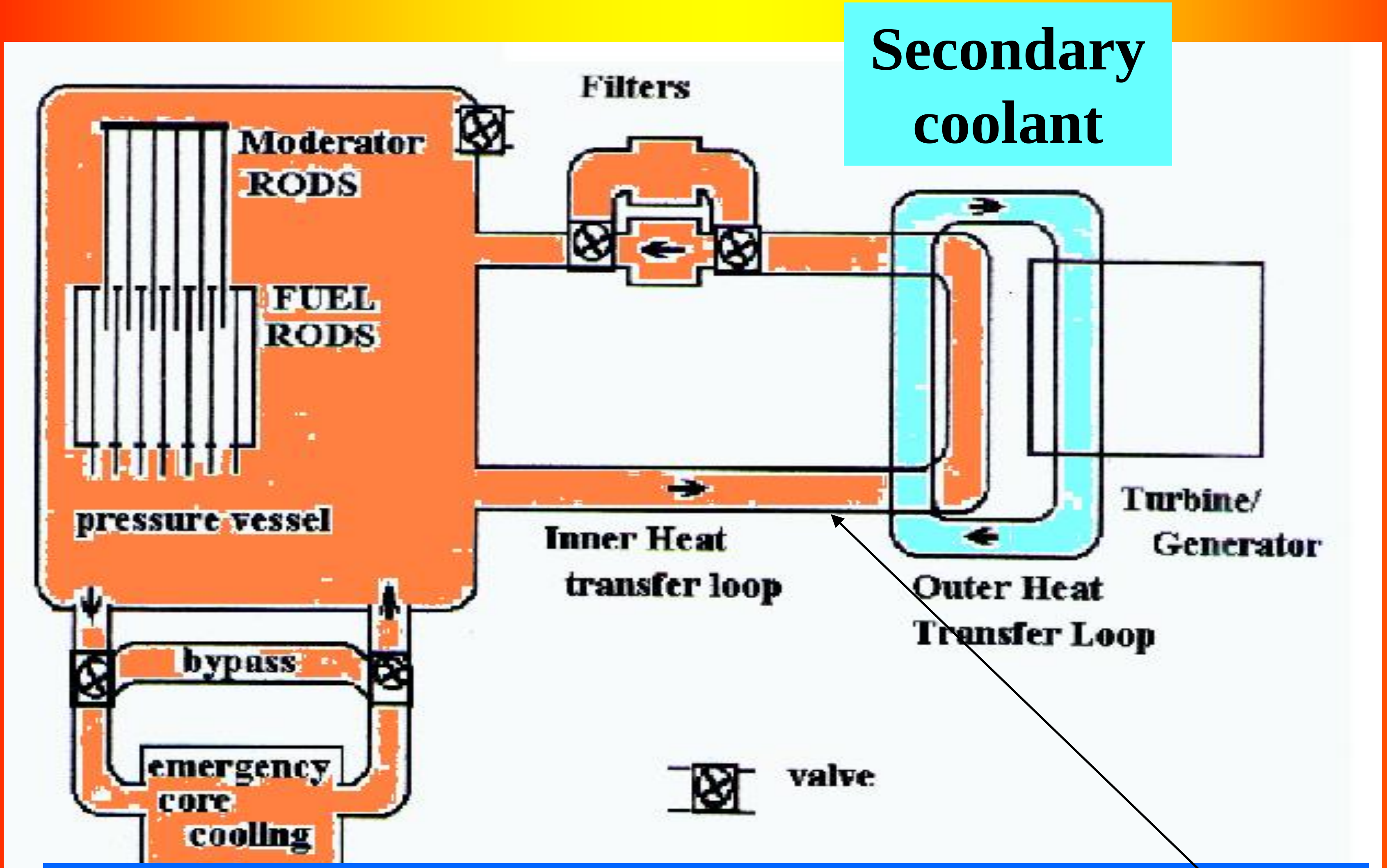
When ___________________ are removed the U-235 nucleus is bombarded by neutrons from other naturally fissioning U-235 nuclei.

Naturally fissioning Uranium -235 means it can absorb a neutron and split spontaneously.

Moderator such as *graphite or water* slow the neutrons down so that they (the neutrons)

temporarily stick to the nucleus of the fuel isotope U-235. A fraction of a time later the unstable nucleus splits releasing nuclear fragments called **daughter nuclides** and 2-3 new neutrons. The new neutrons are potentially able to cause three more fissions and the rate increases exponentially causing a **chain reaction**.





In a PWR, there are two separate coolant loops (primary radioactive coolant and secondary non radioactive). which are both filled with ordinary water (also called light water).

Controlling the chain reaction

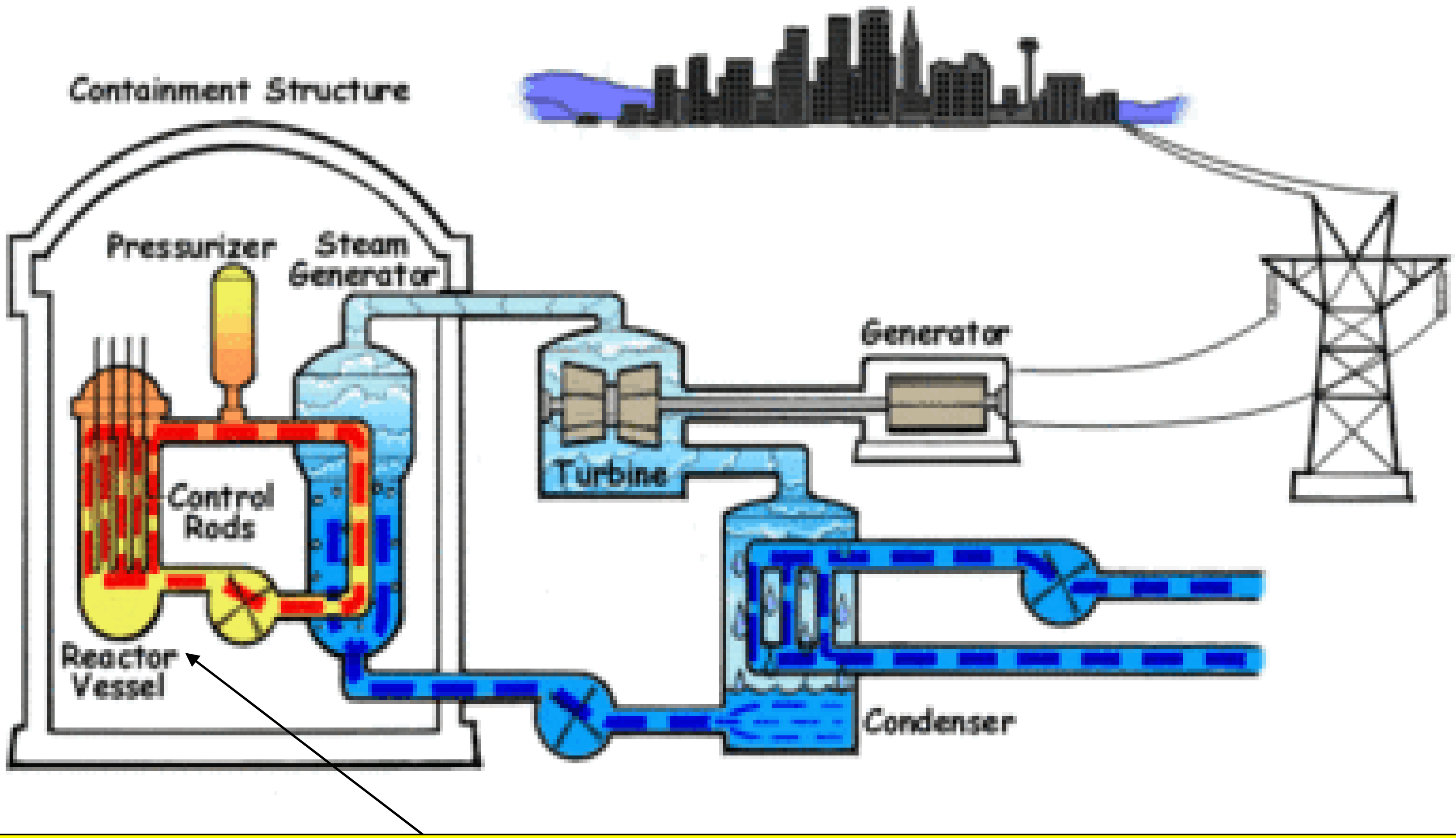
First you can alter the release and absorption of neutrons with control rods filled with neutron absorbing material like cadmium.

Removing control rods speeds up the fission process.

Returning control rods to fuel assembly slows down the reaction as long as it is not too fast or too hot.

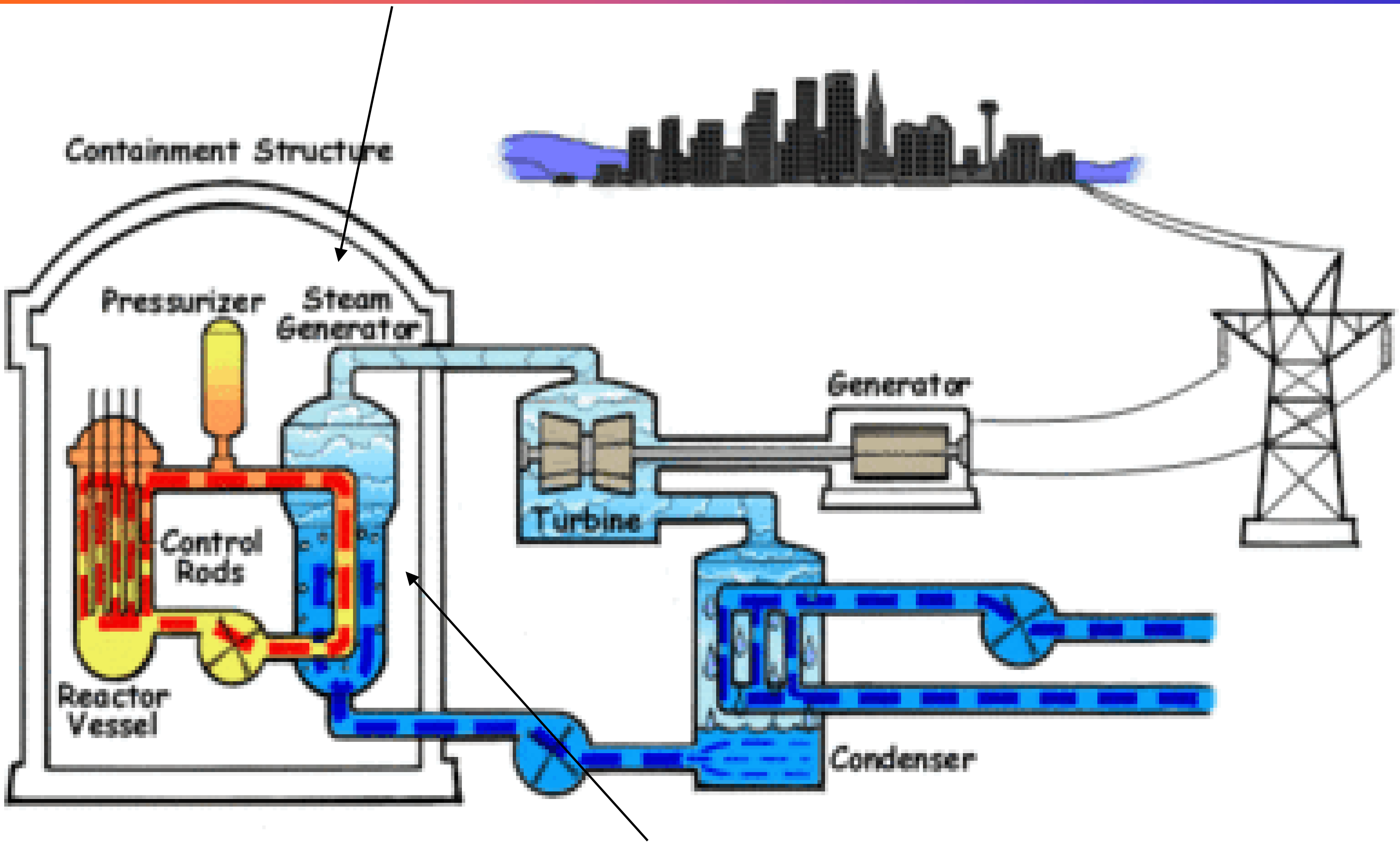
The reactor	Fuel	Control Rods	Critical mass
Big Gym	Naturally occurring sophomores	Teachers with gunny sacks	Leadership kids with ping pong balls

Boric acid is added to make borated water



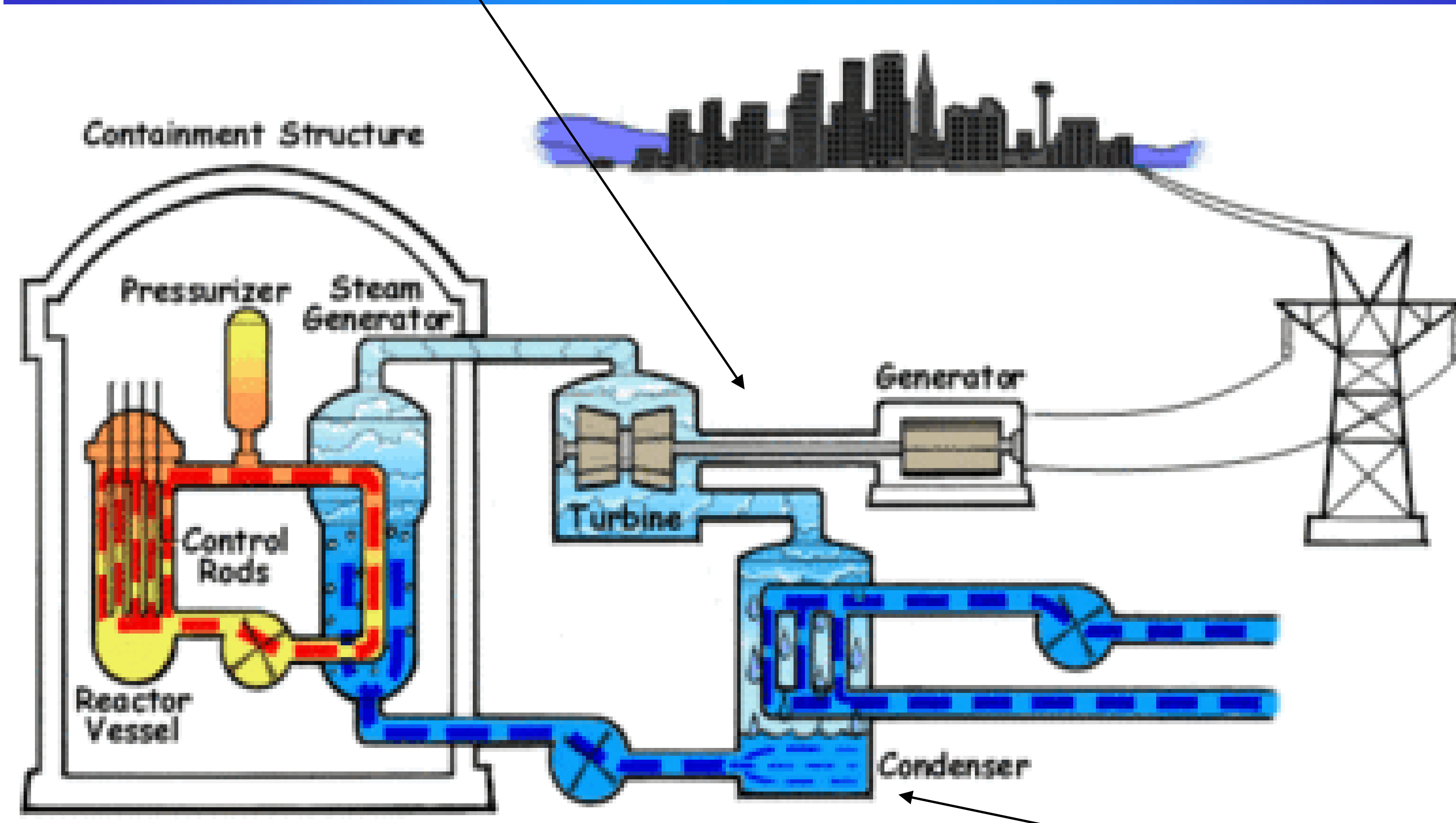
3. Pressurized, 150 atm, borated water flows though reactor at 315 °C, absorbing heat and neutrons.

4. Heat from pressurized light water is transferred to a secondary loop: heated water generates steam.



5. Reactor vessel water and steam does not mix, just the heat is transferred between pipes.

6. Steam spins the turbines, and turbines spin generators, thus generating electricity.



7. Steam flows into cooling tower pipes; heat exchange between coolant pipes and steam pipes causes water to condense.

Why is the water pressurized?

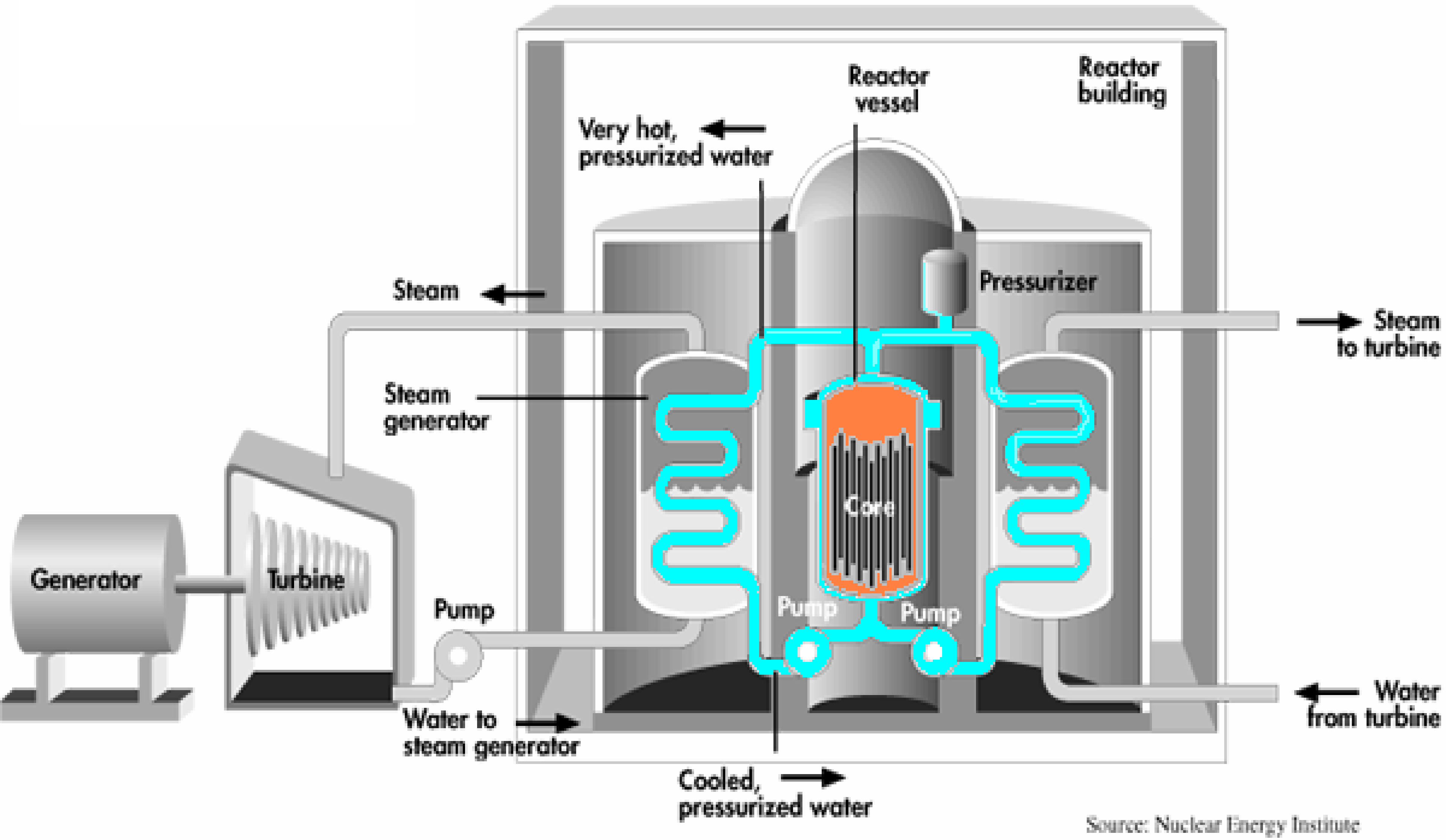
•Pressurization at 150 atm keeps 315 oC water from boiling.

•Specific heat capacity of water = 1.0 cal/g ^{o}C, and the heat capacity of steam is 0.4 cal/g ^{o}C.

•So water absorbs more energy than steam per degree Celsius, and is therefore a more efficient coolant.

• If the water in the tank and the primary circulation loop were to boil, heat would build up quickly in the core. Over heating would cause a reactor meltdown (China Syndrome).

8. Borated water in the inner loop transfers heat from the core. An inevitable small amount of rust and corrosion may cause the inner loop become contaminated with radiation.



Note Check

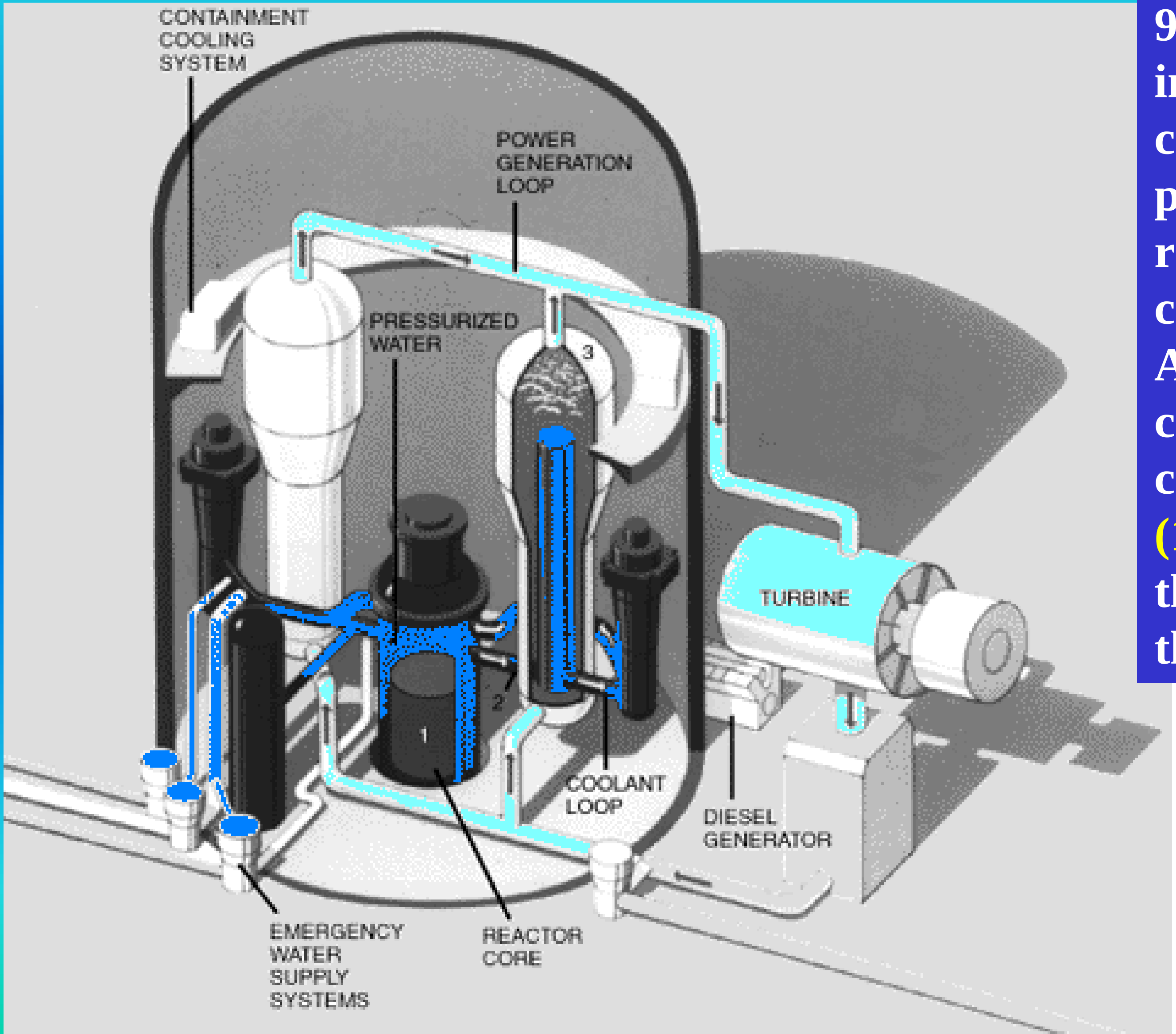
removed

Heat generated in fission process is ________ from the core of the reactor with separate cooling systems.

Water or graphite is used to remove the heat and fresh cold water is circulated at a rate of about 15,000 L/s to keep the core from overheating.

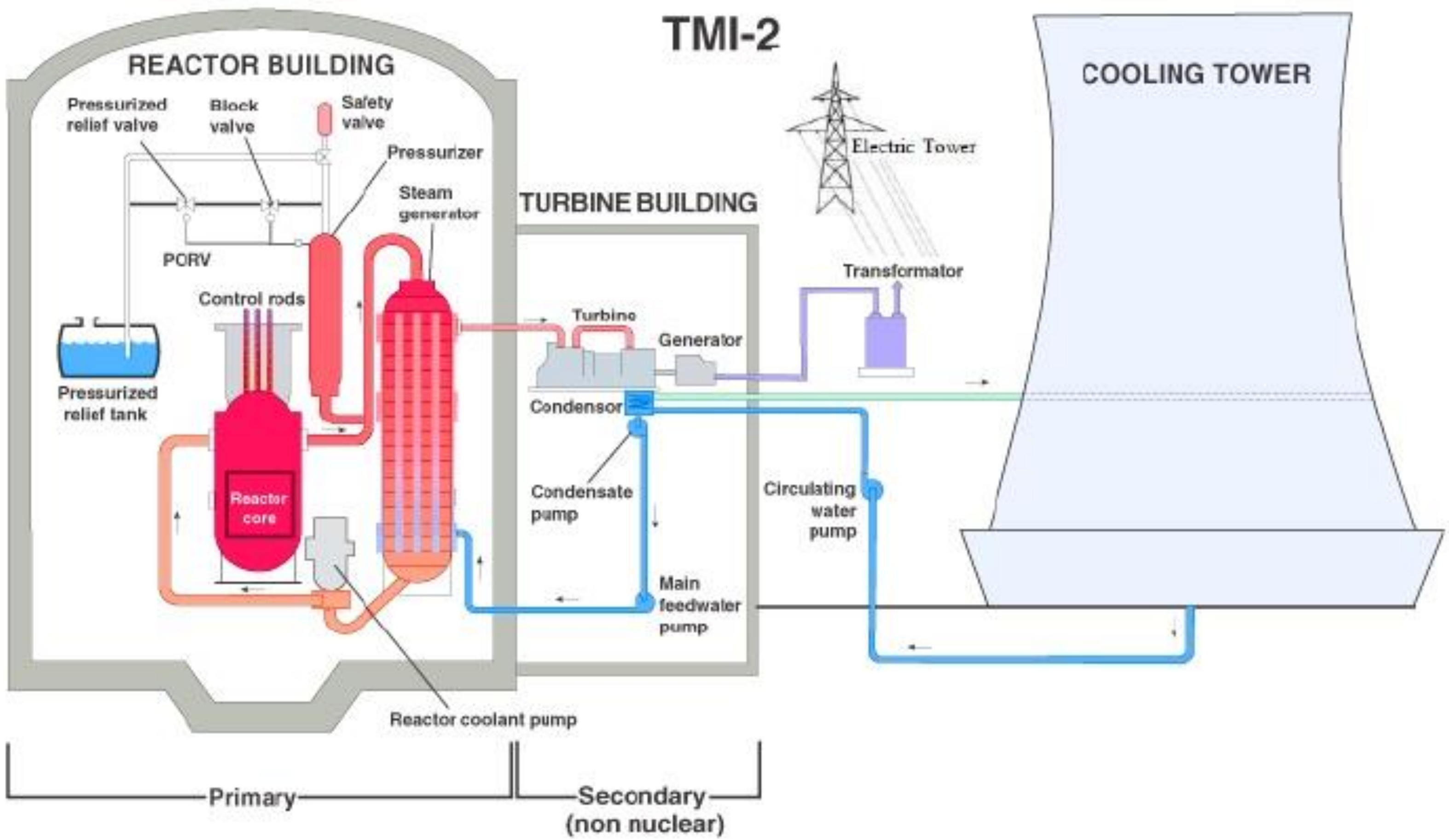
Back up emergency core cooling systems are designed to be used if one of the systems experiences failure of a pump or valve.

Emergency Core Cooling System (ECCS).

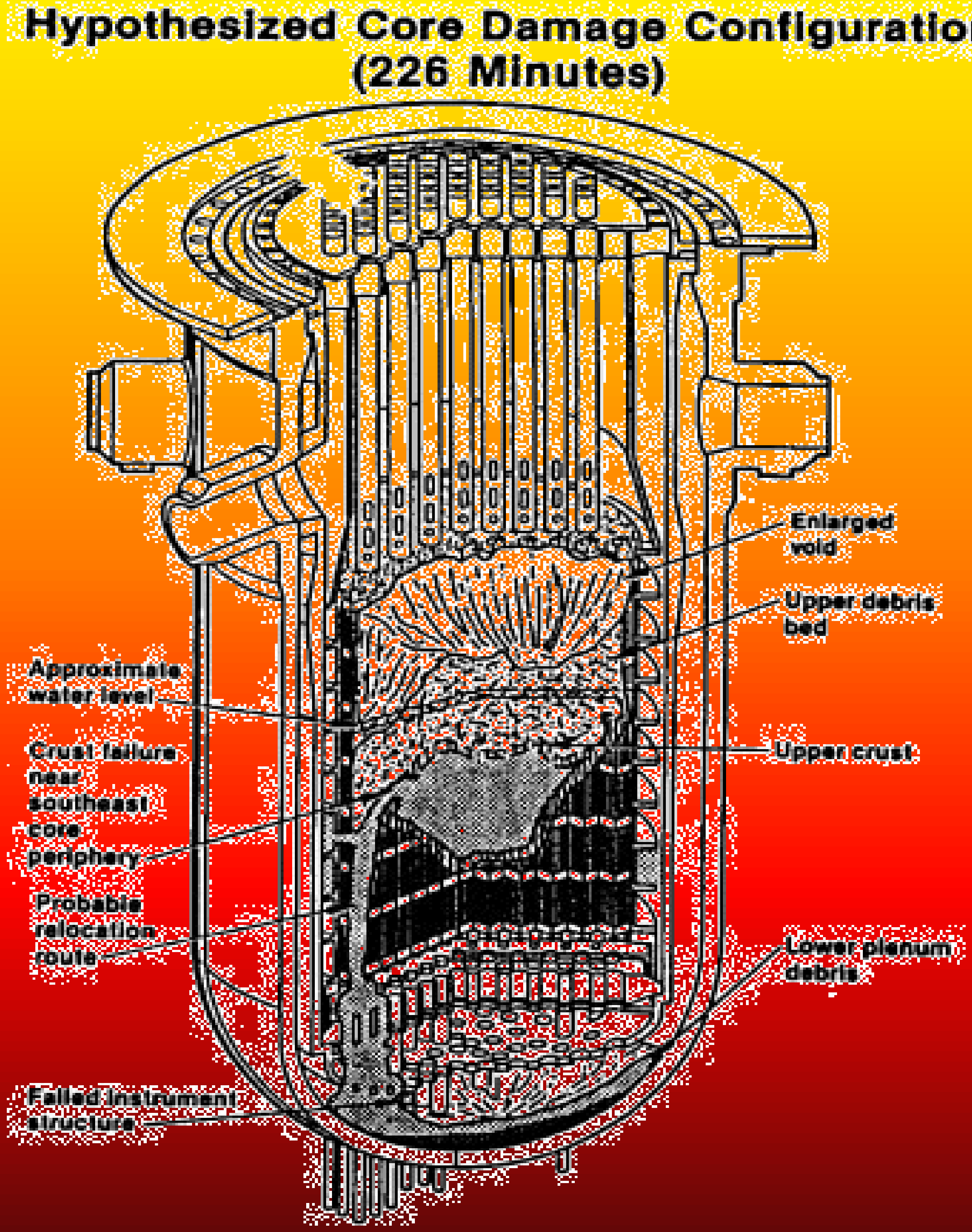


9. There are filters in this inner loop to capture the small particles which are radioactively contaminated. Additional pumps circulate emergency cooling water (15,000 L/s) through the core, which form the ECCS.

Three Mile Island Pressurized Water Reactor Schematic



Credit: U.S. Nuclear Regulatory Commission.
Graphic Adjustments; L. Landolfi



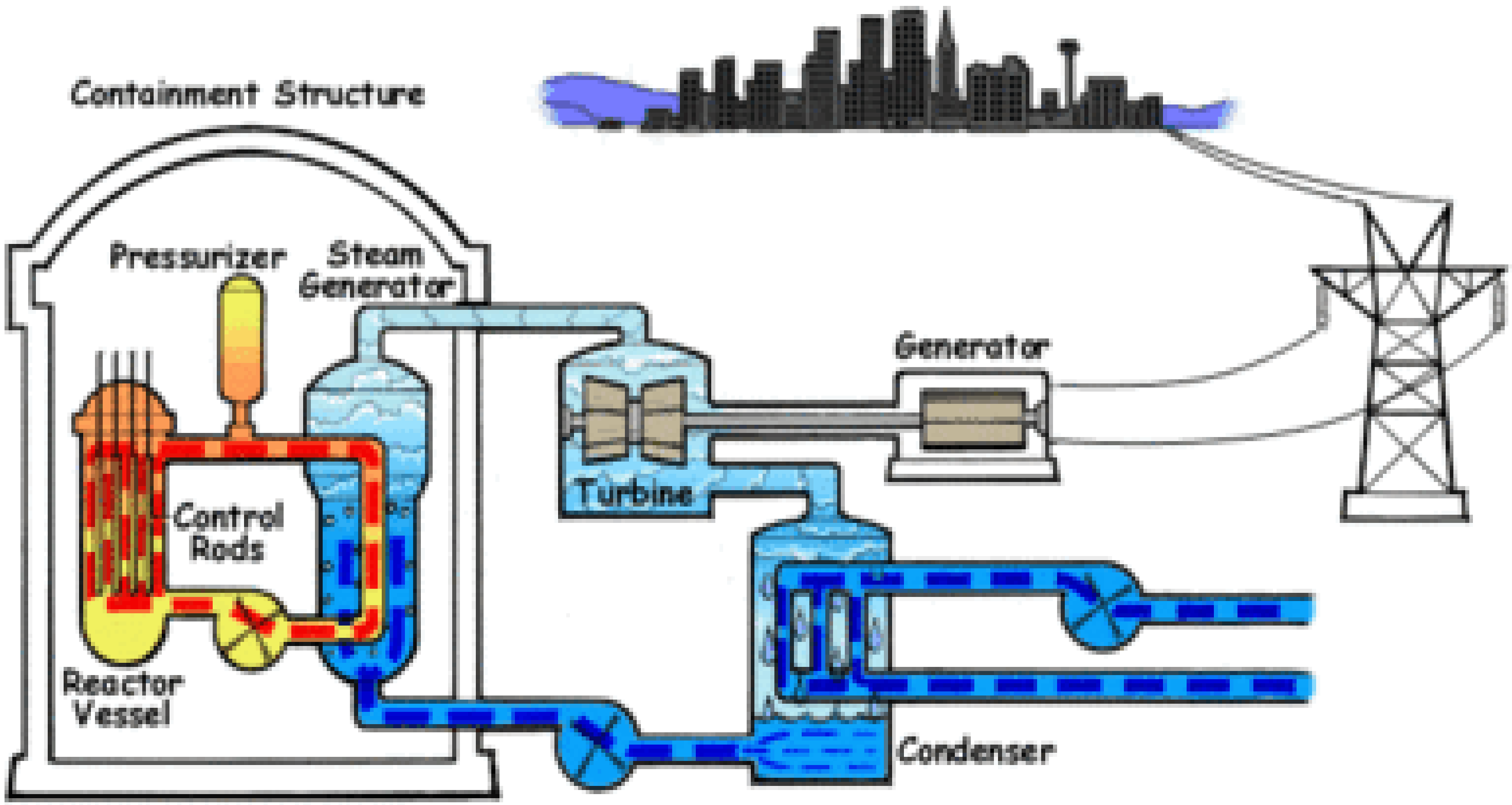
TMI-accident

Where the core is exposed…the fuel rods melt. China Syndrome means if the core gets too hot it melts the earth all the way to China.

Why can’t the water boil?

- Steam is a much poorer conductor of heat. The fuel rods are supposed to always stay under water. To prevent boiling, the tank and primary loop are maintained at very high pressure.
- Note that there is a pressure relief valve to prevent excess pressure from bursting the tank.

Containment Structure



Heavily reinforced concrete contains the pipes for the coolant and the reactor vessel core.

Quiz

Please answer the next six questions on a sheet of paper.

1. What happens to start a chain reaction?

   A. Fuel rods are turned on.

   B. Control rods are inserted.

   C. Control rods are removed.

   D. Neutrons are inserted.

2. What is the purpose of the pressurized water?

A. To remove heat from the core

B. To remove radiation from the core

C. To produce neutrons for the chain reaction

D. To condense the steam from the turbine.

3. About how much water moves through the core per second?

A. 100, 000 Liters/s

B. 50,000 Liters/s

C. 15, 000 Liters/s

D. 1,000 Liters/s

4. Since steam is a poor conductor of heat, if the water in the core coolant changed to steam…

A. The core would over heat.

B. The fuel rods would melt

C. The reactor vessel would melt its container and travel to China (China Syndrome).

D. All of the above are a possibility.

5. The containment building houses the

A. Reactor Vessel

B. Nuclear Waste

C. Steam Turbine

D. Electrical Generators

6. What kind of water moves within a pressurized water reactor core?

A. Borated water

B. Steam

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