Nuclear Reactors: Science and Operation

ft. the MIT Research Reactor (MITR-II)

Welcome!

Week 1: Intro, reactor core
Week 2: Process systems
Week 3: Control and operation
Week 4: Radiation shielding
Week 5: Safety systems
Week 6: Virtual tour or CYOA

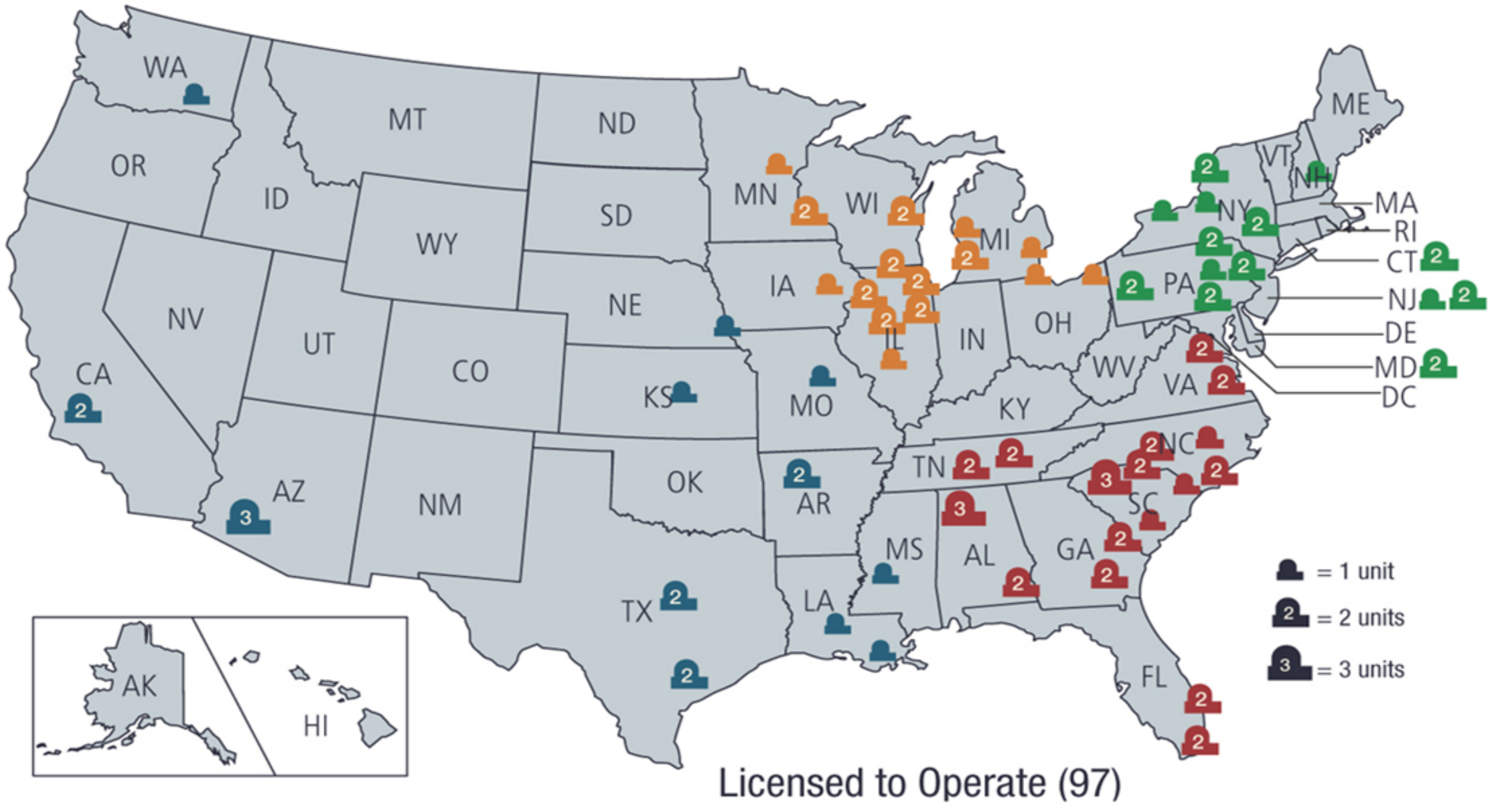
A little about me: Rising junior at MIT majoring in mathematics, currently training to be an operator at MITR! I can be reached at s15628-teachers@esp.mit.edu.

Nuclear power in the US

Nuclear power plants generate ~20% of electricity in the US. There are ~100 commercial reactors and ~35 research reactors.

MITR is one of the oldest (operating since 1958!) research reactors, and the second-largest university reactor (by power output).

U.S. Operating Commercial Nuclear Power Reactors



Licensed to Operate (97)

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

As of August 2019

Let’s get started..

All matter is made up of things called atoms.

Atoms are the smallest division of something you can get that still behaves the same way. We can break down atoms - in fact that’s what nuclear reactors do! - but the products don’t behave the same as the original.

The center of an atom is called the nucleus, and sometimes when nuclei (plural) react, interesting things happen - hence the name “nuclear reactor”!

What’s in a nucleus?

Nuclei are made up of two types of particles: protons and neutrons.

When nuclei react, they generally do one of two things: split (fission) or combine (fusion).

Nuclear power plants today make use of fission. Fusion can generate much more power (it’s what powers the Sun!) and is much cleaner, but is really, really hard to do.

What kinds of atoms and nuclei are there?

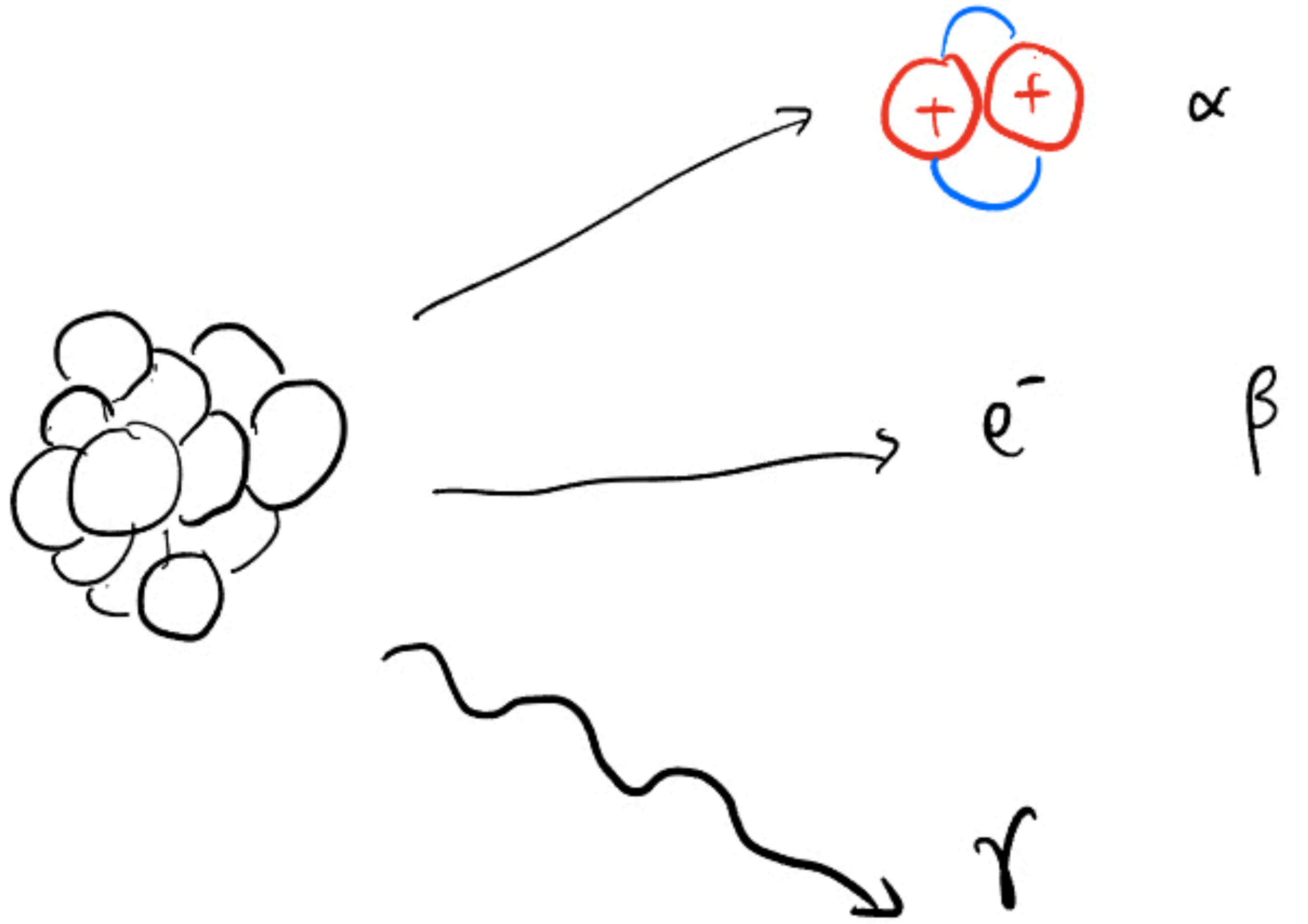
Atoms are classified by the number of protons they contain. A type of atom is called an element, and atoms of the same element share most of their chemical properties. Some elements include oxygen, iron and gold.

Nuclei of the same element are classified by the number of neutrons they contain. Isotopes of an element are atoms of the element that have different numbers of neutrons in the nucleus. For example, carbon normally has 6 protons and 6 neutrons, but another common form has 8 neutrons. When referring to a specific isotope, we normally use the name of the element followed by its nucleon number, the total number of protons and neutrons it has (e.g. Carbon-14 has 6 protons and 8 neutrons.)

Ok, now how do we split nuclei?

Some isotopes are stable, meaning that if you leave them for a long time they won't change. Most common materials are this way (otherwise they'd break down and we wouldn't find them...)

Other isotopes are unstable, meaning that they will break down on their own. This is known as radioactive decay, and it is a completely random process. Some isotopes decay almost instantly, but others may decay slower. There are three main types of radioactive decay: alpha, beta and gamma.



Ok, now how do we split nuclei?

When we send neutrons into nuclei, sometimes a nucleus will absorb a neutron, causing it to become a different isotope. The incoming energy of the neutron is also absorbed, making this an excited nucleus. Often, this new nucleus is unstable.

At this point, a couple of different things can happen:

- The nucleus spits out another neutron.
- The nucleus releases the energy as gamma rays and settles down.
- The nucleus splits into smaller nuclei, releasing some energy and maybe more neutrons. This can cause a fission chain reaction.

Fission chain reactions - the key to nuclear power

When a Uranium-235 (the most common nuclear fuel) atom splits, on average ~2.43 neutrons are produced. These neutrons can go on to cause more atoms to split, causing a chain reaction.

Under normal conditions, it’s difficult to achieve a critical mass - criticality is the point at which the fission chain produces at least as many neutrons as it consumes, so the reaction can sustain itself. This is because many of the neutrons are lost to the environment.

Where does the energy come from?

You might have heard of Einstein's famous $E = mc^2$.

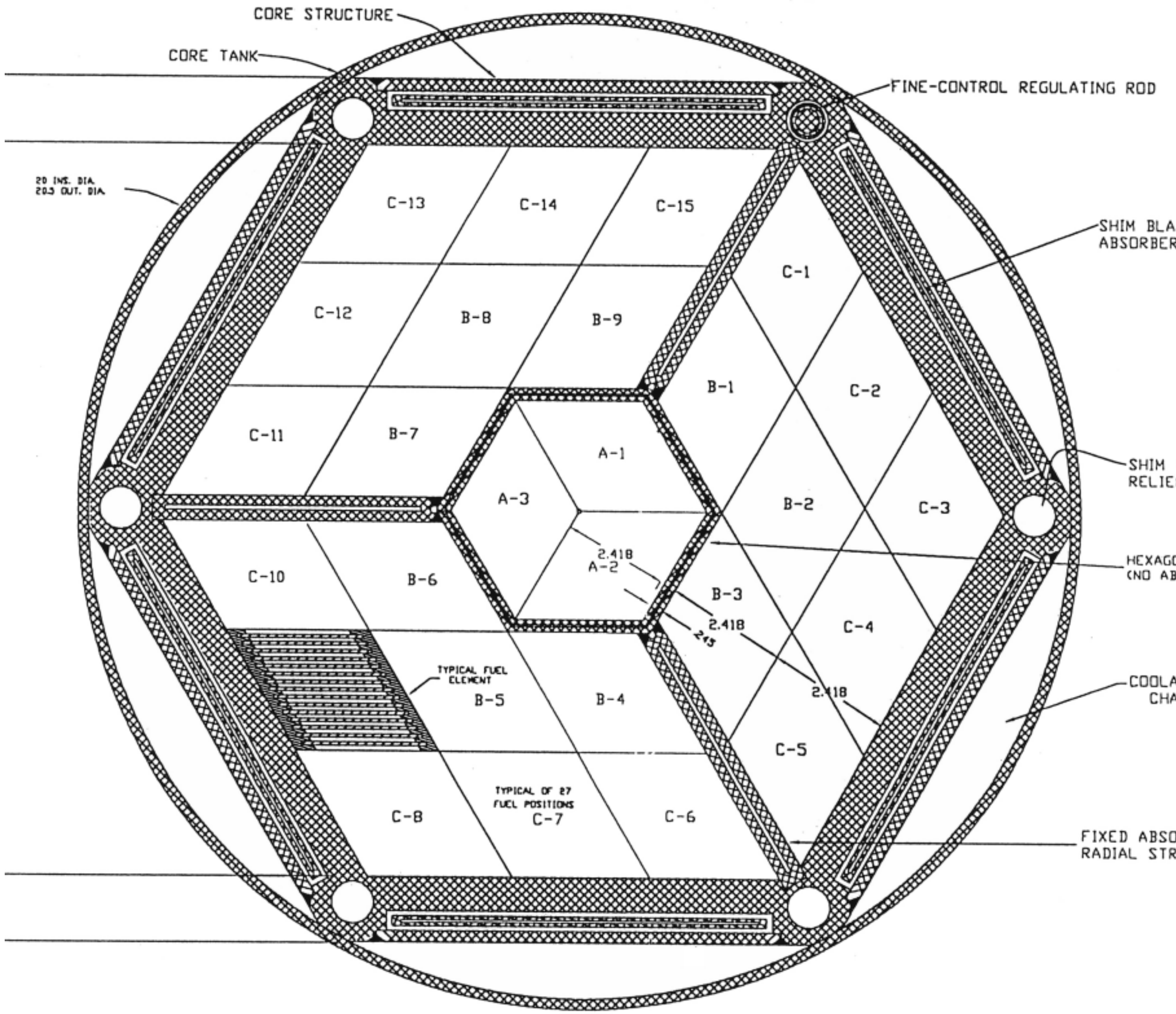
Every nucleus has a property called a mass defect, which is essentially the difference between the sum of the mass of the protons and neutrons they contain, minus the actual measured mass of the nucleus.

How can there be a difference? Binding energy - some energy is stored in the bonds between particles. When nuclei break apart, the mass defect/binding energy can change, and excess energy is released.

The core

Holds the nuclear fuel where the magic happens :0

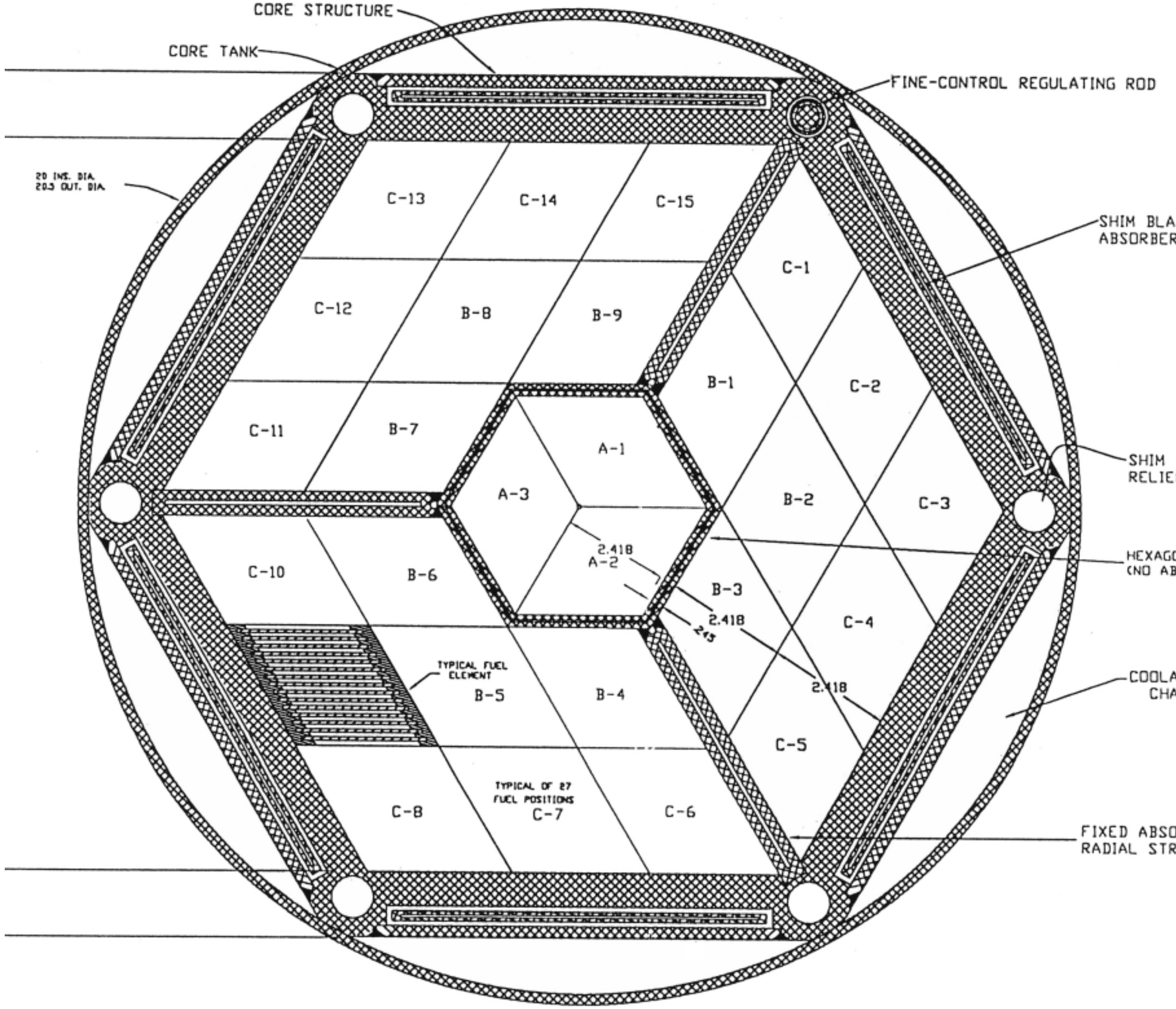
Generally, reactor cores have some number of fuel elements, which each hold some nuclear fuel. Usually, this is uranium-235: Uranium is an element with 92 protons, and the 235 indicates 235 total nucleons, which are protons plus neutrons. U-235 is an isotope of uranium.



The core

MITR-II's core has 27 locations for fuel elements, arranged in three rings labeled A, B and C. These have 3, 9 and 15 positions respectively.

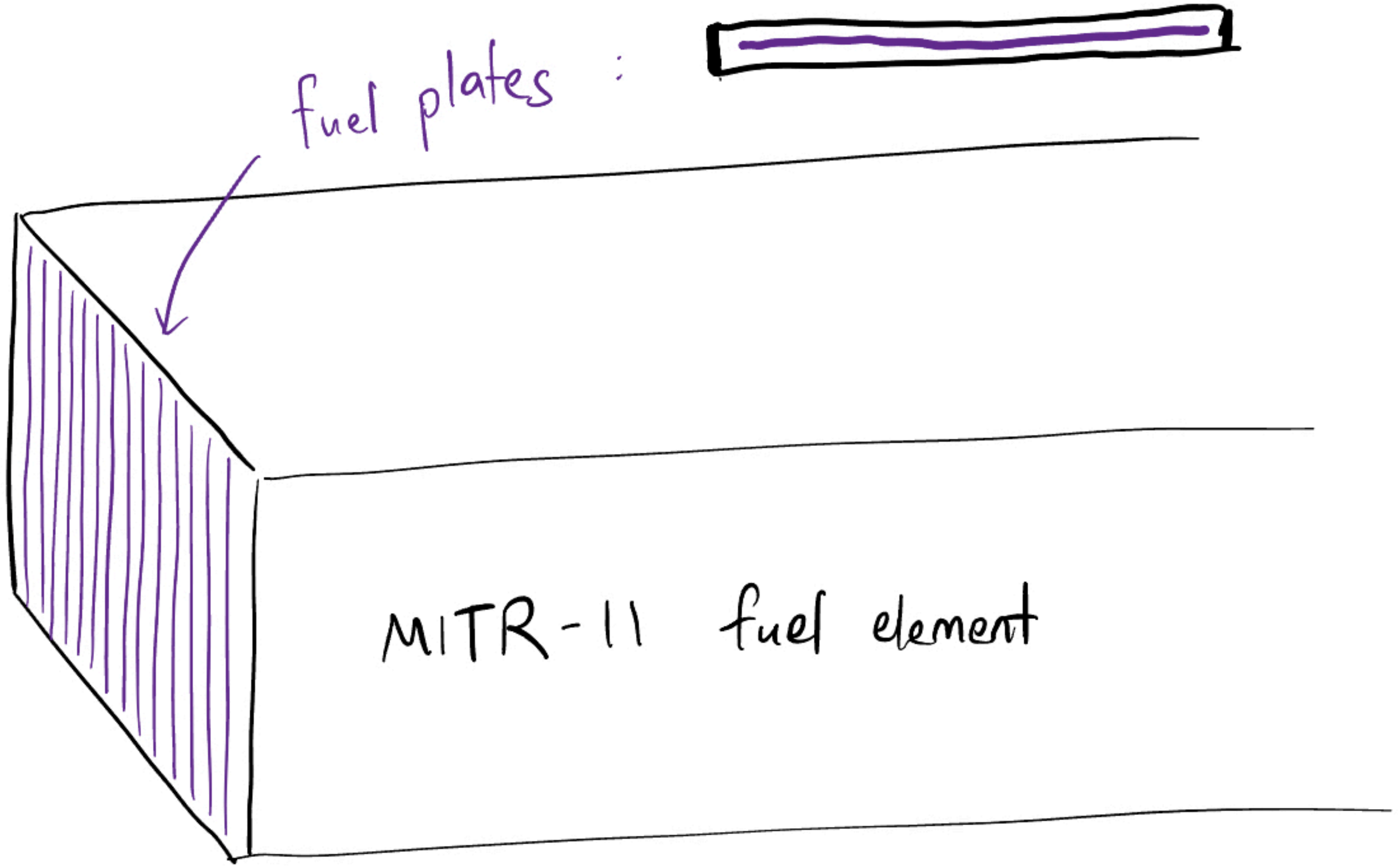
Time for a poll: how big do you think the core is? Think back on the picture of our reactor building...



A fuel element

Fuel elements can take many shapes and sizes at different reactors; at MITR, they're prisms with a diamond-shaped cross-section.

Each fuel element holds many fuel plates, which are like aluminium sandwiches with uranium oxide inside.

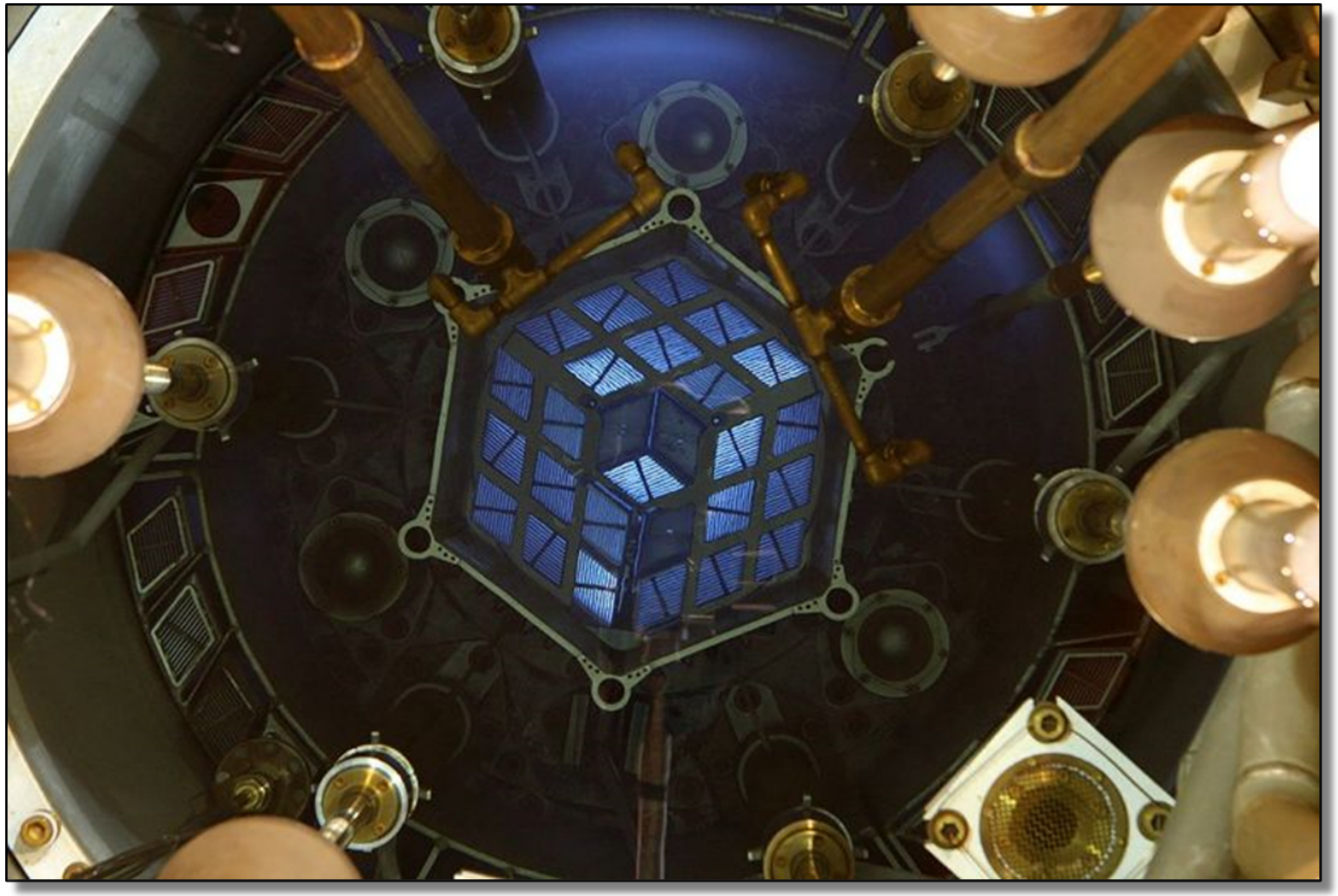


Around the core

At the MIT reactor (MITR), the core is surrounded by two tanks of water: the core tank containing light water, and the reflector tank containing heavy water.

Light water acts as a coolant and neutron moderator.

Heavy water acts as a neutron reflector.

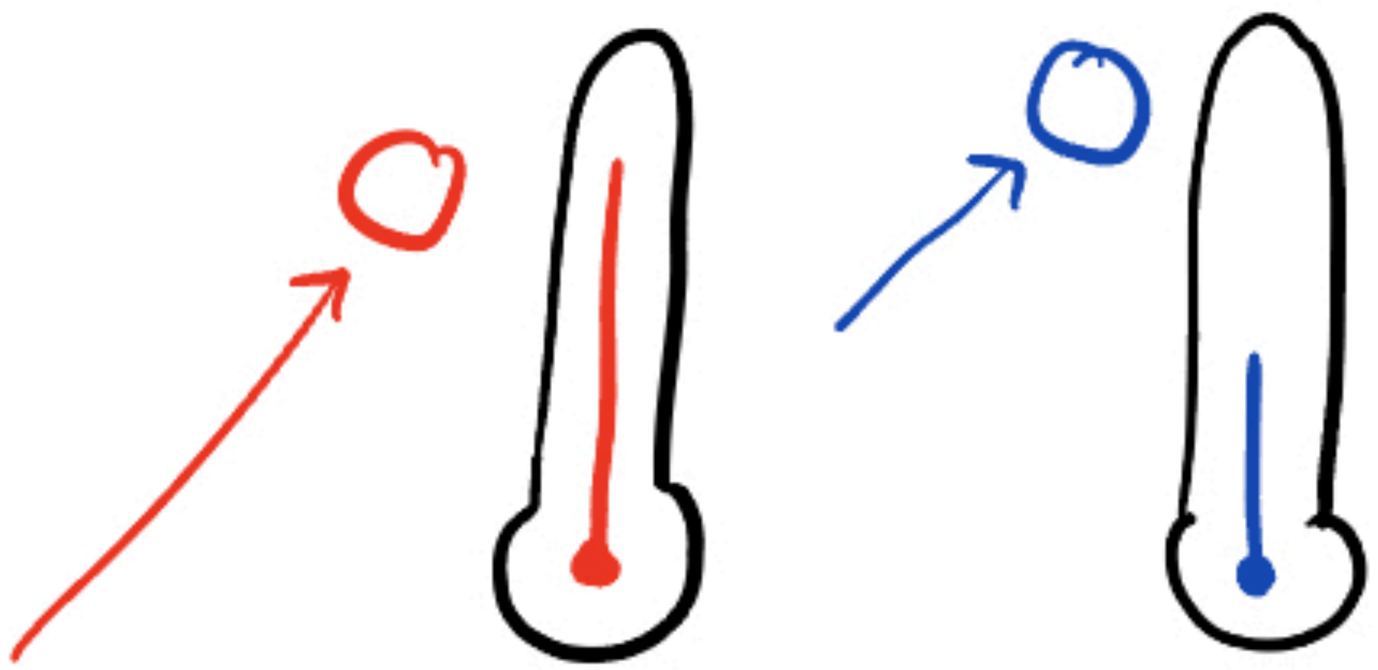


Fast and thermal neutrons

Almost all of a neutron’s energy is in kinetic energy. Fast neutrons refer to high-energy, fast-moving neutrons often emitted directly by a fission.

Thermal neutrons are slower, lower-energy neutrons that have lost energy from collisions with surrounding matter. We call them "thermal" because they’re slow enough to be at normal temperatures.

"Temperature" is a measure of microscopic kinetic energy!



Reaction cross-sections

The chance that a particular nuclear reaction takes place is known as the reaction cross-section, often measured in barns (b), a very small unit of area.

Cross-sections for fast neutrons are generally lower than for thermal neutrons (imagine that it’s harder to catch a fastball). This is why we thermalize the neutrons, to make it easier for the neutrons to create more fissions!