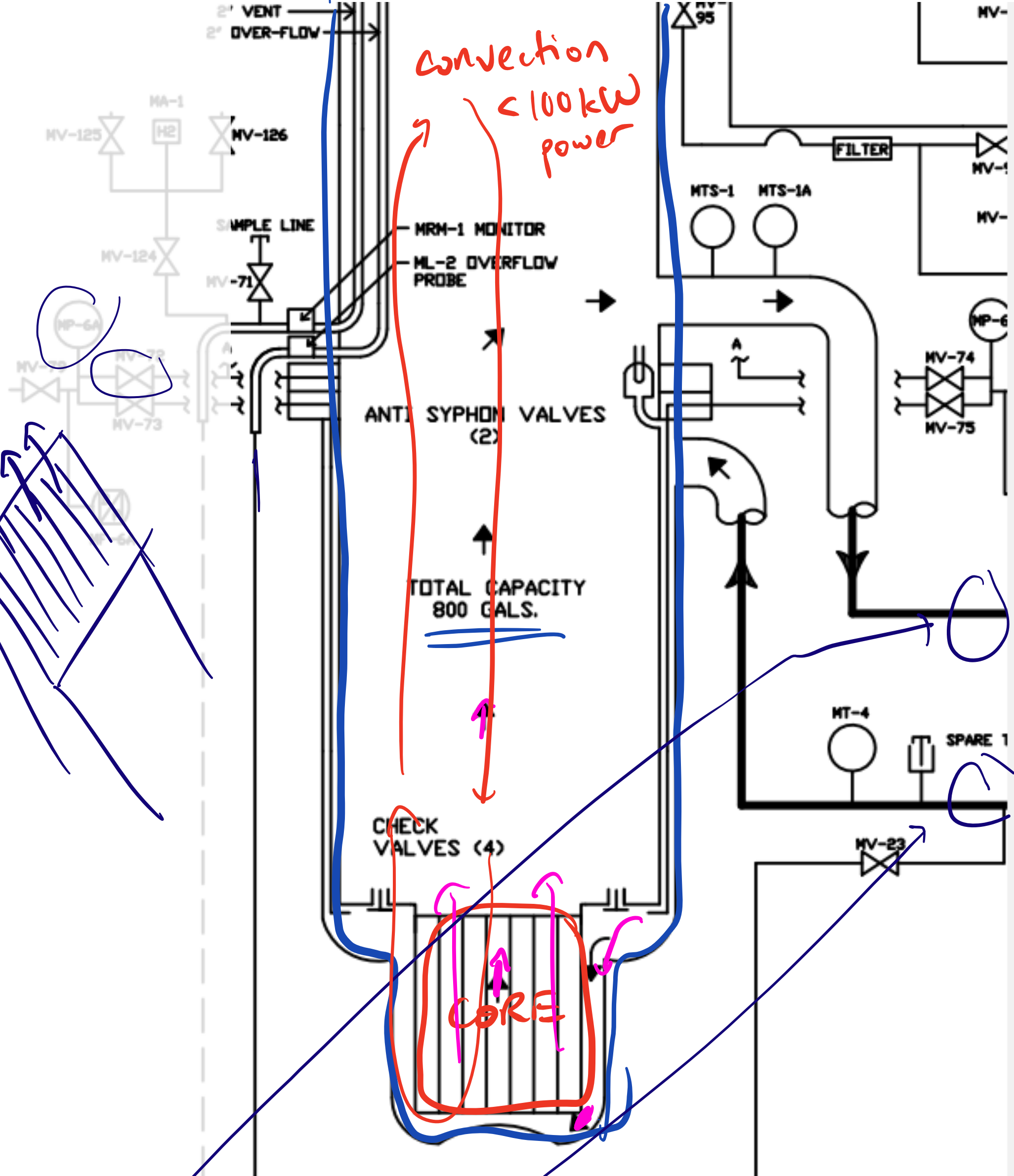
Nuclear Reactors: Science and Operation

ft. the MIT Research Reactor (MITR-II)

Primary cooling

Primary coolant is the coolant that is directly in contact with the core. It's what removes heat from the core itself to prevent fuel from melting (at MITR, this is the design basis accident).

Primary coolant systems normally consist of a core tank filled with light water, pumps to circulate coolant, and a way of removing heat.



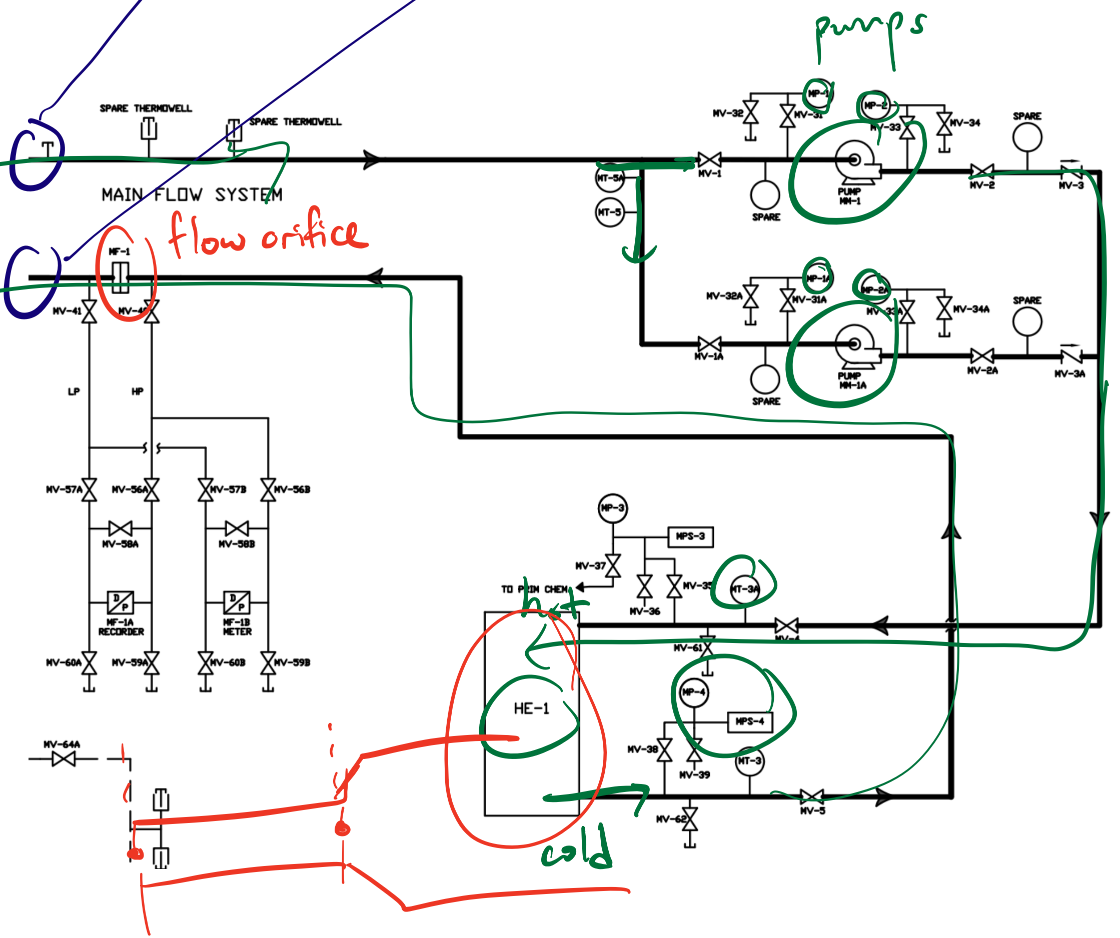
TS (Tech Spec):
1800 gpm @ full power

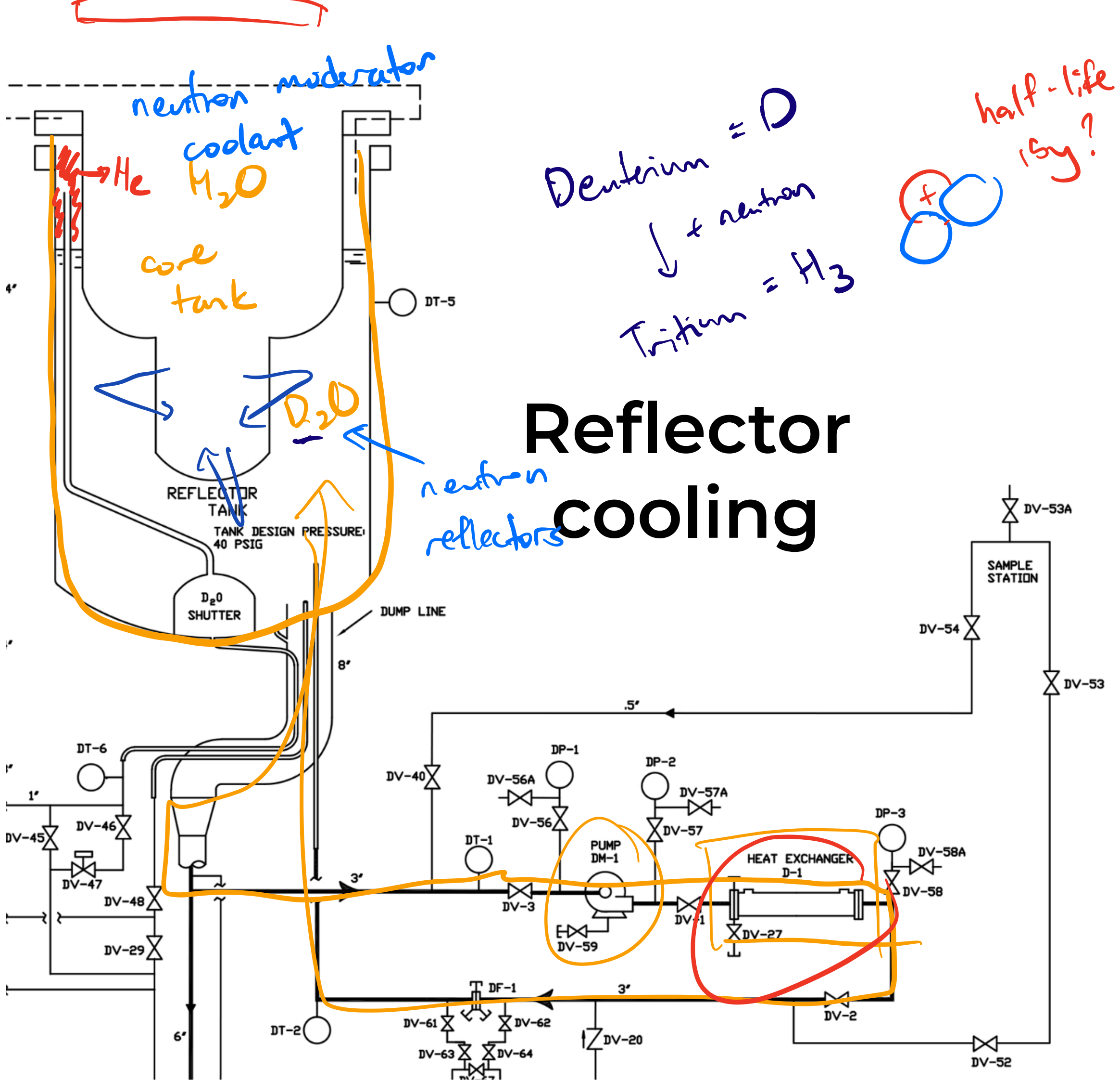
Primary cooling

Hot water rises to the top of the core tank and is drawn into the outlet pipe by two pumps.

These pumps push the water through a heat exchanger where it gets cooled, then sent back to the core tank.

Time for a poll: how much water is pushed through the system per minute? 2000 gpm





Reflector cooling

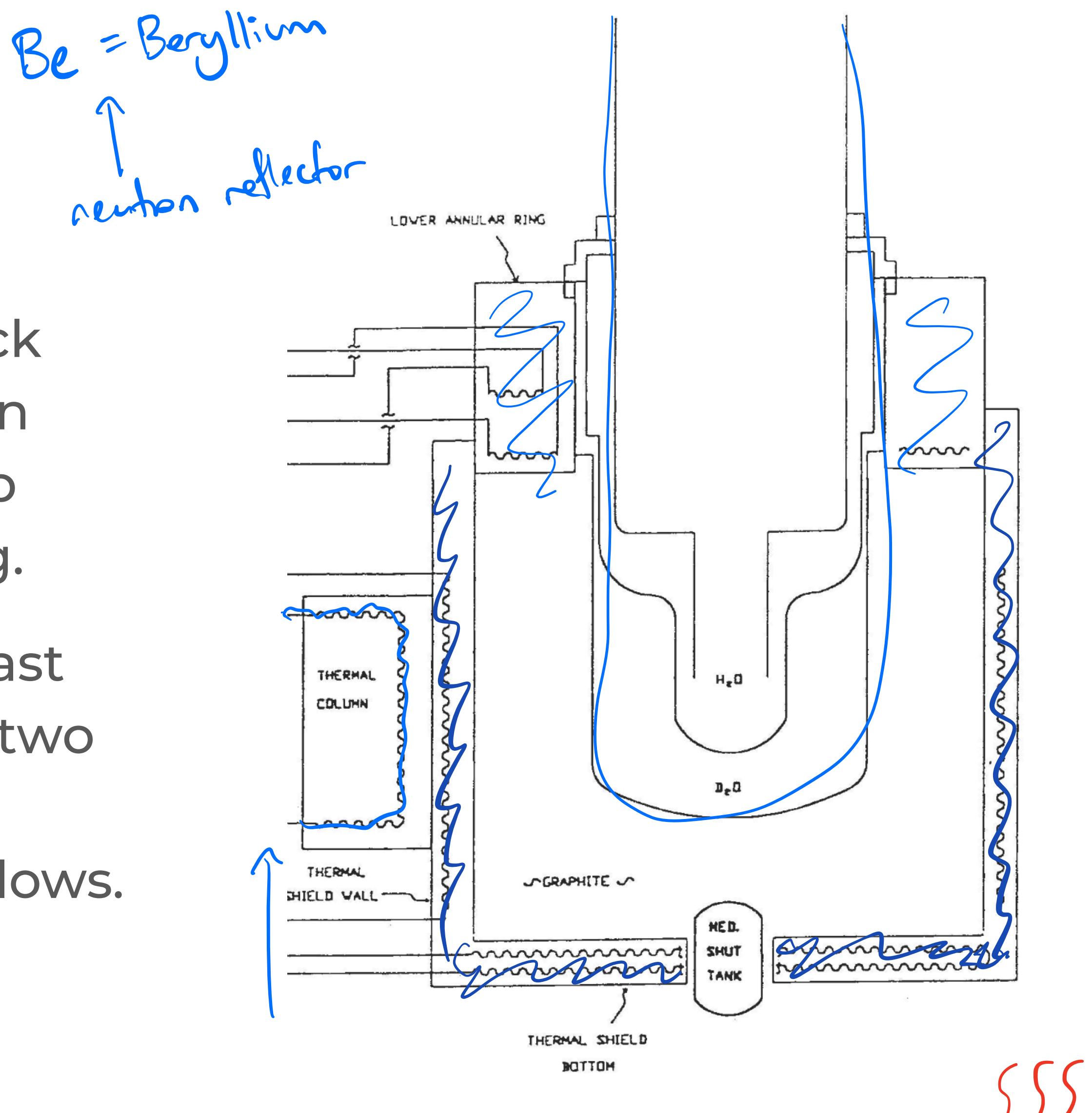
The heavy water reflector tank has its own cooling system; it is very similar to the primary (light water) system.

One concern with heavy water is that deuterium can become tritium under irradiation, which is a longer-lived, more dangerous radioisotope. The reflector tank is therefore sealed completely to prevent leakage (heavy water is also expensive).

Shield cooling

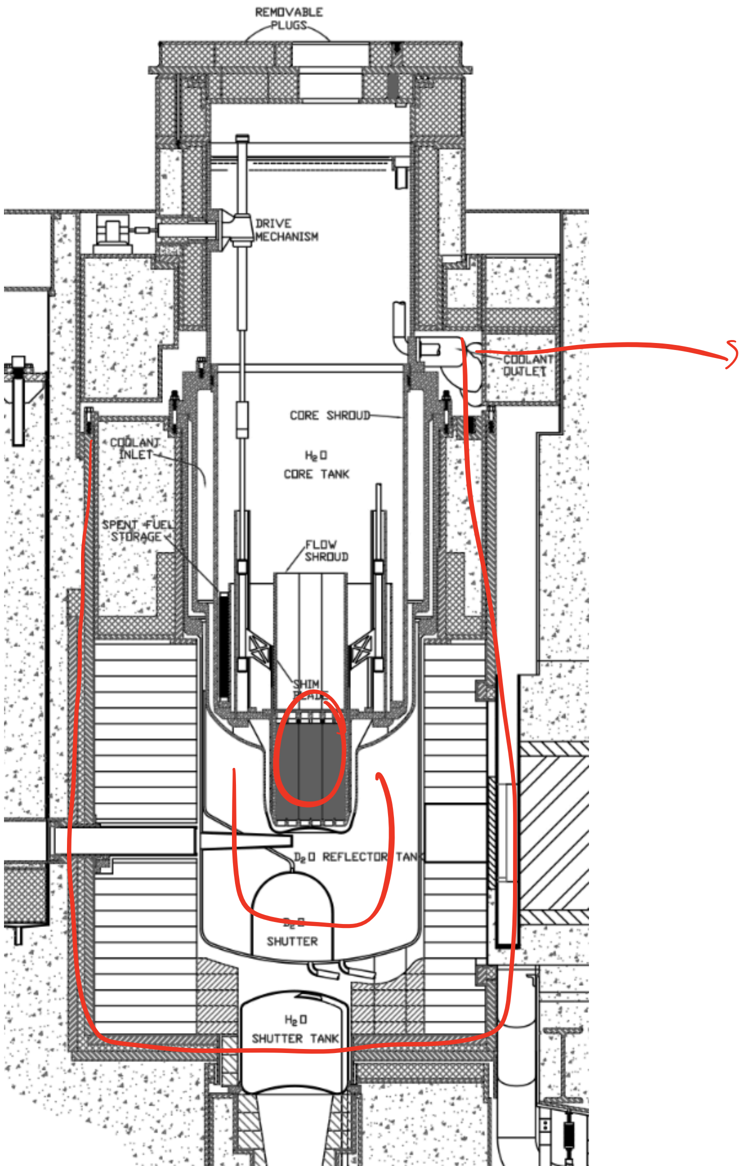
MITR has a steel and lead shield around the tanks in order to block gamma radiation (more on this in week 4). This shield also heats up and can melt if not given cooling.

This system is simpler than the last two; each piece of shielding has two cooling coils embedded inside, through which cold light water flows.



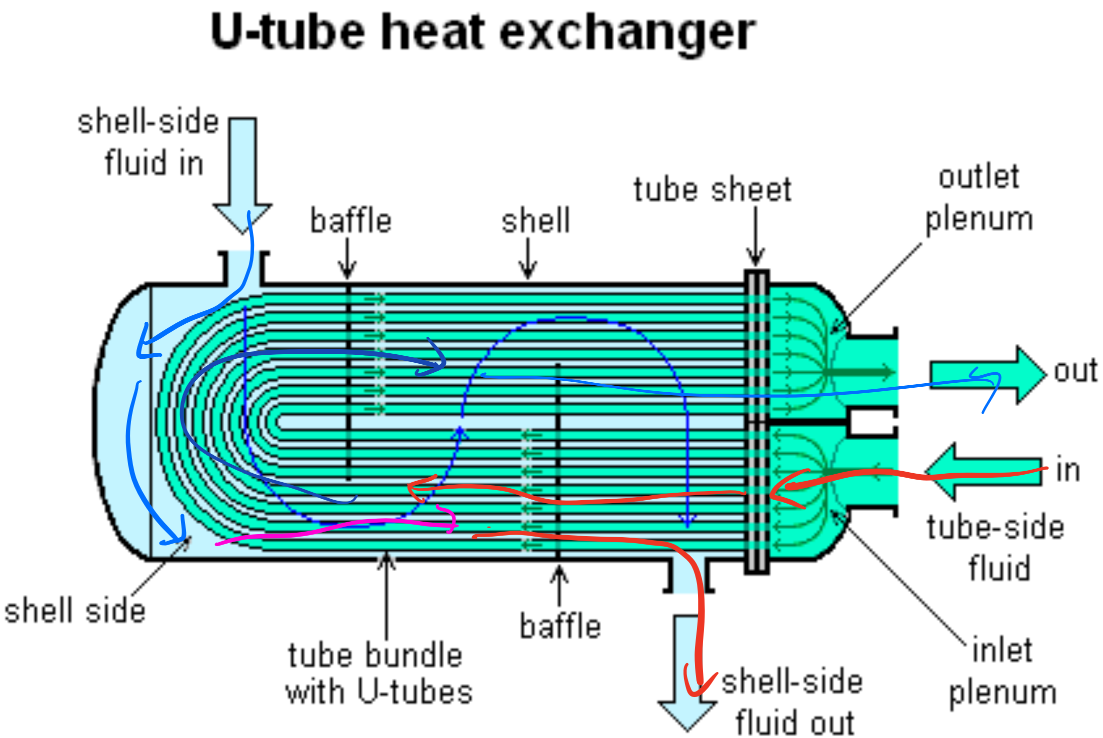
Secondary cooling

All of the above systems draw heat away from critical reactor components, which then needs to be dissipated somewhere. This is the job of secondary cooling - to remove heat from primary cooling systems and dissipate it elsewhere.



Secondary cooling

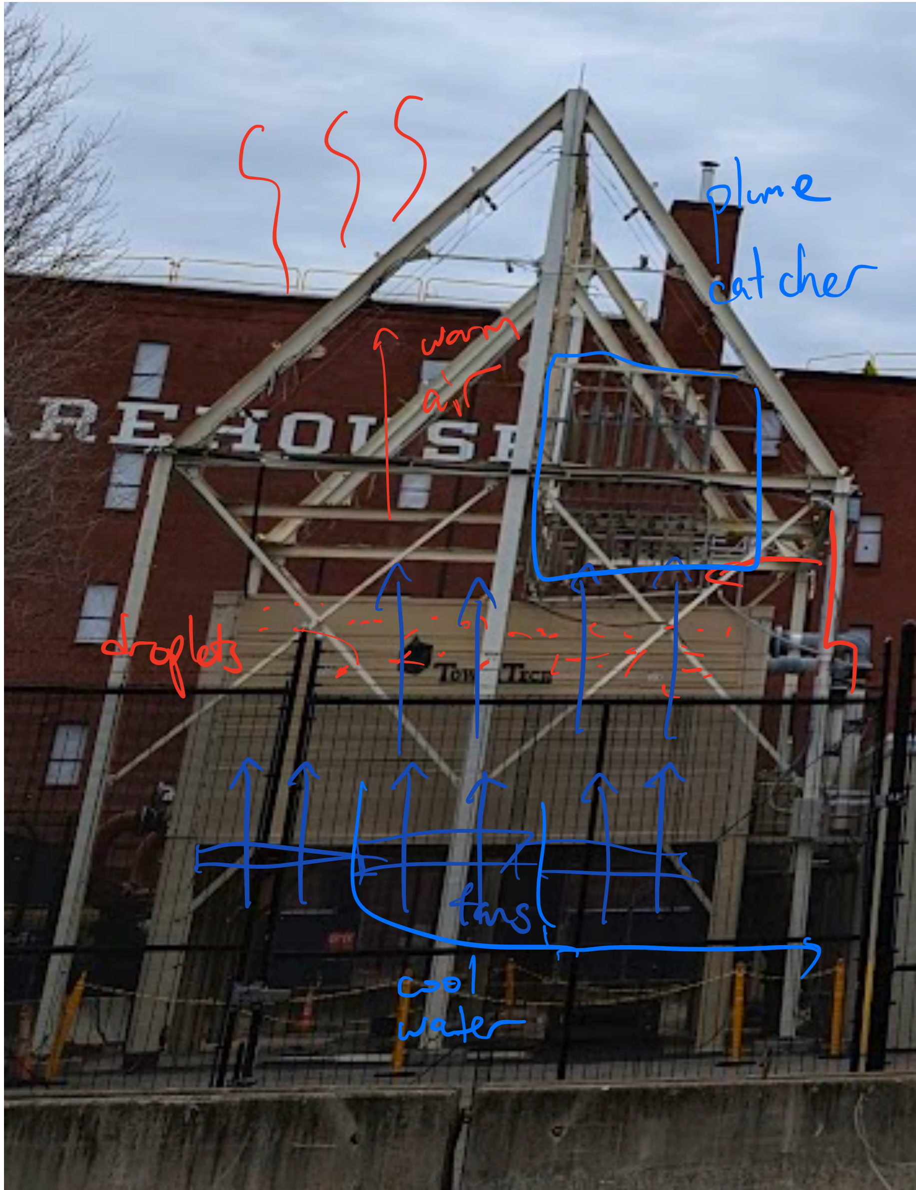
Secondary coolant meets the primary coolant (but doesn't mix!) at a component called a heat exchanger. This cools the hot primary coolant while heating the cold secondary coolant, effectively transferring heat out of the primary system.



Secondary cooling

At the MITR, heat from the secondary system is exhausted to the environment via a pair of cooling towers in the backyard.

These spray warm secondary water as droplets and blow cold air through those droplets; the droplets lose their heat to the air and condense back.

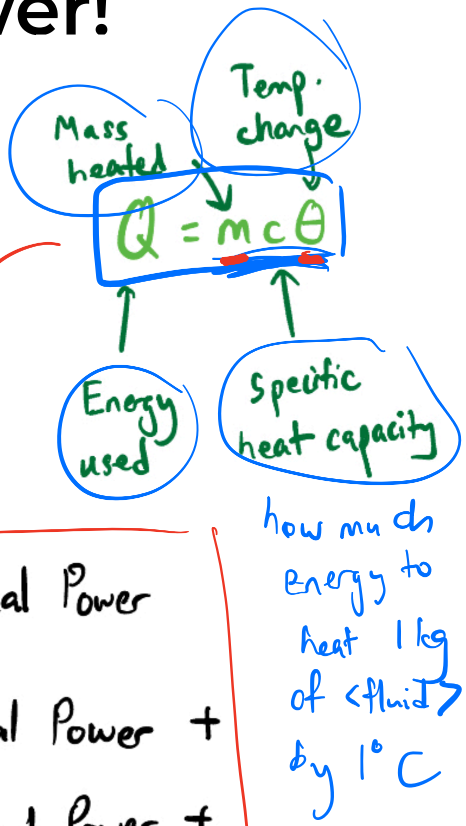


Detour: calculating reactor thermal power!

Last week we mentioned that MITR's power is measured using its thermal (heat) power output. This is actually not a difficult calculation!

Since the heat isn't being converted to any other forms of energy, the heat generated by the reactor must all be exhausted to the secondary system. We just add up the total heat from the primary, reflector and shield systems.

We are making one assumption here...



Total Thermal Power

= Primary Thermal Power + Reflector Thermal Power + Shield Thermal Power

Detour: calculating reactor thermal power!

The big assumption we made is that **the reactor's temperature is stable**; in other words, in equilibrium.

If the reactor is still heating up, then not all of the heat will go into the secondary system.

Making this assumption allows us to get the total thermal power as:

$$= \text{Primary Flow} \times (2.62 \times 10^{-4}) \times \text{Primary } \Delta T + \text{Reflector Flow} \times (2.91 \times 10^{-4}) \times \text{Reflector } \Delta T + \text{Shield Flow} \times (2.62 \times 10^{-4}) \times \text{Shield } \Delta T$$

gallons per minute

H_2O

D_2O

°C

light water

heavy water

Flow rate of water through system

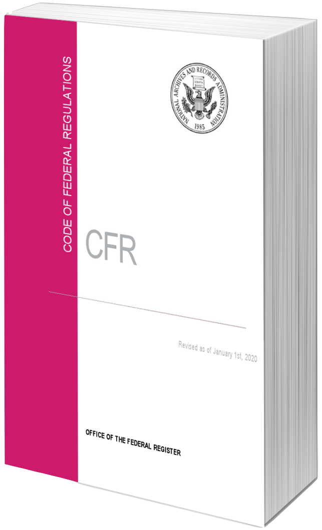
Specific heat capacities for light/heavy water

Delta-T: temperature change

Why are there separate cooling systems?

Main reason: primary water passing by the core will become radioactive! This water should (legally and ethically) never be exposed to the environment.

10 CFR is the federal code governing nuclear facilities.



dilute our waste

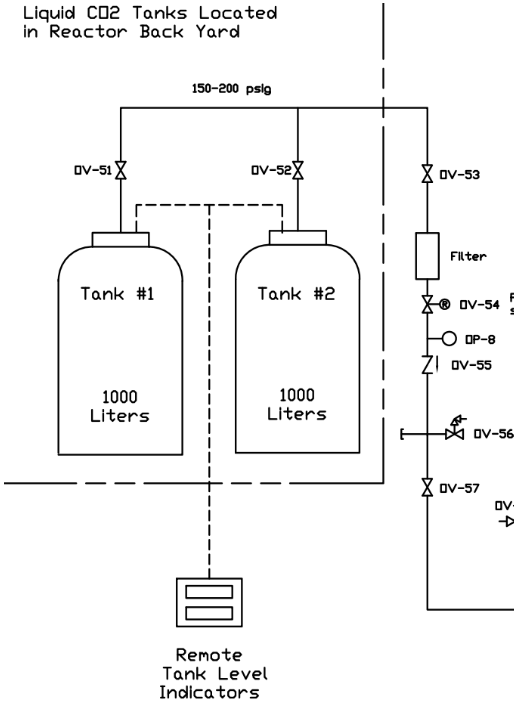
In many cases, it's also impractical to cool primary water by evaporating it, such as MITR's heavy water reflector or many power plants' pressurized coolant.

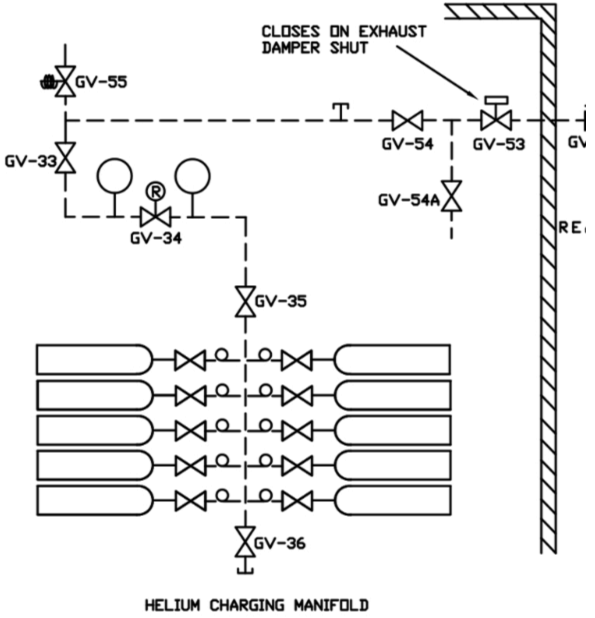
Primary water is also usually kept extremely clean and pure to avoid any corrosion damage to important components.

Gas systems

The core tank of MITR is covered with normal air - it has to be, since any other gas would escape when the reactor top lid is opened.

However, several other sealed systems are filled with nonreactive gases like helium and carbon dioxide, supplied from industrial tanks.





Gas systems

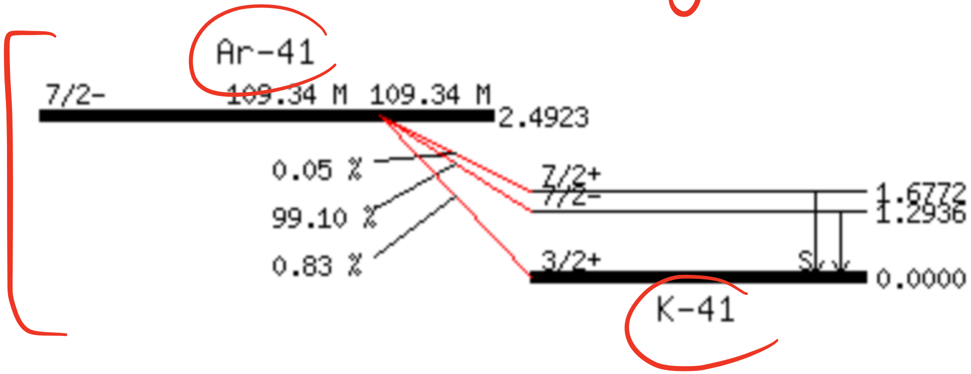
These cover gases remove regular air from systems such as the reflector tank.

Air contains moisture which can cause corrosion, or in the case of the reflector tank, contaminate the heavy water.

noble gas

When irradiated, argon in the air forms argon-41 which is also a dangerous radioisotope.

β decay of Ar-41

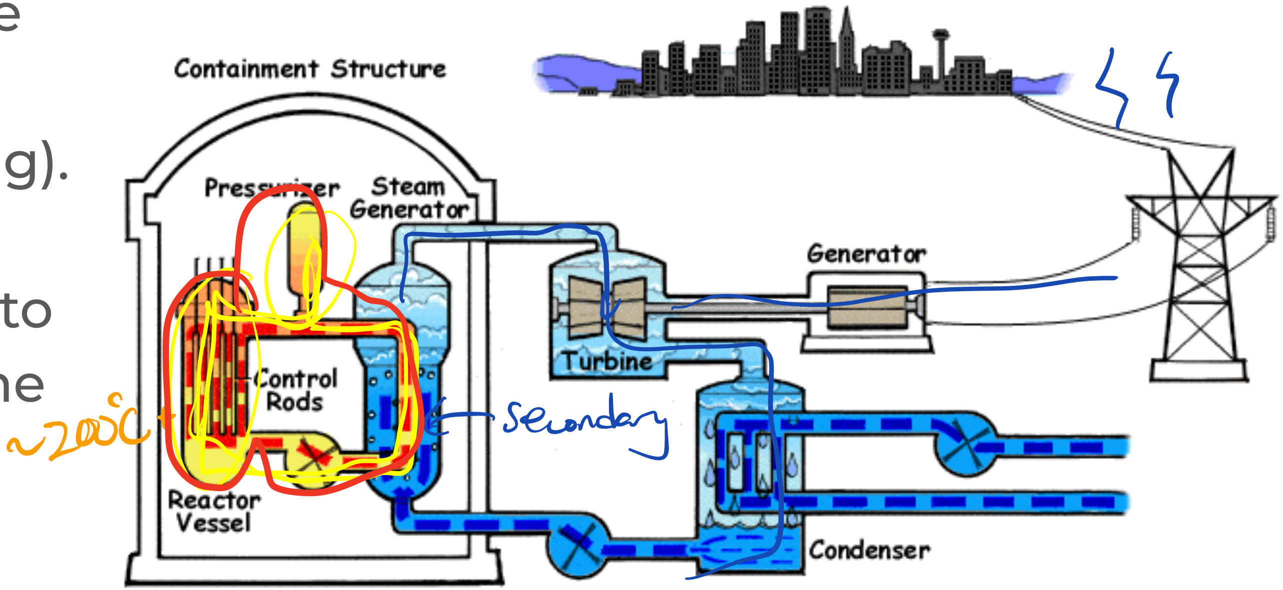


Generating power!

Pressurized water reactors (PWRs) are the most common reactor type in modern nuclear power plants.

PWRs have high-pressure water as their primary coolant (to prevent boiling).

Secondary coolant turns to steam and drives a turbine to generate electricity.



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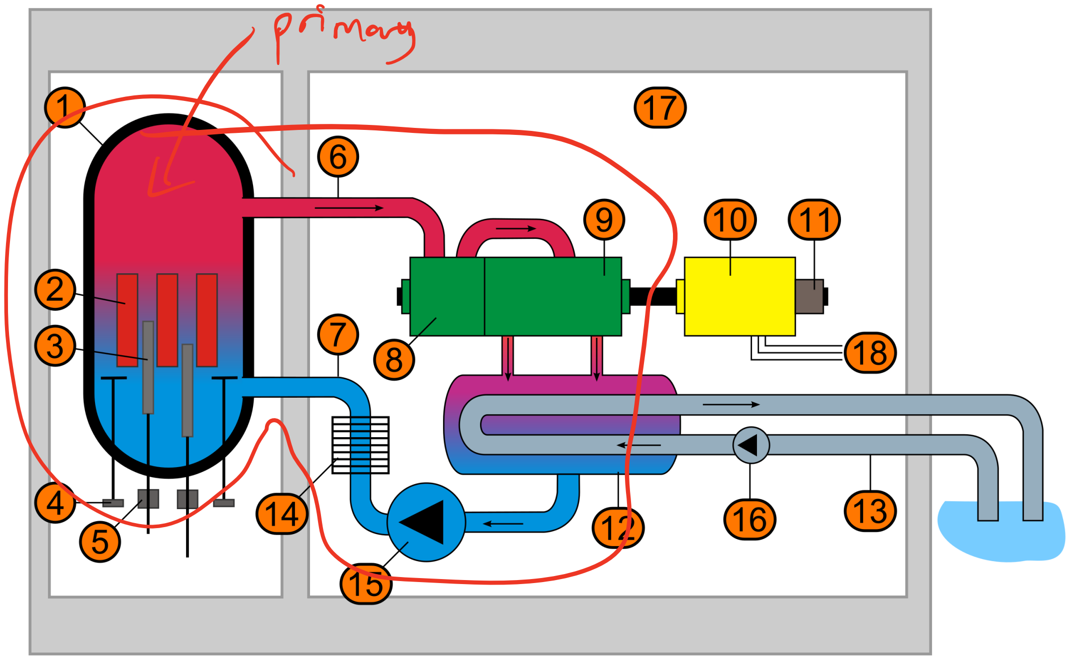
Generating power!

Alternatively, some reactors are boiling water reactors (BWRs) in which the primary coolant boils to steam and drives a turbine directly.

BWRs can be more efficient, but may be expensive to maintain since the radioactive primary coolant flows through the turbines, and they have larger pressure vessels.



Thanks for coming today!

Enjoy a cool picture of the reactor at night :0

(no it's not on fire, the plume is fog from the evaporating secondary coolant, lit up by our outdoor floodlights!)