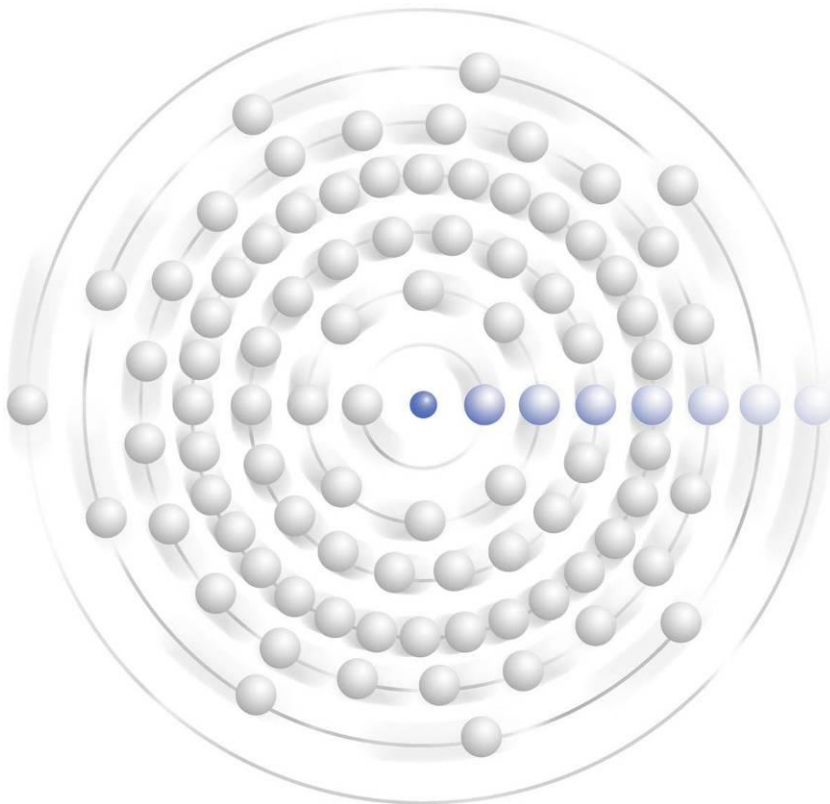




Nuclear Power in the Post-Fukushima Era



Ux Consulting
1501 Macy Drive
Roswell, GA 30076
(770) 642-7745
www.uxc.com

– NOTICE –

The Ux Consulting Company, LLC (“UxC”) shall have title to, ownership of, and all proprietary rights in this Report. Under United States federal copyright law (17 USC 101 et seq.) it is illegal to reproduce this Report by any means without written permission from UxC.

The information contained in this Report is obtained from sources that UxC believes to be reliable. UxC makes no warranty or representation, express or implied, with respect to the accuracy, completeness or usefulness of the information contained in this Report and UxC, to the maximum extent permitted by law, assumes no liability for the use or effects of any of the information or data contained in this Report.

It is UxC’s strict policy not to endorse, promote, or recommend any particular securities, currencies, or other financial products or instruments. Nothing contained in this Report is intended to constitute investment, legal, tax, accounting or other professional advice and the reader should not rely on the information provided in this Report for making financial decisions.

The Ux U₃O₈ Price[®] and other Ux Price indicators are developed by The Ux Consulting Company, LLC (UxC) and are proprietary and exclusive intellectual property of UxC. These price indicators are provided to UxC’s customers through the Ux Weekly[®] publication and are made available on UxC’s public website solely at UxC’s discretion. They may not be reproduced or otherwise used without UxC’s express permission.

UxC[®], Ux Weekly[®], Ux U₃O₈ Price[®], Ux[®], and Ux Consulting[®] are trademarks of The Ux Consulting Company, LLC.

Table of Contents

Introduction & Overview	9
Message to the People of Japan.....	9
Purpose of Report.....	10
Report Limitations.....	11
Structure of Report.....	12
1 – Fukushima Accident Overview & Technical Assessment	14
Overview of Fukushima Daiichi Nuclear Power Plant.....	14
The Earthquake and Tsunami.....	16
Series of Events.....	19
• Detailed Timeline of Events.....	20
BWR and Reactor Accident Technical Background.....	29
• BWR Mark I Technology, Systems, and Terminology.....	29
BWR Functional Diagram.....	38
Decay Heat Removal System Brief Description.....	39
Reactor Core Isolation Cooling (RCIC) Brief Description.....	40
Emergency Core Cooling System (ECCS) Brief Description.....	42
• Spent Fuel, Spent Fuel Pools, and Dry Storage Issues.....	44
Thermal Power Represented by Spent Fuel in the SFP.....	46
General Discussion on Spent Fuel and SFPs.....	47
Dry Casks – Long-term Spent Fuel Cooling.....	47
Decay Heat from Spent Fuel.....	49
• Fukushima Daiichi NPP Decay Heat Issues.....	50
Fukushima Accident Assessment Overview.....	53
Impacts of Earthquake and Tsunami.....	55
• Hydrogen Production and Radioactivity Release from Nuclear Fuel during Loss Of Coolant Accidents (LOCA).....	60
• Units 1, 2 and 3 Residual Thermal Energy After Shutdown.....	62
Road to Recovery and Stabilization.....	67
Plant Status and Data Uncertainties.....	69
• Timeline for Hydrogen Explosions at Units 3 and 4.....	71
• Units 3 and 4 Shared Vent.....	72
2 – Economic and Other Impacts on Japan	76
Impacts on Fukushima Region.....	76
Impacts on Japan’s Economy.....	79
Japan’s Impact on the World Economy.....	81
Industries and Companies Affected.....	82
Impacts on Japan’s Government and Public.....	85
• Nuclear Accident Liability Issues.....	86
Impacts on Japan’s Electric Power Industry.....	87
Implications for TEPCO.....	93
Impacts on Japan’s Nuclear Power Program.....	97
• Impacts on Other Japanese Utilities.....	98
Kansai Electric Power Co.....	100
Chubu Electric Power Co.....	100
Tohoku Electric Power Co.....	103
Kyushu Electric Power Co.....	104
Shikoku Electric Power Co.....	105
Chugoku Electric Power Co.....	105
Hokkaido Electric Power Co.....	106
Hokuriku Electric Power Co.....	107
Japan Atomic Power Co.....	107
Electric Power Development Co. (J-Power).....	108
3 – Impacts on Global Nuclear Power	109
Overview of World Response.....	109
North America.....	110
• Existing Nuclear Power Countries.....	110
Western Europe.....	113

• Existing Nuclear Power Countries	115
• Potential New Nuclear Power Countries	121
Eastern Europe	121
• Existing Nuclear Power Countries	124
• Potential New Nuclear Power Countries	128
Asia & Oceania.....	129
• Existing Nuclear Power Countries	131
• Potential New Nuclear Power Countries	134
Africa & Middle East.....	137
• Existing Nuclear Power Countries	138
• Potential New Nuclear Power Countries	138
South America.....	142
• Existing Nuclear Power Countries	142
• Potential New Nuclear Power Countries	143
Nuclear Safety after Fukushima	143
• Initial Reactions.....	144
• International Initiatives	144
Convention on Nuclear Safety	144
International Atomic Energy Agency	145
IAEA Fact-Finding Mission Report	145
Experts' Statement.....	146
European Nuclear Safety Regulators Group (ENSREG)	147
Western European Nuclear Regulators Association (WENRA).....	148
World Association of Nuclear Operators (WANO).....	149
• Possible Future Developments in Nuclear Safety.....	149
Review of Public Opinion Polls on Nuclear Power	151
• United States.....	151
• Canada.....	152
• France.....	153
• United Kingdom.....	153
• Germany	154
• Switzerland.....	154
• Sweden	154
• Italy.....	154
• Lithuania.....	155
• Taiwan.....	155
• Chile.....	155
Shifts in UxC Nuclear Power Forecasts after Fukushima	156
• Post-Fukushima Global Nuclear Power Forecast Overview	156
Alternative UxC Reactor Forecast Cases.....	159
• Global Nuclear Power Forecast Comparisons: Q1 vs. Q2 2011	160
Detailed Review of Forecast Changes	160
Changes to Low and High Forecast Cases.....	162
Ramifications for Other Energy Sources	163
• Regional Energy Fuel Switching Review	165
North America	165
Western Europe	165
Eastern Europe	167
Asia & Oceania	167
Africa & Middle East.....	168
South America.....	169
• Summary Results from Energy Switching Analysis	170
4 – Overall Lessons from Fukushima Accident	172
Main Lessons Overview	172
Accident Scenarios and Design Basis Issues	173
• Additional Areas Requiring Improvement.....	174
Reactor Design and Engineering Issues	175
Operational Issues	179
Regulatory Issues.....	180
• Station Blackout and EDGs.....	181

5 – Implications for Operating Reactors	184
Potential New Safety Requirements	184
• U.S. Nuclear Safety Improvements since TMI	184
• Potential New Regulatory Requirements	187
• Nuclear Energy Institute Activities	190
• Utility Safety Improvement Plans Already Announced.....	190
• Utility Safety Review Action Plans	191
Generic Technical Challenges Presented by Fukushima	193
Possible Solutions to Technical Challenges	195
• Spent Fuel Pool Add-on Cooling Systems.....	196
• SFP Add-on Cooling & Decay Heat Energy Driven AC Generation System	197
• Entirely Passive Add-on Decay Heat Removal System.....	201
Minimally Invasive SFP DHERPA Components	203
• Inherent Safety Solutions.....	204
• Nuclear Fuel Inherent Weaknesses and Possible Solutions	205
Metal Fuels.....	206
Ceramic Fuels	206
Fuel Forms for Oxide Fuels	207
PWR Fuel	207
BWR Fuel.....	207
Oxide Fuel Behavior in Reactors	208
Fuel Alternatives Resistant to Meltdown.....	208
Dispersion Fuels.....	209
Qualification of New Nuclear Fuel	211
• Hydrogen Hazards Mitigation in LWRs	211
Mitigation of Hydrogen Hazards in Existing Reactors.....	214
Mitigation Measures for Hydrogen in Severe Accidents	215
• Containment Venting Issues	220
Engineering Challenges for Different Reactor Designs.....	223
• BWRs.....	223
• PWRs.....	225
• PHWRs	225
• Others	225
Gas Cooled Reactors	225
RBMK Reactors.....	225
Commercial Implications for Operating Reactors.....	227
• New Regulations on Operating Reactors.....	227
• Nuclear Plant Retrofits	228
• Lifetime Extensions.....	228
• Operating Reactor Economics	228
6 – Implications for New Reactors	230
New Reactor Issues Overview	230
Potential New Regulatory Requirements	236
• Review of Reactor Design Bases	238
Engineering Challenges for New Reactor Designs	238
• PWRs.....	239
AP1000.....	239
EPR, APWR, VVERs (AES-2006), and CPR-1000.....	240
• BWRs.....	240
ABWR.....	240
ESBWR	241
• PHWRs	242
Impacts on SMRs and Possible Outcomes.....	243
• Increased Water/Fuel Ratio	243
• Low Power	243
• Low SMR Equipment Weight.....	244
• Integral Designs	244
• Unitized Designs	244
• Passive Safety Features	244
Commercial Implications for New Reactors	245

• Traditional Nuclear Power Leaders	245
• Emerging Nuclear Giants	245
• New Nuclear Power Countries	246
• New Technical Considerations	246
• Political and Public Opinion Hurdles	246
• UxC New Reactor Construction Forecasts	247
• New Reactor Costs	248
7 – Implications for Spent Fuel Management	249
Spent Fuel Management Background	249
Ultimate Disposal of Spent Fuel	249
Spent Fuel Management Options	250
Potential New Regulatory Requirements	251
Potential Impacts on Other Backend Services	255
Summary of Current Policies on Spent Fuel Management	258
Engineering Challenges for Spent Fuel Pools	260
Conclusions	261
8 – Commercial Nuclear Industry Impacts	262
Overview of Potential Market Impacts	262
Impacts on Nuclear Company Stock Prices	262
Impacts on Nuclear Power Utilities	263
• Specific Utility Impacts	267
U.S. Utilities	267
European Utilities	269
Impacts on Nuclear Supply Chain	274
NSSS Vendors	275
• AREVA	275
• Atomstroyexport (ASE)	276
• Chinese Nuclear Plant Developers	276
• Mitsubishi Heavy Industries	278
• Toshiba Corporation	278
• Westinghouse Electric Company	278
• General Electric-Hitachi	279
• Atomic Energy Canada Ltd.	279
Engineering, Procurement, and Construction (EPC)	280
• Bechtel Corporation	280
• Shaw Group	280
• SNC-Lavalin	280
• Kajima Corporation	281
• Hyundai Engineering & Construction (Hyundai E&C)	281
Nuclear Component Suppliers	281
• Alstom	281
• Babcock & Wilcox (B&W)	282
• Curtiss Wright	282
• Chinese Companies	282
• Doosan Heavy Industries and Construction	282
• Siemens AG	283
• Rolls Royce	283
• Heavy Forgings Suppliers	283
SMR Designers	283
• Westinghouse	284
• B&W	285
• NuScale	285
• OKBM Afrikantov	285
• Korea Atomic Energy Research Institute (KAERI)	285
Impacts on Back-End Companies	286
Impacts on D&D Companies	287
• Fukushima Daiichi NPP Decommissioning	287

9 – Summary and Conclusions	289
Technical Conclusions	290
• Summary of Technical Issues	290
• Overarching Conclusions from the Fukushima Accident	293
• Implications for Operating Reactors	293
• Implications for New Reactors	294
• Implications for Small Modular Reactors	294
• Technical Implications for Spent Fuel Management	295
• Technical Conclusions Summary	296
Commercial Conclusions	296
• Impacts on Japan	296
• Reductions in Nuclear Power Usage	297
• Nuclear Reactor Economics	297
• Reactor Market Implications	298
• Back-End Market Implications	298
Looking to the Future	298
Glossary	299
Appendix A – Ux Weekly News Briefs on Fukushima Crisis	302
March 14, 2011, Volume 25, Issue 11	302
March 21, 2011, Volume 25, Issue 12	303
March 28, 2011, Volume 25, Issue 13	305
April 4, 2011, Volume 25, Issue 14	305
April 11, 2011, Volume 25, Issue 15	307
April 18, 2011, Volume 25, Issue 16	308
April 25, 2011, Volume 25, Issue 17	309
May 16, 2011, Volume 25, Issue 20	310
Appendix B – UxC Meeting Summaries of Events After Fukushima	312
Briefing on NRC Response to Nuclear Events in Japan	312
U.S. House Science Committee Briefing	313
CSIS-LSU Series on Disaster Management and Emergency Response	314
U.S. Senate Energy & Natural Resources Committee Briefing	316
CSIS Event: “Nuclear Safety After Fukushima”	319
2011 NEI Used Fuel Management Conference	322
2011 NEI Nuclear Energy Assembly	326
Appendix C – List of Worldwide BWRs by Containment Type	328
Appendix D – Nuclear Reactor Technology Primer	330
Basic Reactor Designs	330
• Boiling Water Reactors	330
• Pressurized Water Reactors	331
• Heavy Water Reactors	332
• Gas Cooled Reactors	332
• Light Water Cooled, Graphite Moderated Reactors	333
• High Temperature Reactors	333
• Fast Breeder Reactors	333
Evolution of Reactor Technologies	334
• Generation III and III+ Reactors	335
Reactor Licensing	335
UxC Nuclear Reactor Technology Assessments	337
UxC Small Modular Reactor Assessments	339

Appendix E – 2004 Indian Ocean Tsunami Impact on Madras NPP	341
Appendix F – Earthquake/Tsunami Affected Power Plants in Japan	343
Appendix G – U.S. NRC Short-Term Recommendations after TMI	346
Appendix H – U.S. NRC Long-Term Recommendations after TMI	349
Appendix I – Additional Info Sources on Fukushima Accident	357
Japanese Organizations.....	357
U.S. Organizations	358
European Organizations.....	358
International Organizations	358

List of Figures

Figure 1. Fukushima Daiichi NPP Before the Accident: Close-up of Units 1-4.....	14
Figure 2. Fukushima Daiichi NPP Before the Accident: Aerial View of Entire Plant	15
Figure 3. Fukushima Daiichi NPP Layout.....	15
Figure 4. Tohoku-Pacific Ocean Earthquake Epicenter	16
Figure 5. Tsunami Waves Hitting the Fukushima Daiichi NPP	17
Figure 6. Tsunami Waves Entering Fukushima Daiichi NPP Site	18
Figure 7. Fukushima Daiichi NPP Inundated by Tsunami.....	18
Figure 8. Fukushima Daiichi NPP After the Accident	19
Figure 9. Fukushima Daiichi NPP After the Accident	20
Figure 10. BWR Mark I Design from General Electric.....	29
Figure 11. BWR Mark I Primary Containment Vessel and Pressure Boundary	30
Figure 12. Steam Condensation via Vent-lines	31
Figure 13. Mark I Reactor Building Sectional View	33
Figure 14. GE BWR Mark II Reactor Building	34
Figure 15. GE BWR Mark III Reactor and Auxiliary Buildings.....	34
Figure 16. BWR Reactor Pressure Vessel	35
Figure 17. BWR Fuel Assemblies and Control Blades.....	37
Figure 18. BWR Thermal-Hydraulic Standard Configuration	38
Figure 19. Reactor Heat Removal (RHR) Simplified Diagram	40
Figure 20. Reactor Core Isolation Cooling Simplified Functional Diagram	41
Figure 21. Spent Fuel Pool Representation	45
Figure 22. 70-ton Spent Fuel Rail Shipping Cask	48
Figure 23. Spent Fuel Rail Train Container and Transport Car	48
Figure 24. Spent Fuel Truck Container and Transport Cask	48
Figure 25. Spent Fuel Dry Cask Vertical Configurations.....	49
Figure 26. Spent Fuel Decay Heat Energy vs. Time After Core Discharge	50
Figure 27. Unit Blocks 1-4 and 5-6 at the Fukushima Daiichi NPP	53
Figure 28. Fukushima Daiichi NPP Tsunami Affected Areas	54
Figure 29. Tsunami Inundation Height & Depth Measurements at Fukushima Daiichi NPP	55
Figure 30. Tsunami Impact on Fukushima Daiichi NPP Facilities.....	56
Figure 31. Emergency Systems Gradual Failures at Fukushima Daiichi NPP	57
Figure 32. Core Cooling Degradation Processes	59
Figure 33. Temperature-Induced Fuel Damage and Hydrogen Formation	60
Figure 34. LOCA Progression Leading to Core Meltdown	61
Figure 35. Estimated Core Decay Heat Power Produced by Units 1,2 and 3.....	64
Figure 36. Unit 3 Damage to Secondary-Containment Resulting from H2 Explosion.....	65
Figure 37. Fukushima Daiichi NPP Accident Countermeasures Implementation	68

Figure 38. Fukushima Daiichi NPP Unit 3 and 4 Shared Vent Stack	72
Figure 39. Direct Torus Vent System Diagram	73
Figure 40. Water and Food Product Restrictions due to Fukushima Daiichi NPP Accident	77
Figure 41. Integrated Dose Estimation through May 11, 2012	78
Figure 42. Japanese Automobile Production April 2010 vs. April 2011	83
Figure 43. Japan's Two Power Cycle Regions	88
Figure 44. Japan's Ten Electric Power Companies	89
Figure 45. Japan's Power Conversion Capacity between Cycle Regions	91
Figure 46. TEPCO's Stock Price Movements (January-May 2011)	94
Figure 47. Distribution of TEPCO Shares by Owners (as of September 30, 2010)	94
Figure 48. UxC Nuclear Generating Capacity Forecast, 2008-2030	157
Figure 49. UxC Base, High, and Low Case Nuclear Capacity Forecasts, 2008-2030	159
Figure 50. Post-Fukushima Changes to Base/Low/High Nuclear Forecast Cases	162
Figure 51. Damages to Fukushima Daiichi Unit 4 Extending Below Service Floor	176
Figure 52. EDG-related PRA Boundaries	182
Figure 53. Ultimate Heat Sink Inaccessibility	194
Figure 54. Westinghouse Emergency Fuel Pool Cooling System (EFPCS)	197
Figure 55. Basic FP-ERS Configuration	199
Figure 56. Natural Circulation Loops	202
Figure 57. Decay Heat Energy Removal Passive Add-on (DHERPA)	204
Figure 58. Thermal Conductivity of Zirconium and UO ₂	206
Figure 59. Temperature Profile for Fuel Pellet with Different Materials	207
Figure 60. TRISO Fuel	210
Figure 61. Irradiation Effects on TRISO Fuel	210
Figure 62. Modeled Behavior of Uranium Dioxide and "Dispersion Fuel"	211
Figure 63. Major Modifications and Upgrades to U.S. BWRs with Mark I Containment Systems	224
Figure 64. Westinghouse AP1000 Passive Containment Cooling Water Storage Tank	230
Figure 65. AP1000 Spent Fuel Pool and Ancillary Equipment Layout	232
Figure 66. AREVA EPR Spent Fuel Pool Configuration	235
Figure 67. New Reactor Startups and Total MWe Added, 2009-2020	247
Figure 68. Boiling Water Reactor Graphical Depiction	330
Figure 69. Pressurized Water Reactor Graphical Depiction	331
Figure 70. Evolution of Nuclear Reactor Generations	334
Figure 71. Madras Nuclear Power Plant in Tamil Nadu, India	341
Figure 72. Map of Electric Power Plants in Japan	343

List of Tables

Table 1. TEPCO's Fukushima Daiichi Nuclear Power Plant Overview Data	14
Table 2. Burnup vs. Enrichment	49
Table 3. Decay Heat Power Remaining to be Transferred to UHS	63
Table 4. Fukushima Daiichi NPP Accident Status as Reported by JAIF on March 16, 2011	66
Table 5. Fukushima Daiichi NPP Accident Status as Reported by JAIF on April 12, 2011	66
Table 6. Japanese Automobile Production April 2010 vs. April 2011	83
Table 7. Manufacturing from Prefectures in Tohoku Region.....	84
Table 8. Japan Electric Power Data as of March 31, 2010	90
Table 9. TEPCO's Top 10 Shareholders as of February 4, 2011	95
Table 10. Impacts on Other Japanese Utilities.....	98
Table 11. Global Reactions to Fukushima: North America	110
Table 12. Global Reactions to Fukushima: Western Europe	113
Table 13. Global Reactions to Fukushima: Eastern Europe	122
Table 14. Global Reactions to Fukushima: Asia & Oceania	129
Table 15. Global Reactions to Fukushima: Africa & Middle East.....	137
Table 16. Global Reactions to Fukushima: South America.....	142
Table 17. Reactor Units & Nuclear Capacities Anticipated by Country by 2030.....	157
Table 18. UxC Base, High, and Low Case Nuclear Reactor and Capacity Forecasts, 2008-2020	159
Table 19. Global Nuclear Power Forecasts – Before & After Fukushima	160
Table 20. Individual Country Nuclear Power Forecast Changes Post-Fukushima	160
Table 21. Electricity Fuel Switching Post-Fukushima & CO ₂ Emissions Impacts	170
Table 22. Redundancy of Safety-Related AC Power Sources.....	178
Table 23. Mitigating Countermeasure to Hydrogen Hazards in LWRs	213
Table 24. Active vs, Passive Hydrogen Mitigation Systems	213
Table 25. Small to Mid-size Containment Hydrogen Hazard Countermeasures	215
Table 26. New Reactor Startups by Year, 2009-2020	247
Table 27. Spent Fuel Final Repository Status by Country	258
Table 28. Stock Price Shifts After Fukushima for Major Nuclear Companies.....	263
Table 29. Global Nuclear Power Utilities.....	264
Table 30. Existing BWRs in the World by Containment Types	328
Table 31. Current Global Reactor Technology Breakdown.....	330
Table 32. U.S. Reactor Design Certification Status	336
Table 33. Reactor Designs analyzed in UxC NRTA 2008 Report.....	338
Table 34. Current 12 Leading Global SMR Designs	340
Table 35. Japan Power Plants Affected by Earthquake & Tsunami.....	343

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 Fund¹, 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 rebuild 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