The Oil Drum
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The Fukushima Disaster and Other Irreproducible Experiments

Posted by JoulesBurn on April 20, 2011 - 3:30pm

The situation at the Fukushima nuclear reactors has evolved to one of chronic catastrophe or, more optimistically, feed and bleed followed by dialysis. For the viewer at home, the long-awaited debut of picture-taking robots inside the reactor buildings nicely complements the airborne fleet of drones that have been providing grist for armchair forensics experts everywhere. While we keep getting reassured that the Fukushima crisis is not as severe as Chernobyl, I will instead look a few years further back in an effort to learn something about the present dilemma. Fukushima should be more comparable to the Three Mile Island meltdown in 1979 than Chernobyl, but it has apparently left the former eating its radioactive dust. Why? Can anything be learned from this?

The full extent of the damage at Fukushima and the sequence of events will not be fully known for a long time. However, it is currently believed that there has been considerable damage to nuclear fuel rods, both in the reactors and in the spent fuel pools, caused by the loss of coolant (water) after the earthquake/tsunami. Subsequent to this, high levels of radioactive iodine and cesium were measured in air, ground, and water samples near the plant, and trace levels were measured across the Pacific ocean. In particular, high levels of Iodine-131 were measured, causing a run on iodine tablets everywhere. This seemed to me to be a rather expected development, given what happened in Chernobyl - though there were many irrational optimists who claimed that the fuss would all blow over soon (no pun intended). For a look on the dark side there was the MIT Worst Case Scenario:

> If multiple failures prevent these actions from being taken, as was the case at Three Mile Island, the fuel rods heat up until the uranium oxide reaches its melting point, 2400-2860 C (this figure depends on the makeup and operating history of the fuel). At this point, the fuel rods begin to slump within their assemblies. When the fuel becomes sufficiently liquid, slumping turns to oozing, and the "corium" (a mixture of molten cladding, fuel, and structural steel) begins a migration to the bottom of the reactor vessel. If at any point the hot fuel or cladding is exposed to cooling water, it may solidify and fracture, falling to the bottom of the reactor vessel.

While doing some background reading on previous nuclear accidents, I came across a curious aspect of the Three Mile Island mishap that I haven't seen discussed in relation to Fukushima. In that case, essentially all of the fuel rods in the reactor were damaged when the water was inadvertently forced out of the reactor vessel, and half of the uranium oxide fuel pellets melted due to heating from radioactive decay. It was expected that this would be accompanied by a release of volatile fission fragments (krypton, xenon, iodine, cesium), first from the fuel into the reactor vessel and then into the containment vessel, with a fraction escaping into the environment. The noble gases apparently made it out, but the iodine didn't. This surprised everybody.

Radioiodine Chemistry: The Unfinished Story:

> The impetus for developing predictive tools for modeling of radioiodine behavior arose from the events that occurred during the accident at Three Mile Island Unit 2 (TMI-2). During that accident, that resulted in severe damage to the fuel in the core, an extremely small fraction of the core radioiodine was found airborne (and less released). This was in sharp contrast to the licensing assumptions regarding the behavior of radioiodine.

From the first European Review Meeting on Severe Accident Research (ERMSAR-2005), Aix-en-Provence, France, 14-16 November 2005 (somewhat alarming that the first meeting wasn't held until 2005)

The aforementioned licensing assumptions were:

- 50% of the core inventory of iodine is instantaneously released to containment,
- 50% of the iodine in containment is deposited onto surfaces rapidly, and
- The distribution of iodine entering containment was considered to be: 91% I_2, 5% aerosol particulates, and 4% volatile organic iodides.

These assumptions were based on models of what was believed to be the likely scenario for an accident such as this. But the actual physics and chemistry is extremely complex, and it is almost certain that the experimental data (if any) upon which this was based was incomplete at best. So, now with TMI, we had an experimental dataset with one entry.

More from a 1992 report titled Models of Iodine Behavior in Reactor Containments:

> The first attempt to predict iodine behavior' involved many assumptions and few models based on experimental data The large releases that were predicted were not verified by experience, namely the accident at Three Mile Island (TMI). In fact, the predictions were so overly conservative that they were of questionable value. This situation prompted a flurry of research into mechanisms of iodine behavior and motivated the quest for more mechanistic models for predicting accident consequences.

Besides research, though, there was also the second-guessing of assumptions. Back to the 2005 Aix-en-Provence report:

> The actual situation at TMI-2 showed that these early assumptions were incorrect and that reliance on them could lead to *inappropriate safety design decisions and inappropriate emergency management plans and provisions*. The TMI-2 event triggered a large effort to understand the progression of beyond design basis accidents, a significant component of which was an effort to improve the understanding of iodine behavior. One result of that effort was the establishment in the United States of a new

> methodology for predicting source terms. The new treatment was documented in US NUREG-1465 which updated the assumption for iodine speciation in containment as: 95% CsI, 5% I2, and 0.15% volatile organic iodides [5].

The italicized (mine) phrase in the above to me reads "we were wasting money worrying about nothing". Enter Fukushima.

Why was I-131 seemingly a bigger problem at Fukushima? Of course, there are several difference between it and TMI, including pressurized water vs. boiling water reactors and the present involvement of the spent fuel pools (which were empty at TMI).

From THE THREE MILE ISLAND ACCIDENT AND POST-ACCIDENT RECOVERY (7MB pdf):

> Unit 2 is slightly larger than Unit 1 and operated at just under 3000 MW thermal power and produced just under 1000 MW of electricity

> One of the storage facts about Unit 2 is that it first achieved criticality exactly one year before the accident. It went into operation just 3 months before the accident. In a few ways, this was fortunate because the spent fuel pools were empty and were available after the accident for storage of contaminated water.

> In the TMI-2 accident, the safety systems scrammed the reactor at about 4 AM on March 28, 1979, and it was the decay heat that was not adequately removed, leading to rupture of the fuel rods about 2-3 hours later.

> About 60% of the gases Kr and Xe were released from the fuel and into the containment bldg.—about 10% was released through the Aux Bldg. to the atmosphere. The Xe in the containment building decayed within ~2 months, but the Kr was eventually vented under controlled conditions. Fortunately the uranium fuel and most of the fission products are not dissolved in the primary water which is maintained at a pH of >7. About 50% of the iodine and cesium were released and dissolved in the water.

> Iodine is a relatively volatile material and for the purpose of reactor licensing, the NRC assumes that 25% of the I-131 will be released from the water. A recent study, made because of the TMI accident findings, has shown that iodine is present mostly in the iodide state and as such is essentially non-volatile.

Which, as before, is summarized nicely in the article as:

> Radioiodine control may not be as much of a problem as originally thought.

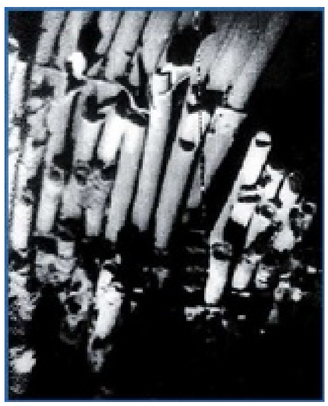
Iodine chemistry is rather complex in its own right. Adding radiation-induced chemical reactions, acres of oxide surfaces for catalyzing reactions, multiple phases, heat, dissolved salts, etc. to the mix certainly adds to the bewildering array of possibilities. I'm not going to try to unravel this here, though. I'll wait for the report from the second meeting at Aix-en-Provence.

Looking beyond iodine, there are also the medium-lived cesium isotopes which are released. There is presumably information in the relative yields of these and in comparison with those of iodine, but after reading this:

Specific Features of Cesium Chemistry and Physics Affecting Reactor Accident Short Term Predictions

I believe there is so much variability depending on fuel burn extent and other factors that knowing what actually came out of the Fukushima fuel rods won't be possible until they are cool enough to stab it with their steely knives. What should be learned? Probably that you never know for sure until you do the experiment.

The problem is, we really don't want to do the experiment. Might have to cover the lab in concrete for a long time. As for other irreproducible experiments? Macondo, Quantitative Easing, CO_2 emissions,...



TMI-2 fuel rods (or perhaps seafloor tubeworms)