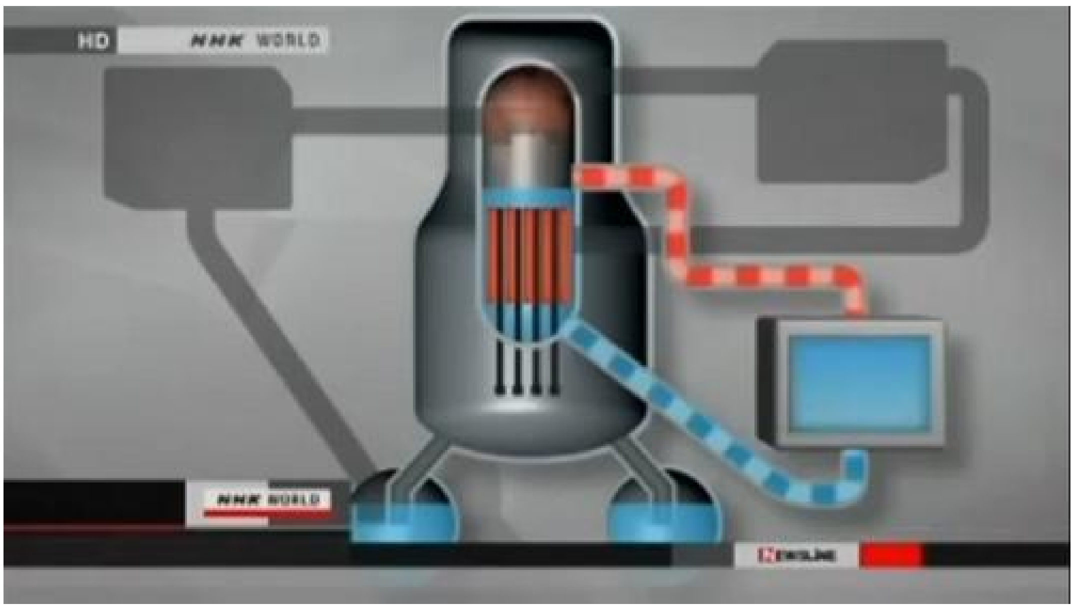
How does a nuclear meltdown work? (w/ Video)

March 17 2011, by Lisa Zyga



This illustration of a nuclear reactor shows water entering the core and surrounding the fuel rods (vertical red bars). When the water level decreases, the fuel rods begin to heat up and face the risk of melting. Image from video below.

(PhysOrg.com) -- When working properly, nuclear reactors produce large amounts of heat via nuclear fission reactions. The heat converts the surrounding water into steam, which turns turbines and generates electricity. But if you remove the water, you also remove the most important cooling element in a nuclear reactor and open up the possibility for nuclear meltdown.

A handful of nuclear meltdowns of varying degrees of severity have occurred since the 1950s, when researchers began building and testing nuclear reactors. The most serious instance happened in 1986 in Chernobyl, Ukraine. Plagued by design flaws and operator errors, the plant experienced fires, explosions, and radiation leakage. As a result, 30 people died of acute radiation syndrome, and thousands of cases of fatal cancers and birth defects have been reported in the following years. Today, limited access is allowed inside a 30-km (19-mile) exclusion zone surrounding the area.

By comparison, the Three Mile Island accident in Harrisburg, Pennsylvania, was much less serious. In 1979, a minor cooling system malfunction led to a series of events that caused a partial meltdown that damaged one of the reactors. However, very little radiation was released into the environment due to the surrounding primary containment vessel. Although the accident caused public concern, no deaths or adverse health effects have been officially attributed to the meltdown.

In Japan, the current nuclear crisis at the Fukushima Daiichi power plant lies somewhere in between Three Mile Island and Chernobyl, according to recent news reports. Last Friday's 9.0-magnitude earthquake and 10-meter (33-foot) tsunami waves that traveled up to 10 km (6 miles) inland overpowered several of the plant's safety measures. Although employees at the plant have been risking their lives to try to keep the reactors cool, the chance of a serious meltdown seems to be increasing.

Inside a reactor

Inside the core of a nuclear reactor are thousands of long, thin fuel rods made of zirconium alloy that contain uranium. When a reactor is turned on, the uranium nuclei undergo nuclear fission, splitting into lighter nuclei and producing heat and neutrons. The neutrons can create a self-sustaining chain reaction by causing nearby uranium nuclei to split, too.

Fresh water flows around the fuel rods, keeping the fuel rods from overheating and also producing steam for a turbine.

But if not enough water flows into the reactor's core, the fuel rods will boil the water away faster than it can be replaced, and the water level will decrease. Even when the reactor is turned off so nuclear reactions no longer occur, the fuel rods remain extremely radioactive and hot and need to be cooled by water for an extended period of time. Without enough water, the fuel rods get so hot that they melt. If they begin to melt the nuclear reactor core and the steel containment vessel, and release radiation into the environment, nuclear meltdown occurs.

Japan's cooling problems

When the earthquake struck Japan, three of the six reactors (Reactors 4, 5, and 6) at the Fukushima power plant were already off for routine inspections. Earthquake tremors triggered the automatic shutdown of the other three reactors, Reactors 1, 2, and 3 (along with eight other nuclear reactors at other power plants). To stop the chain reaction, control rods that absorb neutrons were inserted in between the fuel rods.

But the fuel rods are still hot, since radioactive byproducts of past fission reactions continue to produce heat. When the earthquake tore down the power lines, the plant's main cooling system stopped working. As a backup measure, diesel generators turned on to spray the fuel rods with coolant. But the tsunami that occurred shortly after the earthquake was larger than the plant's designers had anticipated, and water flowed over the retaining wall and into the area with the generators, causing them to fail. The next backup measure for cooling the fuel rods was a battery system, but the batteries lasted only a few hours. Later, technicians brought in mobile generators and also attempted to inject seawater into the nuclear reactors, which makes them permanently unusable but could help prevent a complete meltdown.

While the nuclear technicians searched for better cooling options, the water levels continued to decrease, exposing the tops of the fuel rods. Pressure also began building in some of the reactors. So far, at least three explosions have occurred in Reactors 1, 2, and 3. The explosions happened when the fuel rods began to melt and release gases that reacted with the surrounding steam, producing hydrogen. To release some pressure and prevent explosions, technicians vented some of the reactors, which also released some radioactive material into the environment. Officials have said that the pressure in Reactor 2 dropped significantly after the explosion there, suggesting that the explosion breached the steel containment structure - the reactor's "last resort" for containing leaked radiation.

Also, a fire ignited at Reactor 4, thought to be caused by a large pile of spent fuel rods in a pond. Spent fuel rods need to be kept fully submerged in water for cooling, but the lack of water has left some of the rods partially exposed. Smoke from the fire temporarily increased radiation levels around the reactor, so preventing future fires is very important. The Fukushima plant has seven ponds of spent fuel rods from the past few decades. By some estimates, there may be as many as half a million spent fuel rods that are still radioactive and could catch fire if not kept cool.

Japanese officials have stated that radiation around the nuclear reactors has risen to the level where it would adversely affect a person's health. Officials have implemented a 20-km (12-mile)-radius evacuation zone, and have advised people to stay indoors. The US has told its citizens living in the area to stay at least 50 miles away from the power plant. Some people have been taking prophylactic iodine as a safety measure; consuming this non-radioactive iodine before exposure to radioactive iodine can fill a person's thyroid and hopefully prevent absorption of the radioactive variety. Fortunately, westerly winds have so far blown much of the radioactive material out to sea.

Overall, because the extreme events that caused the cooling problems are so rare and unexpected, it's difficult to predict exactly what will happen next for Japan's nuclear plants.

More information: via: IEEE Spectrum, The Wall Street Journal, Scientific American, and National Geographic