No.52

Fukushima Accident Summary(2)

2011-July-03, Ritsuo Yoshioka

(Text in blue are Yoshioka's comments)

1) Earthquake and Tsunami

(Please see Summary-1 report for detail.)

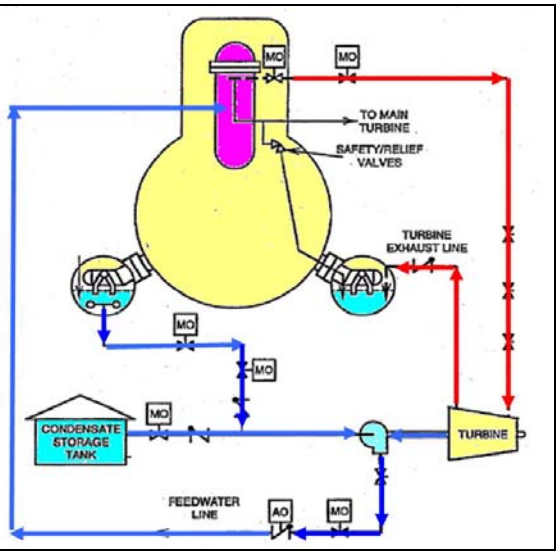
14:46 March 11th 2011	Tohoku Pacific Earthquake (magnitude 9.0) hit. All external electric power sources for F1/2/3/4/5/6 were lost. The emergency Diesel Generators (DG) started automatically.

15:41	A huge 14-15 meter Tsunami attacked, and flooded all DGs except one in F6. F2 had one air-cooled DG installed at the common fuel storage pool facility near F4, but the tsunami also attacked this facility and the DG stopped. So, F1/2/3 were forced into Station Black-Out (SBO), although some of the batteries survived at F3/4. The tsunami also destroyed most of the sea-water cooling systems. Core cooling function, thus, was lost for F1/2/3, and the fuel pool cooling function was lost for F1/2/3/4.

2) Fukushima-2 Reactor

Melt-down process

March 11th

14:50	Immediately after the earthquake, Reactor Core Isolation Cooling System (RCIC) was manually started. RCIC is an emergency pump system driven by a steam-turbine that is turned by steam from the reactor, and RCIC feeds water to the reactor core either from the storage tank or the suppression chamber. Battery to control RCIC was alive after the tsunami. (This RCIC saved F2 during the initial SBO stage, but the heat accumulated in the suppression chamber could not be removed, because the tsunami had destroyed the sea-water cooling system.)	

March 12th

04:20	RCIC started to use water from the suppression chamber due to lowered water level in the storage tank.

March 13th

	Situation remained the same.

March 14th

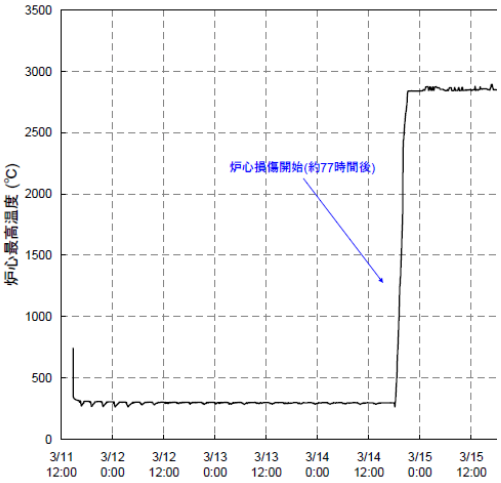
11:00	Blow-out panel dropped. This panel is installed to release overpressure, in case it happens at the top floor of the reactor building. (This panel occasionally drops just by earthquakes or some shocks. So, the hydrogen explosion at the top floor of F3, which occurred at the identical time, may have caused it.)	

13:25	RCIC stopped. (The cause is not clear. Batteries may have been used up, or maybe the suppression chamber temperature exceeded its limit.) (Core degradation began. Fuel cladding temperature increased to 1,200deg.-C, and zirconium oxidation of the cladding tube began. Fuel cladding tube collapsed, and high temperature fuel pellets fell to the bottom of the Reactor Pressure Vessel (RPV). Also, a large amount of hydrogen was generated.)
16:34	Safety Relief Valve (SRV) opened. Reactor pressure decreased from 7Mpa to 0.5Mpa.
16:34	Sea water might have been injected, but not sure.
19:54	Sea water injection was confirmed. (6.5-hours of no core-cooling)
	RPV pressure finally decreased to zero before March 16th. (This means that RPV broke sometime between 14th and 16th, due to the hot fuel at its bottom.)

Primary Containment Vessel (PCV) venting

Since PCV pressure was always lower than the break point (0.55Mpa) of the rupture disk, F2 never had PCV venting.

2 months later, TEPCO issued a report of calculation results. After RCIC had stopped, about 50% of the fuel pellets reached 2,800deg.-C during the night of March 14th, and dropped to the bottom of RPV.
At this point in time, PCV might have kept its integrity, but the explosion in the following day broke the PCV.



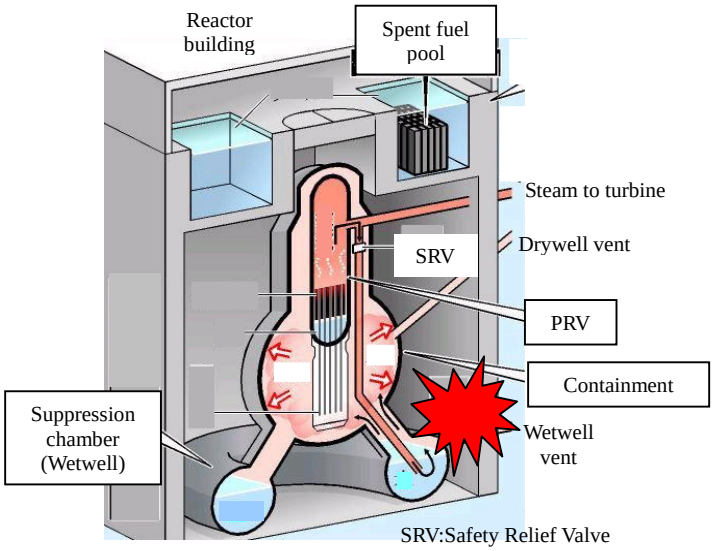
F2 max. fuel temperature

Hydrogen explosion

March 15th

6:10	There was a hydrogen explosion at the suppression chamber, and the PCV integrity was lost. This caused a large amount of radio-active water to leak into the turbine building. (This is explained later.) (I believe all the safety experts recognize that in case of a severe accident, large amount of hydrogen is generated at the reactor core. Maybe since PCV of BWR is filled with nitrogen gas, the possibility of hydrogen explosion is overlooked. For example, there is no description on hydrogen explosion within the reactor building in a famous severe accident report: NUREG-1150 "An Assessment for Five Severe Accident Risks".

One of the mysteries is the place of explosion.
F1 had an explosion at the top floor of the reactor building, but F2 had a blow-out panel ejection on March 14th. The panel prevented the same explosion as F1, however, it happened at another place.
Since PCV of BWR is filled with inert gas, it is probable that hydrogen explosion occurred outside the suppression chamber. The place had the highest concentration of hydrogen from the reactor core. There are always some small leaks at pipes or flanges. Overpressure might have accelerated this phenomenon.

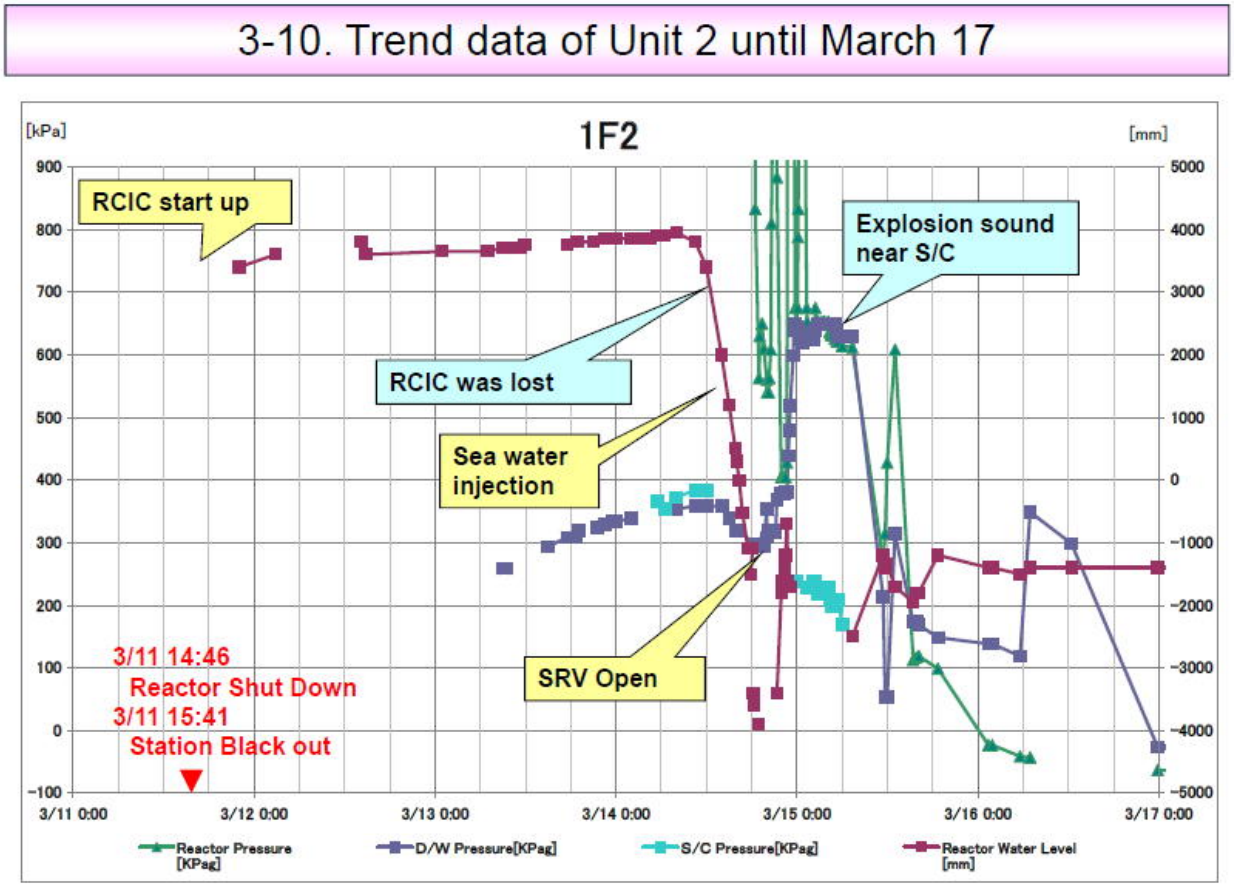


April 13th

TEPCO, on April 13th, reported results of radio-activity measurement of water in F2 turbine building. Iodine vaporizes at 184deg.-C, Cesium at 671, Barium at 1,897, and Strontium at 1,382. Although Barium has a very high vaporizing temperature, it decays from Cesium and Xenon with half-lifetimes of about a minute. So, strontium is the decisive element to determine the maximum fuel temperature.

Nuclides	million Bq/cc (April 13th)
Iodine-131	2.00
Cesium-134	2.60
Cesium-137	2.80
Barium-140	0.24
Strontium-89	0.70
Strontium-90	0.14

So, my conclusion is that Fukushima-2 is in “half melt-down” status, that is fuel pellets reached 1,400deg.-C or higher, but lower than 2,800deg.-C. Hot fuel fell to the RPV bottom, opened holes there to fall further to the bottom of PCV.
I presume that a hydrogen explosion broke the PCV. Of course, I cannot fully deny the possibility that hot fuel dropped to the PCV bottom to break it, a situation similar to F1.

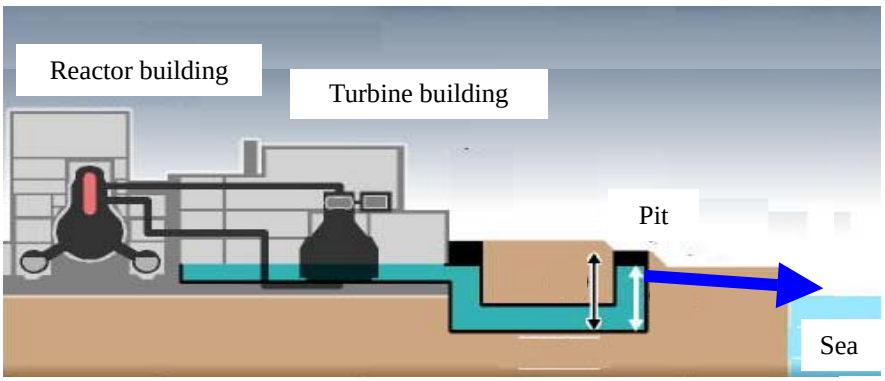


(from Governmental report to IAEA)

Sea contamination

April 2nd

Very high radiation (400mili-Sievert/hour) was observed at a location 2-meters away from the “Pit” of F2. The pit is the exit of the water in the turbine building to the sea. When F2 was shut-down on March 11th, there was radio-activity of 4.2e18 Bq(Becquerel) of Iodine-131 in the whole core. This Iodine went to the suppression chamber, and went out to the basement of the turbine building, because PCV was already broken. This high value means that water in the Pit has almost the same radiation level as the water in the core.
TEPCO also announced that Iodine-131 was measured at the sea in front of F2, and its value was as high as 5.40-millions Bq/cc. Since the basement of buildings is not water-tight, some amount of leakage is expected. This means that sea contamination had begun. TEPCO is installing barriers to the sea, and the leakage is decreasing.
(Nuclear fuel material such as Uranium/Plutonium has not been found in the above water, but I guess since RPV and PCV were broken, such material could go out with water. Also, underground of these buildings may already been contaminated.)



Spent fuel pool

Fortunately or unfortunately, the roof of F2 is intact, and we cannot see inside the building where the F2 spent fuel pool is. Spent fuel cooling function was lost since March 11th, but sea water was injected after March 20th.
On April 18th, TEPCO showed a radio-activity measurement of the water taken from the spent fuel pool. I-131 was only 0.004-million Bq/cc, but Cesium-134 was 0.16-million Bq/cc, and Cesium-137 was 0.15-millions Bq/cc.
(Since there was essentially no Iodine-131 in the spent fuel, the measured radio-activity must have come from the spent fuel that might have been damaged. The cause of this spent fuel failure, if it had occurred, is not clear. Since the decay-heat of spent fuel is small, dry-out of the spent fuel is unlikely.)