# Executive Summary

In the wake of Japan's Fukushima Daiichi Nuclear Power Plant accident, the Atomic Energy Council (AEC) has asked Taiwan's Nuclear Power Plant operator (TPC) to re-evaluate its capability to cope with extreme natural disasters, including earthquakes, tsunamis, extreme rainfalls and mudslides resulted from the related hazards, and take possible countermeasures. AEC has completed its assessment and verification of TPC's reports, and is committed to continuing its efforts in cross-ministerial coordination and cooperation with national organizations and stakeholders. The reassessment program comprises of two parts: 1) nuclear safety assurance, and 2) radiation protection and emergency response preparedness, which were implemented in two stages: near-term (by June 2011) and mid-term (by December 2011) assessments. The report on the first-stage assessment, approved by the Executive Yuan in October 2011, is available on AEC's website. This report covers the near-term and mid-term assessment results for both parts. The report provides a comprehensive background on radioactive hazards, and how to protect against them, as well as an overview of the enhancement measures to nuclear safety and security for the accidents in light of the Fukushima Daiichi accident. Lessons learned from the Fukushima accident as well as relavant information available internationally were used as reference during preparation of this report.

The direct cause of the nuclear accident at Fukushima, an earthquake with magnitude 9.0 resulting in an over 14 meter high tsunami, is far beyond the design basis against most extreme natural events experienced. Although there have been huge tsunamis attacking the east coast of northern area in the main island of Japan, design provisions at the

Fukushima Daiichi site appear to only have been made to protect against a 5.7 meter high surge above sea level. The nuclear power plants of TPC, both operating and being under construction, should follow the same criteria to examine the design basis. In addition, AEC's regulation on design basis analysis requires TPC to demonstrate that adequate protection is in place for an extremely rare natural event, developed based on extrapolation from the historical record. AEC then requires TPC to show that there are no "cliff-edge" effects based on the specification of EU stress tests. While the investigation of the accident scenarios in Japan is still left to be clarified, there is sufficient information to develop initial lessons learned for AEC. Based on our preliminary conclusions and first-stage requirements, AEC refers the actions recommended by USNRC to be taken without delay and the best international engineering practices considered in the nuclear industry by taking the nuclear regulatory cases into account to the second-stage report. There are some emerging lessons, and these are proposed as requirements for further work.

After reviewing the TPC's near-term action submittals required by AEC, two issues related to the current licensing basis of the nuclear power plants were found: the elevation measurement did not comply with FSAR in Chinshan plant, and the design for tsunami protection was not adequate at the ECW pump room in Kuosheng. These issues were later confirmed resolved upon site inspection. While the assessment of post-Fukushima evaluation reveals neither immediate nuclear safety concern nor threat to the public health and safety, AEC requests that TPC focus on strengthening its re-evaluation on design basis against earthquakes, tsunamis and heavy rainfalls, and enhancing its capability to mitigate a prolonged station blackout (SBO) for further improvement.

Many areas of improvement have been identified in the issues of nuclear safety assurance. The key areas include the enhancement of capability to mitigate a prolonged station blackout, protection against tsunami hazards, spent fuel pool cooling, hydrogen detection and explosion prevention, severe accident management, protection against seismic hazards, critical infrastructure, and safety culture, which are further stated in the following.

**Prolonged Station Blackout**

Grid supplies were lost when the earthquake struck the area around Fukushima, but serious problems arose at the Fukushima Daiichi site because of prolonged unavailability of electrical power. The long-term independent on-site emergency electrical supplies then provide assurance of safety on the site, when coupled with the timely restoration of a reliable off-site grid supply. The robustness, reliability and potential for extended unavailability in severe hazard conditions of the plant emergency power systems need to be re-evaluated in light of the Fukushima accident.

The on-site emergency electrical supplies at the TPC site involve diesel generators (DG) and back-up batteries. By reviewing plant layouts, the protection against flooding and the interplay between on-site and off-site electrical supplies, consideration should also be given to the provision of additional, diverse means of providing robust long-term electrical supplies independent of the grid for emergency cooling, emergency control and instrumentation systems. AEC requests TPC to install an additional sixth air-cooled desiel generator. TPC has procured 4.16kV and 480V mobile diesel generators and on-site protable, diverse equipment to increase robustness of the plant to respond to the Fukushima-like events. Such dedicated supplies may be located on or near the site with suitable robust connections. AEC also requests TPC to evaluate the establishment of a coping time of 24 hours for a loss of all AC power, and establish the requirement necessary to implement an “extended loss of all AC power” coping time of 72 hours for core and spent fuel pool cooling and for reactor and containment integrity. The fifth DG should be used as dedicated backup for on-line maintenance related to cold shutdown and fuel replacement. AEC requires TPC to strengthen SBO mitigation capability and update its design basis by following Recommendation 4.1 in the near-term task force (NTTF) report of USNRC.

**Protection against Tsunami Hazards**

External flooding has also been considered in the report as an impact on siting and site/plant layout. The simulations of threat for nuclear power plants by tsunamis have been provided by the National Science Council (NSC). TPC needs to reanalyze the tsunami hazard of nuclear power plants based on the US related laws and regulations which are standardized by the state-of-the-art technology, and to strengthen their flooding design data. AEC requests TPC to adopt the installation of flood barrier walls around the area where equipment essential for ensuring safety is located or enhancement of seals and water-tightening of building doors based on six meters above the current design basis tsunami level, and install deep wells or cooling towers as an alternative backup of ultimate heat sinks (UHS) for emergency service pumps before completion of the reanalysis. AEC requires TPC to strengthen flooding mitigation capability and update its design basis if necessary, by following Recommendations 2.1 and 2.3 regarding flooding mitigation in the NTTF report of USNRC.

**Spent Fuel Pool Cooling**

TPC’s spent fuel management strategy has necessitated increased spent fuel pool storage capacity at reactor sites, an interim spent fuel storage installation (ISFSI) is also under construction at Chinshan plant. The spent fuel pool is a robust structure filled with water to cool the fuel and provide shielding from gamma radiation. The pool is designed with cooling systems to maintain water temperatures around 30°C to 40°C and water levels several meters above the top of the fuel assemblies. After several years of storage, the residual decay heat within the fuel was decayed to a level where the spent fuel could be transferred into dry casks for further storage. Dry cask storage has inherent security advantages over spent fuel pool storage, but it can only be used to store older spent fuel.

The spent fuel assemblies in the pool should be evaluated with the reconfiguration in a "checkerboard" pattern (i.e. center hot spent fuel assembly surrounded by four cold assemblies) so that newer, higher decay-heat fuel elements are surrounded by older, lower decay-heat elements. AEC orders TPC to provide sufficient safety-related instrumentation to monitor key spent fuel pool parameters (i.e., water level, temperature, and area radiation levels) from the main control room. AEC also requests TPC to provide safety-related AC electrical power for the spent fuel pool makeup system. AEC requires TPC to strengthen the capability to monitor the level of spent fuel pool under severe accidents by following Recommendation 7.1 relating to spent fuel pool instrumentation in the NTTF report of USNRC.

**Hydrogen Detection and Explosion Prevention**

A considerable quantity of hydrogen could be generated by chemical reactions between zirconium fuel cladding and steam on loss of cooling like that happened in Fukushima Daiichi plant. In the case of BWR plants, the hardened routes for venting containment heat from the reactor vessel have been installed, following the TMI (Three Miles Island) response actions. Additionally, an explosion occurred in the suppression pool of

Fukushima Daiichi Unit 2, possibly breaching the primary containment. This indicates that more attention should be given in the design and safety assessment to the robustness of the Mark I containment installed in Chinshan plant. Given the experience at the Fukushima plant, AEC requests TPC to prudentially review if the systems for venting containments with potentially significant concentrations of combustible gases are sufficiently robust. AEC requires Chinshan plant to conform the requirement from Recommendation 5.1 in the NTTF report of USNRC. The other nuclear power plants of TPC are required to evaluate the installation of radioactive substance filtering device to the hardened vent systems in accordance with the standards of European Union nations.

**Severe Accident Management**

Reviewing the Severe Accident Management Guidelines (SAMG) can provide support for operator actions and also allow assessment of the suitability of operator actions in coping with Fukushima type events, based on the information on the success or otherwise of the postulated operator actions. In particular such a review should consider the critical safety functions prioritization, wider plant requirements, and the level of details and prescription currently offered. TPC should continue its effort to gain better understanding the improvements that the nuclear industry has made in dealing with severe accident phenomenon in terms of requirements and approaches. The current simulator models used to support the formal training of severe accident management have their limitation. TPC needs to consider reasonable practicability and safety benefit of extending routine training in severe accident response, and refine the Ultimate Response Guideline (URG). AEC requires TPC to strengthen and integrate onsite emergency response capabilities such as EOPs, SAMGs, and EDMGs, into the URG by following Recommendation 8 in the NTTF report of USNRC.

**Protection against Seismic Hazards**

The Fukushima reactor's shutdown systems operated effectively in response to the event. It indicates the robustness of seismic design adopted for these Japanese plants. AEC has learned from the earthquake experience on Japan's nuclear power plants, and in recent years has requested TPC to perform the necessary studies, including the supplemental geological investigation of sea area, land territory, geological stability and seismic hazard analysis nearby the nuclear power plants. Based on the relevant information of seismic margin assessment of operating nuclear power plants, the subsequent reinforcement work is to strengthen seismic design to cope with natural disasters. TPC needs to reanalyze the seismic hazard of nuclear power plants based on the US related laws and regulations which are standardized by the state-of-the-art technology, and to strengthen their seismic design data accordingly. TPC needs to reinforce the seismic resistant capability for the structure of non-seismic technical support center, and completes relevant requirements as set forth in Recommendations 2.1 and 2.3 regarding seismic hazards in the NTTF report of USNRC.

**Infrastructure Resilience**

The severe disruption of the electrical grid, communications and transportation systems on Fukushima event was one of the important observations. It was a significant contributory factor to worsen the accident while the conditions lasted for several days. The reactor safety is reliant on the resilience of the local infrastructure in circumstances of extreme events affecting both the nuclear site itself and the surrounding area. TPC needs to enhance on-site accident management capabilities and incorporate the off-site resources. The interdependency on the resilience of nuclear plants and off-site infrastructure should be re-examined through the lessons learned from the Japan event. This might highlight the need for the enhancement of plant's sustainabilities for extended periods in terms of electrical power, coolants and necessary supplies. The Fukushima Daiichi accident in Japan showed the value of hardened on-site emergency response centres. AEC requires TPC to prepare emergency response workplace at nuclear power plants by referring to the guidance of seismic isolation buildings of Japan, and completes relevant requirements as set forth in Recommendation 9.3 in the NTTF report of USNRC.

**Safety Culture**

Many of the above considerations are intrinsically linked to nuclear plant safety culture. The events at Fukushima have highlighted a number of issues that should be reviewed for each TPC plant and, if necessary, provided as reference to the revisions of the practices of safety culture. An acceptable safety culture will be required to provide an appropriate basis for any changes to plant and arrangements for severe accidents. There is a particular need to consider longer term analysis of fault sequences taking account of the development of the accident sequence over time and the potential loss of services, such as cooling and electricity, as well as the potential for repair and recovery to a stable state. While demanding TPC to improve its nuclear safety culture, AEC will strengthen regulatory oversight of licensee safety performance (i.e., the Reactor Oversight Process).

AEC requests TPC to deliberately implement and complete the nuclear regulatory safety-issue follow-ups cases identified in the second-stage report for safety improvement. TPC may submit alternative plans approved by AEC to provide the equivalent function to conform the requirement of nuclear regulatory cases. To keep up with the pace of international countermeasures after Fukushima, AEC is actively involved in such activities as to have the national reports in the specification of

EU's Stress Test reviewed by international counterparts, and to examine rigorously the 10-year periodic safety review of nuclear power plants in the near future.

As for the part on radiation protection and emergency response preparedness, the re-assessment of nuclear emergency preparedness and response comprises three aspects: 1) relevant laws, regulations and implementation mechanisms, 2) emergency planning and preparedness, and 3) the implementing capability of emergency response.

The improved plans or measures are based on the lessons learned from Fukushima accident (beyond design basis) after a review on the current status of related issues as a baseline. It includes expanding the Emergency Planning Zone (EPZ), reviewing the Nuclear Emergency Response Act and related regulations, establishing a mechanism to respond to compound disasters, re-assessing the mission and functions of response units, and enhancing the capabilities and abilities of the nuclear emergency preparedness and response system. All the measures are to ensure the nuclear emergency preparedness and response system more efficient and effective.

Concerning the impacts of released radioactive material resulted from the Fukushima nuclear accident as well as new construction of nuclear power plants in mainland China and Korea, the capability for assessing dose resulted from overseas nuclear accidents should be established in an effort to provide early warnings and take appropriate radiation protection measures. As a result of the re-assessment, the EPZ has been expanded from 5 km to 8 km for all three nuclear plants in Taiwan. It is also essential to advance the effective range and processing speed of the existing accident dose assessment system, based on the lessons learned from the Fukushima accident. In order to enhance domestic capability of radiation fallout monitoring in a timely manner, we have purchased mobile detection equipment with automatic data transmission capability, and actively establishing aerial and marine monitoring systems and capability, strengthening radiation hazard response capacity and setting up a radiation monitoring preparedness platform, so as to be prepared in the event of a compound disaster.