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Physics in the news

The Japanese nuclear crisis

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At 14.46 p.m. on 11 March a magnitude 9.0 earthquake occurred off the coast of Tōhoku, Japan. This earthquake released 1.3×10^{20} J of energy, equivalent to 32 gigatonnes of TNT or nearly 950 000 times the energy of the nuclear weapons dropped on Hiroshima and Nagasaki combined. The earthquake triggered a devastating tsunami that struck the coast of Japan just half an hour later.

The Fukushima Power Plant

The Fukushima I Nuclear Power Plant (also known as Fukushima Dai-Ichi) is a six-reactor nuclear power plant on the coast of Ōkuma. At the time of the quake only three of the six reactors were working and these automatically shut down ('scrammed') upon detection of the quake: control rods were raised into the reactor, absorbing the neutrons produced by the fission of the uranium fuel and stopping the nuclear chain reaction. Reactor units 1 and 2 used pure uranium oxide fuel; unit 3 used mixed oxide (MOX) fuel, composed of uranium oxide and a small amount of plutonium oxide.

Coolant water

After shutdown the core of a nuclear reactor continues to generate heat, initially about 7% of the energy generated by the reactor when running. This is due to the radioactive decay of the fission fragments — the 'pieces' left over after the uranium atoms have split — that remain inside the nuclear fuel. This decay heat must be extracted from the reactor to prevent the fuel rods from overheating and melting. This is done by circulating coolant water through the reactor.

Because the earthquake had cut off the power plant from the electrical grid, and because the reactors were no longer generating electricity, large diesel generators kicked in to power the emergency coolant pumps. When the tsunami struck the plant it destroyed the diesel fuel tanks that were positioned at the water's edge. Without a supply of fuel the diesel generators failed and coolant was no longer circulated through the reactor.

The six Fukushima I reactors are boiling water reactors (BWRs), giant kettles with nuclear fuel rods as the elements. The heat from the fission reactions inside the fuel rods turns water into steam and this steam drives a turbine that in turn drives a generator. Without a flow of coolant to extract the decay heat, the temperature and pressure inside the reactors began to increase.

Steam

In order to relieve the build-up of pressure inside the reactor the plant's operators decided to vent some steam from inside the reactor. This steam was radioactive due to the interaction between the hydrogen and oxygen atoms of the water and the neutrons from the fission reactions. A two-step process converts hydrogen into deuterium (^{2}H) and then into tritium (^{3}H); tritium is a beta emitter with a half-life of 12.3 years. Far less dangerous is an 'np' reaction, which converts normal ^{16}O and a neutron to radioactive ^{16}N and a proton. ^{16}N is a beta emitter with a half-life of only 7.13 seconds.

With the temperature and pressure inside the reactor still increasing the zirconium cladding of the fuel rods began reacting with coolant steam to form zirconium oxide and hydrogen. Electrical igniters normally burn this hydrogen gas before it can build up to dangerous levels, but they failed due to the lack of power. When the built-up hydrogen gas ignited it blew off the walls and roof of the reactor building, It is worth noting that the walls and roof are designed to do this in order to prevent the force from being focused inwards on the reactor itself.

The plant's operators are currently pumping seawater and boric acid into the reactors in order to cool them and using water cannons to keep the reactor's spent fuel ponds cool and prevent nuclear fission reactions from recommencing. Boric acid contains boron, a neutron 'poison' that absorbs excess neutrons. The situation now appears to be under control, a tribute to the hard work of the 'Fukushima 50', a group of workers who remained behind at the plant to combat the effects of the fourth largest earthquake on record.

Find out more

PHYSICS REVIEW article

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MIT's Department of Nuclear Engineering

http://mitnse.com/

Author's blog

http://www.MrReid.org