NUCLEAR SAFETY AND NUCLEAR ECONOMICS:
HISTORICALLY, ACCIDENTS DIM THE PROSPECTS FOR NUCLEAR REACTOR CONSTRUCTION; FUKUSHIMA WILL HAVE A MAJOR IMPACT

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EXHIBITS

SUMMARY

History has shown that each major nuclear accident has caused a re-examination of the risks of nuclear power leading to more stringent safety requirement and higher costs. The failures that led to the ongoing catastrophe at Fukushima are being scrutinized in the United States and other countries. An analysis of the current re-evaluations of nuclear power and a comparison with the substance and economic impact of past, post-accident reviews provides important insights into the prospects of new nuclear reactor construction in the decade after Fukushima.

- Before Fukushima, the mythical "nuclear renaissance" had already proven to be a bubble with the air rapidly leaking out of it. Fukushima will make it even more difficult to inflate.

Economics

Fukushima is magnifying the economic problems that the "nuclear renaissance" faced, which are the very problems that have plagued nuclear power throughout its history. Nuclear power has always suffered from high cost and continuous cost escalation, high risk and uncertainty. With long lead-times and large sunk costs, nuclear is a risky investment in an environment filled with ambiguities. That is the reason that the "nuclear renaissance" never got started.

The nuclear reactor disaster at Fukushima will increase the cost and further undermine the economic viability of nuclear power in any country that conducts such a review.

- The Japanese government has recently estimated that the cost of power from nuclear reactors will be 50 percent higher than estimated seven years ago.
- This increase is consistent with the impact of past accidents.

Safety risks render the nuclear industry uninsurable in commercial markets. Fukushima reminds the financial markets that the liability of a major accident will instantaneously bankrupt the utility owner, absent the socialization of costs.

- The cost of the Fukushima accident has been estimated as high as $250 billion and rising, which essentially bankrupted Tokyo Electric Power Co., the fourth largest utility in the world.
- Estimates of the cost of a severe accident in the U.S. are in this range or higher.
- Although the bailout of nuclear power cushions the blow, it also constrains the growth of profit, which makes the sector less attractive to investors.

Safety

Fukushima has stimulated vigorous reviews around the world in part because it is severe (the worst accident affecting a nuclear reactor in a market economy) and in part because it occurred in a nation that was assumed to have a high standard of safety and superb technical expertise. Although the technical challenges are different with each accident, the challenges perceived by those responsible for nuclear safety in the wake of the Fukushima accident are quite substantial and reflect general historic themes.

- faulty design,
- insufficient backup systems,
- human error,

- inadequate contingency plans, and
- poor communications.

Even more striking are the persistent institutional failures revealed by a comparison between the post-accident evaluations of TMI and Fukushima, including

- Failure of voluntary, self-regulation;
- Denial of the reality of risk;
- Lack of safety culture;
- Lack of a comprehensive, consistent regulatory framework;
- The challenge of continuous change and the failure to resolve outstanding safety issues;
- Failure to require existing reactors to add safety measures because of cost; and,
- Complexity, confusion and chaos in the response to a severe accident.

With the global nuclear safety institutions expressing strong concerns, particularly the advanced industrial nuclear nations, and the aftermath of Fukushima likely to command attention for years as the extent of the damage and the challenge of decommissioning unfold, the issues are likely to continue to have traction.

Policy

The reviews stimulated by accidents are not limited to safety issues. In the wake of Fukushima re-evaluations of energy options and nuclear risks and economics have substantially dimmed the prospects for construction of new nuclear reactors.

- Major policy reviews by governments have led several nations to decide to scale back or abandon their commitments to nuclear power (including important large industrial national like Japan, Germany);
- Financial institutions have conducted extensive reassessments of the economic prospects of nuclear power and concluded that the costs will rise;
- Utilities with nuclear plans in several national have continued to be downgraded by the rating agencies, and
- Several major firms have abandoned the sector altogether or been forced to scale back their activities.

As all stakeholders re-examine all aspect of energy policy, the risks of nuclear reactors increase and the attractiveness of nuclear power compared to other options decreases. From a big picture perspective, Fukushima has had and is likely to continue to have an electrifying impact on the development of nuclear power because it combines the most powerful message from TMI on cost escalation with the most powerful message from Chernobyl on the risk of nuclear reactors in a nation where it was not supposed to happen. And, it has taken place in an environment where information and images flow instantaneously around the world, so the public sees the drama and trauma of losing control of a nuclear reaction in real time.

PROVIDING A CONTEXT FOR UNDERSTANDING FUKUSHIMA

Throughout the history of the commercial nuclear industry, the safety and cost of nuclear reactors have been a constant source of concern, analysis, and debate. Nuclear accidents are exclamation points in the continuous narrative of safety and economics.[1] Each of the three major accidents in the 50-year history of commercial nuclear power (Three Mile Island, Chernobyl, and Fukushima) has prompted a thorough re-examination of every aspect of nuclear power. It would be irresponsible for stakeholders and public authorities not to do so.[2]

History has shown that each major nuclear accident has caused a re-examination of the risks of nuclear power leading to more stringent safety requirement and higher costs. The failures that led to the ongoing catastrophe at Fukushima are being scrutinized in the United States and other countries. Fukushima will increase the cost and further undermine the economic viability of nuclear power in any country that conducts an honest and thorough review.

An analysis of the current re-evaluations of nuclear power and a comparison with the substance and economic impact of past, post-accident reviews provides important insights into the prospects of new nuclear reactor construction in the decade after Fukushima.

THE NEED TO IMPROVE SAFETY INCREASES THE COST OF NUCLEAR POWER:
The impact of Fukushima on cost is substantial and consistent with past cost increases.

Post-Fukushima, the Japanese government recently estimated that the cost of power from nuclear reactors will be 50 percent higher than estimated seven years ago.[3] This increase is consistent with the impact of the accident at Three Mile Island (see Exhibit 1).

Nuclear costs in the U.S. were increasing before the accident at Three Mile Island (TMI), but the rate of increase grew after the accident as the nuclear industry was required to incorporate more safety features. Costs increased because the additional safety measures added expenses and because the construction period, which is a primary driver of costs, increased significantly. Construction costs are the single most important determinant of nuclear costs, accounting for about half of the total in Japan and three-quarters in the U.S.[4] Thus, an increase of about two thirds in construction cost, which occurred in the U.S. after TMI accident (compared to the pre-TMI trend), will translate into a 50 percent increase in the busbar cost of electricity.

SAFETY REVIEWS FOLLOWING MAJOR ACCIDENTS REVEAL SEVERE SAFETY ISSUES THAT HAVE NOT BEEN ADEQUATELY ADDRESSED AND RESOLVED BY THE INDUSTRY:
Fukushima raises a host of such issues.

Fukushima has stimulated vigorous reviews around the world, in part because of the severity of the accident, in part because it is the worst accident affecting a nuclear reactor in a market economy and in part because it occurred in a nation that was assumed to have a high

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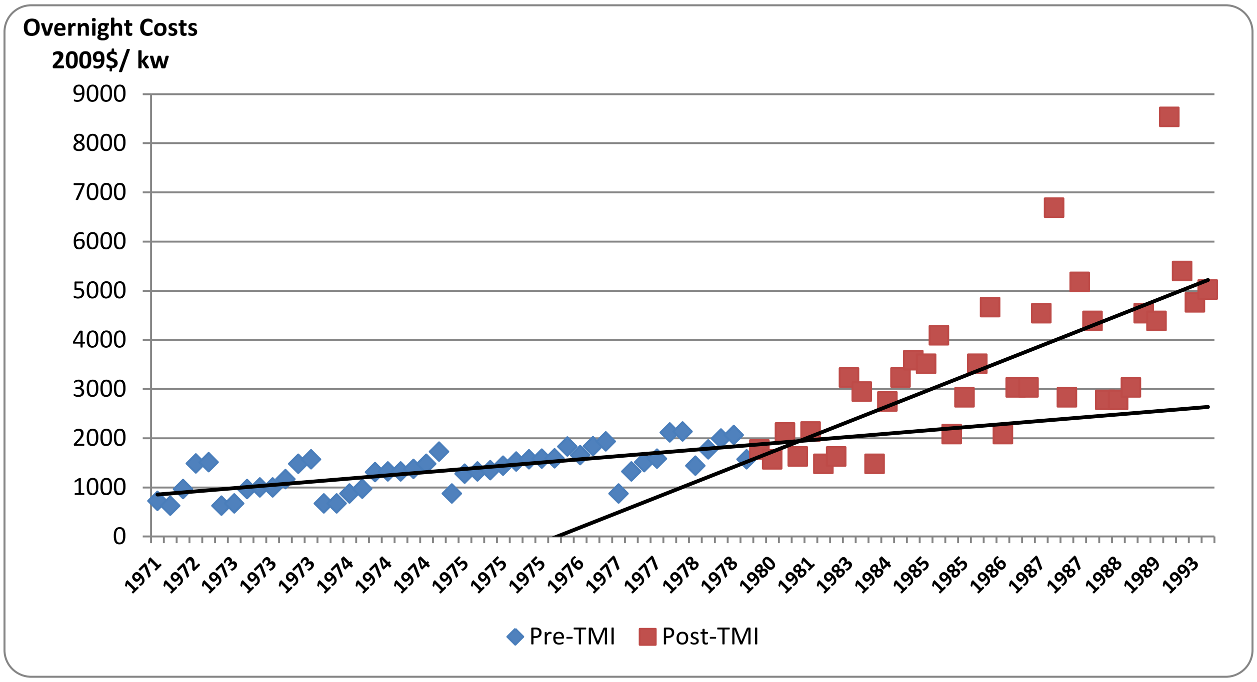
[1] Joseph P. Tomain, *Nuclear Power Transformation* (Bloomington: Indiana University Press, 1987), p. ix, writing shortly after Chernobyl described nuclear accidents as follow: "TMI and Chernobyl serve as more than convenient mileposts in the history of nuclear power. TMI made the Unites States aware of unforeseen costs, just as Chernobyl made the world aware of unforeseen risks. These accidents are reminders of the complexities, risks, and costs of government-sponsored and regulated enterprises."

[2] Mark Cooper, "Testimony of Dr. Mark Cooper, "Nuclear Economics after Fukushima," before the *Standing Committee on Natural Resources House of Commons,* Ottawa Canada, March 24, 2011

[3]Mari Iwata, "Update: Japan Panel Endorses 50% Jump in Gov't Nuclear Power Cost Estimate,' *Dow Jones News Wire*, December 19, 2011; Tsuryoshi Inajima, "Japan Says Nuclear Power cost may be 50% Higher than Estimated," *Bloomberg,* December 19, 2011.

[4] Mark Cooper, *The Economics of Nuclear Reactors: Renaissance or Relapse* (Institute for Energy and the Environment, Vermont Law School, June 2009).

EXHIBIT 1: NUCLEAR CONSTRUCTION COST ESCALATION: REACTORS COMPLETED BEFORE AND AFTER TMI



Source: Mark Cooper, Policy Challenges of Nuclear Reactor Construction: Cost Escalation and Crowding Out Alternatives, Institute for Energy and the Environment, Vermont Law School, September, 2010

standard of safety and superb technical expertise.[5] Since the accident, there have been major safety reviews by regulators across the globe (including Japan, the U.S., and Europe).[6]

Exhibit 2 summarizes the safety issues identified by nuclear technical safety organization (TSOs) around the globe in light of Fukushima. Exhibit 2a summarizes the analysis presented by representatives of four TSOs in France, Japan, Belgium, and Germany [7] to a major conference of TSOs conducted seven months after the accident at Fukushima. Exhibit 2b contains the Japanese self-evaluation presented to the International Atomic Energy Agency (IAEA). Exhibit 2c outlines the recommendations of the Nuclear Regulatory Commission's (NRC) Near Term Task Force.

The challenges perceived by those responsible for nuclear safety around the world in the wake of the Fukushima accident are quite substantial. As a representative from Spain to the Eurosafe conference put is, put it "Nothing will be the same after Fukushima."[8] Ten days after that conference, the French TSO issued a report that would affect virtually every reactor in France, based on considerations such as the possibility that multiple units at a site could fail, cutting off all power for cooling, a lack of hardened ventilation systems to protect against seismic events, the need to incorporate evolving earthquake knowledge into risk assessment, etc. The French report also noted that full reviews of all reactors were ongoing. The historical experience in the U.S. and

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5 Mark Cooper, "The implications of Fukushima: The US perspective," *Bulletin of the Atomic Scientists July/August 2011 67: 8-13*

6 See Exhibit 2 for summaries of findings of the major reviews

7 Institut De Radioprotection et de Surete Nucleaire, "Nearly 450 experts from 39 countries gather in Paris for the 13th edition of the Eurosafe Forum and draw technical lesson from the Fukushima accident, November 18, 2011.

8 Jose M. Bernaldo de Quiros, "New Safety Requirement and Long-Term Operation Policy," *Eurosafe Forum, Experience Feedback on the Fukushima Accident*, November 8, 2011

the fundamental changes in safety regulation that are emerging from the reviews of the Fukushima accident suggest that the escalation of cost will persist across the global industry, not just in Japan.

EXHIBIT 2: THE NEED FOR EXTENSIVE IMPROVEMENT IN SAFETY PRECAUTIONS: EUROSAFE

Exhibit 2a: Evolution of the Technical Safety Program after the Fukushima Experience Accident

Plant Vulnerabilities
- **Possible Event Causes**
  - Siting
  - Internal
  - Organizational
  - Combinations of causes
- **Probabilistic Safety Assessment**
  - Evolution of Knowledge
    - Seismology, geology, meteorology, etc.
  - Scope
    - Natural Phenomena
      - Seismic Tsunami, Tornado, Flooding
    - Attacks
    - Whole Site
  - Multiple Unit Vulnerabilities
  - Loss of Cooling
  - Loss of Heat Sink
  - Loss of Power (Station Black Out)

Behavior of Fuel
- Spent Fuel Pools
  - Loss of Water
  - Presence of Debris
- Hydrogen
  - Production
  - Transport
  - Explosion
  - Role of Cladding
- Use of Unusual Measures
  - Seawater for Cooling

Severe Accident Progression
- **Core Degradation**
- **Cliff - Edge problem**
- **Emergency Management**
  - Infrastructure and Competence
    - Organization
    - Training and Tutoring
    - Exercise and Preparation
  - Preparedness for Unforeseen
  - Standard of Preparedness
  - Standard of Competence

Human Reliability Assessment
- **Under Accident Stress**
  - Multiple Units
  - Extreme Radiation
  - Fatigue Due to Isolation

Need for External Support

Maintenance of Resources Over Time

Communications-Information
- **For Responders**
- **Between Safety Regulators**
- **For the Public**

Source: Eurosafe Forum, Experience Feedback on the Fukushima Accident, November 8, 2011; D. Degueldre, T. Funshashi, O. Isnard, E. Scott de Martinville, M. Sognalia, "Harmonization in Emergency Preparedness and Response;" P. De Gelder, M. Vincke, M. Maque, E. Scott de Martinville, S. Rimkevicius, K. Yonebayashi, S. Sholmonitsky, "The Evolution of the TSO Programme of Work after the Fukushima Daiichi NPS Accident

EXHIBIT 2: CONT'D.

Exhibit 2b: Lessons Learned reported to the IAEA Ministerial Conference and 2011 General Conference

Prevention of severe accident	Design Basis	1. Revision of design basis earthquake/tsunami
	Enhancement of safety functions	2. Power supplies 3. Reactor/Containment cooling 4. Spent Fuel Cooling
	Accident management measures	5. Enhancement of regulatory requirements
	Additional considerations	6. Multi-unit site issues 7. Plant layout (e.g. elevation of SFP) 8. Water tightness (essential systems)
Mitigation and preparedness for severe accidents	Enhancement of mitigation measures	9. Hydrogen explosion prevention measures 10. Enhanced containment vent
	Improvement of accident response activities	11. Response environment and equipment 12. Radiation control (equipment, training, etc.) 13. Severe accident response training
	Enhancement of instrumentation	14. Instrumentation for reactor, PCV, SFP, etc.
	Central control of external support	15. Rescue Teams, equipment, experts, etc.
Response to nuclear emergency	Combination of nuclear emergency and natural disaster	16. Preparedness for loss of general infrastructure
	Radiation monitoring and prediction	17. More organized environmental monitoring 18. Effective use of radiological prediction system
	Organization and communication	19. Improved coordination among response organizations 20. Improved public communications
	International cooperation	21. Improved communication and response to proposed assistance
	Evacuation and radiation protection	22. Clarification of criteria
Enhancement of safety infrastructure	Regulatory organization	23. Unification of regulatory bodies into independent "Nuclear Safety and Security Agency"
	Regulatory frameworks and approaches	24. Revision of regulations, standards and guides 25. Enhancement of system independence and diversity 26. Effective use of PSAs
	Human resources	27. Enhancement of human resources in the areas of Nuclear safety and emergency preparedness
Strengthening of safety culture	Strengthening of safety culture	28. Reconstruction of safety culture in all organizations involved in nuclear activities

Source: Yoshiro Nakagome, *JNES's Response to TEPCO Fukushima NPS Accident,* November 2011,

EXHIBIT 2: CONT'D.

Exhibit 2c: Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident

Clarifying the Regulatory Framework

1. The Task Force recommends establishing a logical, systematic, and coherent regulatory framework for adequate protection that appropriately balances defense-in-depth and risk considerations. (Section 3)

Ensuring Protection

2. The Task Force recommends that the NRC require licensees to reevaluate and upgrade as necessary the design-basis seismic and flooding protection of structures, systems, and components for each operating reactor. (Section 4.1.1)
3. The Task Force recommends, as part of the longer term review, that the NRC evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods. (Section 4.1.2)

Enhancing Mitigation

4. The Task Force recommends that the NRC strengthen station blackout mitigation capability at all operating and new reactors for design-basis and beyond-design-basis external events. (Section 4.2.1)
5. The Task Force recommends requiring reliable hardened vent designs in boiling water reactor facilities with Mark I and Mark II containments. (Section 4.2.2)
6. The Task Force recommends, as part of the longer term review, that the NRC identify insights about hydrogen control and mitigation inside containment or in other buildings as additional information is revealed through further study of the Fukushima Dai-ichi accident. (Section 4.2.3)
7. The Task Force recommends enhancing spent fuel pool makeup capability and instrumentation for the spent fuel pool. (Section 4.2.4)
8. The Task Force recommends strengthening and integrating onsite emergency response capabilities such as emergency operating procedures, severe accident management guidelines, and extensive damage mitigation guidelines. (Section 4.2.5)

Strengthening Emergency Preparedness

9. The Task Force recommends that the NRC require that facility emergency plans address prolonged station blackout and multiunit events. (Section 4.3.1)
10. The Task Force recommends, as part of the longer term review, that the NRC pursue additional emergency preparedness topics related to multiunit events and prolonged station blackout. (Section 4.3.1)
11. The Task Force recommends, as part of the longer term review, that the NRC should pursue emergency preparedness topics related to decision making, radiation monitoring, and public education. (Section 4.3.2)

Improving the Efficiency of NRC Programs

12. The Task Force recommends that the NRC strengthen regulatory oversight of licensee safety performance (i.e., the Reactor Oversight Process) by focusing more attention on defense-in-depth requirements consistent with the recommended defense-in-depth framework. (Section 5.1)

Source: Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident, U.S. NRC, July 12, 2011.

The U.S. short-term recommendations reflect each of the major areas of concern, but the near-term list is much shorter.[9] Moreover, even though the U.S. list of safety concerns raised by Fukushima is shorter, it has become a focal point of dispute among the five NRC commissioners and a target of criticism from the industry.[10]

ACCIDENT REVIEWS REVEAL CHRONIC INSTITUTIONAL FAILURES:

Fukushima reveals a lack of safety consciousness

Each reactor accident is different and entails specific system failures that allowed the accident to occur and spin out of control, but there are common technical themes: faulty design, insufficient backup systems, human error, inadequate contingency plans, and poor communications. The list is particularly long in the case of Fukushima. However, perhaps more striking than the technical issues raised by Fukushima, are the persistent institutional failures revealed by a comparison between the post-accident evaluations of TMI and Fukushima. [11] For decades, the nuclear industry has been plagued by:

- Failure of voluntary, self-regulation;[12]
- Denial of the reality of risk;[13]
- Lack of safety culture;[14]

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[9] The detailed list of steps in the appendix puts more meat on the bones and moves the U.S. recommendation closer to the international recommendations.

[10] George Zornick, "Meltdown at the Nuclear Regulatory Commission," *The Nation,* December 12, 2011

[11] Analysis of the causes of Chernobyl could be easily short circuited because of the nation and technology involved (as the World Nuclear Association put it, " Chernobyl Accident 1986 The April 1986 disaster at the Chernobyl nuclear power plant in Ukraine was the product of a flawed Soviet reactor design coupled with serious mistakes made by the plant operators. It was a direct consequence of Cold War isolation and the resulting lack of any safety culture." http://www.world-nuclear.org/info/chernobyl/inf07.html). However, it could not be dismissed as a reminder of the catastrophic consequence of the loss of control of nuclear reactions (as a number of UN agencies put it in 2002, *The Human Consequences of the Chernobyl Nuclear Accident A Strategy for Recovery* "The affected population - those exposed to radioactive fallout, remaining in the affected areas, or forced to relocate - continue to face disproportionate suffering in terms of health, social conditions, and economic opportunity. Hundreds of thousands of people have been evacuated from the most severely affected areas…. However, some tens of thousands remain in areas polluted…. The accident has also imposed a heavy burden on the national budgets through the cost of clean-up, compensation and recovery….The Report argues that the environmental effects of Chernobyl cannot be considered in isolation from their socio-economic and health aspects or from the changing institutional context of the three countries concerned…The Report finds that, while physical processes are gradually reducing the level of radioactive contamination in the environment, the most vulnerable groups of people in the affected areas are facing a complex and progressive downward spiral of living conditions induced by the consequences of the accident and the events that followed."

[12] The TMI Task Force concluded that, under the self-regulatory approach, the industry had failed to pay adequate attention to key safety issues. (U.S. Nuclear Regulatory Commission, *TMI-2 Lessons Learned Task Force: Status Report and Short-Term Recommendations,* August 1979, NRC, 1979: 1-2)" Specifically, the primary deficiency in reactor safety technology identified by the accident was the inadequate attention that had been paid by all levels and segments of the technology to the human element and its fundamental role in both the prevention of accidents and the response to accidents. Thus, our policy recommendations and our specific ideas for stimulating and accomplishing change concentrated heavily on operations reliability and the associated design and licensing review measure that support or augment operations reliability. But an important qualifier must be added to this conclusion. That is, if the basic responsibility for public safety is to *remain in the private sector,* in the hands of the individual licensees for commercial nuclear power plants, then significant change in the attention to operations reliability must take place in the licensed industry." The Fukushima Task Force identified key voluntary measures that had been on the table since TMI that the industry had not taken up with vigor and concluded that "Continued reliance on industry initiatives for a fundamental level of defense-in-depth similarly would leave gaps in the NRC regulatory approach (U. S. Nuclear Regulatory commission, *Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident,* NRC, July 12, 2011., NRC, 2011: 16-17). It recommended that several important safety processes that had been voluntary should become mandatory (NRC. 2011: 29). In its report to the IAEA, the Japanese government recommended that "accident management measures should be changed from voluntary efforts to legal requirements and be developed by using a probabilistic safety assessment."(Tatsujiro Suzuki, "Deconstructing the Zero-risk Mindset: the Lessons and Future Responsibilities for a post-Fukushima Nuclear Japan, "*Bulletin of the Atomic Scientists, 2011:* 67(5), Suzuki, 2011: 14)

[13] The TMI report found that the industry had failed to adopt Probabilistic Risk Analysis (NRC, 1979: 3-2). The Fukushima Task Force found a number of analytic and data tools that had not been adopted (NRC, 2011: 28).

[14] The report of the President's Commission on the Accident at Three Mile Island concluded that an entirely different attitude toward risk should be adopted. "[T]he belief that nuclear power plants are sufficiently safe grew into a conviction. One must recognize this to understand why many key steps that could have prevented the accident at Three Mile Island were not taken. The Commission is

- Lack of a comprehensive, consistent regulatory framework;[15]
- The challenge of continuous change and the need to retrofit existing reactors;[16]
- Failure to resolve important outstanding safety issues;[17]
- Failure to require existing reactors to add safety measures because of cost;[18] and,
- Complexity, confusion and chaos in the response to a severe accident.[19]

With the global nuclear safety institutions expressing strong concerns (particularly those within the advanced industrial nuclear nations), and the aftermath of Fukushima likely to command attention for years to come as the extent of the damage and the challenge of clean-up and decommissioning unfold,[20] the safety and cost issues are likely to continue to have traction.

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convinced that this attitude must be changed to one that says nuclear power is by its very nature potentially dangerous, and, therefore one must continually question whether the safeguards already in place are sufficient to prevent major accidents. A comprehensive system is required in which equipment and human beings are treated with equal importance." (Kemeny Commission, 1980: 25). "In Japan, probabilistic safety assessment – or probabilistic risk assessment as it is sometimes referred to – has not always been effectively used in the overall review process at nuclear power plants. And Fukushima is a raw example of this… is necessary to move Japanese safety regulation to something that is more risk-based and more effective – and this would mean a departure from being a "zero-risk" culture." (Suzuki, 2011: 11)

[15] In the analysis of TMI, the Task Force criticized the "quiltwork" approach to regulation and lack of an "articulate" overall NRC policy, (1979: 1-2). Thirty years later, the NRC Task Force on Fukushima criticized the NRC's approach as a "patchwork" that resulted in "gaps" (NRC, 2011: pp. viii, 18-20), warranting action "to confirm, augment, consolidate, simplify, and strengthen current regulatory and industry programs in a manner that produces a single, comprehensive framework for accident mitigation, built around NRC-approved licensee technical specifications," (NRC 2011,49), The Japanese self-evaluation concluded that "a national response to a nuclear emergency be established, and that a safety regulatory infrastructure be developed." (Suzuki, 2011: 10).

[16] The post-TMI Task Force noted the occurrence of "beyond-design events, (NRC, 1979: 3-1) and acknowledged the continual challenges that nuclear safety faces in a section entitled "Preparation for the Unusual." The Fukushima Task Force reached a similar conclusion that continuous change was inevitable in the safety space. It emphasized the importance of "beyond design challenges." (especially NRC, 2011: pp. 10-11). The Fukushima Task Force recommendation makes a series of distinctions that allow existing reactors to continue operating, while new safety rules are imposed that will apply fully to new reactors. "As new information and new analytic techniques are developed, safety standards need to be reviewed, evaluated, and changed as necessary, to insure that they continue to address the NRC requirements to provide reasonable assurance of adequate protection of public health and safety. The Task Force believes, based on its review of the information currently available from Japan and current regulation, that the time has come for such a change." (NRC 2011: 18).

[17] The TMI Task Force report points out that the TMI-2 accident highlighted the need to address "Unresolved Safety Issues" and proposed measures to ensure "expeditious resolution of these issues." (NRC, 1979: 4-6). The Fukushima Task Force found that the Policy Statement on Safety Goals, adopted sixteen years after TMI (i.e. sixteen years before Fukushima) "does not present a completely clear and consistent framework for decision making." (NRC, 2011: 4). The Fukushima Task Force identified a number of important systems that had not been updated (NRC, 2011: 37).

[18]NRC, 1979: 4-3, "a byproduct of the specification of a safety goal would be the clarification of backfitting decisions. Under this example, a proposed backfit would not need to provide substantial additional protection (as currently inferred under 10 CFR 50.109); anything required for safety would be sufficient. Similarly, a decision to backfit would naturally precipitate the need to backfit all nuclear plants, since it was required for safety, without agonizing over value impact studies or case-by-case determinations. "(NRC, 2011, p. 20). "The commission has clearly established such defense-in-depth severe accident requirements for new reactors… thus bringing unity and completeness to the defense-in-depth concept. Taking a similar action, within reasonable and practical bounds appropriate to operating plants, would do the same for operating reactors."

[19] The Kemeny Commission found a breakdown at all levels in the TMI accident and concluded that "Wherever we looked, we found problems with the human beings who operate the plant, with the management that runs the key organizations, and with the agency that is charged with assuring the safety of nuclear power plants." (citation are to the excerpts published in *The Bulletin of the Atomic Scientists,* January 1980, hereafter, *Kemeny*, 1980: 25). "The response to the emergency was dominated by an atmosphere of almost total confusion. There was a lack of communications at almost all levels. Many key recommendations were made by individuals who were not in possession of accurate information, and those who managed the accident were slow to realize the significance and implications of the events that had taken place." (Kemeny, 1980, 25-27). NRC-post Fukushima "These modified technical specifications would consolidate… important elements of emergency procedures, guidance, and tools in a manner that would clarify command and control and decision making during accidents" (NRC, 2011, p. 49). A similar breakdown occurred at Fukushima. "Within hours of this disaster, came the painful realization that the nuclear infrastructure – from technical matters, like backup generators, to more administrative concerns, like which agency is responsible for injecting coolant into a reactor – was flawed and devastatingly complex." (Suzuki, 2011: 9).

[20] Phred Dvorack and Mitusru Obe, "Japan Plots 40-Year Nuclear Cleanup," *Wall Street Journal*, December 22, 2011

SAFETY RISKS RENDER THE NUCLEAR INDUSTRY UNINSURABLE IN COMMERCIAL MARKETS:[21]
Fukushima reminds the financial markets that the liability of a major accident will instantaneously bankrupt the utility owner, absent the socialization of costs.

The cost of the Fukushima accident has been estimated as high as $250 billion,[22] and will likely continue to increase. Tokyo Electric Power Co., the fourth largest utility in the world, was essentially bankrupted instantaneously by the accident.[23] Even though the financial bailout of the nuclear power cushions the blow, it constrains future profit prospects, making the sector less attractive to investors.[24]

The cost of Chernobyl thus far is well over $700 billion.[25] A comprehensive assessment of the potential cost of major accidents in the U.S. was made soon after Three Mile Island.[26] Adjusting the estimate from that study for inflation, population growth and the increase in property value would put the average cost of a severe accident above $400 billion, with an accident at the reactors closest to the largest population centers running as high as $1.5 trillion.[27] Thus, although major accidents are frequently portrayed as human and environmental catastrophes, reactor accidents are also potential economic catastrophes.

The numbers are so large they are difficult to put in perspective for analysts, not to mention the public. For example, studies commissioned by the World Health Organization estimate that there were an average of 350 natural disasters per year in the first decade of the 21st century with total damages for all disasters of about $100 billion per year.[28] By this measure, a single, severe nuclear accident can impose costs that are larger than the costs of thousands of natural disasters that take place over many years.

The massive consequences of a major accident place an intensive spotlight on a fundamental reality of nuclear power. It is uninsurable in normal financial markets. Fifty years ago, as the commercial nuclear industry was starting up in the U.S., two of the largest vendors of nuclear reactors made it clear that they would not build any reactors if they were not shielded from

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[21] This section is drawn from Mark Cooper, Nuclear liability: The market-based, post-Fukushima case for ending Price-Anderson, *Bulletin of the Atomic Scientists*, October 5, 2011

[22] News on Japan. Com, "Fukushima cleanup could cost up to $250 billion," June 1, 2011. http://newsonjapan.com/html/newsdesk/article/89987.php, http://www.jaif.or.jp/english/news_images/pdf/ENGNEWS01_1306919449P.pd, September estimates were higher -- $74 to $260 billion (Eliot Caroom, "The U.S. Ill-equipped to Deal with Japan-like Nuclear Meltdown," New Jersey Star Ledger, September 20, 2011, Greg McDonald, "U.S. Insurance Fund Can't Cover Major Nuclear Disaster, News Max, September 21, 2011,

[23] Jason Clenfield and Norie Kuboyama**, "**Tepco Falls Most on Record as Bankruptcy Concern Resurfaces, *Bloomberg,* June 6, 2011.

[24] Gary Jackson, "Japanese Utilities Downgraded by Moody's, *Fundweb,* July 1, 2011, notes that all electric utilities were downgraded because Fukushima would cause a more hostile environment for rate increases.; Joseph P. Tomain, *Nuclear Power Transformation* (Bloomington: Indiana University Press, 1987, explores the battle over cost overruns.

[25] Estimates vary and increase over time, with the cost in Belarus put at $235 (in 2003, The Chernobyl Forum, 2003-2005, *Chernobyl's Legacy: Health, Environmental and Socio-Economic Impact,* with indications that the cost in other neighboring areas were at least as large) and $287 billion in 2007 (Friends of the Earth Europe, 2007). Costs in the Ukraine were put at $336 billion in 2007. The total of over $600 billion would be higher in 2010 dollars. The Chernobyl Forum: 2003-2005, Chernobyl's *Legacy: Health, Environmental and Socio-Economic Impacts* (p. 32) notes that *"*the costs of the Chernobyl nuclear accident can only be calculated with a high degree of estimation, given the non-market conditions prevailing at the time of the disaster and the high inflation and volatile exchange rates of the transition period following the break-up of the Soviet Union in 1991." The fact that the complex impacts are still being studies 20 years after the event, as described in the report are testimony to the severity of major nuclear accidents and the complexity of their impact.

[26] CRAC-II, http://en.wikipedia.org/wiki/CRAC-II.

[27] The multiplier is 5, with inflation accounting for more than a doubling of costs. Indian Point 3 is the site of the most costly accident

[28] Debby Guha-Sapir, et. al., *Annual Disaster Statistical Review 2010* (Centre for Research on the Epidemiology of Disasters, 2011), pp. 20-21.

the liability of a nuclear accident. General Electric (GE) said it would not proceed "with a cloud of bankruptcy hanging over its head.[29]

Since the risks of nuclear reactors appeared to be uninsurable in the marketplace, Congress enacted a limit on liability as a form of "infant industry" protection to foster the nascent commercial nuclear industry's growth.[30] Thus, Congress socialized the cost of nuclear accidents with enactment of the Price-Anderson Act. However, the infant never outgrew the need for the subsidy. Recent analyses and the accident at Fukushima support the conclusion that nuclear reactors continue to be virtually uninsurable via the private insurance market.[31]

ACCIDENTS STIMULATE REVIEWS FAR BEYOND SAFETY.
Fukushima has triggered broad reviews of energy economics and energy policy.

The reviews stimulated by accidents are not limited to safety issues. In the wake of Fukushima re-evaluations of energy options and nuclear risks and economics have substantially dimmed the prospects for construction of new nuclear reactors:

- Major policy reviews by governments have led several nations to decide to scale back or abandon their commitments to nuclear power (including important large industrial national like Japan and Germany); [32]
- Financial institutions have conducted extensive reassessments of the economic prospects of nuclear power and concluded that the costs will rise (e.g.-USB);[33]
- Utilities with nuclear plans in several nations have been downgraded by rating agencies;[34] and
- Several major firms in advanced industrial nations have abandoned the sector[35] or been forced to scale back their activities.[36]

As all stakeholders re-examine each aspect of energy policy and regulation, the risks of nuclear reactors increase and the attractiveness of nuclear power compared to other options decreases.[37] The arenas for these evaluations are varied, including legislatures, regulatory commissions, and the marketplace. Specifically:

- Policy makers demand an improvement in the quality of regulatory oversight and an increase in the standard of care (regulatory risk), the weighting of societal costs and benefits shifts away from nuclear power toward other alternatives (policy risk), and

[29] Tomain, 1987, p. 9.
[30] Barry Brownstein "The Price-Anderson Act: Is It Consistent with a Sound Energy Policy?" *Policy Analysis*, no. 36, April 17, 1984
[31] Vericherungsforen Leipzig, *Calculation of a Risk-Adjusted Insurance Premium to Cover the Liability Risks Resulting from the Operation of Nuclear Plants,* April 1, 2011, Antony Froggatt, *Nuclear Industry Status, Prospects and 3rd Party Liability,* February 15, 2010.
[32] Among the major nuclear nations, Germany has decided to eliminate nuclear power and Japan has scaled back its plans for the future, while shuttering a number of reactors. Italy, Switzerland and Mexico have decided not to pursue new nuclear reactors.
[33] Per Lekander, Stephen Oldfield, and Jim von Riesemann, *Can Nuclear Power Survive Fukushima?,* UBS, April 4, 2011.
[34] Germany (Argus, "Rating Agencies Moody;'s downgrades German EnBW," (December 20, 2011); The U.S. (Moody's, *Moody's downgrades the senior unsecured rating of SCANA to Baa3 and the senior unsecured rating of South Carolina Electric and Gas to Baa2 ; Outlooks revised to Stable*, September 15, 2011) and Japan (Gary Jackson, "Japanese Utilities Downgraded by Moody's, *Fundweb,* July 1, 2011, notes that all electric utilities were downgraded but the cause was the Fukushima accident, which would cause a more hostile environment for rate increases.
[35]John Downy, "Impact in Charlotte unclear as Shaw Group Exits Westinghouse," *Charlotte Business Journal,* September 9, 2011; BBC-UK, *Seimens to Quit Nuclear Industry,* September 18, 2011; Sonal Patel, "Siemens Joins Trend to Quit Nuclear," *Power,* November 1, 2011, also identifies Scottish and Southern as contemplating exiting the sector.
[36] Areva's problems have been legion, although press account link the scrapping of some plans at least tangentially to Fukushima (Vaiju Naravane, "As Losses Mount, Areva goes in for huge job cuts," *the Hindu,* December 13, 2011; Martin Lynch, "Areva Halts Nuclear Projects to Reduce Debts, *Industrial Info Resources,* " December 19, 2011,
[37] The risk categories are defined and analyzed in Mark Cooper, *All Risk, No Reward,* Institute for Energy and the Environment, Vermont Law School, November 2009.

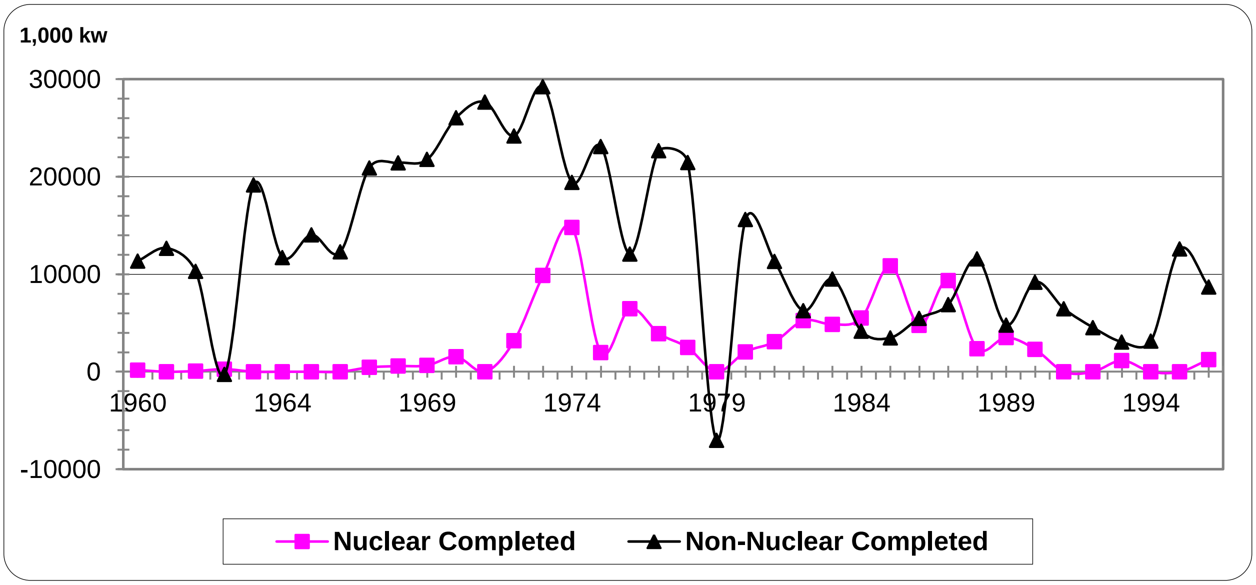
commitments of long term resources are slowed because the value of gathering more information has increased (technology and policy risk);

- Safety regulators impose more safety measures, which require more resources to be expended (execution and marketplace risk), particularly for retrofits of existing plants that may be required (policy risk); and
- Financial analysts and firms in the industry conclude that the cost of nuclear reactors will increase to meet the demands of safety (marketplace risk), making the construction period longer and the reactors more difficult to complete (execution risk), while the cost of capital increases as reactors will be seen as more risky (financial risk).

Exhibits 3 and 4 presents data on several key aspects of the development of nuclear reactors in the U.S. that highlight the complex relationship between nuclear safety and nuclear economics.

Exhibit 3 shows the annual additions to generating capacity for nuclear and the change of total capacity net of nuclear. In every year of the commercial nuclear era, with a couple of exceptions, the U.S. added more non-nuclear capacity in every year than it added nuclear capacity. Since nuclear historically has been generally a small percentage of the total capacity, one can argue that if it had been economically preferable, more nuclear capacity could have been added.

EXHIBIT 3: ANNUAL CHANGES IN GENERATING CAPACITY

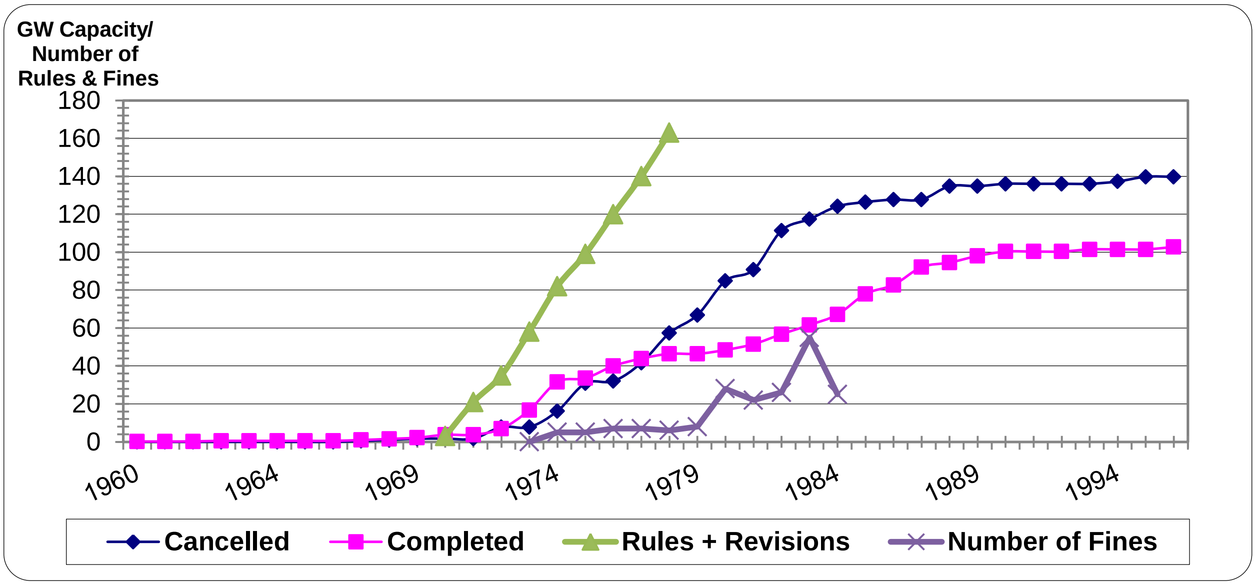


Source: U.S. Bureau of the Census, *Statistical Abstract of the United States (*Winter Peak Capacity) various issues, *Historical Statistics of the United States, Colonial Times to 1970, (*Installed Generating Capacity)

This inference is reinforced in Exhibit 4, which shows the cumulative additions of nuclear capacity and the cumulative total of cancelled capacity. By 1979, before TMI, more capacity had been cancelled than completed. There was capacity on the drawing boards that could have backed out non-nuclear capacity, if it had been economic. It was not economic and cancellations continued at a steady pace so that cancellation always exceeded completed reactors. More capacity was cancelled after TMI than was completed after TMI.

The question becomes, what was going on in the early 1970s that took such a big bite out of the nuclear future. The answer is provided by Exhibit 4, represented by the increase number of rules imposed before and the number of fines imposed after TMI. We have already seen that costs were rising prior to the TMI accident. In fact, the NRC had already concluded that a great deal more attention should be paid to safety. Komanoff showed that even with a very small number of small operating reactors in the late-1960s, the Atomic Energy Commission's, Advisory Committee on Reactor Safeguards[38] "concluded that a variety of reactor transients have occurred, a variety of protective features have malfunctioned or been unavailable on occasion, and a variety of defects have been found in operation."

EXHIBIT 4: CUMULATIVE COMPLETED AND CANCELLED CAPACITY, RULES AND FINES



Sources: For completed and cancelled reactors I have updated data sets provide and used by John Koomey and Ken Hultman, "A Reactor Level Analysis of Busbar Costs for US Nuclear Plants, 1970-2005," *Energy Journal,* 2007. "No, the Three Mile Island Accident in 1979 Was Not a Major Cause of US Nuclear Power's Woes," *Climate Progress* June 25, 2011; Charles Komanoff, *Power Plant Escalation: Nuclear and Coal Capital Costs, Regulation, and Economics,* Van Nostrand, 1981, chapter 4.

Motivated by this safety concern in the pre-TMI period the NRC was convinced the danger of accidents would grow dramatically as the number and size of the reactors in operation grew and their locations moved closer to population centers. They sought to reduce the risk by increasing required safety measures. The growth of standards and guides was dramatic, from three in 1970 to 143 by 1978, which had a corresponding impact on the cost of reactors.[39] Writing in 1981, Komanoff concluded that the poor safety performance of the industry would combine with an across-the board review of safety after TMI that would maintain safety driven cost escalation.[40]

[38] The Atomic Energy Commission was the NRC's predecessor)]

[39] Charles Komanoff, Power *Plant Escalation: Nuclear and Coal Capital Costs, Regulation, and Economics,* Van Nostrand, 1981, p. 55.

[40] Adverse operating experience has also given rise to numerous regulatory guides and "unresolved safety issues." Major examples are: the 1975 Browns Ferry fire, which led to costly new rules for fireproof construction and ventilation; reactor control breakdowns in 1978-1980 due to power failures to instruments that have prompted consideration of increased separation of "safety" from "non-safety" instruments; and the 1979 TMI accident which has sparked an across-the-board review of fundamental regulatory premises. (Komanoff, 1981: 27).

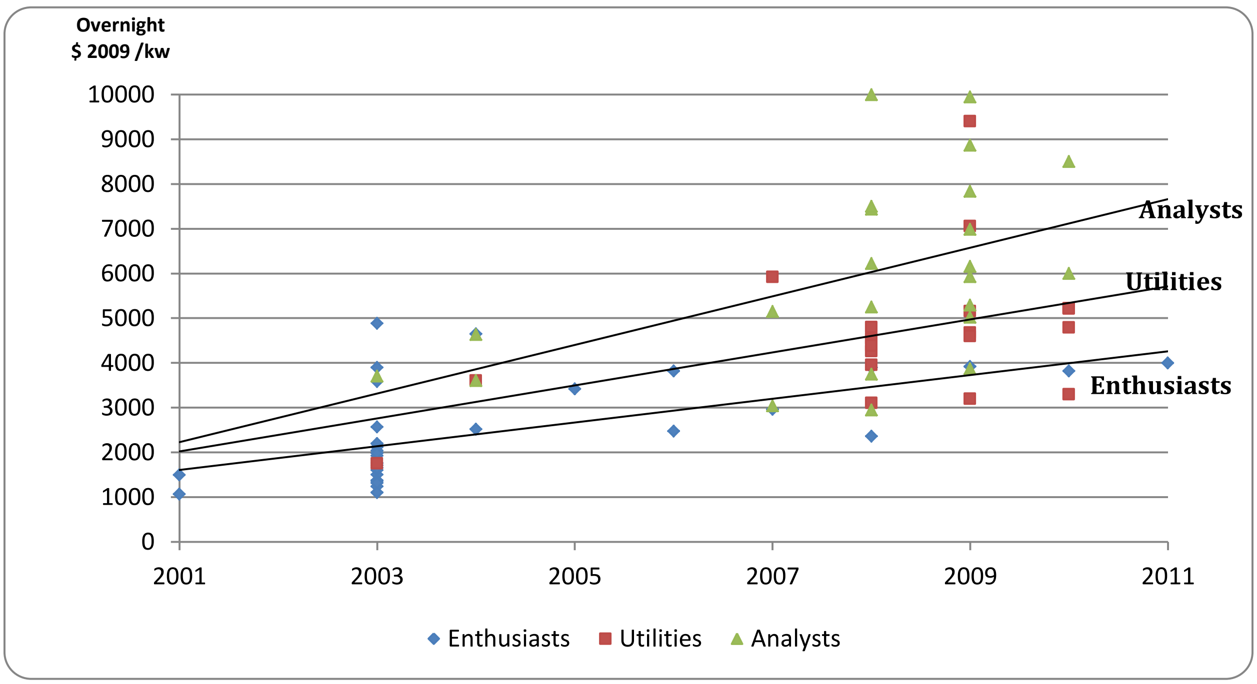
Tomain argues that the increase in fines after TMI reflected a determination by the NRC that it had to make sure that its safety regulation had teeth.[41]

Thus, the story of the nuclear industry in the 1980s was equal parts cost escalation and reactor cancellations and the underlying theme was a need for greater attention to safety. This is a likely outcome in the contemporary, post-Fukushima environment, except that the "nuclear renaissance" had not generated many actual orders for new reactors, so there was no need to cancel orders and have abandonment proceedings. Even before Fukushima, the "nuclear renaissance" had already proven to be more of a rapidly deflating bubble than a renaissance. Fukushima will make it even more difficult to inflate.

THE "NUCLEAR RENAISSANCE" HAD FIZZLED BEFORE FUKUSHIMA BECAUSE OF HIGH COSTS
Fukushima will add risk and cost to make nuclear power even less attractive.

The increase in risk associated with the post-accident reviews and the history of cost escalation, before and after accidents will make investors and governments look less favorably on nuclear power. This inclination is compounded by the fact that the cost of new nuclear reactors was highly uncertain before Fukushima (as shown in Exhibit 5). Since the first estimates were put forward by nuclear "Enthusiasts" in an effort to create the impression of a "nuclear renaissance," cost estimates have increased dramatically and the numbers that were originally hyped to kick off the "renaissance" proved to be far too low. Although the Enthusiasts have since raised their cost projections somewhat, Wall Street analysts still use construction cost projections that are at least 50 percent higher.

EXHIBIT 5: ESCALATION OF PROJECTED CONSTRUCTION COSTS DURING THE "NUCLEAR RENAISSANCE"



Source: The database was described in detail in Mark Cooper, *The Economics of Nuclear Reactors: Renaissance or Relapse* (Institute for Energy and the Environment, June 2009). It is continuously updated and the most recent data is presented above.

[41] Tomain, 1987, pp. 129-130.

Fukushima will magnify the economic problems that the "nuclear renaissance" faced, which are the very problems that that have plagued nuclear power throughout its history. Nuclear power has always suffered from high cost and continuous cost escalation, high risk and uncertainty. With long lead-times and large sunk costs, nuclear is a very risky investment in an environment filled with ambiguities and competitive alternatives. Thus, new reactors are the antithesis of prudent investment.[42] That is the reason that the "nuclear renaissance" never materialized. Hype and speculation of dozens of projects quickly gave way to a handful that became increasingly dependent on massive public subsidies to move forward. Before Fukushima, the Energy Information Administration, which had been one of the early Enthusiasts, had already conceded that only four reactors would be built over the next two decades.[43] After Fukushima, even that number is in doubt.

From a big picture perspective, Fukushima has had and is likely to continue to have an electrifying impact because it combines the most powerful message from TMI on cost escalation with the most powerful message from Chernobyl on the risk of nuclear reactors in a nation where it was not supposed to happen. And, it has taken place in an environment where information and images flow instantaneously around the world, so the public sees the drama and trauma of losing control of a nuclear reaction in real time.

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[42] Mark Cooper, "Least-Cost Planning For 21st Century Electricity Supply Meeting the Challenges of Complexity and Ambiguity in Decision Making,," Mid America Regulatory conference, June 5, 2011, pp. 1-2. Presentation states "a prudent, integrated, least cost resource plan must be hedged against **risk**, maximize options to reduce **uncertainty**, be flexible with respect to outcomes that are, at best, **vague** and be insulated against **ignorance** of the unknown… Acquisition of central station facilities, particularly nuclear, makes long-term commitments in exactly the wrong way for the current decision making environment. It commits to assets that have high risk (e.g. fossil fuel and nuclear facilities) or create large exposure to uncertainty (large size, high capital costs, or long lead times) with technologies that have vague long-term prospects (unstable resource availability and poorly understood environmental impacts)."

[43] U.S. Energy Information Administration, *Annual Energy Outlook,* various issues. Contrasting the 2009 projection to the 2011 projection shows a halving of projected additions to nuclear capacity in 2030. The 2010 report also shows retirements of nuclear capacity equal to 10 percent of additions. The 2090 report showed no retirements.