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Explainer: What Caused The Incident At Fukushima-Daiichi

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Energy

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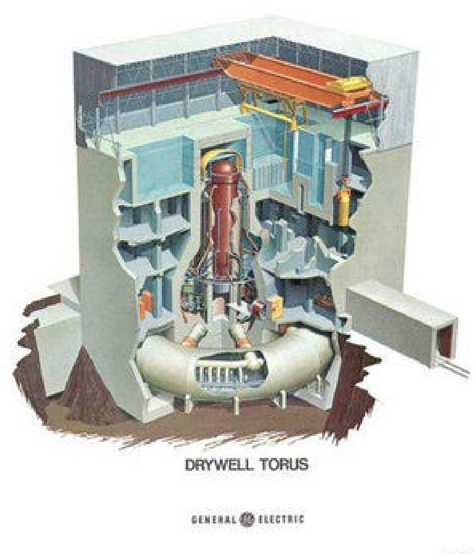
This article was written for Forbes by Kirk Sorensen, a nuclear technologist who operates the site energyfromthorium.com, where he has posted some insightful explanations of what happened at Fukushima-Daiichi and thoughts on the future of nuclear power.



A cut-away of G.E.'s Mark 1 containment structure used in the Fukushima reactors

In the mid-afternoon on Friday, March 11 the seismic sensors at the Fukushima-Daiichi nuclear power plant in the Fukushima Prefecture of Japan registered the earliest indications of the largest earthquake in modern Japanese history. They executed a preprogrammed response and began to drive all of the long control rods into the three reactors that were currently operating at the site. The control rods caused each generation of fission to produce fewer neutrons and fewer fission reactions. In three minutes the reactors were making 10% of their rated power from fission; in six minutes they were making 1%, and within by ten minutes nuclear fission as a source of heat had ended in the first three units at Fukushima Daiichi. It would never begin again.

Each fission reaction splits the nucleus of an atom of uranium-235 or plutonium-239 into two smaller atoms and releases a great deal of energy. The energy release from nuclear fission is roughly a million times greater per unit weight than fossil fuels, which is why nuclear fission is such a compelling long term energy source. The two "fission products" that result are highly radioactive but decay towards stability very quickly. There are about 80 different sequences of decay that fission products can follow, and roughly a quarter reach a completely non-radioactive state within a day. Within a month, about three-quarters are stable, and within a year about 80%. But in the first few hours after a nuclear reactor shuts down these fission products are producing significant amounts of heat and unlike fission, this heat generation can't be turned off. It has to run its course to completion. Therefore, managing what is called "decay heat" is one of the most important aspects of operating a nuclear reactor safely. To remove the heat, today's reactors have an abundance of safety systems, all of which have the same mission—keep removing decay heat from the nuclear fuel. As the reactors at Fukushima-Daiichi cooled down, the tsunami hit.

The tsunami destroyed the diesel generators that provide power to drive the pumps that circulate the water coolant through the reactor that removes decay heat. Without an active removal of decay heat, the reactor was adding heat to the water faster than it was taking it out, and the temperature was rising. Because this was a reactor that operated on water that was already at its boiling point, this also meant that the pressure inside the reactor was rising as well.

The reactors at Fukushima-Daiichi are called boiling-water reactors (BWRs) and were manufactured by General Electric. They have a primary and a secondary containment structure, both made from thick reinforced concrete, to protect against the release of radioactive materials. Inside the primary containment are two vessels called a "drywell" and a "wetwell". The drywell is a large steel pressure vessel that looks like a giant upside-down pear and holds the reactor and primary pumps, and the wetwell is a large toroidal vessel that looks like a donut. The wetwell is connected to the drywell by a number of wide pipes. Both the drywell and the wetwell are surrounded by a secondary containment vessel (or shield building) also built from reinforced concrete about a meter thick. This rectangular secondary containment building is the structure that most people have seen in pictures of the reactor. At the top of the secondary containment building is a steel frame structure with "blowout" panels that holds the crane used to remove solid nuclear fuel during fueling and refueling.

The designers of the reactors at Fukushima-Daiichi had anticipated situations where pressure was rising in the core. So long as power was available, pumps would circulate hot fluid from the reactor to the wetwell where it would be condensed. Heat removal could continue indefinitely in this way. But it all relied on a power source, and power had been lost due to the tsunami's destruction of the diesel generators.

The water in the reactor is susceptible to damage from radiation, causing it to split into its components, hydrogen and oxygen. Normally, circulation would channel the hydrogen and oxygen to a recombiner where they would be restored back to water, but in the hours after the reactors were shut down, hydrogen was accumulating and separating in the wetwell and reached a point where it was vented into the sparse steel-frame structure at the top of the reactor building. It was only a matter of time before the hydrogen reached a level where it would detonate, and one after another, the first unit, then the third unit, and finally the second unit, suffered hydrogen explosions that blew off the steel panels and left the top of the reactor building exposed. The reactor vessels remained intact as did the reinforced concrete containment buildings, but each reactor building lost its hat due to the hydrogen explosions.

Initially there was hope of saving the reactors to generate power again after the crisis had passed. But as that hope faded and the need to remove the steadily-decreasing decay heat remained, operators at Fukushima-Daiichi took measures that would cool the reactors but would ruin them for future operation, such as the decision to try to cool the reactors with seawater. It will be necessary for some time to actively cool the reactors while the decay heat continues to decrease, but within a few months it will be possible to depressurize the reactors and assess their internal states. There may have been some melting and damage to the fuel—it is not known at this time.

What is known is that this is a situation very different than Chernobyl or Three Mile Island. There was no operator error involved at Fukushima-Daiichi, and each reactor was successfully shut down within moments of detecting the quake. The situation has evolved slowly but in a manner that was not anticipated by designers who had not assumed that electrical power to run emergency pumps would be unavailable for days after the shutdown. They built an impressive array of redundant pumps and power generating equipment to preclude against this problem. Unfortunately, the tsunami destroyed it.

There are some characteristics of a nuclear fission reactor that will be common to every nuclear fission reactor. They will always have to contend with decay heat. They will always have to produce heat at high temperatures to generate electricity. But they do not have to use coolant fluids like water that must operate at high pressures in order to achieve high temperatures.

Other fluids like fluoride salts can operate at high temperatures but at safer, lower pressures. Fluoride salts, unlike water, are impervious to radiation damage and don't evolve hydrogen gas which can lead to an explosion. Solid nuclear fuel like that used at Fukushima-Daiichi can melt and release radioactive materials if not cooled consistently during shutdown. Fluoride salts can carry fuel in chemically-stable forms that can be passively cooled without pumps driven by emergency power generation. A reactor based on this technology would avoid the extreme situation that was encountered at Fukushima-Daiichi. It may be in our best interest to pursue them in building the next generation of nuclear power plants.

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