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Nuclear Fission

Physics summary: Fission is when a neutron collides with, for example, a uranium nucleus, turning it into an unstable nucleus that disintegrates or fissions into several other nuclei and neutrons. Since on average at least two neutrons are produced from every fission process, if each neutron collides with another uranium nucleus, at least double the number of fissions will occur. This cascade effect can quickly go out of control and result in a *supercritical* nuclear reaction process. If, on the other hand, only *one* neutron from each fission process triggers *one* new fission event, the process is more controlled and is said to be *critical*. It is also possible to have a subcritical process where less than one fission reaction occurs per neutron and the fission processes eventually die out.

Relevance to today's world: During fission, heat is released. Nuclear power plants harness that heat by turning it into work. In a nuclear reactor, the energy released by the fission processes is used to heat a liquid or gas coolant that circulates into and out of the reactor core. Outside the core the coolant passes through a heat exchanger which in turn drives a conventional heat engine. The engine then turns the heat into electrical work – *i.e.* electricity. (In real reactors this heat exchange takes more than one step to prevent the heat exchanger from becoming radioactive.) In order for the nuclear power plants to keep working, the nuclear reactions must be self-sustaining, but in a controlled way – *i.e.* they operate under the critical condition.

However, at least two famous incidents occurred in which the nuclear reactors went supercritical – or at least partially supercritical. The first one was on March 28, 1979 at the Three Mile Island Nuclear Power Plant where the core began to go supercritical and a partial meltdown occurred before the core was flooded with coolant and the core became subcritical. The second incident was on April 25-26, 1986 at the nuclear power plant in Chernobyl, Russia where the whole core went supercritical, causing a complete meltdown, and creating a fireball that blew off the reactor's heavy steel and concrete lid. A vast number of radioactive fission products were spewed into the air and almost all animal and plant life within a 10km radius around the power plant were killed due to radioactive poisoning.

Reason for Demonstration: this demonstration is a real attention-getter and crowd-pleaser because of the fire and noise involved. Partially because of this, students have little trouble remember how fission works and the three types of fission processes. The last part of the demonstration on the supercritical reaction helps students appreciate the serious nature of a nuclear reactor meltdown.

Demonstration: *A video of this demonstration appears on the web at McGraw-Hill's Online Learning Center.*

In this demonstration hydrogen-filled balloons represent uranium nuclei and fire represents neutrons. For a fission process to occur, neutrons must bombard a uranium nucleus – *i.e.* fire must touch one of the hydrogen-filled balloons. When this happens, the fire will melt the balloon material and ignite the hydrogen in side the balloon – *i.e.* more "neutrons" will be released. Depending on the spacing of the "uranium" balloons, the released neutrons may or may not cause another "fission" process.

To start the "fission" processes at the beginning of each demonstration, a lit candle is attached to the end of a long metal rod. The flame of the candle acts as the initial neutrons that bombard the first hydrogen balloon or uranium nucleus.

To hold the hydrogen-filled balloons in place for each type of reaction, twist-tie them to a wire mesh. The balloons must be filled just a few minutes before the demonstration is to be performed, since the hydrogen leaks out quickly and insufficient fireballs are created to explode a nearby balloon.

(1) **Subcritical** – this process requires that if, for example, there are three uranium nuclei present, then only one or two of the nuclei will fission. For only one fission process to occur, the hydrogen-filled balloons need to be spaced very far apart – how far depends on how full the balloons are. For balloons filled to about eight inches in diameter, the balloons should be spaced about a foot apart. An L-shaped arrangement of the balloons will minimize the space required for this demonstration. To produce two fission reactions from three nuclei, space the two vertically-arranged balloons about three inches apart with the third balloon off to the side about a foot away.

With both arrangements, to begin the fissioning, light the candle and bring it up to the bottom-most hydrogen balloon. Once the balloon's plastic has melted, the hydrogen inside will ignite creating a fireball that will rise and ignite the next balloon above it, if that balloon is close enough. If it is not, the ignited hydrogen quickly disperses and will not light the next balloon.

As a warning: when the hydrogen ignites, it creates a very loud boom that, as a student once described, could wake the dead.

(2) **Critical** – this process requires that one neutron from each fission process produces only one more fission process. This reaction occurs in a controlled manner and is the operating principle of nuclear reactors. To produce such a reaction with the balloons, they need to be spaced evenly – an arc works best. Again depending on how large and full the balloons are will determine how far apart they need to be spaced. One such arrangement that works is spacing balloons about eight inches in diameter roughly four inches apart along the circumference of a three-foot radius circle.

Lighting the bottom-most balloon will create a fireball that will make the balloon above it explode, which in turn will make the next one above explode and so on. If the balloons are spaced correctly, the explosions should happen one at a time until the last balloon has "fissioned".

(3) **Supercritical -** this process requires that each fission process produces more than one neutron and *each* neutron causes only fission process. This reaction quickly

becomes uncontrollable resulting in the meltdowns mentioned above. The huge and rapid fireballs that are created during this demonstration give a visual idea of how tremendously dangerous this a supercritical reaction is. To produce such a reaction with the balloons, they need to be spaced in an inverted pyramid. Start with a single balloon at the bottom, then two balloons on the next row above with each balloon on either side of the one below it, and finally four balloons on the next row above – again with each balloon on either side of the one below it. The rows should be spaced about four inches apart with the balloons within a row roughly four inches apart, though the ones on the top row will not be evenly spaced.

Lighting the bottom-most balloon will create a fireball that will explode *both* balloons above it simultaneously and then both of these will explode the two balloons above them simultaneously. If the balloons are spaced closely enough, all of this appears to happen at once with a tremendous booming sound.