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Fukushima Dai-ichi status and slow burning issues

Posted by Euan Mearns on March 25, 2011 - 11:00am

With no buildings blowing up at Fukushima for a couple of weeks now, global media attention has shifted back to Libya where there is lots of violence to watch. Does this mean that trouble at the 4 wrecked reactors on the East coast of Japan is over?

With the restoration of mains power to the site, there is talk in the media that the situation is now under control. The rate of deterioration has certainly slowed, but there are five slow-burning issues, one working in favor of the authorities and four working against, that will determine the eventual outcome:

1) **Radioactive decay** of fission products is steadily declining as they burn up, though the rate of decline is slowing as we burn through the short half lives into the intermediate and longer half life inventories of isotopes.

2) **Heat accumulation** will rise for so long as circulation cooling is absent until a steady state is reached between the reactors and spent fuel and the surrounding buildings.

3) **Corrosion** of the stainless steel reactor vessel, pipes and pumps in a salt water environment they are not designed to withstand.

4) **Salt accumulation** in the reactor cores.

5) **Radioactive material** spread and accumulation in the surrounding environment.

*Status of Fukushima Dai-ichi from **Japan Atomic Industrial Forum** on 24th march. Significance: Red = Severe (need immediate action); Yellow = High; Green = low. Click to enlarge.*

The Japan Atomic Industrial Forum is publishing daily updates on the status at Fukushima Dai-ichi (Fukushima from now on). These have not changed materially for several days, now suggesting that the situation has stabilised for the time being. But just reading the report (table up top) shows how serious the situation is and there are a number of slow burning issues which could lead to a rapid deterioration at any point. The authorities need to rescue all 4 reactors and their fuel ponds.

Status

Summary of headline data:

Core and fuel integrity - damaged in units 1, 2 and 3.

Core cooling - not functioning in units 1, 2 and 3, not required in 4 that is de-fueled.

Building integrity - severely damaged units 1, 3 and 4.

Water level of the reactor pressure vessel - fuel exposed partially or fully in units 1, 2 and 3.

Fuel integrity in spent fuel pools - unknown in units 1 and 2, possibly damaged in units 3 and 4*.

Cooling of spent fuel - water level low in units 3 and 4, but continue to hose in water.

* Given that reactor building 4 was destroyed by a couple of large hydrogen gas explosions that must have come from reduction of water and oxidation of zircalloy fuel cladding, it seems quite certain that the fuel in ponds of unit 4 is damaged.

Slow burning issues

Radioactive decay

As discussed in **this earlier post** and illustrated by **this chart** (borrowed from **energyfromthorium** blog), the amount of heat being produced in reactor cores and spent fuel ponds is declining all the time as the fission products decay away. However, two weeks on from the incident, most of the short half life fission products are gone. And so, while the rate of heat production has declined significantly from the start, from now on the rate of decline in heat production is slow and that heat still being produced needs to be disposed of some how.

Heat accumulation

The normal way to dispose of heat is to pump it away in circulating cooling water (see the massive flows of water either side of the seawall in the picture below). With the cooling pumps out of action due to loss of power, the only way to remove heat is by conduction through water. With the reactors shut down, the rate of heat production will now be much less than 1% of that produced by fission power, but the heat still needs to be removed. The following statement from **this report** is revealing:

> A similar operation is planned for later today at unit 4 and the surface temperatures of the buildings appear to be below 100ºC.

This suggests that the reactor buildings are essentially the heat sinks being used to absorb much of the heat being produced. For fuel rods cooled by water emersion at atmospheric pressure, the maximum temperature the coolant can reach is 100˚C (or it will boil) and since heat is always transferred from higher to lower temperatures, the maximum temperature the buildings can reach is 100˚C by conduction through water at atmospheric pressure. When they reach this temperature there is no where for the radiation heat produced to go and the source temperatures may continue to rise. I'm not sure what the exact outcome might be, but fuel rods catching fire or melting are two possible outcomes.

The following statement from **this report** gives further cause for concern:

> Tepco noted that the temperature of the containment vessel of unit 1 had built to some 400ºC, compared to a design value of only 138ºC. However, the strength of the component is such that it can withstand the stresses this imposes, said Tepco, and its structural integrity is expected to be maintained. "There is no substantial problem

> regarding the containment vessel's structural soundness under conditions of pressure 300 kPa and temperature 400ºC."

If the reactor steel pressure vessel and the concrete containment are still pressurised then it is possible to raise the temperature of water above 100˚C, but a temperature of 400˚C still signals a serious heat dissipation issue at Unit 1. If either the pressure vessel or containment system are at atmospheric pressure then it suggests that the reactor pressure vessel is ruptured and nuclear fuel is in contact with the concrete containment system.

It is quite clear that Tepco is aware of this problem hence the race to restore mains AC power to see if the pumping system works which will allow heat to be pumped away using the reactor's and cooling pond's water cooling systems. How much of this is going to work?

The six reactors at Fukushima Dai-ichi in happier days. The 4 buildings in trouble are those to the left numbered 1 through 4 from right to left. Note the torrents of cooling water discharge either side of the sea wall, designed to withstand waves of 5.7 meters but reportedly swamped by a 10 meter high wave.

Corrosion

Seawater has been pumped into the reactor pressure vessels and the void between the pressure vessel and concrete containment for a couple of weeks now (see cutaway diagram). In **this earlier post** I quoted TOD commenter **donshan** who spoke authoritatively on corrosion issues:

> I do question the use of seawater cooling. I hope the Japanese have considered the danger they have created by introducing oxygenated seawater into this stainless steel piping and pressure vessel at boiling temperatures. These stainless steels are extremely susceptible to chloride stress corrosion cracking.
>
> Since residual weld stresses and tensile stress in piping, valves, control tubing, etc. are always present, Standard Operating Reactor water quality standards require keeping chlorides at parts per billion levels. Seawater has about 3.5% or 35 grams per liter of salinity!!! (i.e. 35,000,000 parts per billion).
>
> I have no way of knowing how many days they have before a stainless steel component suddenly cracks, but if it were me, I would be advocating an emergency program to get pure deionzied cooling water back into this stainless steel system ASAP. In laboratory tests in boiling chlorides, cracking of stainless in tensile stress can occur within days - they have at most a few months if they keep boiling sea water in this system and yet another disaster occurs.

It is impossible to know the physical state of the stainless steel reactor vessels, pipe work, and valves, but if **donshan** is correct then eventually we may see catastrophic failure of a vital component that leads to loss of pressure, loss of an active source, or mixing of some part that is very hot with water.

An initial response to corrosion does not have to be catastrophic but cumulative corrosion may be eating away at the fabric of these reactors making recovery more difficult.

Cutaway diagram of a boiling water reactor of similar design to the 4 wrecked units at Fukushima. Given the scale of the damage to the reactor buildings I find it astonishing that there has not been much wider dispersal of radioactive materials around the site, especially spent fuel rods that are not contained by enclosed, armored concrete structures.

Salt accumulation

Pumping seawater into the reactor core to help conduct heat away from the fuel causes the water to boil leading to a build up of salt in the steel pressure vessel. TOD Editor JoulesBurn circulated **this report** to the TOD group:

> Richard T. Lahey Jr., who was General Electric's chief of safety research for boiling-water reactors when the company installed them at the Fukushima Daiichi plant, said that as seawater was pumped into the reactors and boiled away, it left more and more salt behind.
>
> He estimates that 57,000 pounds of salt have accumulated in Reactor No. 1 and 99,000 pounds apiece in Reactors No. 2 and 3, which are larger.
>
> The big question is how much of that salt is still mixed with water and how much now forms a crust on the uranium fuel rods.
>
> Crusts insulate the rods from the water and allow them to heat up. If the crusts are thick enough, they can block water from circulating between the fuel rods. As the rods heat up, their zirconium cladding can rupture, which releases gaseous radioactive iodine inside, and may even cause the uranium to melt and release much more radioactive material.
>
> Some of the salt might be settling to the bottom of the reactor vessel rather than sticking to the fuel rods. But just as a heating element repeatedly used to warm tea in a mug tends to become encrusted, in cities where the tap water is rich with minerals, boiling seawater is likely to leave salt, mainly, on the fuel rods.
>
> The Japanese have reported that some of the seawater used for cooling has returned to the ocean, suggesting that some of the salt may have flowed out again. But clearly a significant amount remains.
>
> A Japanese nuclear safety regulator said on Wednesday that plans were under way to fix a piece of equipment that would allow freshwater instead of seawater to be pumped in.
>
> He said that an informal international group of experts on boiling-water reactors was increasingly worried about salt accumulation and was inclined to recommend that the Japanese try to flood each reactor vessel's containment building with cold water in an effort to prevent the uranium from melting down. That approach might make it harder to release steam from the reactors as part of the "feed-and-bleed" process that was being used to cool them, but that was a risk worth taking, he said.

Notably the procedure of venting steam seems to have been abandoned. Either it has been decided this is no longer necessary or it has been recognised that the process of allowing seawater to boil away and for salt to accumulate can no longer be sustained. This is a balancing act between allowing pressure to build and venting steam and hydrogen and radiation and allowing salt to accumulate.

Radiation

Understanding the scale of release of radioactive material and accumulation in the environment is difficult to decipher from the information that is being released. Official data released from the reactor site show radiation levels within tolerable limits.

Radiation levels above the reactors were too high a week ago to allow helicopters to hover to dump water. This could be due to air convection systems around the heating reactor buildings carrying radioactive gasses and particles upwards and / or direct exposure to fuel rods in cooling ponds that had boiled partially dry?

There are now many reports of 'high' levels of radiation from radioactive materials in seawater, food and urban water supplies suggesting that radioactive material contamination around the site is growing. **Workers trying to reconnect power supplies** to pumps are being exposed to very high doses working within the bowels of the reactor buildings.

This report suggests that daily emission levels from Fukushima may be around one twentyth of Chernobyl which is very serious indeed.

> The commission found that the amount of iodine being released every hour stood at some 30-thousand to 110-thousand terra-becquerels. The estimated figure is relatively lower than the one-point-eight million terra-becquerels of iodine that was released hourly during the nuclear disaster in Chernobyl in 1986.

My interpretation of this is that the site readings may provide deceptive comfort while environmental contamination is being spread via air born systems going upwards and outwards and via water draining into the sea.

Summing up

Fukushima is like a cancer eating away at the habitat of the east coast of Japan. Whilst the situation appears to be stable, a number of slow burning processes must inevitably be eating away at the heart of these reactors. The solution to a number of these problems is to restore fresh water circulation to each of the cores and the spent fuel ponds. Whether or not the pumping systems work remains to be seen. Disposing of the salty radioactive sludge from inside the reactor vessels presents another major challenge.

It seems possible that the current meta stable condition may persist for many more weeks, and all the while the release and accumulation of radioactive isotopes in the environment will continue. And there is still risk of a catastrophic failure due to heat or corrosion that would result in the status degrading rapidly. It is too early to call this crisis over.