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# Initial Technical Lessons Learned following the Post-Quake, Post-Tsunami, Fukushima Dai-ichi, Units 1-6, Nuclear Power Plant Accident

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## Extended Abstract

Following a magnitude 9.0 earthquake and as high as ~14m tsunami, the Fukushima Dai-ichi (D1) and Dai-ni (D2) Nuclear Power Plants (NPPs, Units 1-4[U1-4] at D1, U5-6-2 at D2i) experienced a series of multiple incidents caused by inadequate cooldown of decay heat in both the reactor and in the co-located spent fuel pool (SFP). The reactors at D1, U1-6 were constructed as part of a GE/Hitachi/Toshiba collaboration and began commercial operation, during 1971-1979; U1-5 are GE-BWR, Mark-I, U6 is a Mark-II. Two GE ABWRs are due to start construction in April 2012. Although the Units at D1 and D2 automatically shutdown at the onset of the quake and with near immediate loss of off-site power, the back-up diesel generator operated (~30minutes) until the tsunami inflicted considerable (unknown) damage to auxiliary and back-up systems (most prominently the back-up diesel general and batteries). This initiated the onset of lack of decay heat cooling. Additional aftershocks continued for about one-week. During initial week, March 11-18, there were up to three larger (likely $H_2$ explosion) explosions, vapor/steam jets and fires that further stressed the RPV, the containment and (weather) confinement buildings. One of the later explosions conceivably damage the primary (coolant) containment and thus, water found n the adjacent basement of the turbine building pointed to high-levels of radiation including fission products. Additional large volumes of contaminated were found in the U-shaped electrical conduit 'trenches' off of U1-3 and spreading into other areas such as beneath the reactor site.

This paper (under preparation) outlines the initial list of lessons learned from the multiple sequence of events, some interpretations of the news releases and the aspects of safety culture that contrast Japan and the U.S. during crisis management. It is based largely on events of the first 3 weeks and professional interpretation of publically accessible information. It is being released without peer review and in this summary form. Only the provisionally conclusive lessons learned are noted below.

1) Nuclear R&D institutions must consider alternatives to zirconium-based and zircaloy cladding so that chemical reactions that generate hydrogen is prevented. We (as an industry) need to accelerate development and deployment of non-hydrogren producing cladding materials; that is, assuming that the coolant/ moderator/ reflector remains (light) water.
2) Having multiple (reactor) units at one site, having more than two units on site needs critical review in terms of post-accident response and management. We must consider the energetic events at one unit exacerbating the situation (safe shutdown) at the other.
3) Further, there is a definite need for a backup (shielded) reactor plant control center that is offsite (remote) so that the accidents can be managed with partial to full extent of reactor plant status (P, T, flowrates, valve status, tank fluid levels, radiation levels).

4) There is a need for standby back-up power, via diesel generator and battery power, at a minimal elevation (100feet/31m) above and some distance from the plant (thus remotely located). This is needed to offset loss of off-site power for plants subject to environmental water ingress (foremost tsunami). Spare battery power should also be kept off-site and in a confirmed 'charged' state.
5) It is clear that the spent fuel pool (SFP) cannot be in proximity of the reactor core, reactor pressure vessel or containment itself. The SFP, in current form, is essentially an open volume subcritical assembly that is not subject to design requirements generally defining a reactor core. Yet, unless thermohydraulic cooling is maintained, it is subject to the similar consequences as a reactor core without adequate cooling. Therefore, we need new passive designs of the SFP, away from the actual plant's reactor core.
6) Thus needs to be a re-definition of the spent fuel pool. A new standard and design requirement is needed for the spent fuel pool. It should be 'reclassified' as a subcritical assembly with a potential to go critical with no active or passive control (rod or soluble 'poison') mechanism. Further it needs to be some distance from the reactor plant.
7) We need to identify key valves for emergency core cooling and require them to be non-electrically activated. Otherwise these valves need a secondary means of open and closed status that is remotely located.
8) If an 'in-containment' SFP is maintained, then the fuel transfer crane system must be designed so that it is available to remove the fuel during a post-accident phase. OR a second means such as a robotic arm needs to be available.
9) There needs to be a volumetric guidance analysis for ultimate (decay heat) cooling contingency plans so that not only limitations on volume are understood but also transfer of liquids from one volume to another. Spare tanks and water-filled tanks need to be kept on site as uptake tanks for 'runoff' in case of addition of cooling during accident management phases. Spare means to produce boric acid needs to be available off-site. Earthquake-proof diesel generator housing also need to be water-proof. Remote diesel generators are also needed with access to equally remote diesel fuel tanks (also see 4).
10) For nuclear power plants located in or near earthquake zones, we cannot expect structural volumes and 'channels' to maintain structural integrity. We should also expect the immediate ground underneath these structures to be porous (earth). Thus design of these volumes and channels should be such that they minimize connections to other (adjacent) volumes from which contaminated (liquid) effluents can flow.
11) Color-code major components so that in case of an accident such as the Fukushima NPP accident, we will be able to quickly identify the major components from digital images.
12) An international alliance of nuclear reactor accident first responders and thereafter, a crisis management team is needed. This does not seem to be available at any significant level at this time. We (the global nuclear industry) cannot wait 3 weeks for international participation.
13) We should consider and work toward international agreement on standards for regulated levels of radiation (activity) and radiation exposure to the general public and separately, those under emergency and extended 'recovery' phases. We should also be consistent in definition and practice of evacuation zoning. We should also strongly encourage acceptance and use of SI unit for activity and exposure and not use culturally-based numbering customs (in Japan, one counts in orders of ('man')$10^4$, ('oku')$10^8$, $10^{12}$ etc.)
14) Under emergency and crisis management, wider access roads are needed to and from NPPs. The access roads need to be clear of debris and of such width to accommodate large-scale trucks needed as first response and thereafter. A means to access the plant via water, such as ocean, calls for infrastructure (boats, water-containing barge, jet-skis etc) is needed as part of a contingency plan for those plants located near body(-ies) of water.