Reflections on Fukushima

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Dr. Nils J. Diaz
Managing Director, The ND2 Group, LLC
Chairman, ASME Task Force- Japan Events

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The Great East Japan Earthquake

- Our deepest sympathy continues to be extended to the people of Japan that suffered through the extraordinary earthquake of March 11, 2011 and the ensuing tsunami.
- The earthquake/tsunami combination exacted major destruction of life and property that taxed every component of the Japanese Government and society, with about 20,000 deaths and untold property and environmental damage.
- The already stressed emergency response capabilities were complicated and exacerbated by the accidents at the Fukushima Daiichi nuclear power plant, and vice-versa.
- The Japanese people had to contend with the aftermath of a great natural disaster and the strenuous stress from a serious and evolving nuclear accident affecting multiple reactors over a seemingly long period of time, and persistent.

The Fukushima Daiichi Accidents

- The earthquake and tsunami were catastrophic events beyond the design basis of the Fukushima Daiichi reactors; the accidents involved significant core damage and uncontrolled release of radioactive materials to the environment.
- The importance of effective public communications was evident. At times, the press almost made it look like the nuclear accidents were worse than the natural disaster.
- The importance of effective severe accident management and command and control was also evident.
- The nuclear accident outcome, although there are no direct fatalities and continuing expectations of no significant radiological health effects, resulted in a major environmental disaster regionally, and a traumatic curtailing of nuclear power generation across Japan.

Nuclear Electricity Generation

after 50+ years, still dependent on consistent and stable

Policies

Energy

Climate

Environment

Economy

Quality of Life and Well-Being

National Security

Social and Political Stability

Infrastructure

the financial, industrial and regulatory infrastructure to maintain operating reactors and deploy new ones

Reflection

- the constant need for socio-political stability -

New Nuclear Deployment

- **2000 Dominant Issues**
  - Interest Rates/Inflation, Financial Risk, Electricity Demand, Socio-Political Climate, Technical Maturity, Operating Plant Performance, Environmental Impact, Spent Fuel Disposition, Competition/Economic Deregulation, Regulatory Risk, Public Confidence, National Security and **Nuclear Safety**
- **2011 Before-Fukushima Dominant Issues**
  - *Plant Cost and Financing (Competitiveness)*
  - *POLICIES (Socio-Political and Regulatory Considerations)*
- **2011 Post-Fukushima Dominant Issues**
  - *POLICIES (Socio-Political and Regulatory Considerations)*
  - *Plant Cost and Financing*
  - Safety and Environment
  - Public Confidence

Reflection

- the constant need for socio-political stability -

And now, perhaps more than ever, we realize that for nuclear power:

- Nothing is easy, virtues are demanded from nuclear than are not demanded of others.
- Socio-political stability and financial support are dependent on operations without major radioactive releases, regardless of origin, event , location or public health impact.
- A major uncontrolled release of radioactivity is unacceptable and fixes are required for low probability-high consequences events, to further minimize the potential radioactive releases and environmental and/or public health impact.

Reflection
Nuclear Power Before Fukushima

- 25 years without a nuclear reactor accident provided assurance of safety worldwide. The two prior accidents:
  - TMI: Light Water Reactor (LWR), caused by internal event (open valve) and human factors, resulting in core degradation but no public health & safety/environmental effects.
  - Chernobyl: Graphite Reactor, caused by internal event, major errors in operation (human factors), resulting in core melting/burning, uncontrolled radioactive releases with major public health & safety and environmental consequences.
- No LWR accident until Fukushima had resulted in significant external radioactive contamination.
- No external event before Fukushima resulted in core degradation and uncontrolled radioactivity release (including Armenia).
- Regardless of initiating events, all accidents resulted in loss of core cooling after deficient accident management and human errors.

The Fukushima Daiichi Nuclear Plant Accidents

What should have happened?

- Provide adequate heat removal for the reactor core and safety-related heat sources even during accident conditions.
  - The above dominant reactor safety criteria is met by: maintaining core cooling; maintaining cooling of spent fuel pools; maintaining containment integrity; maintaining command and control; effective accident management complemented by emergency preparedness to prevent or minimize radiological releases to the public and the environment.

What happened?

- *Loss of power resulted in lack of heat removal and core degradation.*
- Multi-unit reactor accidents, most complex nuclear power scenarios ever.
- A major environmental radiological contamination, apparently without serious radiological public health and safety consequences.

Fukushima – Immediate Global Consequences

Reactor Safety Returns as an Issue for operating reactors

- **US**: major effort by US NRC and industry to rapidly assess improvements needed for beyond-design-basis events, now embodied in the US NRC "Recommendations for Enhancing Reactor Safety in the 21st Century", and multiple addenda and related documents.
- **Germany**: premature shutdown of 7 units and de-facto moratorium on new construction.
- **Italy**: 1 yr moratorium, indefinite delay of new nuclear construction.
- **European Union**: "stress tests" for 143 reactors to determine capability to handle severe accident conditions (9/30/2011).
- **China**: review reactor safety and emergency preparedness.
- **Chile**: pause emerging nuclear program pending safety review.
- **Mexico**: pause in new reactor build assessment.
- **Switzerland**: moratorium
- **Globally**: a reexamination of the safety and role of nuclear power.

US Nuclear Power Plants: Rules and Status

- The US is well prepared -overall- to handle severe external events, commensurate with region-wise phenomena.
- U.S. nuclear plant designs are required to consider the most severe of the natural phenomena that have been historically reported for the site and surrounding area with sufficient margin to ensure performance of safety functions, including seismic events, floods, tsunamis, hurricanes, tornadoes.
- U.S. nuclear power plants are designed to cope with a station blackout event that involves a loss of offsite power and onsite emergency power. The NRC's detailed station blackout regulations at 10 CFR 50.63 address this scenario, and now B.5.b supported.
- In the aftermath of the 9/11 terrorist attacks, the NRC moved quickly to ensure that safety margins would be maintained under extreme conditions like life fires and explosions. The so-called **B.5.b requirements**, now codified, do provide extra margin for preventing, minimizing and managing reactor accidents, and were enacted on the basis of adequate protection, even though they were clearly significantly beyond the design basis of reactors.

Severe Accident Management Considerations – B.5.b –

- The NRC Staff and the nuclear industry developed guidance in 2005 for implementing **B.5.b requirements**, including best practices and strategies for mitigating losses of large areas of the plant and measures to mitigate fuel damage and minimize radiological releases, **using on-site and off-site pre-deployed resources**.
- The B.5.b requirements address low-likelyhood, high-consequence events that warranted enhancements to defense-in-depth, redefining the level of protection that was regarded as adequate.
- Practices include adding make-up water to spent fuel pools, spraying water on spent fuel, enhanced initial command and control activities for challenges to core cooling and containment, and enhanced response strategies for challenges to core cooling and containment.
- B.5.b-type safety enhancements, if effectively and timely implemented in Japan, should have mitigated the events facing the operator of the Fukushima Daiichi reactors, and very specifically dealt with "station blackout" and cooling of core and fuel pools.

US Post-Fukushima Lessons Learned

- The US NRC has repeatedly stated their main conclusion that:

  "The current regulatory approach, and more importantly, the resultant plant capabilities allow the Task Force to conclude that a sequence of events like the Fukushima accident is unlikely to occur in the United States and some appropriate mitigation measures have been implemented, reducing the likelihood of core damage and radiological releases. Therefore, continued operation and continued licensing activities do not pose an imminent risk to public health and safety."

- It should be noted that the "stress tests" conducted in Europe for 143 nuclear power plants reached the same conclusions.
- The US NRC has now endorsed 7 specific areas for rapid improvement (10/18/11)

US Regulatory and Industry Actions Post-Fukushima

- The US NRC and the nuclear industry are continuing to learn from the Fukushima accidents, making improvements toward a new safety level.
- The new level will enhance the existing safety paradigm to include additional protection from severe external events, which will be integrated into the designed defense-in-depth and risk insights, establishing a stronger safety network, including accident and emergency preparedness.
- New safety paradigm: additional defense-in-depth and risk-informed regulation addressing low probability, high consequence external events.
- The main enhancements will first occur on seismic & flooding protection, strengthening station blackout capabilities, hardening vents in BWRs, enhancing spent fuel cooling capabilities, and strengthening on-site and off-site severe accident and emergency capabilities.
- An enhancement of the B.5.b measures is being conducted.
- Eventually, a more coherent regulatory framework will evolve given due consideration to 40 years of reactor safety learning.

US Current Status of Post-Fukushima Lessons Learned

- The short term NRC's Fukushima Task Force has now essentially delivered their recommendations for improving the safety framework of existing and new reactors (US NRC ML1118618071, SECY-11-0124, SECY-11-0137).
- The prioritization effort clearly separates required and recommended actions in accordance with the potential and relative safety enhancement, and the estimated time for implementation.
- The recommendations and requirements are prioritized into 3 tiers, with Tier 1 having the highest priority, following the original 12 recommendations of the report issued on 7/12/11.

US NRC Fukushima Task Force Tier 1 Recommendations

2.1 Seismic and flood hazard reevaluations

2.3 Seismic and flood walkdowns

4.1 Station blackout (SBO) regulatory actions

4.2 Equipment covered under Title 10 of the *Code of Federal Regulations* (10 CFR) 50.54(hh)(2)

5.1 Reliable hardened vents for Mark I and Mark II containments

7.1 SFP instrumentation

8 Strengthening and integration of emergency operating procedures, severe accident management guidelines (SAMGs), and extensive damage mitigation guidelines

9.3 Emergency preparedness regulatory actions

US NRC Fukushima Task Force
Tier 2 Recommendations

7 SFP makeup capability (7.2, 7.3, 7.4, and 7.5)

9.3 Emergency preparedness regulatory actions (the remaining portions of Recommendation 9.3, with the exception of Emergency Response Data System (ERDS) capability addressed in Tier 3)

Tier 3 Recommendations

- **2.2** Ten-year confirmation of seismic and flooding hazards
- **3** Potential enhancements to the capability to prevent or mitigate seismically induced fires and floods (long-term evaluation)
- **5.2** Reliable hardened vents for other containment designs (long-term)
- **6** Hydrogen control and mitigation inside containment or other buildings
- **9.1/9.2** Emergency preparedness (EP) enhancements for prolonged SBO and multiunit events (dependent on availability of critical skill sets)
- **9.3** ERDS capability (related to long-term evaluation Recommendation 10)
- **10** Additional EP topics for prolonged SBO and multiunit events(long-term)
- **11** EP topics for decision-making, radiation monitoring, and public education (long)
- **12.1** Reactor Oversight Process modifications reflecting recommended defense-in-depth framework (dependent on Recommendation 1)
- **12.2** Staff training on severe accidents and resident inspector training on SAMGs

The Bottom Line

- Ensure that seismic and flood hazards (external events) are properly evaluated and consider in a new design basis or by additional measures with similar protective effects.
- Ensure station blackout is covered under severe accident conditions and protection is provided commensurate with the capability to provide power and cooling (8 hrs & 72 hours).
- Ensure reliable hardened vents are provided for specific reactor containments (hydrogen control).
- Ensure emergency operating procedures (severe accident, extensive damage) and matching emergency preparedness capabilities are in place, including training.
- Ensure that multi-units events are covered.

Reflection
Nuclear Power After Fukushima

- A major, multi-unit LWR accident has occurred in one of the world's most industrialized nation, with severe core degradations and large uncontrolled radioactivity releases.
- Therefore, low probability, high consequences events are unacceptable and existing and new reactors must be changed.
- Changes to be enacted in the US on the basis of adequate protection, clearly significantly beyond the original design basis.
- A new safety paradigm is established.
- The new safety paradigm will be further define by a prudent combination of defense-in- depth and risk insights.

"we should be mindful of striking a proper balance between confirming the correctness of the design basis and expanding the design basis of U.S. plants." US NRC

Effective and Efficient Nuclear Power Regulation

- “There is no credible nuclear industry without a credible regulator and there is no credible regulator without a credible nuclear industry” N. J. Diaz, RIC-1999.
- Nuclear regulatory authorities must have the independence to make safety-related decisions and the authority for their implementation.
- The mission is the same across the globe: to “Enable the use and management of radioactive materials and nuclear fuels for beneficial civilian purposes in a manner that protects public health and safety and the environment, promotes the security of the nation, and provides for regulatory actions that are open, effective, efficient, realistic, and timely.” **(United States NRC Strategic Objective, FY 2004-FY 2009)**

Reflection
The Global Need for Energy

"It was (is) *the survival of unprecedented multitudes of human beings at ever increasing standards of living, together with a new intolerance toward the persistence of conditions of poverty that had previously been accepted as inevitable." George Gilder*

- Reliable, economical and well-distributed electricity continues to be indispensible to address the world's quality-of-life needs, with predictable prices and a low carbon footprint.
- Base loaded electricity generation is an affordable and dependable option to increase security of supply, minimize the carbon footprint and stabilize electricity costs.
- Nuclear electrical generation should continue to grow and be an important part of the world energy base-load portfolio for its energy security, strategic value, fuel diversification, economical and environmental contributions, with an enhanced safety framework.