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RST Assessment of Fukushima Daiichi Units,
Based on most recent available data and input from INPO, GEH, EPRI, Naval Reactors (with Bettis and KAPL), and DOE/NE

2100 hrs 3/26/2011

The purpose of this document is to provide the NRC Reactor Safety Team's assessment and recommendations for the Fukushima-Daiichi reactors to the USNRC team in Japan. Our assessments and recommendations are based on the best available technical information. We acknowledge that the information is subject to change and refinement.

UNIT ONE

ASSUMPTIONS: (based on input from multiple data source: JAIF, NISA, TEPCO, & GEH)

Core Status: Core is contained in the reactor pressure vessel, reactor water level is unknown. The volume of sea water injected to cool the core has left enough salt to fill the lower plenum to the core plate. (GEH, INPO, Bettis, KAPL).

Vessel temperatures and pressures:
149ºC at bottom drain and 197ºC at FW nozzle (NISA 1800 JDT 3/25)
RPV at 65.7 psia (increasing trend), DW and torus pressure at 40 psia (decreasing trend) (NISA 1800 JDT 3/25).

Core Cooling: Currently fresh water injection with no boron, injecting through feedwater 120 l/min or 31.7 g/m (NISA); Injection flow rate will be maintained above the minimum debris retention injection rate (MDRIR). Recirculation pump seals have likely failed. (GEH) ;Injection flow rate above MDRIR could not be maintained through core spray. Assume RHR is not available.

Primary Containment:
Not damaged, 40 psia Drywell and Torus hydrogen and oxygen concentrations are unknown. The status of the nitrogen purge capability is unknown. An explosive mixture is possible.

Secondary Containment:
Severely damaged (hydrogen explosion).

Spent Fuel Pool:
Fuel covered, no seawater injected - (JAIF, NISA, TEPCO). The fuel in this pool is all over 12 years old and very little heat input (<0.1 MW) (DOE)

Rad levels: DW 4780 R/hr, Torus 3490 R/hr (source instruments unknown),
Outside plant: 26mR/hr at gate (variable) (INPO 0900 hrs 3/25/11)

Other: Electric power available, equipment testing in progress (JAIF, NISA, TEPCO)
External AC power to the Main Control Room of U-1 became available at 11:30 JDT 3/24/2011. Lighting in Main Control Room operating in U-1.

Reactor water is in the Turbine Building basement (NISA).

NOTE: Recommendations are based on validity of above assumptions.

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ASSESSMENT:

Damaged fuel that may have slumped to the bottom of the core and fuel in the lower region of the core is likely encased in salt and core flow is severely restricted and likely blocked. The core spray nozzles are likely salted up restricting core spray flow. Injecting fresh water through the feedwater system is cooling the vessel but limited if any flow past the fuel. GE believes that water flow, if not blocked, should be filling the annulus region of the vessel to 2/3 core height. There is likely no water level inside the core barrel. Natural circulation believed impeded by core damage. It is difficult to determine how much cooling is getting to the fuel. Vessel temperature readings are likely metal temperature which lags actual conditions.

The fuel pool is slowly heating and has not reached saturation. Overhead photos (on~3/19) show entire fuel floor covered by grey-brown debris of building roof.

The primary containment is not damaged.

RECOMMENDATIONS: (for consideration to stabilize Unit 1)

Follow guidelines of SAMG-1, *Primary Containment Flooding*, Leg RC/F-4, *Can you restore and hold RPV injection rate above the Minimum Debris Retention Injection Rate (MDRIR)*?

1. Inject into the RPV with all available resources while maintaining total RPV injection flow at the current flow rate (must maintain greater than MDRIR). Systems to use are:
    a. core spray, even at reduced flow rate
    b. feedwater system
    c. other systems as they become available

2. Restore nitrogen purge capability. When restored, establish purge and vent cycle to minimize explosive potential.

3. RPV injection can be maximized when the containment has been purged with nitrogen and vented.

4. No overt action is necessary to inject into the primary containment. The primary containment injection flow path is through the RPV.

5. Vent containment: (see Additional Considerations A.1. through A.8. below)
    a. To maintain containment pressure below the primary containment pressure limit.
    b. As necessary to maintain RPV injection above MDRIR.

6. Stop injecting from sources outside of primary containment prior to primary containment water level reaching the drywell vent. The goal is to raise primary containment water level to at least the top of active fuel (TAF). (see Additional Considerations C.1. through C.3. below).

Additional Considerations

A. The following considerations apply to containment venting:

1. If the primary containment is vented then purge the drywell with nitrogen at maximum flow.

2. If the torus is vented then purge the torus with nitrogen at maximum flow.

3. Attempt to inert with nitrogen prior to venting and especially before utilizing containment spray, but do not delay venting or spraying the containment if that is needed, just to inert.

4. Steam/condensing could jeopardize inert environment, as the spray will remove steam which is preventing hydrogen detonation

5. Hydrogen gas production is more prevalent in salt water than in fresh water. Oxygen from the injected seawater may come out of solution and create a hazardous atmosphere inside primary containment. The radiolysis of water will generate additional oxygen. Maintain venting capability.

6. Containment spray should be secured before 2 psig to prevent opening vacuum breakers.

7. Spray water on steam plumes and planned containment vents for scrubbing effect.

8. Avoid atmospheric thermal inversion (in the afternoon) when venting to minimize dose.

B. Additional Miscellaneous considerations

1. When flooding containment, consider the implications of water weight on seismic capability of containment.

2. Borate water if possible. (With salt in vessel, consider effect of acidic conditions in vessel when deciding how much boron to add.)

3. Ensure spent fuel pool level is maintained as full as possible.

4. CRD injection is desired for cooling directly to the core and for cooling material on bottom of vessel.

C. Potential methods for monitoring containment level:
   1. HPCI suction pressure
   2. Drywell instrument taps
   3. Radiation monitoring instruments

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UNIT TWO

ASSUMPTIONS: (based on input from multiple data source: JAIF, NISA, TEPCO, & GEH)

Core Status: Core is contained in the reactor pressure vessel, reactor water level is unknown.

Core Cooling: Fresh water with boric acid injection (TEPCO), bottom head temperature 104C, feed water nozzle temperature 107C (NISA 1800 JDT 3/25/11) (JAIF, NISA, TEPCO) Recirculation pump seals have likely failed. (Industry)

Primary Containment:
Damage suspected (JAIF, NISA, TEPCO)

Secondary Containment:
Damaged (JAIF, NISA, TEPCO), hole in refuel floor siding (visual).

Spent Fuel Pool:
Fuel covered, seawater injected on March 20, fuel pool temperature 52°C (JAIF, NISA, TEPCO 1800 JDT 3/25/11).

Rad Levels: Drywell 4560 R/hr; Torus 154 R/hr (source instruments unknown);
Outside plant: 26mR/hr at gate (variable) (Industry).

Other: External AC power has reached the unit, checking integrity of equipment before energizing.

ASSESSMENT:

Damaged fuel may have slumped to the bottom of the core and fuel in the lower region of the core is likely encased in salt, however, the amount of salt build-up appears to be less than U-1, based on the reported lower temperatures. Core flow capability is in jeopardy due to continued salt build up.

Injecting water through the RHR system is cooling the vessel, but with limited flow past the fuel. Water flow, if not blocked, should be filling the annulus region of the vessel to 2/3 core height. Based on the reports of RPV level at one half core height, the reactor vessel water level is believed to be even with the level of the recirculation pump seals, implying the seals have failed. While core flow capability may be affected due to continued salt build up, RPV water level indication is suspect due to environment. Natural circulation believed impeded by core damage. It is difficult to determine how much cooling is getting to the fuel. Vessel temperature readings are likely metal temperature which lags actual conditions.

Low level release path: fuel damaged, reactor coolant system potentially breached at recirculation pump seals, primary containment damaged resulting in low level release.

There may be some scrubbing of the release if the release path is through the torus and water level is maintained in the torus.

Fuel pool is heating up but is adequately cooled.

NOTE: Recommendations are based on validity of above assumptions.

RECOMMENDATIONS: (for consideration to stabilize Unit 2)

Follow guidelines of SAMG-1, *Primary Containment Flooding*, Leg RC/F-4, *Can you restore and hold RPV injection rate above the Minimum Debris Retention Injection Rate (MDRIR)*?

1. Inject into the RPV with all available resources while maintaining total RPV injection flow at the current flow rate (must maintain greater than MDRIR). Systems to use are:
    a. core spray, even at reduced flow rate
    b. feedwater system
    c. other systems as they become available

2. Restore nitrogen purge capability. When restored, establish purge and vent cycle to minimize explosive potential.

3. RPV injection can be maximized when the containment has been purged with nitrogen and vented.

4. No overt action is necessary to inject into the primary containment. The primary containment injection flow path is through the RPV.

5. Vent containment: (see Additional Considerations A.1. through A.8. below)
    a. To maintain containment pressure below the pressure limit
    b. As necessary to maintain RPV injection above MDRIR

6. Stop injecting from sources outside of primary containment prior to primary containment water level reaching the drywell vent. The goal is to raise primary containment water

level to at least the top of active fuel (TAF). (see Additional Considerations C.1. through C.3. below)

Additional Considerations

A. The following considerations apply to containment venting:

1. If the primary containment is vented then purge the drywell with nitrogen at maximum flow.

2. If the Torus is vented then purge the torus with nitrogen at maximum flow.

3. Attempt to inert with Nitrogen prior to venting and especially before utilizing containment spray, but do not delay venting or spraying the containment if that is needed, just to inert.

4. Steam/condensing could jeopardize inert environment, as the spray will remove steam which is preventing Hydrogen detonation.

5. Hydrogen gas production more prevalent in salt water than in fresh water. Oxygen from the injected seawater may come out of solution and create a hazardous atmosphere inside primary containment. The radiolysis of water will generate additional oxygen. Maintain venting capability.

6. Containment spray should be secured before 2 psig to prevent opening vacuum breakers.

7. Spray water on steam plumes and planned containment vents for scrubbing effect.

8. Avoid atmospheric thermal inversion (in the afternoon) when venting to minimize dose.

B. Additional Miscellaneous considerations

1. When flooding containment, consider the implications of water weight on seismic capability of containment.

2. Borate water if possible. (With salt in vessels, consider effect of acidic conditions in vessel when deciding how much boron to add.)

3. Ensure Spent Fuel Pool level is maintained as full as possible.

4. CRD injection is desired for cooling directly to the core and for cooling material on bottom of vessel.

C. Potential methods for monitoring containment level:
1. HPCI suction pressure
2. Drywell instrument taps
3. Radiation monitoring instruments

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UNIT THREE

ASSUMPTIONS: (based on input from multiple data source: JAIF, NISA, TEPCO, & GEH)

Core Status: Core is contained in reactor vessel, reactor water level is unknown.

Core Cooling: Freshwater injection via fire line initiated 1802 JDT 3/25/11 (NISA), bottom head temperature 111C, feed water nozzle temperature Unreliable (JAIF, NISA 1800 JDT 3/25/11, TEPCO) Recirculation pump seals have likely failed.

Primary Containment
Damage suspected (NISA, TEPCO) "Not damaged" (JAIF 10:00 3/25)

Secondary Containment
Damaged (JAIF, NISA, TEPCO)

Spent Fuel Pool
Low water level (JAIF, NISA, TEPCO), spraying and pumping sea water into the SFP via the Cooling and Purification Line (NISA)

Rad Levels: DW 5100 R/hr, torus 150 R/hr (Industry);
Outside plant: 26mR/hr at gate (variable) (Industry); 100 R/hr debris outside Rx building (covered).

Other: External AC power has reached the unit, checking integrity of equipment before energizing.

ASSESSMENT:

Damaged fuel may have slumped to the bottom of the core and fuel in the lower region of the core is likely encased in salt, however, the amount of salt build-up appears to be less than U-1, based on the reported lower temperatures. Core flow capability is in jeopardy due to continued salt build up.

Injecting water through the RHR system is cooling the vessel, but with limited flow past the fuel. Water flow, if not blocked, should be filling the annulus region of the vessel to 2/3 core height. Based on the reports of RPV level at one half core height, the reactor vessel water level is believed to be even with the level of the recirculation pump seals, implying the seals have failed. While core flow capability may be affected due to continued salt build up, RPV water level indication is suspect due to environment. Natural circulation believed impeded by core damage. It is difficult to determine how much cooling is getting to the fuel. Vessel temperature readings are likely metal temperature which lags actual conditions.

Low level release path: fuel damaged, reactor coolant system potentially breached at recirculation pump seals, primary containment damaged resulting in low level release. There may be some scrubbing of the release if the release path is through the torus and water level is maintained in the torus.

Fuel pool is heating up but is adequately cooled, and fuel may have been ejected from the pool (based on information from TEPCO of neutron sources found up to 1 mile from the units, and very high dose rate material that had to be bulldozed over between Units 3 and 4. It is also possible the material could have come from Unit 4). Unit 3 turbine building basement has flooded. Samples of water indicate some RCS fluid is present (TEPCO sample table – 3/25/11). Several possible sources (MSIV leakage, FW check valves, Rx building sump drains) were identified, however the likely source is the fire water spray onto the reactor building. Additional evaluation is needed.

RECOMMENDATIONS: (for consideration to stabilize Unit 3)

Follow guidelines of SAMG-1, *Primary Containment Flooding*, Leg RC/F-4, *Can you restore and hold RPV injection rate above the Minimum Debris Retention Injection Rate (MDRIR)?*

1. Inject into the RPV with all available resources while maintaining total RPV injection flow at the current flow rate (must maintain greater than MDRIR). Systems to use are:
    a. core spray, even at reduced flow rate.
    b. feedwater system.
    c. other systems as they become available.

2. Restore nitrogen purge capability. When restored, establish purge and vent cycle to minimize explosive potential.

3. RPV injection can be maximized when the containment has been purged with nitrogen and vented.

4. No overt action is necessary to inject into the primary containment. The primary containment injection flow path is through the RPV.

5. Vent containment: (see Additional Considerations A.1. through A.8. below)
    a. To maintain containment pressure below the pressure limit.
    b. As necessary to maintain RPV injection above MDRIR.

6. Stop injecting from sources outside of primary containment prior to primary containment water level reaching the drywell vent. The goal is to raise primary containment water level to at least the top of active fuel (TAF). (see Additional Considerations C.1. through C.3. below)

Additional Considerations

A. The following considerations apply to containment venting:

   1. If the primary containment is vented then purge the drywell with nitrogen at maximum flow.

   2. If the torus is vented then purge the torus with nitrogen at maximum flow.

   3. Attempt to inert with nitrogen prior to venting and especially before utilizing containment spray, but do not delay venting or spraying the containment if that is needed, just to inert.

   4. Steam/condensing could jeopardize inert environment, as the spray will remove steam which is preventing hydrogen detonation.

   5. Hydrogen gas production is more prevalent in salt water than in fresh water. Oxygen from the injected seawater may come out of solution and create a hazardous atmosphere inside primary containment. The radiolysis of water will generate additional oxygen. Maintain venting capability.

   6. Containment spray should be secured before 2 psig to prevent opening vacuum breakers.

   7. Spray water on steam plumes and planned containment vents for scrubbing effect.

   8. Avoid atmospheric thermal inversion (in the afternoon) when venting to minimize dose.

B. Additional Miscellaneous considerations

   1. When flooding containment, consider the implications of water weight on seismic capability of containment.

2. Borate water if possible. (With salt in vessel, consider effect of acidic conditions in vessel when deciding how much boron to add.)

3. Ensure Spent Fuel Pool level is maintained as full as possible.

4. CRD injection is desired for cooling directly to the core and for cooling material on bottom of vessel.

C. Potential methods for monitoring containment level:
1. HPCI suction pressure
2. Drywell instrument taps
3. Radiation monitoring instruments

UNIT FOUR

ASSUMPTIONS: (based on input from multiple data source: JAIF, NISA, TEPCO, & GEH)

Core Status: Offloaded 105 days at time at accident (JAIF, NISA, TEPCO)

Core Cooling: Not necessary (JAIF, NISA, TEPCO)

Primary Containment:
Not applicable (JAIF, NISA, TEPCO)

Secondary Containment:
Severely damaged, hydrogen explosion. (JAIF, NISA, TEPCO)

Spent Fuel Pool:
Low water level, spraying with sea water, hydrogen from the fuel pool exploded, fuel pool is cool heating up very slowly (JAIF, NISA, TEPCO) Temperature is unknown (NISA).

Rad Levels:
No information.

Other: External AC power has reached the unit, checking electrical integrity of equipment before energizing. (JAIF, NISA, TEPCO)

ASSESSMENT:

Given the amount of decay heat in the fuel in the pool, it is likely that in the days immediately following the accident, the fuel was partially uncovered. The lack of cooling resulted in zirc water reaction and a release of hydrogen. The hydrogen exploded and damaged secondary containment. The zirc water reaction could have continued, resulting in a major source term release.

Fuel particulates may have been ejected from the pool (based on information of neutron emitters found up to 1 mile from the units, and very high dose rate material that had to be bulldozed over between Units 3 and 4. It is also possible the material could have come from Unit 3).

RECOMMENDATIONS:

1. Maintain coverage of spent fuel pool with fresh borated water.
2. As possible, put spent fuel cooling and cleanup in service.

UNIT FIVE

ASSUMPTIONS: (based on input from multiple data source: JAIF, NISA, TEPCO, & GEH)

Core Status: In vessel (JAIF, NISA, TEPCO)

Core Cooling: Functional (JAIF, NISA, TEPCO)

Primary Containment:
Functional (JAIF, NISA, TEPCO)

Secondary Containment:
Vent hole drilled in rooftop to avoid hydrogen build up (JAIF, NISA, TEPCO)

Spent Fuel Pool:
Fuel pool cooling functioning Temperature 37.9 C (NISA 1800 3/25/11) (JAIF, NISA, TEPCO)

Other: External AC power supplying the unit, Unit 6 (?) diesel generators available. Fuel Pool Cooling lost when pump failed (JAIF, NISA, TEPCO)

ASSESSMENT:

Unit five is relatively stable.

RECOMMENDATIONS:

Repairs complete on RHR pump used for fuel pool cooling.

Monitor

2100 hrs 3/26/2011

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UNIT SIX

ASSUMPTIONS: (based on input from multiple data source: JAIF, NISA, TEPCO, & GEH)

Core Status: In vessel (JAIF, NISA, TEPCO)

Core Cooling: Functional (JAIF, NISA, TEPCO)

Primary Containment:
Functional (JAIF, NISA, TEPCO)

Secondary Containment:
Vent hole drilled in rooftop to avoid hydrogen build up (JAIF, NISA, TEPCO)

Spent Fuel Pool:
Fuel pool cooling functioning. Temperature 22 C (NISA 1800 JDT 3/25/11) (JAIF, NISA, TEPCO)

Other: External AC power supplying the unit, diesel generators available. Fuel Pool Cooling lost when pump failed (JAIF, NISA, TEPCO)

ASSESSMENT:

Unit Six is relatively stable.

RECOMMENDATIONS:

1. Monitor

ABBREVIATIONS:

GEH – General Electric Hitachi
INPO – Institute of Nuclear Power Operations
JAIF – Japan Atomic Industrial Forum
NISA – Nuclear and Industrial Safety Agency
TEPCO – Tokyo Electric Power Company