Rodent Reactor!

Demonstration

Participants will learn how nuclear fission works through mouse traps going off. Ping pong balls act as neutrons, and the density of mouse traps will act as subcritical, critical, and supercritical conditions of a nuclear reactor.

Number of Participants: 1-100

Audience: Middle (ages 11 -13 and general public) and up

Duration: 10-20 mins

Difficulty: Level 2

Materials Required:

- A large bin/box (24 in x 24 in or larger)
    - An option to increase viewing capability is to replace one of the sides of the bin with a polycarbonate or similar type of clear material. This demo works very well with large setups and in front of large groups. Keep students removed, as the mouse traps will jump ~1 m.
- Pedal Mouse traps- wooden base traps work the best. See Figure 1 for an example.
- Ping pong balls (one for each mousetrap)
    - It can be fun to put in a few different colors to help show the effect
- Optional: Cell phone to capture the event in slow motion. This can then be replayed immediately after the event to explain the science in more detail.

Figure 1: an armed mousetrap with a ping pong ball on top

Setup:

1. There are 3 different phases that can be setup: subcritical, critical, supercritical.
2. Prior to setting up the mousetraps, move the bin to the desired location.
3. To set up the mousetraps, first arm the mousetrap. Carefully place the ping pong ball on the mousetrap. See Figure 1 for an example.
    a. One way to effectively move a large number of armed mousetraps is to place them on a board and then slide them into the box that the demo will take place in.
    b. Note that this can take a significant amount of time to setup.
4. Subcritical:
    a. In the large box, place only a couple of mouse traps (2-5 depending on the size of your box)
    b. Place ping pong balls on the mousetraps.
    c. Once those ping pong balls are set, you can throw a ping pong ball into the box in any random spot. This may set off one or two of the mousetraps, but most likely not all of them.
5. Critical
    a. In the large box, place a decent number of mouse traps (7-15 depending on the size of your box)
    b. On those mousetraps, *carefully* place ping pong balls
    c. Once those ping pong balls are set, you can throw a ping pong ball into the box in any random spot. This will likely set off a slow chain reaction of ping pong balls flying around.
6. Supercritical
    a. In the large box, place as many mouse traps as you can(15-30 depending on the size of your box). See Figure 2.
    b. On those mousetraps, *carefully* place ping pong balls
    c. Once those ping pong balls are set, you can throw a ping pong ball into the box in any random spot. This will set off a fast, almost instantaneous, chain reaction of ping pong balls flying around.

Figure 2: a full array of ping pong balls set on armed mousetraps

Presenter Brief:

Be familiar with the concept of nuclear fission. A radioactive atom (for example uranium) decays naturally and releases a neutron. The density of uranium and other radioactive materials results in that neutron from the just decayed atom colliding with another atom of the radioactive material. The addition of a neutron to a radioactive atom results in the immediate fission of the atom. This fission releases another neutron and the process repeats.

When a radioactive material undergoes fission, it releases energy in the form of heat. This heat can be used to heat water, which in turn creates steam and that steam turns a turbine. That is how nuclear reactors work.

Figure 3: raw, unrefined uranium (Source: Live Science[1])

Vocabulary:

- Neutron: a subatomic particle that has the same mass as a proton, but has no charge.
- Fission: the process of unstable elements to decay and release energy.
- Nucleus: the center core of an atom, composed of neutrons and protons. Has a net positive charge.
- Radioactive: the natural decay of atoms above Lead in the periodic table. Releases energy in the form of heat.
- Decay: the breakdown of atoms, resulting in two smaller atoms and energy.
- Chain Reaction: the self-sustaining fission reaction spread by neutrons which occurs in nuclear reactors and bombs
- Sub-Critical: Any amount of mass below the critical mass and does not result in a sustained chain reaction. This is generally the natural state that radioactive elements are found in. Does produce heat.
- Critical: A very specific mass for a given radioactive element that results in a sustained chain reaction. Nearly impossible to get this mass exactly.

- Super-Critical: Any Mass above critical mass that results in a sustained chain reaction. This is used for nuclear bombs and results in nuclear reactor accidents such as Chernobyl and Fukushima.

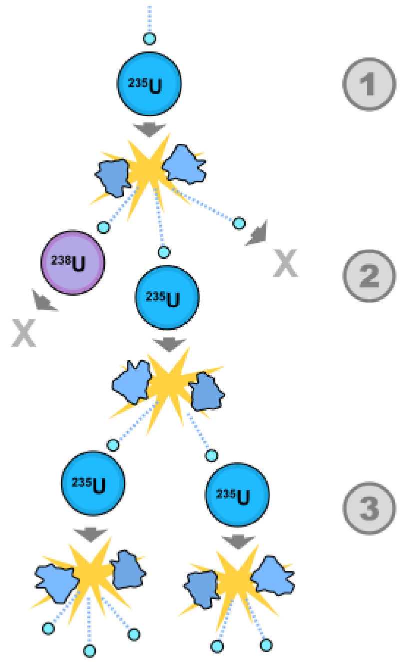

Figure 3: a demonstration of a nuclear chain reaction (Source: Nuclear Fission Wikipedia Page[2])

Physics & Explanation:

Middle (ages 11-13) and general public:

Ask the participants how many of them have heard of nuclear energy. Ask for associations or what they think of when they think of nuclear energy. Answers will most likely be nuclear bombs and Chernobyl. Explain that nuclear energy is safe and easily can be controlled, and that we have nuclear reactors that can give us energy without release of CO_2. It is a clean source of energy and doesn't warm the planet. Very simply, nuclear energy is when a small part of an atom, called a neutron, collides with another atom. When the neutron hits the atom, the atom splits in two and releases energy. Along with the energy, the atom releases neutrons, which collide with more atoms. A beautiful chain reaction (see Figure 2).

Run the demo, and for each stage, explain what is happening.

High School (ages 14+):

Ask the participants how many of them have heard of nuclear energy. Ask for associations or what they think of when they think of nuclear energy. Answers will most likely be nuclear bombs and Chernobyl.

Nuclear energy can be controlled. Nuclear energy is simply radiation and heat from nuclear decay. Nuclear decay happens naturally and results in an atom splitting and emitting heat and another neutron. That neutron that was released from the decaying atom will then interact with another radioactive atom, causing that atom instantaneously undergo nuclear fission. This happens naturally at a rate that does not cause nuclear explosions. This amount of mass is called the subcritical mass. If enough nuclear mass is gathered together, that will cause a chain reaction and is called the critical or supercritical reaction and could cause an explosion as seen in nuclear bombs or nuclear accidents such as Fukushima or Chernobyl. Figure 2 above is a great visualization of the chain reaction process.

However we have stable nuclear reactors so how do we control those? In nuclear reactors we control the rate at which the decaying atoms interact with each other by using a technology called control rods. These rods of nuclear material are surrounded by lead "sheaths" which stop neutrons emitted from natural nuclear decay from going through the lead and interacting with other nuclear rods. We can lift the nuclear material out of these rods so they are exposed and interact with each other more, resulting in a higher rate of nuclear decay and thus more energy to be released. By controlling the exposure of these rods we can keep the reaction subcritical. This allows us to create heat and energy without having the reaction reach the critical or supercritical stage and having an accident with a large nuclear explosion.

Run the demo, and for each stage, explain what is happening. Make sure to highlight the differences between sub-critical, critical, and super-critical phases (see definitions in vocabulary section above).

Additional Resources:

- Basics of Nuclear Fission: https://www.youtube.com/watch?v=mBdVK4cqiFs
- A list and short summaries of different nuclear technologies: https://world-nuclear.org/information-library/non-power-nuclear-applications/overview/the-many-uses-of-nuclear-technology.aspx
- The Demon Core Accident: https://www.newyorker.com/tech/annals-of-technology/demon-core-the-strange-death-of-louis-slotin
- A video of a similar demo: https://www.youtube.com/watch?v=vjqIJW_Qr3c

References:

1. https://www.livescience.com/39773-facts-about-uranium.html
2. https://en.wikipedia.org/wiki/Nuclear_fission