The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Fukushima Dai-ichi status and potential outcomes

Posted by Euan Mearns on March 17, 2011 - 10:54am

*Image dated 16th March, posted by **Undertow**, source **digitalglobe**. Unit 1 to right, reactor building destroyed by hydrogen gas explosion on Saturday 12th March. Unit 3, second from left, destroyed by hydrogen gas explosion on Monday 14th March, venting steam? Unit 2, second from right, explosion causes radiation leak from containment system, venting steam? Unit 4 on left, building destroyed by fire on Tuesday and Wednesday, the likely result of spent fuel rods boiling dry in their cooling pond. Ironically, it is unit 4, shut down at time of incident, with large quantities of radioactive material outside of containment, that is a major cause for concern.*

On Wednesday 16th March, I sensed that the rate of official news flow from the Fukushima nuclear site declined leading to a number of conflicting reports and much speculation about what is going on and what might happen to the crippled reactors.

I am not a nuclear engineer and all should be wary of information reported by non-experts on the internet. Here I try to assemble information (not facts) gleaned from TheOilDrum comments, our email list, as well as mainstream media and news reports, in an attempt to cast light on status and potential outcomes. This involves considerable speculation.

On Friday 11th March, the day the earthquake and tsunami struck the east coast of Japan, reactors 1, 2, and 3 at the Fukushima Dai-ichi site were successfully shutdown by inserting control rods to shut down the nuclear fission chain reaction. Reactor 4 was non-operational at the time of the event, its spent fuel rods being stored in a cooling pond outside of the reactor containment system. The chart shows that heat flow in a reactor drops extremely quickly upon shutdown but that after the passage of days to weeks (where we are now) the rate of heat decay slows. Things are still very hot and need to be cooled. The source of the heat is radioactive decay of the fission products, many of which have very short half lives and decay away in the first minutes to hours, but the longer lived isotopes go on decaying and emitting heat and radiation for days, weeks and years.

*Chart from **energyfromthorium** is for illustrative purposes only.*

There is therefore a world of difference in terms of energy that has to be contained between an operational reactor experiencing difficulties, as was the case with Three Mile Island, and reactors that have been shutdown, as is the case in Fukushima.

On Saturday 12th March, the reactor building of unit 1 was blown apart by a hydrogen gas explosion. The reactor containment vessel survived and there was only minor release of radiation at that time. At this point it was evident that engineers at the plant were having difficulty cooling the reactors and all sorts of speculation began about possible meltdown of the core and what might happen next.

Oil Drum commenter **donshan** left **this comment** on my **Safety of nuclear power and death of the nuclear renaissance** thread which I believe may provide an accurate picture of what is actually going on in the reactor cores:

> I think I can answer this if I am correct that the Japanese reactors use conventional zirconium (Zircaloy) fuel cladding with ceramic uranium oxide fuel pellets inside. I understand that Unit 3 has a mixed oxide pellet including plutonium oxide.
>
> In 1956, my first job as a materials scientist was at the AEC's Hanford Laboratory in Washington State, operated by General Electric. Over 8 years I conducted many laboratory scale high-pressure autoclave experiments on the properties of zirconium alloys in high temperature and pressure water and steam. These tests were classified "secret" back then to prevent our technology from being obtained by the Soviets. Sometimes I fear that even though all this science is now declassified, this early science has not made into the education of today's engineers. I retired in 1995 and have followed TOD for 3 years now, having also worked on natural gas pipeline and geothermal system corrosion, but now feel I have expertise to share on this topic.
>
> The source is the hydrogen is a chemical reaction between the uncovered, overheated fuel assemblies and steam.
>
> $Zr + 2\ H_2O$ (steam) = $ZrO_2 + 2\ H_2$
>
> Zirconium is an extremely reactive metal and has even been used in flash bulbs filled with oxygen. There have been fatal explosions handling zirconium powers. So how is it possible to use zirconium safely in a nuclear reactor?
>
> Like aluminum, zirconium and its alloys (Zircaloy-2) oxidize instantly in air. A thin film of ZrO_2 is so impervious to oxygen diffusion that the reaction stops. Even in 300 C (572F) water or steam at over 1000 psi, the oxidation rate is extremely slow and corrosion properties of Zircaloy fuel cladding are outstanding and safe, AS LONG as they are not overheated and cooling water flow is maintained. In fact, it is standard practice to autoclave fuel rods in hot-pressured water or steam to precoat these rods with the optimum coating of ZrO_2.
>
> But these fuel rods must NEVER be overheated. That is why multiple redundant cooling systems are required. All these backup-cooling systems failed in Japan. Even after reactor shutdown, if the fuel rods are uncovered cladding temperatures can rapidly rise to 800C or higher, due to fission product decay heat. As in any chemical reaction, the rate accelerates rapidly with temperature, but in the case of zirconium, the protective character of a thin ZrO_2 film is destroyed by this high temperature and catastrophic oxidation occurs. However this catastrophic oxidation occurs below the melting point, so I object to the media using the common term "meltdown" which is misleading.
>
> This loss of the last battery-powered cooling, led to the fuel rods becoming uncovered in a manner similar to that in the Three Mile Island accident (although due to different reasons). When overheated in steam, the oxidation reaction above accelerates exponentially. As the zirconium oxidizes, the coating thickens, cracks, and turns white from internal fractures that increase the diffusion rate of steam to the metal. It then has the look and mechanical properties of eggshells. Hydrogen from this process is released, but is also absorbed by the underlying metal cladding, which causes embrittlement and metal fracture. Soon cracks form in the cladding, releasing the trapped fission products inside. This is not "melting', but rather catastrophic disintegration of the cladding

> structural integrity and containment of fission products. If the process continues, the cladding can fracture away, exposing the fuel pellets, which in the worst-case scenario can drop out and collect on the bottom of the reactor vessel. It is the worse case scenario that I believe is causing the Japanese to inject boric acid. Boron is a neutron absorber and will prevent any possibility of a pile of fuel pellets on the bottom of the vessel from going critical and restarting the chain reaction.
>
> These reactors are now a total loss, but I am still disturbed by their inability to bring in portable diesel generators and restart the back-up cooling. I guess the chaos of the catastrophe is the cause.
>
> 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:
> http://www.tpub.com/content/doe/h1015v1/css/h1015v1_134.htm
>
> 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 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. I am sure there are competent scientists in Japan's nuclear industry and government regulators. I hope they are on top of this threat!

It appears that large quantities of hydrogen gas have been produced in all three reactors based on Donshan's well-informed explanation. Severely corroded fuel rods with exposed fuel pellets may be inside the reactor housing or gathering as debris on the floor of the reactor vessel.

On Monday 14th, the reactor building of unit 3 exploded in similar manner to unit 1 but, at this point, there was still no significant radiation leakage, and the containment vessel seemed to be doing its job. It became evident that the Japanese engineers were losing the battle to keep the reactor cores submerged in water and adequately cooled.

On Tuesday 15th March, a third explosion in unit 2 resulted in serious radiation leak. This was a game changing event since contamination of the site by radioactive materials created a much more hazardous operational environment and many of the staff, who seemed to be fighting a losing battle in any case, were evacuated.

Donshan points out that Unit 3 was running on a mixed oxide fuel (MOX) that includes plutonium. This provides a further hazard since Pu is extremely radiologically poisonous.

The reactor building of unit 4 caught fire on Tuesday. Successfully extinguished, the building caught fire again on Wednesday 16th March and fears grew that spent fuel rods lying in a cooling pond outside of containment had boiled dry exposing the reactor site to large quantities of radiation. The photograph up top shows unit 4 to the left and it is clearly badly damaged even though the reactor was non-operational at the time of the incident.

Unit 3 is also reported to have spent fuel outside of containment that is giving rise to concern. In email correspondence Joules Burn had this to say:

> I have been watching the NHK feed and grimly laughing at the helicopter operation. Here is some info:
>
> Capacity of spent fuel pools: 1200-1500 tons water 15 meters deep
> Needed to cover rods: 15 meters, 400-500 tons water
>
> For reactor 3, they think there might be enough water that they only need < 100 tons, perhaps less
>
> One helicopter can drop 7.5 tons/load. BUt it can't hover, due to the radiation level. If I heard right, those on board are limited to 100 mSieverts/hour (check the time units). They had measured 250/hr at 30 meters and 87/hr at 90 meters. They dumped from 90 meters. See image. Looks more like crop dusting. There was one drop which looked a little better, but at the speed they are going, hitting the building with much is not likely.
>
> They tried some fire trucks, but they could get close enough. Next, they used some vehicles used for crowd control (see cartoon truck image). The water cannons can be fired from inside the vehicle. Two trucks can carry 10 tons, the others less. They shot a total of 30 tons water at #3 and called it a day. They will do more tomorrow.

The **NHK link** is reporting radiation levels 30 Km from the plant that provide annual safe dosage in six hours.

This time line and analysis posted on Wikipedia seems to provide a good chronology of events and status of units 1 to 4 (also units 5 and 6 located on another site). Of note, water levels inside the containment vessel remain below the level necessary to submerge the core, and the vessel is being vented continuously. This latter point seems a sensible approach. It will prevent pressure build-up in the containment vessels that could result in explosion but risks continuously venting small amounts of volatile radioactive materials.

What next?

At this point, it is necessary to lurch towards pure conjecture. Day by day, the status at Fukushima has worsened and until the situation is stabilized, it is impossible to predict the final outcome.

Much will depend on the status and location of the fuel rods and pellets in the reactor cores. If these remain largely intact and in place then they will be easier to cool and to moderate, i.e. to have the neutrons being released absorbed by boron or the control rods already in place.

If one of the cores is disintegrating and gathering as debris on the vessel floor then it becomes much more difficult to circulate cooling water and to absorb neutrons being produced. We have had much debate about whether or not it is possible for the fission chain reaction to re-start in a pile of reactor rubble. The consensus is that this is unlikely though possible. Should this happen then the energy to be contained escalates and the situation becomes more critical. Colleagues Joules Burn and Engineer Poet suggest that restarting the fission chain reaction would be self destroying since the energy produced would blow apart the pile of rubble, shutting down the fission process immediately.

The possibility remains that an explosion (hydrogen gas?) or fire (burning what?) destroys one of the containment vessels, rendering the site uninhabitable, in which case the fate of the other reactors would be left to nature. Fire in particular could spread high levels of radiation over a substantial area. Stuart Staniford at **earlywarn.blogspot** has produced this picture of what a Chernobyl scale disaster could mean for Japan.

Using military helicopters to drop water on the site seems like an act of desperation. France and the USA are sending charter planes to evacuate their nationals from Tokyo.