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Preliminary review of *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. Nuclear Regulatory Commission, July 12, 2011[1]

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I will first set forth the main conclusions and recommendations of the Near-Term Task Force Review and then proceed to my own analysis of the document.[3]

A. Main conclusions of the Near-Term Task Force Review

The main conclusions of the Near-Term Task Force Review are as follows:

- The existing regulatory approach and nuclear plant capabilities "allow" the conclusion that an accident like the Fukushima Daiichi nuclear power plant (referred to below as Fukushima, for brevity) accident "is unlikely to occur in the United States." (p. vii)
- Some effective measures to reduce the probability of core damage and radioactivity releases had already been taken before Fukushima. (p. vii)
- The NRC framework includes "design-basis" events and "beyond-design-basis" events. The latter has led to a regulatory "patchwork…of requirements and voluntary initiatives for maintaining safety" (p. 18). Seismic events that lead to core damage, fires, and station blackout (SBO), which appears to be the chief triggering technical event that led to the meltdowns and other problems at Fukushima, are "beyond-design-basis" events.
- The Task Force concluded that the combination of the NRC's "defense-in-depth philosophy" and probabilistic risk assessment, which should be "state of the art," were a

[1] On the Web at http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf.
[2] Arjun Makhijani is president of the Institute for Energy and Environmental Research in Takoma Park, Maryland. He would like to thank Rochelle Becker of the Alliance for Nuclear Responsibility and Tom Clements of Friends of the Earth for the literature and other information they provided on short notice in the preparation of this review. The analysis and conclusions are, of course, those of the author alone. This report was reissued with minor editorial corrections on July 21, 2011
[3] Page numbers in parentheses in the main text refer to the Near-Term Task Force Review. Other references are footnoted.

satisfactory basis for the NRC's regulatory framework, though it "can be strengthened by including explicit requirements for beyond-design-basis events." (p. viii)

- While the regulatory approach for evaluating natural hazards is "robust," the evolving knowledge and the lack of reestablishment of a design basis reflecting this new knowledge means that "significant differences may exist between plants in the way they protect against design-basis natural phenomena and the safety margin provided." (pp. 28 and 29). The issue of secondary damage, such as fires and floods caused by earthquakes needs to be reopened. (p. 32)
- Current station blackout requirements only provide for four to eight hours of battery power. Heavy snowfalls and high winds have been considered as initiating events for station blackouts, but not earthquakes. Neither reactor coolant system integrity nor spent fuel pool cooling are required to be maintained. The events at Fukushima (prolonged station blackout, depleted or damaged batteries, loss of instrumentation and lighting) show that the current requirements are insufficient and need to be expanded (p. 35)
- Boiling water reactor Mark I and Mark II designs, unlike other light water reactor designs, have no positive way (such as controlled combustion) to prevent a hydrogen buildup in the event of a core meltdown. Therefore, in these reactors the pressure must be kept low through cooling or the hydrogen must be safely vented (p. 42). The operators at Fukushima could not vent the containment, possibly because of the station blackout, and this likely contributed to the buildup of hydrogen and to the hydrogen explosions. The NRC needs to ensure that the vents are designed to operate reliably (pp. 40-41).
- Spent fuel pool instrumentation is minimal (for instance, generally, the water level in the pool is not indicated in the control room) and depends on AC or DC power, which would not be available in prolonged station-blackout conditions. Safety-related AC power supply and other measures relating to defense-in-depth are not currently required (pp. 44-45).
- The current 10-mile emergency planning zone for radiation exposure from the plume release by the plant is adequate (because capabilities exist to expand it) as is the 50-mile radius for controlling radiation exposure via food, though exercises and preparedness can be improved, as for instance under station blackout conditions. (pp. 59-61)
- "Misinformation and hysteria during a nuclear emergency challenge the agency's goal of public confidence." There is a "continued gap in the public knowledge with respect to KI [potassium iodide]." (p. 61)
- Implementation of voluntary industry initiatives regarding severe accident management guidelines (SAMGs) and extensive damage mitigation guidelines (EDMGs) is inconsistent across the industry, "so much so that the SAMG inspection would have resulted in multiple violations had it been associated with a required program" (p. 64), indicating the strengthening of implementation was needed.

One of the most important conclusions in regard to spent fuel pools is that continued dense storage of spent fuel in pools far beyond their original design capacity is safe enough, provided the cooling and instrumentation systems are upgraded to provide water sprays more reliably and station capabilities to deal with prolonged station blackouts are upgraded.

It is therefore implicit that the Task Force concluded that dry storage of aged spent fuel was important enough for improving safety in light of Fukushima. The Near-Term Task Force

Review notes that U.S. reactors have spent fuel pools with capacities of under 2,000 to 5,000 fuel assemblies. The average loading currently is 3,000 assemblies. The four reactor spent fuel pools had totals of 292, 587, 514, and 1,331 fuel assemblies (Units 1, 2, 3, and 4 respectively) for a total of 2,724 assemblies.

An implicit conclusion of the report is that self-assessment by reactor operators on critical safety issues can be allowed to continue. For instance, the Task Force recommended that "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." (p. ix, emphasis added).

B. Recommendations of the Task Force Task Force Review

We will not summarize all the recommendations here, but highlight some that are relevant to the analysis provided in subsequent sections.

1. Enhanced design basis

The NRC should create an enhanced-design-basis framework to replace the design-basis plus beyond-design-basis framework now in place. This would remedy the patchwork of requirements that now characterize beyond-design-basis issues.

2. Seismic and flooding issues

The NRC should "require licensees to reevaluate and upgrade as necessary the design-basis seismic and flooding protection of SSCs [structures, systems, and components] for each operating reactor." A rulemaking should be initiated to require a review of these hazards every 10 years and take action as necessary "to protect against the updated hazards." Licensees should do "walkdowns to identify and address plant-specific vulnerabilities and verify the adequacy of monitoring and maintenance for protection features such as watertight barriers and seals in the interim period until longer term actions are completed to update the design basis for external events." (p. 30)

3. Station blackouts

The capacity to deal with a complete station blackout should be extended from four hours to eight hours. Put in place equipment and procedures to extend the capability to cool the core and spent fuel pool for 72 hours and maintain offsite equipment and "the ability to deliver equipment to the site" within the 72 hour period to enable the personnel to handle an extended station blackout. The procedures and equipment should address situations of one reactor or more than one reactor at a site. The NRC should revise its regulations to reflect these new requirements.

4. Vents

The NRC should take the regulatory action needed to ensure that licensees install hardened vents on Mark I and Mark II boiling water reactors that are reliable..

5. Spent fuel pools

The NRC should require licensees to improve spent fuel pool instrumentation related to safety such as instruments to measuring water level, temperature, and radiation. The instrumentation should be able to withstand natural hazards and the readouts of the instrumentation should be in the control room. The emergency water spraying systems should be "seismically qualified" and should include "an easily accessible connection to supply the water (e.g., using a portable pump or pumper truck) at grade outside the building" (p. 45). There should be a rule change reflecting the new requirements.

6. Emergency planning

The NRC should promulgate new regulations to "require that facility emergency plans address prolonged SBO and multiunit events" (p. 56). This would include planning improvements regarding personnel, radiation dose evaluation, training, and equipment. In the interim, the NRC should order licensees to increase staff and train that staff to be able to respond to multi-unit events. Power for communications should include contingencies for a prolonged station blackout.

The NRC should "work with FEMA [the Federal Emergency Management Agency], States, and other external stakeholders… to identify potential enhancements to the U.S. decision-making framework," examine the resources needed to ensure the ability to deliver offsite equipment to the site, make effective use of radiation measurements, including possibly making them available on the Internet in real time, etc. The "appropriate use of KI" should be a part of emergency management training. (p. 62)

7. Regulatory oversight

The NRC should "strengthen regulatory oversight of licensee safety performance (i.e., the ROP [Reactor Oversight Process]) by focusing more attention on defense-in-depth requirements consistent with the recommended defense-in-depth framework" (p. 64). This should include more staff training (including resident NRC inspector training) to deal with severe accidents.

C. Emergency Management and the Indian Point Nuclear Power Plant

Amongst the most glaring problems in the Task Force report is its treatment of emergency management and evacuation.

The Task Force report treads quite softly, despite the catastrophe in people's lives that is still unfolding as a result of the March 11, 2011, Fukushima Daiichi nuclear power plant accident. The report can only bring itself to say that the radiation releases "exacerbated" the "inconceivable losses" caused by the earthquake and tsunami (p. iii). A palliative undertone pervades the report, from the dedication to the Japanese people and to the workers who have, by all accounts, labored heroically to try to gain control of the situation. In that very dedication, the Task Force assures us, in the passive voice, that there is "the expectation of no significant radiological health effects" (p. iii). It does not even qualify this by saying that health effects might be expected among workers, many of whom have experienced external radiation doses well above ten rem, in addition to doses due to radioactivity that they breathed and ingested.

Figure 1 shows the radiation doses that the U.S. Department of Energy estimates will be experienced by the public around Fukushima in the first year after the accident from external radiation sources and inhalation of re-suspended particles if they stayed outdoors all the time. Building shielding factors, which would reduce dose, and internal radiation dose due to ingestion or incorporation of radioactivity via cuts and wounds, which would increase dose, are not taken into account. Ingestion of soil is especially important for children.[4] Long-term risks will grow since there will be further radiation doses in future years and also from radioactivity deposited after the DOE surveys. Therefore, as a first approximation, the map may be taken as an order of magnitude indication of the risks faced by the public, especially beyond the 20-kilometer evacuation zone, where there were no restrictions on activities in the initial months.

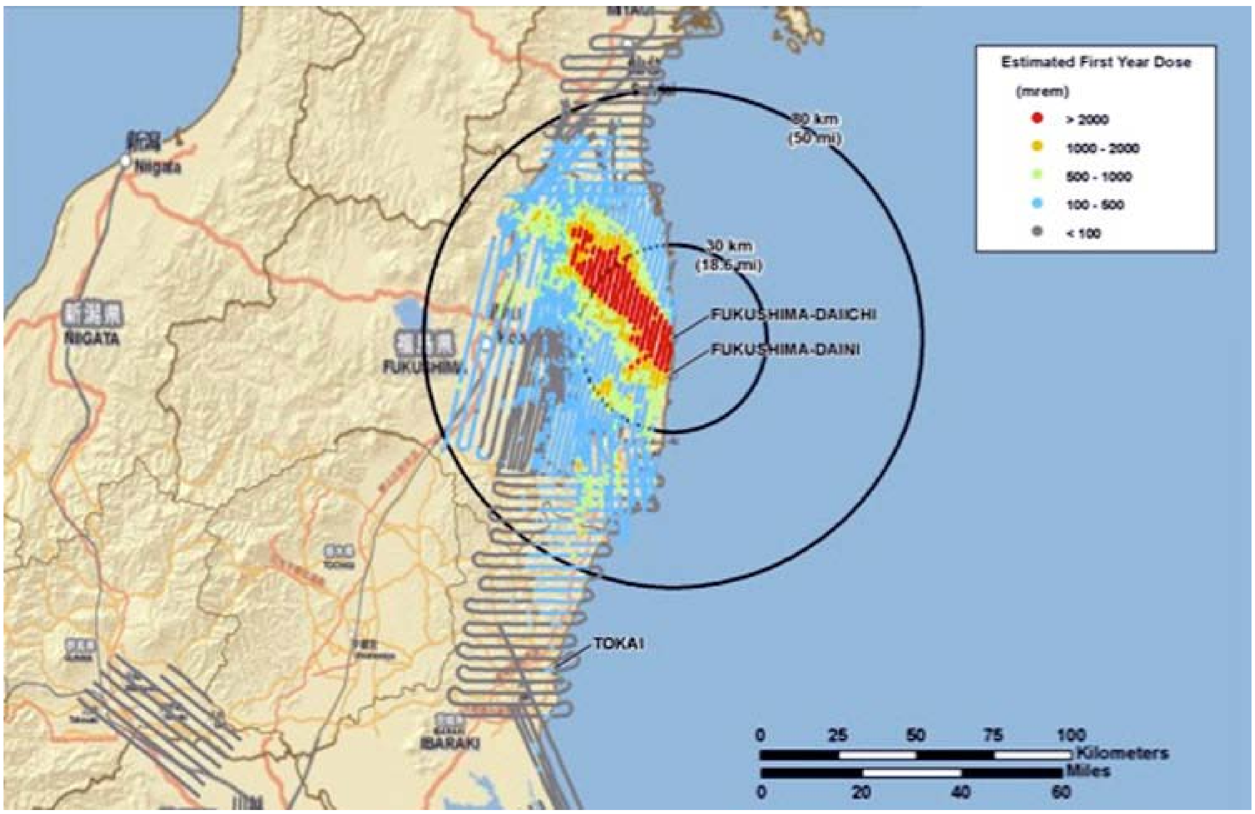

Figure 1: Map of estimated first year radiation dose, estimated by the U.S. Department of Energy.[5]

The red-shaded area represents a dose of more than 2,000 millirem (2 rem). Using the cancer risk coefficient published by the U.S. EPA,[6] the fatal cancer risk at the minimum dose of 2 rem would be about 1 in 1,150.

[4] For the purpose of dose calculations, the EPA recommends a conservative upper limit value of soil ingestion by children of 400 milligrams per day. See EPA Exposure Factors Handbook, EPA/600/P-95/002Fa, August 1997, p. 4-20.

[5] U.S. Department of Energy. National Nuclear Security Administration. *Radiological Assessment - of effects from - Fukushima Daiichi Nuclear Power Plant*. [Washington, DC]: DOE, NNSA, April 18, 2011. On the Web at http://www.energy.gov/news/documents/041811__AMS_Data_April_18__v1.pptx.

There are about 1.7 million people in the cities in the Fukushima prefecture. Many of these cities are within the 20-30 kilometer zone from which people were not evacuated but advised to stay indoors, and in the zone beyond that out to 70 or 80 kilometers, where there is contamination but no restrictions other than those on food. Almost 80,000 people in the 20-kilometer zone were evacuated, probably including thousands of children.[7] There are more in the 20 to 30-kilometer zone where sheltering was recommended and even more in the contaminated area beyond 30 kilometers. It is unclear how many remained and for how long. But given the contamination and the fact that the doses will continue to accumulate after the first, year – the half-life of the main long-lived contaminant, cesium-137 is about 30 years – there are likely to be many excess cancers in the high fallout areas. Thyroid diseases among children would be in addition to these problems, as would cancers among the many hundreds of workers who received doses of several rem up to the limit of 25 rem and sometimes above that limit.[8] Internal doses will likely add to these totals. There would be one excess fatal cancer expected among every hundred workers who got 25 rem (or 1 among every 250 workers who got 10 rem). The occurrence of excess cancers would be about double the fatality rate. The Task Force provided no basis for its statement that there "the expectation of no significant radiological health effects." At the very least it is premature. The available facts point in the contrary direction. [9] Lack of adequate monitoring of the population and the low power of epidemiological studies may make it difficult to determine the actual outcome unless workers and the affected population have careful medical and radiological monitoring (for internal radionuclide deposition).

Had the Task Force considered children, the situation would look even worse. The fatal cancer risk for five-year-old female children is about 2.3 times that when the same dose is received gradually over a 70-year lifetime at all ages.[10] This is because children in general and female children in particular are much more sensitive to radiation than adults.

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[6] One chance in 1,740 of a fatal cancer per rem of radiation dose experienced over a lifetime. See U.S. EPA's Federal Guidance Report 13, 1999, Table 7.3, p. 179. (hereafter, FGR 13).

[7] About 78,200 people lived within the 12 mile radius of the plant and about 62,400 in the 12 to 18 mile radius. (Keith Bradsher, "Japan Prohibits Access to Nuclear Evacuation Zone," *New York Times*, April 20, 2011, at http://www.nytimes.com/2011/04/21/world/asia/21japan.html)

[8] The risk factor for adult male workers is used in this case – one cancer for every 2,500 person-rem of population exposure.

[9] The rather lax treatment of the science of radiation risk is consistent with the NRC's approach to public information. Near the start of the crisis, the NRC informed the public that average U.S. doses from all sources were 620 millirem per year and that, "in general," this yearly exposure "has not been shown to cause humans any harm" (http://www.nrc.gov/about-nrc/radiation/around-us/doses-daily-lives.html). The NRC's statement regarding health damage is highly misleading. A dose of 620 millirem experienced by each person in a population of 311 million people in the United States would be associated with more than 200,000 cases of cancer, about half of which would be fatal. Instead of asking the NRC to put its own house in order regarding informing the public accurately about radiation risks, the report complains that "[m]isinformation and hysteria during a nuclear emergency challenge the agency's goal of public confidence." (p. 61) When the NRC is itself the source of highly misleading information that ignores that National Academies and official EPA risk estimates, is it a wonder that the public lacks confidence in official pronouncements?

[10] Calculated by comparing the risks of fatal cancer for children provided in the 2006 BEIR VII report of the National Academies (Table 12D-2, p. 311) and the FGR 13 lifetime fatal cancer risk coefficient of 0.000575 fatal cancers per rem.

In entirely ignoring any special action that the NRC would need to take to protect children, the Task Force report is arguably in violation of Executive Order 13045. This conclusion is reinforced by the fact that there has been an intense controversy in Japan by the government's decision to allow children to get as much as 2 rem per year of exposure in contaminated schools. This decision has been vigorously opposed in Japan, and that opposition has had considerable support from many people in the United States.

The higher vulnerability of children is recognized in the presidential Executive Order 13045 to protect children from environmental harm. It has been in effect since 1997 and states in part that government should:

> (a)…make it a *high priority to identify* and assess environmental health risks and safety risks that may disproportionately affect children;
>
> and
>
> (b) …ensure that its policies, programs, activities, and standards address *disproportionate risks to children* that result from environmental health risks or safety risks.[11]

The Task Force's report endorsing existing 10-miles emergency planning with better training and equipment can be seen to be utterly inadequate in the case of Fukushima in a number of ways:

- The evacuation zone (in case that is needed) is circular, but the pattern of contamination and radiation dose is more complex, and includes hot spots far outside the ten-mile zone. In the case of Fukushima, there are hot spots about 40 miles from the plant and more moderate fallout patterns even beyond fifty miles (see the blue zone outside the 50-mile radius in Figure 1). In fact, recent reports indicate the hot spots exist far beyond 50 miles. According to the *New York Times* of 19 July 2011, "[c]ontaminated hay has been found at farms more than 85 miles from the crippled Fukushima Daiichi plant, suggesting that the radioactive fallout has reached a wider area than first suspected."[12] The Task Force report contains no discussion of the problem of hot spots or the potential need for irregular evacuation far beyond 10 miles. In some cases in the United States the feasibility of such evacuation would be in serious doubt, to say the least. In fact, in some cases, such as Indian Point, just 25 miles from Manhattan and Limerick, about 30 miles from Philadelphia, even a partial 40-mile evacuation zone defies imagination (see below for further discussion of Indian Point).
- There is currently no requirement for a dense network of monitoring stations downwind from the plant extending out to 50 miles or more. Nor are there intensive training and equipment requirements for local emergency response personnel beyond the ten-mile radius. The concept of the potential for downwind exposure and the equipment and training that would be needed is not part of the regulatory structure and not discussed in

[11] Executive Order 13045: Protection of Children from Environmental Health Risks and Safety Risks, On the Web at http://yosemite.epa.gov/ochp/ochpweb.nsf/content/whatwe_executiv.htm., Italics added.
[12] Hiroko Tabuchi, Radiation-Tainted Beef Spreads Through Japan's Markets, *New York Times*, July 18, 2011, at http://www.nytimes.com/2011/07/19/world/asia/19beef.html?_r=1&ref=world.

the report. In fact, the Task Force just threw up its hands when discussing the potential evacuation and radiological consequences of an elongated plume extending beyond the U.S. ten-mile planning zone by saying that current emergency planning provides "a basis for expansion," but "that every situation will differ, so detailed preplanning in this area is not plausible." It hopes that "information and insights [that] emerge" will help the NRC (p. 61). Yet the vast gaps in the Task Force's discussion of the known facts of the Fukushima situation, including U.S. government measurements and maps, provide little confidence that important facts and sound science will be taken in account when it comes to population protection and emergency planning. Some of the most critical facts have been left out of the Task Force's own report.

1. *Indian Point*

The Indian Point nuclear power plant consists of two operating pressurized water reactors (Indian Point 2 and 3) and one closed reactor (Indian Point 1), which has not been decommissioned, though it has been defueled. The population in the 50-mile zone around the plant is about 17 million, roughly ten times the population of all the principal cities in Fukushima prefecture. Even though the NRC advised Americans within 50 miles of Fukushima Daiichi to evacuate early in the accident, there is no discussion of this decision in the Task Force report. Was it wrong to advise Americans to evacuate at 50 miles, when the Japanese authorities only had a 12.5 mile (20 kilometer) evacuation zone in the early days? If it was not wrong, should there not be at least minimal advance planning out to 50 miles for evacuation in the United States at least for plants like Indian Point which are in very densely populated areas? Is such evacuation feasible in densely populated areas? The report is silent on the question of the implications of Fukushima for Indian Point or any other plants for evacuation out to a fifty-mile radius.

It should be noted that moderate hot spots existed as early as April even outside the 50-mile radius from the Fukushima plant. There is no discussion of meteorological reevaluation of the 10-mile or 50-mile planning zone. It is surprising that the report concluded that with better planning, training, and equipment the existing distances for exposure from plumes and food were adequate without reference to any data from Fukushima and without an attempt to examine the corresponding meteorological investigations and potential regulatory changes that would be needed in the United States.

The signal failure of the Task Force report to carefully reevaluate emergency planning distances and evacuation zones and procedures in densely populated areas is all the more shocking for plants like Indian Point and Limerick. Surely, these plants would not be licensed at their present locations based on current siting guidelines.

Finally, while it is far too early to make accurate estimates of damage to life and property due to Fukushima, it is clear that it will greatly exceed the approximately $12 billion that is the collective liability limit for the nuclear industry in case of a severe accident. The damage from an accident similar to Fukushima at Indian Point would likely be in the hundreds of billions of dollars. Is the federal government ready to bear additional liabilities in the range of hundreds of billions of dollars when it is cutting back on existing commitments?

Recommendation 1: The NRC should require a complete revaluation of emergency planning zones, evacuation, and population protection in light of Fukushima, especially in densely populated areas where evacuation in zones extending out 30 or 40 miles will be essentially impossible and asking ten million or more people to stay indoors for extended periods of months is also equally impossible. While the report discusses the relative merits of evacuation versus sheltering, it seems disconnected from the reality of a form of radiation untouchability that emerged after the start of the accident; it consisted, in part, of fears of contact with people within the 20 to 30 kilometer sheltering zone around Fukushima who were thought to be contaminated. Many people outside that radius were extremely reluctant to enter the zone, while people in the zone were told not to go out. A similar phenomenon affected the survivors of the bombings of Hiroshima and Nagasaki. Is such a situation imaginable for the Bronx or Manhattan? The report does not say.

Japan is also faced with a massive job of cleanup of contaminated zones and the problem of what it will do with radioactively contaminated homes and business property. The Task Force has bypassed this topic as well. It is an acute problem in the Fukushima area; but it would be far more difficult and damaging in the case of reactors like Indian Point, which is in a far more densely populated area, or even in the case of Pilgrim 1 in Massachusetts or Vermont Yankee.

A large part of the problem is that emergency planning is implicitly based on the assumption of short-term releases of radioactivity without severe contamination of large numbers of homes or commercial or government buildings. A corollary is that, just as in the aftermath of Three Mile Island (TMI), people will be able to move back to their homes, farms, businesses, and offices and that there will not be widespread persistent hot spots and large contaminated areas, as there are in the vicinity of Chernobyl and Fukushima. The red, yellow, and blue zones in Figure 1 above are roughly half the area in the 30-kilometer-radius Chernobyl exclusion zone.

Finally, the entire emergency planning regulatory structure is obsolete in regard to: radiation doses, radiation protection, clean-up after the emergency is over, long-term sheltering of populations, supply of provisions for people who are advised to stay indoors rather than evacuate, and the protection of children. The emergency planning regulatory structure is obsolete for two reasons. First, as is clear from the above brief discussion, Fukushima has unveiled a host of issues that are much more complex than discussed in the Task Force report. Second, the existing radiation protection norms for evacuation, specified at 10 CFR 100.11, do not conform to Executive Order 13045 that requires special attention to the protection of children from environmental contaminants.

Recommendation 2: The NRC needs to revamp its entire regulatory structure for emergency planning to take into account (i) the protection of children, required by Executive Order 13045, (ii) the fact that large numbers of people may not be able to return to contaminated homes and jobs for prolonged periods, if ever, and that this needs special attention in densely populated areas, (iii) the irregular nature of the high radiation areas that develop, (iv) cleanup costs in the aftermath of accidents, (v) the need for real-time monitoring equipment to be in place far beyond the 10-mile planning zone, (vi) the need to take meteorological factors into account, often in real time, when informing the population (as, for instance, about potential rainfall and milk contamination), and (vii) the need to thoroughly reevaluate the viability of nuclear power plants in densely populated zones where evacuation in a 30-, 40-, or even 50-mile radius (depending on meteorological factors) may not be feasible.

Recommendation 3: The NRC needs to publish scientific guidelines for communicating radiation risks that respect the established science, notably the EPA's Federal Guidance Report 13 and the National Academies BEIR VII report. The NRC cannot expect the public to trust its pronouncements if it issues highly misleading assurances of public safety as discussed above (see footnote 9 above). The NRC should specifically communicate both individual and population risk (including risks to children by gender).

D. Risks from natural disasters, including seismic risks at Diablo Canyon and San Onofre in California

The Task Force report has made a much more substantial positive contribution to the review of seismic and flooding risks and the inconsistent implementation of safety actions that are voluntary. Specifically, the Task Force points out that as a result of patchwork consideration of beyond-design-basis events, the public near some nuclear power plants may be much less protected than at others. The directness of its recommendations concerning flooding and seismicity ("require licensees to reevaluate and upgrade as necessary the design-basis seismic and flooding protection of SSCs for each operating reactor" (p. 30) and to require a review of these hazards every 10 years) is testimony to the concern made brutally transparent by the unanticipated magnitude of the March 11, 2011, earthquake offshore from the Sendai-Fukushima area.

1. Tornadoes and infrastructure damage

The Task Force did not focus as much on tornadoes (though it mentions them several times) despite the fact that 2011 has been an extraordinary year for them in the United States. The assumption that nuclear power plants, especially Mark I secondary containments, could survive the worst tornadoes needs to be revisited in light of the immense destruction caused by the hydrogen explosions in the four secondary containment buildings at Fukushima.

AREVA, the French nuclear conglomerate, did estimates of the amounts of hydrogen involved in the explosions.[13] AREVA's expert, Dr. Matthias Braun, estimated the amounts of hydrogen as follows:

- Unit 1: 300 to 600 kilograms of hydrogen. The explosion destroyed the upper portion of the secondary containment of Unit 1.
- Units 2 and 3: 300 to 1,000 kilograms of hydrogen. Unit 2 primary containment appears to have been damaged, though the location of the explosion is unclear. A small part of the side of the secondary containment was blown away with steam emanating from it. Unit 3 secondary containment building was very substantially destroyed.

[13] Dr. Matthias Braun, *The Fukushima Daiichi Incident*, AREVA, 1 April 2011, at http://www.seyth.com/ressources/quake/AREVA-Document.pdf. A slide presentation.

The AREVA slides do not deal with the explosion in Unit 4, where the reactor had been defueled. The core was stored in the spent fuel pool.

Tornadoes have a somewhat different mechanism of damage than an explosion, but most intense tornadoes can and have destroyed very substantial buildings, as is clear from Figure 2, which shows a school building destroyed by a "Fujita 5" tornado, which is the most intense level. It is important to note that unlike seismic events, where advanced instrumentation exists to make precise measurements of acceleration and ground motion, severe tornado velocities are a matter of expert estimates rather than precise measurements. One can therefore reasonably expect changes in the science and in the expert estimates in the future.[14] The estimates of the amounts of hydrogen that produced catastrophic damage and the evolving understanding of tornadoes indicate the need for a complete and thorough revaluation of the assumption that Mark I secondary containment buildings are tornado survivable.

Figure 2: Greensburg High School, Greensburg, Kansas, Fujita 5 tornado, May 4, 2007, at http://commons.wikimedia.org/wiki/File:FEMA_-_30070_-_Greensburg_High_School_tornado_damage_in_Kansas.jpg

Recommendation 4: The NRC should require a thorough independent reevaluation of the survivability of all Mark I secondary containment buildings in the worst tornadoes. The

[14] Some changes in tornado velocity estimates for given levels of damage were made in 2007.

evaluation should include an evaluation of tornadoes followed by flooding. There are 23 Mark I in the United States reactors including Browns Ferry 1, 2, and 3 in Alabama, Cooper in Nebraska, Dresden 1 and 2 and Quad Cities 1 and 2 in Illinois, Duane Arnold in Iowa, Hatch 1 and 2 in Georgia, and Monticello in Minnesota.

2. *Seismic issues, Diablo Canyon Power Plant*

While the Task Force has addressed the inadequacies of the current uneven seismic evaluations, it has done so gingerly rather than frankly and thoroughly. A more forceful assessment was surely in order, give that the entire chain of meltdowns, explosions, and events began with an earthquake that was more severe than anticipated in plant design. There is also some evidence that damage caused by the earthquake has great relevance to the failures at the reactors. For instance, damage to vital components due to the earthquake is a possible and even likely partial explanation for the very rapid meltdown that occurred in Unit 1.[15]

The history of seismic issues at the Diablo Canyon Power Plant (Diablo Canyon for short, below) illustrates that the recommendation of reevaluation of seismic issues is not only needed, but long overdue and should be implemented in depth and with some urgency. But it also illustrates that the NRC's decision to mainly rely on its licensees to perform the studies is misplaced, and could severely compromise safety and scientific thoroughness.

The initial design of the Diablo Canyon in 1967 was based on the assumption that there was no serious faulting in the vicinity that could raise safety issues. According to the California Public Utility Commission record, the PG&E consultant concluded that there were "only insignificant faults that have shown no movement for at least 100,000 and possibly millions of years." Active faults were said to be 20 to 50 miles away.[16] The Commission accepted the PG&E consultant's report and granted the Certificate of Public Convenience needed to build a power plant in California.

As the plant was being built, the Hosgri fault was discovered just 3 miles offshore, with a maximum earthquake estimated to be Richter magnitude 7.5. The seismic design of the plant had to be revamped, causing delays and cost increases. PG&E and the NRC (based largely on PG&E seismology reports and investigations) were convinced of the plant's safety. The reactors went online in 1985 and 1986.

In the last decade, a United States Geological Survey scientist, Jeanne Hardebeck, confirmed the existence of a fault just 600 yards offshore from Diablo Canyon. It is called the Shoreline Fault. Currently, there is disagreement about the magnitude of the earthquake that could occur due to this fault, whether it is segmented or connected to the Hosgri Fault (about which there also continues to be some disagreement), the amount of ground-shaking it would produce, and its consequences for Diablo Canyon safety – in other words, there is disagreement regarding just about everything that matters. PG&E believes that maximum magnitude would be 6.5 but the geologist who discovered the fault, believes that a magnitude of 7.2 earthquake or even 7.7 is possible, both of which would be much more severe in its consequences for Diablo Canyon than

[15] "Several hours" after the tsunami according to the Task Force report, p. 10.
[16] California Public Utility Commission Decision 73728, Application 49051, November 7, 1967.

the same magnitude earthquake 3 miles away.[17] This is because the attenuation of the energy in the seismic waves is much smaller and hence the local intensity much larger if the fault is closer to the point of concern, in this case the Diablo Canyon nuclear power plant.

Such disagreement would be normal for a newly discovered fault that has only recently begun to be seriously explored. But the uniform conclusions by PG&E that all the features of the Shoreline Fault, including maximum magnitude, discontinuities, length of the fault, whether it is connected to the Hosgri Fault, and frequency of ground-shaking point in the same direction: Diablo Canyon is safe. Under pressure, PG&E has asked for a delay of 52 months in its relicensing process and will conduct a 3-dimensional seismic study near the plant. Sam Blakeslee, the California state senator who represents the district that includes Diablo Canyon has serious concerns about the use of company staff and consultant seismologists as primary sources of scientific data and analysis. He is also a geophysicist who knows seismic surveys well; he has promised a thorough review,[18] which is about all a state senator can do, because decisions on nuclear safety are preempted by the federal government under the 1954 Atomic Energy Act.

There should, of course, be no bar to a nuclear utility having its own seismology department, as PG&E does. In fact, that is an important capability for a nuclear utility to have. But there is an inherent conflict of interest there that should have been recognized by the Task Force and was not.

The facts of the Great East Japan Earthquake of March 11, 2011, clearly cried out for a detailed analysis of this problem. That earthquake was beyond the design basis. It is thought that the fault line in the vicinity consisted of segments that would not rupture simultaneously and cause a gigantic earthquake. But they apparently did. The eerie parallel with the current controversy around the Shoreline and Hosgri Faults should have leaped out at the Task Force. The consistent complacency of the assurances by the company and the NRC regarding safety until pushed by the California Energy Commission and the state senator who represents the area should not have gone without comment and analysis when considering the lessons of Fukushima for the United States. The fact that the NRC does not revisit seismic and natural hazards issues during review of license renewal applications should also have been analyzed. This problem is partly offset by the Task Force's recommendation for review of natural hazards every ten years. However, from an economic perspective, it is at least as important to review seismic and natural hazard issues during relicensing. That is the time when the applicant, the public, and Public Utility Commissions can consider economic issues associated with the continued operation of the plant and compare them to the alternatives.

3. Seismic issues, San Onofre Nuclear Generating Station

If Diablo Canyon has been characterized by repeated revisions of the seismic threat upwards in the sense of new faults and closer faults being discovered, there has been precious little investigation of seismic issues at San Onofre, located farther south on the California coast

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[17] Susanne Rust, PG&E, USGS disagree on Diablo Canyon fault danger, *San Francisco Chronicle*, July 17, 2011, http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2011/07/17/MN311K9QBV.DTL&tsp=1.

[18] See the PBS video, *Need To Know:Diablo Canyon*, July 15, 2011, at http://video.pbs.org/video/2056655205.

between Los Angeles and San Diego. It was thought that major faults did not exist in the area, but in the year 2000, Harvard University and University of Colorado seismologists concluded that a "blind-thrust fault" existed in the area (the Oceanside thrust) that could cause large earthquakes in the Los Angeles-San Diego area, up to magnitudes of 7.1 to 7.6, though they also estimated they would be infrequent.[19] Blind thrust faults are more difficult to detect because they terminate below the earth's surface.

The NRC did not immediately order a seismic study. Southern California Edison, which owns the plant, has only recently begun a 3-D seismic survey. It is important to note that unlike Diablo Canyon, which is about 25 meters above sea level, San Onofre is just 10 meters above sea level and could more easily be affected be a severe tsunami.

Recommendation 5: The NRC should have its own independent seismology department with sufficient breadth and depth to conduct its own studies and field investigations to develop an independent picture of the seismic risks in the most important areas affecting nuclear power plants. These include the plants in California, but also others in various parts of the country where the design basis may no longer be equal to the present understanding of the seismic risk.

Recommendation 6: The NRC should conduct the most intensive investigations of natural hazards, including earthquakes, floods, and tornadoes as part of the license renewal process or whenever new scientific data (for instance, the 2000 scientific paper on the Oceanside blind thrust fault) becomes available.

E. Hydrogen vents and Mark I and Mark II reactors

The Task Force report acknowledges that operators could not sufficiently vent the reactor containments, but treats the issue rather softly:

> It is unclear whether the operators were ever successful in venting the containment in Unit 1, 2, or 3. The operators' inability to vent the containments complicated their ability to cool the reactor core, challenged the containment function, and likely resulted in the leakage of hydrogen gas into the reactor building, precipitating significant explosions in Units 1, 3, and 4. [pp. 40-41]

The Task Force report never actually states that, whatever the causes, all the venting systems failed in their function, substantially or completely, even if some partial venting occurred on occasion. Nonetheless, it was a case of 100 percent failure *of function*: there were four units in crisis and four hydrogen explosions. No other proof than that actual hydrogen explosions occurred is necessary for a conclusion that there was a 100 percent failure of function.

This is more than a semantic question. While the recommendation that the NRC should ensure that reactors have hardened vents on Mark I and Mark II reactors that will operate reliably is

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[19] Carlos Rivero, John H. Shaw, and Karl Mueller, "Oceanside and Thirtymile Bank blind thrusts: Implications for earthquake hazards in coastal southern California," *Geology* v.28 (October 2000) pp. 891-894. On the Web at http://structure.colorado.edu/~structure/mueller_refs/20_Rivero_etal_2000_OceansideEQs_Geology.pdf.

unexceptionable (all 23 Mark I and three of eight Mark II U.S. reactors have hardened vents installed, [20] but their reliability is in serious doubt after Fukushima), the Task Force did not analyze the underlying regulatory and technical procedures that led to the installation of vents that failed.

The vent system failures were connected, at least in part, to the Fukushima station blackout. That particular issue had actually come up when the NRC was reviewing the design of the vents that were backfitted onto U.S. Mark I and three of the eight Mark II reactors. [21] Japanese Mark I owners used the same or similar vent design, so there was all the more reason for the Task Force to consider carefully whether and how the regulatory process in the United States failed. So far as function is concerned, it did fail because there is now a need to go back and fix a problem that was raised in the U.S. approval process and now has been made tragically evident by Fukushima.

The recommendations of the Task Force do not go far enough regarding station blackouts. The extension of time for dealing with a station blackout from 4 to 8 hours and thence to 72 hours, by prepositioning equipment is well and good, but Fukushima raises the question of whether such measures would be sufficient in case of an accident with infrastructure destruction on the scale of Fukushima. In fact, in the emergency response section, the Task Force itself notes that prearranged resources may not be available in some cases:

> The accident at Fukushima has illustrated the potential increased need for offsite assistance to the licensee. In the case of large natural disasters such as earthquakes, hurricanes, and floods, the phenomena challenging the plant will also have affected the local community. In these cases, **prearranged resources may not be available because of their inability to reach the plant site**, other (potentially lifesaving) priorities within the community, or the destruction of those resources. [p. 60; emphasis added]

The Task Force does not explain how the extension to 72 hours and beyond 72 hours would function to restore power in such a case. If prearranged equipment cannot be delivered, then a large part of the recommendation of dealing with station blackouts is rendered inoperative. This should have been a more important and consistent discussion, because, in some ways, the interval between 8 hours and 72 hours at Fukushima was at least as challenging as the first 8 hours. The hydrogen explosion in Unit 1 occurred almost 25 hours after the earthquake. The worst hydrogen explosion, in Unit 3, occurred at 11:01 on March 14, in just under 70 hours after the earthquake. Further, the reactor core isolation cooling system of Unit 2 also stopped operating on March 14, in under 72 hours, increasing the risk of a subsequent hydrogen explosion.

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[20] The eight Mark II reactors are Columbia, LaSalle 1 and 2, Limerick 1 and 2, Susquehanna 1 and 2 and Nine Mile Point 2. The fact that only three of the eight reactors installed vents illustrates the patchwork nature of voluntary implementation of beyond-design-basis safety measures.

[21] NRC 2011 Task Force, pp 39-40; Hiroko Tabuchi, Keith Bradsher and Matthew L. Wald. "Hidden Dangers: In Japan Reactor Failings, Danger Signs for the U.S., *New York Times*, May 17, 2011, at http://www.nytimes.com/2011/05/18/world/asia/18japan.htm; and Hannah Northey. "U.S. Nuclear Agency Rethinking Major Safety Requirements After Japan's Disaster," *Greenwire*, *New York Times*, June 27, 2011, at http://www.nytimes.com/gwire/2011/06/27/27greenwire-us-nuclear-agency-rethinking-major-safety-requ-68611.htm.

The Task Force has also not adequately explored the consequences of the hydrogen explosions for the period of recovery from the accident. The cranes and other infrastructure for handling spent fuel appear to have been destroyed in Units 1, 3, and 4. A plastic dome will help contain releases, but how will the plant be decommissioned? Will the site become a permanent waste repository on the shore of the Pacific Ocean in a severe earthquake zone? If this does not seem like a suitable answer, which it is not, then how will heavy equipment handling capacity be reinstalled? How will workers be protected? What will an accident on this scale do to decommissioning costs? Should ratepayers pay? Should not the electricity ratepayers' representatives have some rights in safety issues if they are to cover part of the costs? While answers to such questions are still some time off at Fukushima, the questions are clear now and should have been posed.

Recommendation 7: The NRC should examine in a transparent public process the process that led to the installation of a venting system design in the United States that failed to function effectively at Fukushima. This should be part of the process of review of any new venting system.

Recommendation 8: In view of the need for a reliable venting system, the NRC should undertake an urgent and transparent public review examining whether the 23 U.S. Mark I reactors like Browns Ferry, Duane Arnold, Hatch, and others and the eight Mark II reactors are safe to operate.

Recommendation 9: The NRC should evaluate the problem of the destruction of spent fuel handling infrastructure by the hydrogen explosions at Fukushima and its technical, radiological, and economic consequences for recovery, cleanup, and decommissioning.

F. Probabilistic risk assessments and spent fuel pools

As noted, the Task Force considered continued dense storage of spent fuel in reactor pools to be safe enough. No explicit analysis of the vulnerability of Fukushima Units 1 to 4 spent fuel pools and the lessons they might hold for preferring dry storage was done by the Task Force. While the report repeatedly emphasizes the centrality of probabilistic risk assessment (PRA) in safety (along with the defense-in-depth philosophy), the Task Force entirely failed to take into account the fact that three more meltdowns, four hydrogen explosions, and the loss of water from spent fuel pools has drastically modified the underlying data that should go into the analysis. These were not reactors of a completely different design, like Chernobyl, that could be set aside;[22] these were GE Mark I reactors, of which there are 23 currently licensed in the United States.

One in every hundred commercial light water power reactors, the most common design in the world (including all operating U.S. commercial reactors) has now had a partial or full meltdown before 40 years of operation. Three of them, all at Fukushima Daiichi, have had serious containment failures and radioactivity releases. The Task Force refers to NUREG-1150, the NRC's study of severe accident risks and public health risks related to five reactors in the United

[22] With due credit to the DOE it should be noted that after Chernobyl it commissioned a review of its graphite moderated water cooled reactor at Hanford (the N-reactor), shut it down in 1987, and did not reopen it.

States. But it does not ask for a complete revision of this study in light of new data from Fukushima. Neither does it ask for a revision of the spent fuel pool risk assessment (NUREG-1353), which deals with beyond-design-basis spent fuel pool accidents. This document is also obsolete. Fukushima has shown, for instance, that a central assumption in the accident triggering mechanism – that water will drain out of the pool instantly leading to a fire – may not be the only way a pool could lose water. Water may boil into steam, react with zirconium, create hydrogen and a meltdown in the pool, especially as in the case of Unit 4, when the pool contains freshly unloaded fuel (in this case the whole reactor core).[23] The probabilities of spent fuel accidents are also revealed to be low overall in NUREG-1353, as, therefore, are the risk estimates.

The Task Force mentions "state-of-the-art" PRAs. But what is the use of such state of the art analysis if data from the real world are ignored?

The reality of spent fuel pool dangers revealed by Fukushima has validated the conclusion of the National Academies that dry storage is safer than storage in reactor pools.[24] The Task Force should at least have advised a pause in relicensing decisions while the risks of spent fuel pools were reevaluated. It did not note, but should have, that Vermont Yankee, a Mark I reactor of about the same vintage as Fukushima Unit 1, was relicensed by the NRC on March 21, 2011, ten days after the start of the Fukushima disaster without a reconsideration of the issue of wet versus dry storage and while other Fukushima-related safety issues were pending. The dry storage at Fukushima did not release any radiation so far as we know. [25]

Recommendation 10: Both the reactor probabilistic risk assessments and the spent fuel PRAs of the NRC (NUREG-1150 and NUREG-1353) need to be thoroughly updated, using data from Fukushima and elsewhere. Licensees may do their own PRAs, but the NRC must perform its own independent PRA as part of the license renewable process.

Recommendation 11: Fukushima illustrates the importance of dry storage of aged spent fuel. The NRC should order it. The events of 9/11 demonstrated the importance of hardening potential targets against terrorism. The conclusion is that the NRC should order dry storage of as much spent fuel as safely possible and concomitantly order low density spent fuel storage in pools (at operating reactors).

G. New reactor certifications, AP1000 and ESBWR, and existing reactor fuel

[23] This observation depends only on the heating of the water in the Unit 4 pool; it is independent of the source of hydrogen that caused the Unit 4 explosion.
[24] National Research Council, *Safety and Security of Commercial Spent Fuel Storage: Public Report*. Washington, D.C.: National Academies Press, 2006, at http://www.nap.edu/catalog.php?record_id=11263.
[25] Unlike U.S. nuclear power plants, Fukushima has a common spent fuel pool that is much larger than the others (about 2.7 times in volume compared to the pools of Units 2, 3, 4, or 5). (David Wright, "More on Spent Fuel Pools at Fukushima," *All Things Nuclear*, March 21, 2011, at http://allthingsnuclear.org/post/4008511524/more-on-spent-fuel-pools-at-fukushima.). Also only older spent fuel is stored in the common pool, rather than a mix of relatively new and older spent fuel typical of reactor spent fuel pools. The common pool did not release any radioactivity, so far as we know. U.S. reactors generally do not have common spent fuel pools meant exclusively for older spent fuel.

The Task Force report recommends rapid completion of the certification rulemaking of the AP1000, the only reactor design on track to be built at present, and the ESBWR:

> The Task Force notes that the two design certifications currently in the rulemaking process (i.e., the AP1000 and the economic simplified boiling-water reactor (ESBWR)) have passive safety systems. By nature of their passive designs and inherent 72-hour coping capability for core, containment, and spent fuel pool cooling with no operator action required, the ESBWR and AP1000 designs have many of the design features and attributes necessary to address the Task Force recommendations. The Task Force supports completing those design certification rulemaking activities without delay. However, COL [construction/operating license] applicants referencing these designs would have to address prestaging of any needed equipment for beyond 72 hours…to confirm effective implementation of minimum and extended coping, as described in detailed recommendation 4.1. [pp. 71-72]

The Task Force's recognition that the 72-hour passive cooling is not enough in light of Fukushima is sound; but it is at odds with its support of completion of certification rulemaking "without delay." In view of the fact the Task Force report's emergency preparedness section acknowledges that prearranged equipment may not be able to be delivered to the site, surely a second look at the entire design of emergency cooling and emergency power supply is warranted. Moreover, the passive cooling feature necessarily involves a pool of water above the reactor. Given the immense weight and the mobility of the water under ground-shaking produced by an earthquake and the reconsideration of seismic risks around the country, a second look at the entire emergency cooling system is warranted. In addition, the ESBWR has a buffer spent fuel pool in roughly the same elevation relative to the reactor as the Mark I design reactors. The potential for destruction of the spent fuel handling infrastructure in this design also needs to be addressed in light of Fukushima.

The Fukushima accident also indicates the need to carefully examine all instrumentation and emergency water supply systems for spent fuel pools.

Finally, Fukushima and TMI showed the zircaloy fuel rods are at the center of the vulnerabilities of light water reactors, since hydrogen is created by the reaction of zirconium with steam after loss of cooling. There is ample reason to consider redesign of the fuel rod material.

Recommendation 12: Fundamental aspects of the safety systems of the AP1000 and the ESBWR, notably their passive emergency cooling systems, instrumentation and emergency cooling water and power systems for spent fuel pools, and, in the case of the ESBWR, the location of the buffer spent fuel pool, need to be reexamined with explicit lessons learned from Fukushima. As the Task Force notes, some of those lessons will not be clear for some time. For instance, the source of the hydrogen that caused the explosion in Unit 4 was not clear to the Task Force. Certification decisions for these reactors should be deferred until the analysis and lessons of Fukushima, such as definitive answers to the Unit 4 explosion as well as to spent fuel handling at Fukushima Units 1, 3, and 4 are forthcoming.

Recommendation 13: The NRC should commence a process by which to consider and evaluate alternatives to zircaloy fuel rods so as to increase safety and decrease the risk of meltdowns and hydrogen explosions.

H. Some final notes on the liabilities of nuclear power

Under the Price Anderson Act, Congress has limited the liability of the whole nuclear industry to about $12 billion per accident. Yet, according to a 1997 Brookhaven National Laboratory study done for the NRC,[26] the worst-case spent-fuel-pool accident in a densely populated area would result in about 140,000 excess cancer deaths and $540 billion in damages (roughly $700 billion in 2010 dollars. The U.S. government has promised to assume the rest of the liability, though there is no practical legislative provision for it. Large budgetary deficits are expected to persist for some time. It is far from given that the federal government will make people and their property whole (to the extent that it can be done at all). In light of this, should not the states have the right to require higher insurance limits? Would not the rate of mortgage failures increase in the event of an accident? And what of the bondholders who have invested in nuclear power?

Financial questions have been raised in Japan without any clear answers so far. The sums involved will be immense. The numbers of people involved in densely populated areas in the United States could be up to ten times as large as Fukushima (as noted above).

The Task Force has already recommended a number of rule changes, and there are additional ones described above. But this is very inadequate to the magnitude of the questions facing the country regarding continued operation of nuclear power plants and the conditions under which they should operate. While the former question is a policy issue beyond the purview of the NRC, the latter is squarely within it. The immense safety, liability, decommissioning, and property and public health protection questions that have been revealed by Fukushima cannot sustain business as usual. New and urgent questions have arisen. For instance, given the functional failure of venting at Fukushima, should Mark I reactors be relicensed before new hardened vents are designed and tested? Should reactors be relicensed without consideration of costs attendant on new safety measures and regulations. How can a fair comparison with the alternatives be made if that is done? Would such relicensing comply with the National Environmental Policy Act (NEPA) now that it is probable that safety-related changes will be required?

Rulemaking is going to take some time. Actual design and estimate of costs of changes will take even longer. Some very specific and bold actions are needed now to protect the public from excessive risk and expenditure.

Recommendation 14: Fukushima has been by far the most major event to affect the world of light water commercial reactors. It will take time to understand the safety implications. For example, the cause of the hydrogen explosion in Unit 4 was not clear to the Task Force. Given the magnitude of the technical, safety, and regulatory issues confronting existing and new

[26] R.J. Travis, R.E. Davis, E.J. Grove, M.A. Azarm, *A Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants,* BNL-NUREG-52498 and NUREG/CR-6451, Brookhaven National Laboratory, 1997, link on the Web at http://www.osti.gov/bridge/product.biblio.jsp?osti_id=510336.

reactors, decisions regarding the relicensing of the former and the licensing of the latter should be suspended until the analysis of the causes and consequences of the Fukushima accident is reasonably complete and the feasibility of actions needed for safety has been established.

Recommendation 15: The NRC is required to consider alternatives to nuclear power when it reviews license applications. A critical and important recommendation, is that the many and varied costs of Fukushima should be factored into the comparison between power sources. Until there is a clear picture of the costs that will be incurred in implementing the lessons of Fukushima and from the reviews that that necessitates, decisions about relicensing of existing reactors and licensing of new reactors should be suspended. The actual suspension of decisions should be until the later of the times implicit in Recommendation 14 or Recommendation 15.