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Why Fukushima's "spent" fuel rods will continue to catch fire

By: Kirk Murphy Tuesday March 15, 2011 4:26 pm

This cutaway diagram shows the central reactor vessel and thick concrete containment in a typical boiling water reactor of the same era as Fukushima Daiichi 1 (image: www.world-nuclear-news.org)

Update: Japan's chief cabinet secretary, Yukio Edano, is holding a news conference, just started. (10:15pm ET).

Yesterday the spent fuel rod pool at Fukushima Daiichi reactor 4 caught fire. About that time instruments at the plant showed an exponential increase in radiation levels. After the fire was quenched, radiation levels fell. In the hour before I sat down to write this, there was an explosion at the same spent fuel rod pool. As I write, another fire is burning there. NHK reports the radiation level – 300 to 400 milliSieverts – is so high that firefighters cannot approach the area.

NHK reports that by Monday March 14 the temperature in the spent fuel rod pool was 84 DEGREES C: nearly double the usual temperature. NHK reports that there aren't temperature readings for today: technical failure. We do know the pool temperature increased by roughly twenty degrees C per day after loss of power on Friday. And we know that water boils at 100 degrees C.

The spent fuel rod pool at reactor 4 is one of seven pools for spent fuel rods at Fukushima Daichii. These pools are

designed to store the intensively radioactive fuel rods that were already used in nuclear reactors. These "used" fuel rods still contain uranium (or in the case of fuel rods from reactor 3, they contain both uranium and plutonium from the MOX fuel used in that reactor). In addition to the uranium and plutonium, the rods also contain other radioactive elements. These radioactive elements are created in the rods by the intense radiation around the rods when they are in the reactor core (before they are moved to the spent fuel pools).

Six of the spent fuel rod pools are (or were) located at the top of six reactor buildings. One "common pool" is at ground level in a separate building. Each "reactor top" pool holds up to 3450 fuel rod assemblies. The common pool holds up to 6291 fuel rod assemblies. [The common pool has WINDOWS on one wall which were almost certainly destroyed by the tsunami.] Each assembly holdssixty-three fuel rods. This means the Fukushima Daiichi plant may contain over 600,000 spent fuel rods. The fuel rods once stored atop reactor 3 may no longer be there: one of the several explosions at the Fukushima reactors may have damaged that pool.

Now that we have partial meltdown in the reactor vessels – the part of the reactor where nuclear reactions are supposed to happen – in at least three of the Daiichi palnt's six reactors, why bother with swimming pools for fuel rods? Simple. Even after they are no longer usable to drive nuclear fission in the reactor vessels, the "spent" fuel rods are still highly radioactive. Part of that radioactive energy is emitted as heat. That's no surprise: heat from radioactivity is the how the reactor core vessels generate the heat that drives the nuclear plant's turbines to generate electricity. The fuel rods don't know whether they are in the core or in the pools: they keep emitting heat and radioactivity until the radioactive material decays into non-radioactive elements. That process can take years, which is why spent fuel rods are still dangerous years after they leave the reactor core.

How can we prevent the spent fuel rods from bursting into flame once they're out of the reactor core? The Fukushima plant – like many other reactors – keeps the rods in water, which absorbs the heat energy. But the pools – like the water in a teakettle – will boil away unless new water is added. After the Fukushima plant lost power in Friday's 9.0 earthquake and got hit by the tsunami, the plant was no longer able to keep the pools topped up.

How long does it take the water in spent fuel rod pools to boil down to dangerously low levels? Yesterday FDL reader MtnWoman – who worked at TMI for twelve years – told us about the 2000 Nuclear Regulatory Commission study that looked at this very question. For boiling water reactors (BWR) such as the Fukushima reactors, the time required for spent fuel rod pool water levels to drop to dangerouslyy low levels is about 140 hours. The NRC study only looked at rods that had been out of reactors for six months or more: I don't have data about how long the rods at the seven Fukushima pools have been out of reactors. Fortunately for the NRC, they weren't studying fuel rod poos on the upper floors of reactor buildings housing reactor core vessels that had lost adequate cooling and were in partial meltdown. This may explain why the spent fuel rod pool at reactor 4 IGNITED on Monday, roughly 100 hours after the quake and power loss, but before the 140 hours the NRC calculated.

Why did the spent fuel rod pool at reactor 4 catch fire again today? Yesterday the Institute for Energy and Enviromental Research's Arjun Makhijani wrote a very detailed report that answers this question. In his report he quoted extensively

from the 2006 study perfomed by the National Research Council of the National Academies. Their report tells us:

> *"The ability to remove decay heat from the spent fuel also would be reduced as the water level drops, especially when it drops below the tops of the fuel assemblies. This would cause temperatures in the fuel assemblies to rise, accelerating the oxidation of the zirconium alloy (zircaloy) cladding that encases the uranium oxide pellets. This oxidation reaction can occur in the presence of both air and steam and is strongly exothermic—that is, the reaction releases large quantities of heat, which can further raise cladding temperatures. The steam reaction also generates large quantities of hydrogen….*
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> *These oxidation reactions [with a loss of coolant] can become locally self-sustaining … at high temperatures (i.e., about a factor of 10 higher than the boiling point of water) if a supply of oxygen and/or steam is available to sustain the reactions…. The result could be a runaway oxidation reaction — referred to in this report as a zirconium cladding fire — that proceeds as a burn front (e.g., as seen in a forest fire or a fireworks sparkler) along the axis of the fuel rod toward the source of oxidant (i.e., air or steam)….*
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> *As fuel rod temperatures increase, the gas pressure inside the fuel rod increases and eventually can cause the cladding to balloon out and rupture. At higher temperatures (around 1800°C [approximately 3300°F]), zirconium cladding reacts with the uranium oxide fuel to form a complex molten phase containing zirconium-uranium oxide.*
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> *Beginning with the cladding rupture, these events would result in the release of radioactive fission gases and some of the fuel's radioactive material in the form of aerosols into the building that houses the spent fuel pool and possibly into the environment. If the heat from one burning assembly is not dissipated, the fire could spread to other spent fuel assemblies in the pool, producing a propagating zirconium cladding fire.*
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> *The high-temperature reaction of zirconium and steam has been described quantitatively since at least the early 1960s…."*

Translation for laypeople: Without enough water to cover the, the fuel rods will keep on IGNITING, just like trick birthday candles keep re-igniting after we blow them out. Just like trick birthday candles, the only way to put out the fuel rods is to put them under water. That's why even after Monday's reactor 4 spent fuel rod fire was quenched, the spent fuel rod pool caught fire again this afternoon.

Unlike trick birthday candles, the spent fuel rods burn hot (3300 DEGREES F) enough so that the radioactive material in the rods is aerosolized: carried into the atmosphere in clouds of hot smoke. And unlike our trick birthday candles, the spent fuel rods in reactor building 4 are four stories off the ground – just like the other five reactor spent fuel pools at Fukushima. And unlike our trick birthday candles, right now the radioactivity around the spent fuel rods is so high that no one can approach them to put out the fire.

I'm a SLOW typist: by the time I completed this the fire burning at reactor 4's spent fuel rod pool had gone out –

apparently spontaneously. Fortunately, we're not yet at the 140 hour mark by which the NRC calculated spent fuel rods in ideal conditions would be at risk of combustion. That's a good thing, because there's one other big difference between trick birthday candles and spent fuel rods. Trick birthday candles merely drip more wax on the cake. Uncontrolled spent fuel rod fires could pour enough radioactive waste into the atmosphere to cause what a nuclear engineer (at a Vermont plant identical to Fukushima reactors) calls "Chernobyl on steroids".

Let's hope the spent fuel rods at Fukushima are put back under water before we have the opportunity to test her hypothesis.