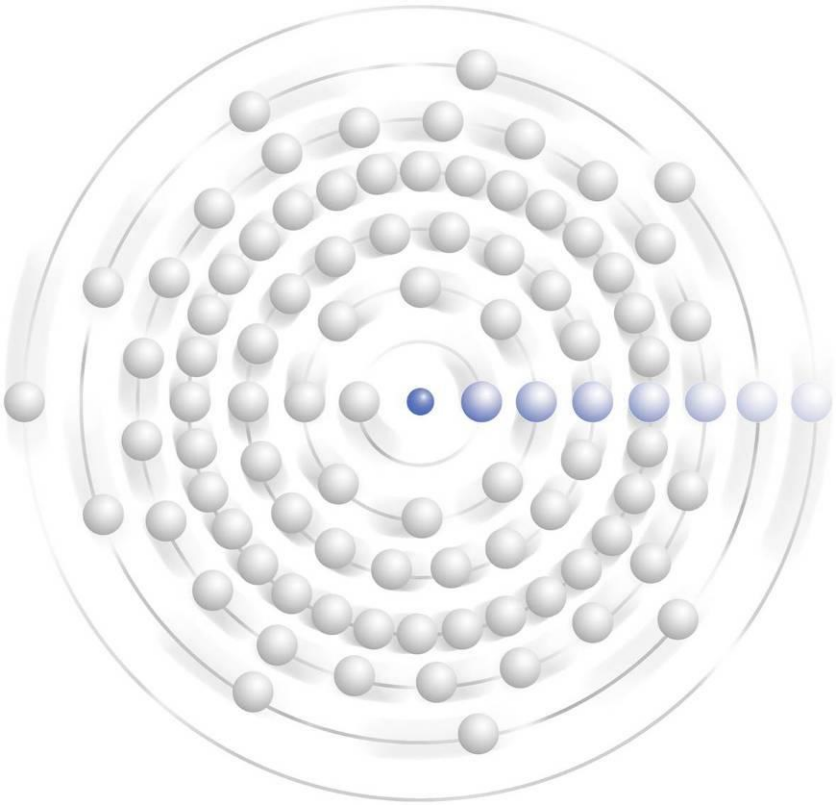
Special Ux Consulting Report June 2011

Nuclear Power in the Post-Fukushima Era



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Introduction & Overview

The nuclear industry has just experienced the second-worst calamity in the history of nuclear power. Following the March 11, 2011, 9.0 magnitude Tohoku-Chihou-Taiheiyou-Oki Earthquake (also known as the Tohoku-Pacific Ocean Earthquake) and its ensuing tsunami, Tokyo Electric Power Company's (TEPCO) Fukushima Daiichi Nuclear Power Plant suffered a prolonged station blackout and subsequent partial core meltdowns among other major malfunctions. The result of this disaster is that four of the six reactors at the site are irreparably damaged, and it appears likely that the whole station will be decommissioned. This unprecedented event has already had long-lasting effects on Japan, the nuclear industry, and the global energy markets. While some of the ramifications are yet to be fully grasped, it is critical to early identify critical aspects that may affect currently operating nuclear fleets worldwide and begin the process of analyzing the likely impacts and mitigation strategies.

The Ux Consulting Company (UxC) has prepared this special report to review the impacts of the Fukushima accident both on a technical as well as commercial level in order to allow for in-depth analysis and forecasting of how Japan and the world will respond to this event.

Message to the People of Japan

UxC takes no joy in writing this report that essentially analyzes one of the worst natural disasters in modern times and clearly the worst disaster to afflict the great country of Japan since World War II. Given the event's enormous importance for the economic impact on Japan and the nuclear power industry globally, UxC feels compelled to provide a third-party, independent perspective on the reactor accident at Fukushima Daiichi in order to support rebuilding efforts in Japan as well as to enhance the global public discourse. Of course, there is no way for our limited efforts to begin to restore the vast amount of loss in human toll and physical and economic devastation left by the earthquake and tsunami. As nearly 25,000 people are either dead or missing from this tragedy, we can only offer our own heartfelt condolences to all that have been so horribly affected by this disaster.

UxC has also provided a small level of assistance through donations to the American Red Cross in their efforts to support the victims as well as the American Nuclear Society's Japan Relief Fund[1], which is dedicated to supporting those directly impacted

[1] American Red Cross: https://american.redcross.org/site/Donation2?5052.donation=form1&df_id=5052&
ANS Japan Relief Fund: http://www.new.ans.org/about/japanrelief/

by the Fukushima Daiichi reactor accident. Ultimately, we are very confident that Japan, and especially the Tohoku region, will recover from this tragic event and re-build to be even stronger and more prosperous in the future.

Finally, UxC hopes that the humble suggestions provided as a result of our preliminary analyses of the Fukushima accident may be used to assist and expedite recovery of safe electricity production from all nuclear power stations operating in Japan and worldwide.

Purpose of Report

UxC began work on this study as soon as the massive implications of the Fukushima accident became clear right after the first hydrogen explosions occurred at the plant. It has now been nearly three months since the accident first began, and many more details are available about how this event transpired, what the main failure modes were, how the recovery can take place, and how this incident is being perceived in Japan and throughout the world. While it is clearly still too early to write any final analysis of the accident and its lessons, this report relies on a large amount of data collection, investigative research, and critical analysis in order to provide an unbiased and independent view of the accident, some initial conclusions, and suggestions for a prompt recovery. Thus, it is important to understand the preliminary nature of the assessments found in this report, even though they are already quite exhaustive.

While it may be early to say conclusively, from all early indications, the Fukushima accident will go down in history as the second worst nuclear power accident after the 1986 Chernobyl tragedy in Ukraine. Although the amount of radiological releases is so far reported as smaller than Chernobyl, the broad impacts of the Fukushima accident are on a similar scale. Still, as the Fukushima accident has shown the world that nuclear power plants remain very complex and can have major accidents, this event has also offered insights as to how to improve its management in order to better minimize the risks involved. It is critical to understand that the loss of human life and property from the earthquake and tsunami dwarf the actual damage caused so far by the Fukushima reactor accident. Of course, this conclusion may provide no solace to the hundreds of thousands of residents near the plant that have been forced to evacuate and may have their entire lives altered forever as a result.

In terms of the broader impacts of this accident on the world, the main issues will involve lessons to be learned to ensure that similar reactor accidents shall not happen again. For sure, nuclear power will again be stained with a label of being "very risky," but in a world where few good energy options exist, it is also clear that many countries will continue to rely on this non-emitting, baseload power source for long into the future. Although nuclear power's share of the world energy supply may not grow as fast as before the accident, it will surely remain on a net growth path due to the expansion plans in major countries, like China, Russia, South Korea, and India.

Thus, while nuclear power has been severely damaged by the Fukushima accident, the lessons learned can only translate into technological improvements resulting in

lower risks, therefore it is not impossible to restore its image and reputation. Some of the critical aspects to this recovery include a need for more focus on important safety aspects as well as public education along with consideration of critical reactor technical and engineering issues that may need to be addressed. As will be presented throughout this report, there are many ways in which nuclear power can recover and become even more sustainable if the lessons of the Fukushima accident are converted into rapidly implemented technological, regulatory, and procedural improvements.

Ultimately, we state emphatically that this report is by no means intended to place blame or criticize any specific entity or technology. While some of the analysis presented in the report identifies weak points, UxC unbiased experts believe that there exist modern technology fixes (note that the Fukushima Daiichi designs were conceived in late sixties) and that all of these issues can be properly addressed and overcome given adequate attention.

Report Limitations

As explained, this report is just a beginning in the process to analyze the implications of the Fukushima accident. Moreover, while every effort has been made to ensure accuracy in the data and information provided, given the fast moving nature of this story, there may be some small aspects of the report that are either outdated or have been superseded by events on the ground. However, the overarching analysis and initial conclusions should continue to be valid for longer into the future. Of course, UxC will not stop following this critical event, as it impacts every aspect of the global nuclear industry, and is likely that future updates to the reporting and analysis in this report will be necessary.

It should also be noted that much additional analysis of the Fukushima impacts on different aspects of the global nuclear industry is also found in many other UxC standard reports and services, including:

- *Ux Weekly*, *SpentFUEL*, and *Store Fuel* newsletters covering the entire nuclear fuel cycle on a weekly basis
- *Nuclear Industry Value Chain* annual report (February 2011 edition with April 2011 Post-Fukushima Addendum) analyzing each nuclear industry market sector
- *Nuclear Power Outlook* quarterly detailed reports on global nuclear power trends with updated nuclear power forecasts every three months
- *Market Outlook* reports on each front-end nuclear fuel sector: *Uranium, Conversion, Enrichment,* and *Fabrication*
- *Policy Watch* web-based reporting service on important policy-related issues impacting the global nuclear industry

Furthermore, this report provides the results of preliminary technical analyses and subsequent suggested mitigation strategies focused on the BWR Mark I design. The

report also offers basic analyses regarding the expected behavior of selected nuclear reactor designs (operating and new) if subjected to the same Fukushima Daiichi accident scenarios. Since this remains an overview report on the broader implications of the accident, UxC is prepared to provide additional in-depth technical analyses evaluating modern reactor designs and their coping capabilities in view of the Fukushima Daiichi accident or related issues through specialized consulting services.

Finally, we would point out that many other organizations around the world (e.g. IAEA, NRC, WNA, NEI, JAIF, FORATOM, etc.) are doing very important work in terms of reporting and responding to the Fukushima accident. As a small, but independent company, UxC clearly has no intention to duplicate these efforts, and we refer to many of these organizations' activities throughout the report. Moreover, as provided in our list of references to these organizations at the end of the Appendix, UxC recommends all those seeking a complete understanding of this critical event to also closely examine the information put forth by all of these leading institutions.

Structure of Report

This comprehensive report reviews nearly every aspect of the Fukushima Daiichi NPP accident and provides detailed assessments and analysis on both technical and commercial levels. In addition to this **Introduction & Overview**, the report includes multiple chapters as follows:

Chapter 1 – Fukushima Accident Overview & Technical Assessment offers an in-depth review of the accident sequence as well as technical issues that arose during the accident.

Given the broad impacts of the accident, **Chapter 2 – Economic and Other Impacts on Japan** begins this discussion by examining the immediate effects on the Fukushima region, Japan's economy, the electric power and nuclear industry in Japan, among other sectors.

Chapter 3 – Impacts on Global Nuclear Power presents an exhaustive review of the various responses to the Fukushima accident by countries with existing or potential new nuclear power plants. Additional sections examine implications for the international nuclear power safety regime as well as global public opinion on nuclear power. Finally, this chapter reviews the major changes to UxC's proprietary nuclear power forecasts through 2030 as a result of the Fukushima accident and analyzes the implications from the reduction of nuclear power utilization for other forms of energy as well as carbon emissions.

Chapter 4 – Overall Lessons from Fukushima Accident turns to our detailed technical analysis of the Fukushima accident in order to assess likely engineering, operational, as well as regulatory safety changes that may result from a lessons learned approach to the accident.

Chapter 5 – Implications for Operating Reactors considers the specific technical, regulatory, as well as commercial issues that the Fukushima accident implies for the roughly 440 operating nuclear reactors around the world.

Chapter 6 – Implications for New Reactors approaches the same technical, regulatory, as well as commercial issues resulting from the Fukushima accident and applies them to new reactor designs and projects around the world.

Given the critical questions on spent fuel that the Fukushima accident has raised, **Chapter 7 – Implications for Spent Fuel Management** examines the potential changes to spent fuel management under this changed landscape.

Chapter 8 – Commercial Nuclear Industry Impacts provides specific analysis of the Fukushima impacts on the various companies involved in the nuclear reactor supply chain and related industry sectors.

Chapter 9 – Summary and Conclusions offers UxC's overarching conclusions from this detailed analysis of the Fukushima accident in order to help put this event in better context.

In addition, a **Glossary** provides explanations of the main technical abbreviations used throughout this report.

There are numerous additional information sources and data found in the eight separate **Appendix** chapters at the end of this exhaustive report. The appendix includes:

- A detailed "Nuclear Reactor Technology Primer" in order to educate any non-technical readers
- *Ux Weekly* news briefs on the ongoing Fukushima crisis and UxC meeting summaries of relevant conferences after Fukushima
- Data lists on boiling water reactor (BWR) containments and Japanese power plants impacted by the earthquake and tsunami
- Additional background information on previous tsunami events impacting nuclear power plants as well as the nuclear safety improvements required since the Three Mile Island (TMI) event in the U.S. in 1979
- A comprehensive list of web-based sources for the many other international organizations that have been providing important information and analysis of the Fukushima accident