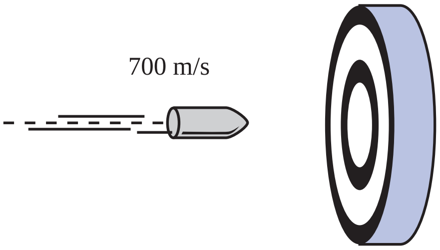
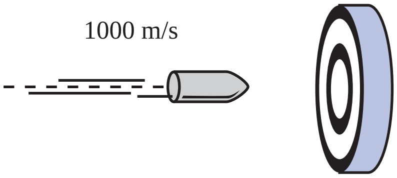
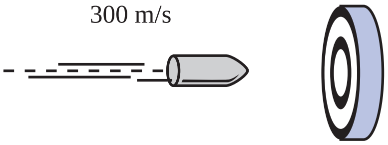
Cross Sections

Basically, in nuclear physics, cross sections are the probability that a certain reaction will occur between two particles for a given set of parameters. Simply, a cross section can be roughly thought of as a target, like one at a shooting range. The probability that a reaction will occur is analogous to the probability of a random bullet hitting its target.

Unfortunately, a nuclear cross section are a little more complicated than that due to quantum mechanical effects. At atomic scales, the wave properties of matter become important and strongly effect the interactions between particles. This means for a specific target, the target’s size varies depends on the energy of the bullet, type of bullet and target, and the kind of interaction between them. Using the shooting range analogy, the target would be larger for bullets with certain speeds, but smaller at others.







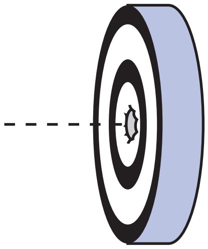
In nuclear power, the “bullets” are neutrons, and the “targets” will be atoms of nuclear fuel, moderators, control rods, and poisons.

In addition, the bullet could interact with the target in different ways, it could be absorbed in to it, be deflected, or cause the target to break apart. This leads to the three important types of cross sections that are important in nuclear energy:

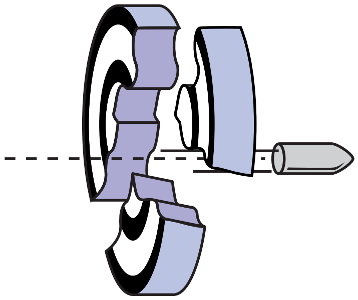
- Absorption: Probability that a neutron will be absorbed and prevent other reactions from occurring. Control rods are used to absorb neutrons and poisons steal neutrons that could have been used for fission reactions.

- Fission: Probability that a neutron will cause a fission reaction (cause an atom to split). This is important for releasing energy stored in nuclear fuel.

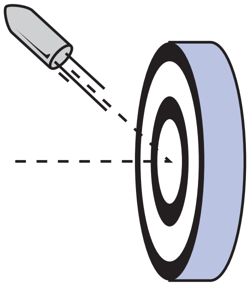
- Scattering: Probability that a neutron will bounce off an atom and give up some of its energy but otherwise leaving the target atom unchanged. Moderators such as ordinary water, heavy water, and graphite slow neutrons to appropriate speeds to assist fission reactions by scattering.



Absorbtion



Fission



Scattering

While the analogy of a bullet and target is not entirely correct, the analogy does give a good intuitive idea of the processes.

There are two kinds of cross sections, microscopic and macroscopic. Microscopic cross section refer to cross sections of neutrons reacting with a specific atom, like the isotope U^{235}. Macroscopic cross section give a description how neutrons interact with bulk materials such as concrete, water, steel, etc. Both cross section are determined experimentally by

$$\Delta P = \frac{\rho N_A}{M}\sigma\Delta d \qquad \text{(dimensionless)}$$

with ΔP being the change in probability that a reaction occurs for a given change in penetration distance Δd, N_A is Avogagro's number, M is the atomic (molecular) mass, ρ is the density, and σ is the cross section of being measured. Cross sections have units of area and are given in units of m^2 or barns (where 1 barn = 10^{-28} m).

Using the average *microscopic* cross section, one can determine the reaction of a particular nuclear fuel:

$$\text{neutron reaction rate} = N\Phi\sigma_{ave} \qquad \text{(reaction/s)}$$

with N is the number of nuclei available for reaction, Φ is the average neutron flux (neutron/m^2 s, and σ is the cross section for the reaction of interest. For *macroscopic*, bulk materials, the formula is slightly different:

$$Y = \frac{\sigma N}{V} \qquad \text{(reactions/neutron m)}$$

where σ is the cross section, N is the number of nuclei, and V is the volume of the material. For composite materials such as steel reinforced concrete, the right side of the equation can be replaced by a summation for each component:

$$Y = \sum_i \frac{\sigma_i N_i}{V_i} \qquad \text{(reactions/neutron m)}$$

These two equation shows the number of reactions that will occur for each neutron, per meter thickness of material.

Another way of looking at this is mean free path of the neutron. The mean free path tells how far (on average) a neutron will travel before it interacts with another nucleus. The mean free path is given by:

$$\lambda = \frac{1}{Y} = \frac{V}{N\sigma} \qquad \text{(neutron m/reaction)}$$

So why are cross sections important?

Cross sections are extremely important to reactor design and control. They provide an idea of how much fuel is needed, how fast will the fuel be consumed, what fuel arrangement to use, how much spacing between fuel pellets is needed for moderators, the number and size of the controls rods, etc.