Briefing document on Fukushima Nuclear Plant Events, 3/18/11

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Chronology of events:

- Reactors scram (emergency shutdown) at time of earthquake
- Back-up diesel generators knocked off line by tsunami about 1 hour after quake (20 ft wave)
- Off-site power connections destroyed by tsunami
- Battery power used for emergency operation operate as intended, but only provide power for 8 hours
- All electrical power to site was cut, ie, "blackout".
- A detailed timeline of events can be found on IEEE web site at http://spectrum.ieee.org/tech-talk/energy/nuclear/timeline-the-japanese-nuclear-emergency).

Design of "Boiling Water Reactors" and events at Fukushima:

- These reactors use water for multiple purposes—to move heat from reactor core, as a working fluid for turbine cycle, and as a "neutron moderator" for the chain reaction.
- Water does not come into direct contact with radioactive fuel — zircalloy cladding on fuel rods prevents contact. Uranium fuel surface temperatures are about 9000°F, zircalloy melts at about 5000°F so removing heat continually from the core is critical to safe.
- Temperature and pressure of the reactor is kept at about 550°F and 1100 PSI under normal operation.
- To maintain these temperatures and pressures, constant forced cooling of reactor core is required, provided through large recirculation pumps, in order to keep surface of the fuel rods below the melting temperature of the zircalloy cladding.
- Recirculation pumps are understood to be very critical and there are two pumps installed on each reactor (1 can sufficiently cool reactor). There are also multiple redundancies in power for electric pumps—from the turbine (under normal operation), from other reactors on-site, from offsite grid connected power, from on-site diesel generators, and from emergency battery bank (4 hours required in US, 8 hours in Japan).
- The Fukushima site lost all power for pumps in tsunami (turbine and on-site power lost at earthquake, diesel generator and offsite power lost in tsunami, and batteries died as expected after 8 hours).
- When a reactor scrams (experiences an emergency shutdown), the reactor still generates significant "decay heat" that must be removed from reactor core.
- If recirculation pumps are not operable, core temperatures quickly rise, causing commensurate pressure rise from steam.
- Pressure in system must be relieved, either by venting or by bursting pipes—controlled venting is preferred—but results in a drop in water level in reactor. Initial release of steam is not highly radioactive, as fuel rods are still intact at this time and the radioactive material is not in direct contact with the cooling water remaining in the core.
- As the water level drops, the zircalloy cladding on the fuel rods is eventually exposed to steam, which cannot conduct heat away from fuel rods adequately. Therefore, fuel surface temperatures rise above the melting temperature of zircalloy.

- Zircalloy also oxidizes when exposed to the steam, stripping oxygen from water molecules and generating free hydrogen (H_2), which presents an explosion hazard when vented.
- Damage to the zircalloy cladding also exposes uranium fuel to primary coolant, contaminating the steam with radioactive particles.
- Subsequent venting releases both hydrogen gas and radioactive particles.
- Water can be injected only if pressure is sufficiently relieved—the "bleed and feed" cycle that has been mentioned in reporting—which has been used to attempt to reduce reactor temperatures.
- Hydrogen explosions in units 1 and 3 destroyed much of the "secondary containment" system. This secondary containment is designed to blow away rather than cause damage to the primary containment system.
- However, most of the fuel is still contained inside the reactor and primary containment (only a small fraction of the radioactive material is released with the steam).
- Eventually, the pressure is lowered, the temperature is lowered, and the decay heat subsides naturally, and the reactor is "brought under control"—which seems to have occurred.

Spent Fuel Pool issue:

- "Spent fuel pools" are used to store "spent fuel" after it is removed from the reactor during normal operations. Spent fuel pools are covered with water, but are open to the atmosphere inside the secondary containment. They are located above the reactor level in the reactor design used at Fukushima—during refueling operations, the top is removed from the reactor and fuel is lifted from the core area to the spent fuel pool above.
- Spent fuel is cooled by water, but this water is also cooled by pumps and cooling systems during normal operations. Spent fuel is generally stored in this manner for years before the most dangerous radioactive elements decay to the point where the rods can be moved to a longer-term storage location (also usually still at the reactor site in the US and Japan).
- Fukushima reactor 4 was shut down for maintenance at time of earthquake, and fuel from the core that was not completely spent was being stored in the spent fuel pond (fuel is not critical unless arranged in tight configuration and can be stored safely under water in this pool so long as the fuel is spaced such as criticality cannot be achieved).
- If this spent fuel pond is cracked, it may be very difficult to cover fuel with water, which absorbs most of the energy from radioactive decay.
- Workers cannot safely approach spent fuel pool unless it is covered with water.
- If the fuel remains exposed, it could catch on fire, or melt into a mass that could become critical (start a nuclear chain reaction), although criticality is thought unlikely.
- If attempts are made to cover spent fuel with water, a steam explosion could occur.
- Either a fire or explosion would result in radioactive particles being released into the atmosphere, although probably not with the same force as the high pressure steam explosion at Chernobyl.

As of March 18, 2011:

- Measurable radiation has been released to atmosphere in multiple events from the Fukushima site, but releases beyond boundary of plant have been so far relatively modest (worse than TMI, but not nearly as bad as Chernobyl).

- The area around plant was ordered evacuated before most radioactive releases occurred, so public health is not in danger (yet).
- Workers may have been exposed to high levels of radioactive steam inside plants—reports of workers with radiation sickness is not encouraging—deaths among workers may occur (it usually takes 3-4 weeks for the danger of death from high exposure to pass).
- Spent fuel pond event is still developing—there is still significant danger of spreading of radioactive materials into surrounding area—although the likelihood of a vigorous explosion that would eject material high into the atmosphere where significant fallout would occur in Alaska or the US seems very low.

New reactor designs are intended to solve some of the issues:

- There has been a major efforts to create "passive" heat removal systems, so that a loss of electrical power does not result in fuel damage.
- Liquid metal reactors (Toshiba 4S, Hyperion) operate at atmospheric pressure, and are cooled by materials that will not vaporize.
- The use of natural convection (the natural buoyancy of hot fluids to rise) to move coolant past reactor core without pumps is another strategy, proposed by NuScale.
- Use of large "swimming pools" of water to surround much smaller reactor systems
- SMRs also have the advantage of using smaller reactor cores (45 MW for the NuScale system as compared to 1000 MW+ for current systems), which allows for easier heat management
- TRIGA research reactors are intrinsically safer—reaction limited by "Doppler effect" when fuel temperature rise.

What does this mean for Alaska?

It is too soon to tell what all the impacts will be from the events that have taken place in Japan over the past couple of weeks, and are still unfolding. Worker deaths or releases of large amounts of radioactive materials into surrounding area would be tragic at many levels, including the workers and their families, the community, the nation of Japan, and the world nuclear industry. If no deaths occur, and larger radiation releases can be avoided, the nuclear industry can claim that safety systems protected both workers and the public, even under the absolute worst of circumstances. However, this is far from a given at this time considering the possible high levels of exposure for some of the workers. At a minimum, this incident is likely to influence a new discussion about the design and safety of existing and proposed reactors. It is possible that one outcome would be to move the nuclear industry towards smaller, safer, and more modular reactor designs that would be less susceptible to a major failure such as precipitated by the sequence of events that took place in Japan.