EXHIBIT 4

NUCLEAR SYSTEMS ENHANCED PERFORMANCE PROGRAM

Technical Lessons Learned from the Fukushima-Daichii Accident and Possible Corrective Actions for the Nuclear Industry:

An Initial Evaluation

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Table of Contents

Premise

The accident at the Fukushima-Daichii nuclear plant has generated worldwide news and precipitated public concern about the safety of nuclear power in general. The accident has already caused some governments to re-think their nuclear energy policies, notably including the Japanese and German governments. There have been calls for cancellation of nuclear construction projects and reassessments of plant license extensions. This may lead to a global slow-down of the nuclear enterprise, based on the perception that nuclear energy is not safe enough. However, the lessons to be drawn from the Fukushima accident are different.

First, the accident was a result of the worst earthquake and tsunami in Japan's modern history, an event which has caused the loss of over 20,000 lives and up to $300 billion in damages. Second, given the extraordinary magnitude of the initiating events (i.e. earthquake was 9.0 vs design 8.2, tsunami wave was 14 m vs design 5.7 m), the Fukushima-Daichii plant has performed relatively well in some respects and so far there is no evidence of major human errors in handling the crisis. It is noted that the containments at Units 1-3 have not massively failed, in spite of the exceptional loads they have been subject to, i.e. earthquake, tsunami, hydrogen explosions in the reactor buildings, steam discharges from the reactor pressure vessel, exposure to hot seawater, pressure above design limits for days. The release of radioactivity from the plant has been large (with contributions also from containment venting) and some workers have received significant radiation doses (>100 mSv whole-body equivalent), but health risks for them and the general population are expected to be negligible (see Appendix A). In fact, no loss of life has occurred or is expected as a result of the accident. Direct damage and casualties inflicted on Japan by the earthquake and tsunami far exceed any damage caused by the accident at the nuclear plant. The Fukushima accident has been rated at the maximum level (Level 7) on the IAEA nuclear event scale, indicating an accident with large release of radioactivity accompanied by "widespread health and environmental effects", like Chernobyl. However, there are very significant differences between Fukushima and Chernobyl. Briefly, the amount of the release (~10% of Chernobyl), the presence of the containment structures, the radionuclides released (mostly iodine and cesium isotopes vs. the entire core inventory), the physical form of the releases (mostly aqueous vs. volatile), the favorable currents and winds at the site, and the timing of the release with respect to population evacuation resulted in vastly smaller overall consequences. Having said this, it is important to analyze the technical lessons that can be learned from Fukushima, so that the safety of nuclear plants in the U.S. and worldwide can be further enhanced and the attractiveness of nuclear energy sustained over the long term. An initial attempt to identify the key lessons from the Fukushima accident is presented here.

Objectives of the report

This report presents the reflections of members of the MIT Nuclear Science and Engineering faculty on the accident at Fukushima, and is offered as a contribution to the debate on the implications of the accident for the nuclear industry. Our purpose is twofold: we identify and discuss technical issues arising from the accident; and we begin a review of how the lessons learned can be used to improve the safety of current and future plants. The information is organized in six sections: "Emergency Power following Beyond-Design-Basis External Events", "Emergency Response to Beyond-Design-Basis External Events", "Containment", "Hydrogen Management", "Spent Fuel Pools", "Plant Siting and Site Layout". For each area, we present key issues observed at Fukushima and corrective actions that should be evaluated for implementation in current and future plants.

Note of Caution

- The technical feasibility and economic impact of the corrective actions discussed in this report have not yet been fully evaluated; they should therefore not be regarded as recommendations, but rather as ideas to be explored.
- Not all the information needed for a detailed reconstruction and analysis of the accident is yet available. The need for and merit of the corrective actions described in this document should be re-assessed as more accurate and complete information about the accident becomes available.
- The need for and merit of corrective actions should be evaluated on a plant- and site-specific basis. For example, it is noted that some U.S. plants already have water-proof rooms for flooding protection of the diesel generators and related equipment; therefore, the discussion in Section 1 below would not be very relevant to those plants.

1. Emergency Power following Beyond-Design-Basis External Events

Observations from Fukushima:

- The loss of offsite power (due to the earthquake) and onsite AC power (due to the tsunami), combined with the rapid discharge of the DC batteries led to a complete station blackout. The station blackout disabled the Emergency Core Cooling System (ECCS), made it difficult to monitor critical parameters (e.g. reactor water level) and open critical safety valves (e.g. safety/relief valves, isolation condenser return valves, containment vent valves), which in turn led to fuel and containment overheating and damage

Key question:

How can the station blackout scenario be either prevented or sufficiently mitigated to ensure minimal consequences?

Possible corrective actions for current plants:

- At least one diesel generator, its fuel, and related switch gear could be housed in a room at sufficiently high elevation and/or in a water-proof room to preserve onsite AC power in case of tsunamis or floods. Note, however, that seismically-induced stresses increase with elevation. Interestingly, due to the concern over typhoons and storm surges, all of the emergency power generation capacity at Korean plants is currently located in water-proof enclosures, including fuel supplies.

- Utilities and/or FEMA could maintain transportable diesel generators or gas-turbine generators (i.e. jet engines) that would be rapidly brought to the site (e.g. by air, road or water) to restore AC power.

Possible design improvements in future plants:

- A mix of passive and active safety systems may be desirable to defeat the station blackout scenario without relying on external intervention. The right mix should be determined through analysis including risk assessment, taking into account also the possible failure modes of the passive systems upon occurrence of the initiating external event. A key question here is: should a mix of passive and active safety systems actually be required in new plants?

2. Emergency Response to Beyond-Design-Basis External Events

Observations from Fukushima:

- There were concerns that TEPCO could not ensure proper staffing of the plant throughout the accident, if a significant fraction of the local staff had been killed or injured by the earthquake and tsunami.

- The U.S. NRC called for a much larger evacuation zone for U.S. citizens around the Fukushima plant ("This is the same advice that the NRC would give if this incident were taking place in the United States, to evacuate beyond a 50-mile radius," NRC Chairman Jaczko, March 17, 2011). While precautionary, this call did not seem consistent with the magnitude of the radioactivity releases; it undermined the Japanese regulator's credibility, and created anxiety and confusion in the media, local population and general public.

- Communication of radiation levels to the public was made difficult by three factors: the use of three different scientific quantities (dose, dose equivalence and activity), the use of two systems of units (SI units used worldwide and the older units still in use in the U.S.), and a lack of context for understanding the meaning of these radiation levels.

Key questions:

How can proper staffing be assured if a significant fraction of local staff are unable to reach the plant due to the initiating external event? How can the extension of the required evacuation zone be determined when great direct damage is inflicted on the area surrounding the plant by the initiating external event? What is the best method to communicate radiation risk to the public in a simple and effective manner?

Possible corrective actions at current and future plants:

- A rapid-response team of essential workers could be transported to a stricken plant for scenarios in which the plant owner/operator cannot staff the plant properly. In the U.S., training and operating costs for this rapid-response team could be borne by INPO and/or consortia of utilities with similar plants, and also assisted by the Air Force for rapid deployment to the site. The U.S. Federal Aviation Agency (FAA) has a system that may serve as one model. In countries with a smaller nuclear fleet, the rapid-response team may even be international.

- Over-conservative evacuation zones (e.g. >20 miles) should not be implemented in case of accidents initiated by natural catastrophes (e.g. earthquake, tsunami, hurricane) that have already affected the local population significantly. Large evacuations divert resources away from the much greater disaster and may create undue stress on the population trying to cope with the direct consequences of the initiating event. Assessment of the tradeoff benefits between sheltering and evacuation needs re-emphasis. Evacuation strategies should be based on minimizing risk to the public from all causes. Extension of evacuation zones should become a function of both radioactive releases as well as direct damage inflicted on local area by the initiating event.

- Regulators could demand more on-site personnel to have independent and timely sources of information, and the ability to influence the owner/operator behavior during the accident.

- Radiation levels during nuclear accidents should be communicated to the public using a qualitative, intuitive scale vs. the traditional quantities of dose and activity. For example, the units of 'natural background dose equivalence rate' could be adopted. To avoid the necessity of adjusting for local background variations, the world average dose-rate from natural sources should be used: 2.4 mSv/year or 0.27 μSv/hr. If contaminated food and drink are interdicted or otherwise avoided, the impact of living in an environment contaminated with ^{137}Cs or ^{131}I is an increase in the external gamma-ray component of natural background. However, this component normally contributes only 20% to an individual's total natural background radiation dose. Therefore, expressing elevated external gamma-ray doses in multiples of the natural external gamma-ray component leads to an overestimate of the perceived level of impact in the minds of the public who are likely unaware of the full range of natural radiation sources to which they are exposed. Thus the elevated levels due to contamination should be presented in terms of the factor by which total natural background radiation is exceeded. This approach has several advantages. First, no effort is needed to understand the unit used. For instance, 10 times natural background is easier to grasp than 2.7 μSv/hr since no prior learning in a specialized field is required. Second, there is never a need to convert between unit systems or to be mindful of numerical prefixes (milli-rem, micro-Sv, etc.). Third, this method of conveying information about radiation levels reinforces the concept that some level of radiation exposure is both natural and normal. Fourth, given the very significant influence that the *rate* of dose delivery has on the biological impact of a given total dose, a quantitative comparison of the low dose-rate radiation from a contaminated environment with the low dose-rate radiation received from natural background is more scientifically valid than a comparison with the rapidly-delivered radiation doses from medical imaging which are received in only a few seconds. Finally, use of this unit implies no estimation of the magnitude of the health hazard from the radiation levels. This is important since, although we know that natural background levels vary around the world, with some people receiving doses factors of several greater than the world average with no adverse effects, we do not know at what dose-rate human health would be negatively affected.

3. Hydrogen Management

Observations from Fukushima:

- Deficient fuel cooling resulted in overheating of the fuel, enabling rapid oxidation and generation of large amounts of hydrogen, which ultimately led to the explosion/destruction of the reactor buildings at Units 1 and 3. It appears that hydrogen leaked into the reactor buildings from the containment vessel head when the pressure in the containment rose significantly. Timely hydrogen venting through the stack was prevented by inoperability of the provided AC-powered valves which had to be accessed and opened manually

Key question:

How can hydrogen generation and accumulation be reduced?

Possible corrective actions at current and future plants:

- Venting of pressure vessels should be via strong pipes connected to the stack (this is currently a U.S. practice, but it is not clear if it is followed in all other countries). Critical venting valves should be designed to be accessible and operable also when AC/DC power is not available.

- Plants should have the air atmosphere in the pool areas more directly connected to the plant stacks. Also, fail-open (on power loss) louvers in the buildings could be used.

- More hydrogen recombiners (passive) and igniters (active) could be considered for small releases in the upper regions of a building, where hydrogen may accumulate. Also, catalytic recombiners could be used in the ventilation system and inside the containment where it is not already done now.

- Hydrogen flares for massive venting of containment gases could be explored.

- Use of materials that generate hydrogen upon oxidation with steam could be reduced or eliminated, e.g., replace Zircaloy cladding with less reactive metals, and ultimately a ceramic, such as SiC.

4. Containment

Observations from Fukushima:

- Due to the station blackout, the operators had to vent (vs cool) the containment to prevent containment over-pressurization. Moreover, containment venting was delayed by AC-powered valves which had to be opened manually. As a result, some gases leaked into the reactor building, which had no ventilation (again due to the station blackout), resulting in hydrogen accumulation and ultimately explosion/destruction of the reactor buildings at Units 1 and 3.

Key question:

How can the need for containment venting be eliminated? If containment venting is necessary, how to ensure it is done in a timely and reliable fashion, so that radioactivity releases are minimized?

Possible corrective actions at current plants:

- When containment cooling is not available, the containment should be vented directly to the stack via valves that can be opened in a timely fashion, with some kind of backup power

(AC or DC) or manually. A catalytic recombining system that automatically activates upon loss of power could also be explored.

Possible future improvements:

- Use of passive containment cooling could eliminate the need for venting as a means to reduce containment pressure, when AC power is not available.
- Use of the filtered/vented containment concept (French-Swedish examples) could provide a balanced approach to controlling containment pressure and radioactivity releases to the atmosphere when containment cooling is not available. Early containment venting can reduce the source term for severe accidents by as much as two orders of magnitude.

5. Spent Fuel Pools

Observations from Fukushima:

- Elevated location of the spent fuel pools exposed them to damage from hydrogen explosions in the reactor buildings at Units 1, 3 and possibly 4.
- Disablement of spent fuel pool cooling and the possibility of earthquake-induced damage to the pools were the cause of great concern, which spurred one-week-long unconventional cooling efforts with helicopters and water cannons. While it was later established that the fuel assemblies in the pools remained underwater throughout the accident, the Fukushima experience does underscore the importance of reliable long-term cooling and protection of the spent fuel pools at nuclear plants.

Key questions:

How can the spent fuel pools be better protected from external events? How can reliable cooling of the spent fuel be ensured in case of station blackout? How can the source term of the spent fuel pools be reduced?

Possible corrective actions at current plants:

- Current spent fuel pools could be retrofitted with a passive cooling system that can survive the initiating external event.
- The policy on full core unloading into the pools during refueling shutdowns and spent fuel pool packing may have to be reviewed.
- Spent fuel assemblies could be moved to dry storage as quickly as possible. Could re-design dry casks with a "top hat" chimney to enhance air cooling for the hotter fuel assemblies. However, (i) one must ensure that casks so refitted do not tip over due to an earthquake or hurricane/typhoon, (ii) if the casks are breached, radioactivity release is un-mitigated (unlike in pools where water provides some scrubbing effect), (iii) the decay heat in pools is dominated by recently-discharged fuel, so moving the older fuel to dry casks may

not have that significant an impact on pool heat-up time in the event of an accident. These uncertainties make it unclear whether accelerated dry storage is actually preferable to other options, such as on-site spent fuel pools or centralized interim storage.

Possible future improvements:

- Spent fuel pools could be housed in containment-like structures separate from the reactor building. Note that some PWR plants have spent fuel pools inside the actual containment.

- Regional or national consolidated spent fuel interim storage facilities could be built. This would reduce the spent fuel inventory at the plant, which in turn would reduce the source term in case of spent fuel pool accidents. Interestingly, Japan has recently completed a reprocessing plant at Rokkasho and in 10-15 years it is likely that all their spent fuel will be shipped there rather than stay at reactor sites for long periods of time.

- A national spent fuel repository could be created. The large inventories of spent fuel in U.S. reactor pools are a consequence of delays of the U.S. repository program that was to have initiated spent fuel removal from reactor sites by 1998. The U.S. has an operating geological repository for plutonium wastes generated from defense activities near Carlsbad, New Mexico, because of a broad national consensus that such a repository was required. A similar consensus is required for a second repository for spent nuclear fuel.

6. Plant Siting and Site Layout

Observations from Fukushima:

- Due to this site's compact layout, problems at one unit created negative safety-related situations at adjacent units. For example, the hydrogen explosion at Unit 3 disabled some fire pumps used for seawater injection at Unit 2. Also, it has been suggested that the fire/explosion at Unit 4 was caused by leakage of hydrogen released from Unit 3 through shared duct-work with Unit 4. Units 5 and 6, which are far from Units 1-4, were unaffected by the hydrogen explosions at Units 1 and 3.

- A single external event (the tsunami) disabled all 13 diesel generators at the station simultaneously.

- The Fukushima-Daini and Onagawa plants, both in the vicinity of Fukushima-Daichii, survived the earthquake and tsunami without major damage.

Key question:

How can common cause failure and unit-to-unit contagion be prevented?

Possible corrective actions at current plants:

- Layout diversity and separation at multi-unit sites could be enhanced. For example, at least one diesel generator room could be placed sufficiently above grade (for protection against tsunamis), and one below grade (for protection against plane crashes). Also, in future plants the administrative buildings and parking lots could be located between units to enhance physical separation between those units.

Possible future improvements:

- An obvious approach for future plants would be to choose sites away from highly seismic areas and coasts, to greatly reduce (and perhaps eliminate) the possibility of damage due to massive earthquakes, tsunamis and floods. It is noted that people tend to congregate near coasts and faults (river valleys); therefore, there are strong synergies between minimizing the probability of an adverse external event and maximizing the distance from densely populated areas. The vast majority of nuclear plants worldwide are already located away from highly seismic areas (see Figure 1). Notable exceptions are the plants in Japan, Taiwan and California; however, the larger seismic challenge (i.e. higher expected ground motions) in these regions is currently overcome by a more stringent seismic design of the plants located in these regions. The strategic question here is: should there be a requirement to avoid identified vulnerabilities or should plants be allowed to design against them?

- The number of allowable units at a single plant site could be determined based on an analysis which accounts for the following, often conflicting, factors: (i) reduction of common cause vulnerabilities, (ii) availability of staff and resources to address a severe accident impacting all units simultaneously, (iii) reduction of potential source terms, (iv) high standardization (shared learning), (v) shared equipment (with implications on both economics and safety), and (vi) low environmental impact of multi-unit cooling.

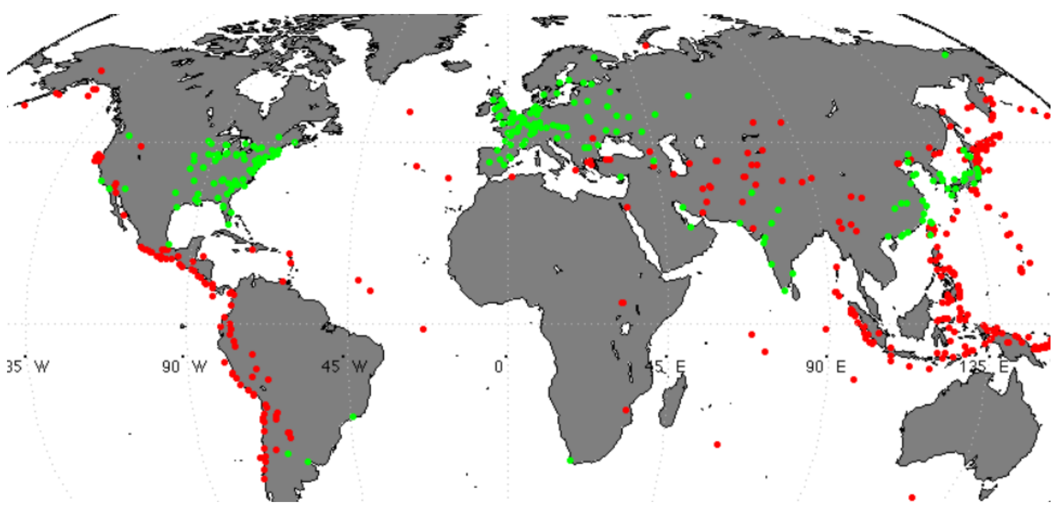

Figure 1. Location of current and planned commercial nuclear power plants (green dots) and all earthquakes of magnitude ≥7.0 from 1973 to 2010 (red dots). (Figure courtesy of MIT graduate student Mark Reed)

A few closing thoughts

The initial response of the nuclear industry and the U.S government to the Fukushima accident has been measured and rational (see Appendix B). However, the risk of over-reacting to an accident, particularly one as dramatic as Fukushima, remains high. The industry is concerned about the near-term effect of Fukushima on the process of life extension of current plants and the support for new construction projects. Under the pressure of the public and the media, the government may be compelled to push for sweeping policy and regulatory changes, which may ultimately prove to be unnecessarily onerous on existing and future plants. Decision-making in the immediate aftermath of a major crisis is often overly influenced by emotion. Therefore, the following questions should be addressed after searching for vulnerabilities at existing plants, but before enacting significant changes in nuclear energy regulations and policy. Does an accident like Fukushima, which is so far beyond design basis, really warrant a major overhaul of current nuclear safety regulations and practices? The answer is country-dependent; for example, the design-basis selection process for tsunamis in Japan will likely require some significant changes, in particular regarding the use of historical tsunami "data" in estimating the risk of future large tsunamis. However, the critical question is: how, in the design-basis selection process, do we establish when safe is safe enough? Where do we draw the line? It seems that a rational approach to this question would ultimately need to be based on a risk-informed comparison of nuclear energy with other energy sources (particularly its most credible competitors, such as coal and natural gas), including their effects on climate change, global economy, stability and reliability of the energy supply, and geo-politics. But can the decision makers take a risk-informed approach to energy policy?

When it comes to safety, it is important to bear in mind that all engineered structures (e.g. power plants, bridges, skyscrapers, dams, highways) will fail if subjected to loads far enough beyond what they were designed for. Are the design basis selections of energy industry structures posing high environmental hazard, such as oil drilling platforms offshore, coal mines and water dams, consistent with those of nuclear plants? If not, are we as a society irrationally accepting higher risks from certain technologies than others?

APPENDIX A – PUBLIC HEALTH IMPACT OF FUKUSHIMA

Radionuclides of Concern

While there are many radionuclides that can be released at the time of a reactor accident, not all have the potential to impact public health because of issues related to: abundance, decay scheme, half-life, and chemistry (which ultimately affects route into the body, anatomical area of concentration, and residence time). Noble gases such as krypton and xenon rapidly disperse in the atmosphere; heavy elements are non-volatile so, if released outside the containment, tend to stay at the plant or in the near vicinity. The isotopes of particular concern are ^{131}I and ^{137}Cs. Both decay by a combination of beta and gamma emission, which means they can represent both an internal and an external hazard. They are released in relatively high abundance and their half-lives (8 days and 30 years, respectively) are sufficiently long that they do not decay before being widely distributed in the local environment, yet are sufficiently short that enough nuclei will decay to result in significant and measureable doses in the time scales important to human life.

Measured external gamma dose-rates following the tsunami and subsequent damage to the cooling systems at the Daiichi nuclear power plants spiked on March 15 and 16 and thereafter gradually declined. The rate of decline is a result of the combined effects of environmental dispersion and physical decay with a mix of the short half-life ^{131}I and the much longer half-life ^{137}Cs. Nine weeks after the emission spike the effective half-life of the measured gamma dose-rate was approximately 70 days. The effective half-life continues to increase but will always be smaller than the physical half-life of ^{137}Cs due to effects of weathering and further distribution in the environment. Peak gamma dose rates at different geographical locations depended on both distance from the damaged plant and on wind and rain patterns. Iodine and Cs reach the ground via dry deposition but deposition is hastened by rainfall which can lead to local areas of high activity. Wet and dry deposition onto crops and subsequent human ingestion, or ingestion by cattle followed by consumption of contaminated milk, is the most common route into the body. Radioiodine was of most concern in the immediate aftermath of the accident both from an external dose perspective and because of the potential for induction of thyroid cancer, particularly in children (internal dose). Drinking water restrictions based on ^{131}I levels were in place for a number of days, particularly for infants for whom a maximum level of 100 Bq/L was recommended[1].

It is ^{137}Cs that represents the most significant long-term hazard of a contaminated environment. Chemically it behaves like potassium which is found in all of our cells, so it is readily taken up and used if available. Like iodine it will settle out of the radioactive cloud onto fields and crops.

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[1] In the U.S., risks from inhaling or ingesting radioactive isotopes are tabulated in the EPA's "Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report No. 13 (EPA 402-R-99-001)" published in 1999. The risk coefficient for fatal cancer from ^{131}I is 1.85 x 10^{-10} per Bq. Using this number and assuming lifelong consumption of 1.2 kg of food contaminated at a level of 100 Bq/kg we calculate a risk of: 1.85 x 10^{-10} /Bq x 1.2 kg/d x 2.75 x 10^{4} d x 100 Bq/kg = 0.00061. This risk is tiny compared to the 'natural' risk of fatal cancer (~0.2) and very small compared to other risks encountered on a daily basis. It is also a very conservative estimate of the risk since ^{131}I has substantially decayed and lifetime consumption of food at this contamination level will not occur. For these reasons an activity level of 100 Bq/L is considered safe for infants.[It is important to note that this estimate of risk for ^{131}I is not based on actual data for ^{131}I-exposure and cancer death; rather it is based on a scientific model of risk as a function of dose (the linear, no-threshold model) whose validity at low doses and especially at low dose-rates has not been demonstrated.]

Since it binds tightly to moist soil it is not readily taken up via the root structures of plants however it can enter plants upon falling onto the surface of leaves. Elevated levels of ^{137}Cs in several foodstuffs required restrictions on consumption and prompted a number of countries to limit imports from Japan for some time. All drinking water interdictions were lifted in early May however several foodstuffs still showed radiation levels that exceed regulation values set by Japanese authorities.

Radiation Doses

Attempts are ongoing to keep the cumulative radiation doses to the Japanese public below 20 mSv in the first year following the reactor accident. [Doses will be substantially lower in subsequent years due to environmental dispersion and physical decay of residual ^{137}Cs.] This effort involves (i) monitoring radioactivity levels in foodstuffs and water and prohibiting sale and consumption where necessary , (ii) recommending sheltering indoors in areas where cumulative dose-rates over one year are expected to be > 10 mSv, and (iii) relocation of residents from within a 20 km radius zone around the plant. 70,000-80,000 residents were relocated in the first month after the accident but relocations are continuing in areas where residents are predicted to receive doses in excess of 20 mSv in the first 12 month period.

Doses to people living further from the Daiichi plant are much lower. In Tokyo, 240 miles away, residents can expect an additional cumulative radiation dose of 1 mSv from the first year, a 40 % addition to the 2.4 mSv they already receive from natural sources. As of the first week of May, external gamma-dose rates in Tokyo are 0.09 µSv/hr, a factor of almost two above natural gamma dose-rate levels (0.05 µSv/hr). Since external gamma dose contributes ~ 20% to the total background dose (the remaining dose components are cosmic rays, internal radionuclides, and radon daughters), this increase in gamma ray exposure added 16% to the daily radiation dose to Tokyo residents.

Health Implications

The impact of low doses of radiation on our health is assumed to be an increase in the probability of being diagnosed with cancer. No other natural disease shows a significant elevation following exposure to low dose radiation and no unusual or unique diseases are created. Radiation-induced cancers have a latent-period of 20-30 years (shorter for leukemia) and tend to appear at the same time in irradiated as in unirradiated populations. Since the cancers induced by radiation are the same types of cancers observed 'naturally', determining the number of *additional* cancers caused by a small dose of radiation when baseline cancer rates are already high has not been possible for doses in the 20 mSv range (or even higher).

Although no data have ever demonstrated that 20 mSv over 1 year results in measureable harm, this dose range has long been relevant to the occupational radiation protection field and thus there has been a need to generate radiation risk estimates, even in the absence of actual data. These estimates come primarily from the long-term evaluation of the A-bomb survivor population and are a result of adopting a hypothetical model of extrapolating the risk per unit dose at high dose levels down to the low dose range. While some models incorporate a threshold dose below which no radiation-induced cancers will be diagnosed and others predict health benefits rather than health detriment from small doses delivered over time (eg. factors of several times natural background doses) the model adopted for use in occupational radiation protection is a simple linear model that assumes the risk of harm per unit dose is the same at all doses. Use of this extrapolation model in the generating of risk estimates incorporates a number of assumptions appropriate to radiation protection in the workplace but not appropriate to determining the hazards of an environment contaminated with a long-lived radionuclide. Accordingly, scientific bodies evaluating risk often specifically caution *against* extending these strategies to predicting the long term effects of small doses to a large population. Unfortunately, more applicable risk estimates do not exist and so this caution is routinely ignored when the potential impact of low doses is of interest.

The linear extrapolation model has long been viewed as a conservative approach to estimating radiation risk at low doses and, in particular, for low doses accumulated over long periods of time. It can be used, however, to generate an upper estimate of the risk posed by the radiation doses encountered from a contaminated environment. Using the linear extrapolation model, the U.S. National Academies of Sciences' BEIR VII committee estimates that 1 cancer could result if 100 people received a single dose of 0.1 Sv (a risk of 0.01/0.1 Sv), with lower doses resulting in proportionally lower risk. Thus, a dose of 20 mSv (if delivered acutely) x 0.1 per 0.1 Sv = 0.002. In other words, the 20 mSv dose ceiling pursued by the Japanese authorities represents a 0.2 % chance of being diagnosed with cancer later in life, in addition to a 42 % risk an individual already faces from 'natural' causes. This estimate is expected to be high by a factor of 2-10 and possibly more, according to NCRP 64, to account for the reduced impact of protracted radiation delivery, relative to the same dose received all at once.

20 mSv over the course of a year represents a factor of 8 times the average natural radiation background level. It is the equivalent to 2-3 abdominal CT exams for a lean individual, or equivalent to one CT exam for someone who is overweight. However 20 mSv received over the course of one year is expected to have significantly less biological impact than the same dose received via medical imaging since the dose is protracted over time.

The Cost of Dose Avoidance

Permanent and long-term relocation can reduce exposure to radiation to essentially zero levels above natural background. What is gained is the elimination of any possibility of the tiny additional risk of cancer (maximum risk of 42.2 % instead of 42.0 % at 20 mSv) predicted by the linear extrapolation model. This cancer, if it appears, will be diagnosed many years, perhaps decades, in the future. But this gain comes with very significant costs. The costs include loss of home or farm (48,000 homes and over 400 livestock or dairy-farming households are in the evacuation region), loss of privacy (shelters are crowded and residence time is expected to be measured in months before alternative temporary housing will be available), and loss of community (whole towns and villages have been evacuated). Prohibition against consuming contaminated food and water results in no additional internal dose but, for a country already facing food shortages following a devastating earthquake and tsunami, the loss of valuable foodstuffs and interdiction of farmlands are a significant price to pay.

The costs of dose avoidance are high. A clearer understanding of the actual risks represented by, say 20 mSv, would help residents and government officials engage in a productive dialogue regarding how to make the tradeoff between dose avoidance and loss of important aspects of daily life (home, food, and community). It is also critical that the public gain a wider understanding of the bases on which our radiation risk estimates are derived. The inherent protection of radiation workers built into our estimates of radiation risk have been effective in ensuring that employers keep dose to their workers very low, and thereby the need to actually know the hazard from radiation levels that are 5, 10, or even 50 times background has been avoided. However, this approach is not useful in the situation of a contaminated background where conservative estimates of risk force residents to make significant sacrifices to avoid all dose.

It is also important that residents understand the manner in which protection limits are based on risk estimates. For instance, a limit imposed on employers to restrict exposure of the general public does not correspond to a declaration that doses below this limit are safe but above this limit are not. Concerns have been raised regarding elevated dose-rates at schools in Fukushima prefecture, almost 170 of which have been forced to relocate or close. Raising the maximum allowed annual radiation limit from 1 mSv to 20 mSv in schools led to a significant uproar and prompted one government advisor to resign in protest. Governmental ministers defended the increase from 1 mSv to 20 mSv/year as a necessary measure to guarantee the education of tens of thousands of children in Fukushima prefecture. However many members of the public viewed this step as regulators changing their mind regarding what levels are safe, rather than seeing the situation as a choice between two undesirable situations. Given that the environment *has* been contaminated, the choice to residents of Fukushima prefecture involves accepting the possible 0.2% additional chance of getting cancer in 20-30 years, or delaying the resumption of normal schooling (and a normal life) for an extended period of time.

In the United States the EPA recommends implementation of a return home dose rate that would lead to a maximum dose of 20 mSv in the first year following a reactor accident; many states have adopted this recommendation. This is the same level that has prompted such emotional response from frightened members of the public and even from advisors to the government during the on-going crisis in Japan. Once an accident has taken place and the environment is contaminated, we need to be equipped with the most accurate estimates possible of harm from living with elevated background radiation levels. These can then be weighed against the benefits and drawbacks of dose avoidance strategies. We are not there yet.

APPENDIX B - RESPONSE OF THE U.S. NRC AND NUCLEAR INDUSTRY TO THE FUKUSHIMA ACCIDENT

The U.S. NRC and nuclear industry responded to the accident in Japan, focusing mostly on the issues discussed in this document. In particular:

- In the immediate wake of the accident, the NRC established a task force to do a 90-day review of lessons learned from Fukushima, including prominently the issues of protection against natural disasters, response to station blackouts, severe accidents and spent fuel accident progression. On the issue of station blackout, it is noted that, per the NRC rule of 1988, U.S. plants must determine the coping time, i.e. the time the plant can survive without AC power. Typical coping times at U.S. plants are currently between 4 and 12 hours, determined by the battery capacity. This establishes the time window within which either AC power must be restored or new batteries brought to the site. The adequacy of the current coping times is being reviewed.

- U.S. nuclear utilities approved an industry-wide assessment, to be completed within 30 days under the leadership of INPO, to verify and validate each plant site's readiness to manage extreme events. The assessment includes the following actions:

  - Verifying each plant's capability to manage major challenges, such as aircraft impacts and losses of large areas of the plant due to natural events, fires or explosions. Specific actions include testing and inspecting equipment required to mitigate these events, and verifying that qualifications of operators and support staff required to implement them are current.
  - Verifying each plants capability to manage a total loss of off-site power. This will require verification that all required materials are adequate and properly staged and that procedures are in place, and focusing operator training on these extreme events.
  - Verifying the capability to mitigate flooding and the impact of floods on systems inside and outside the plant. Specific actions include verifying required materials and equipment are properly located to protect them from flood.
  - Performing walk-downs and inspection of important equipment needed to respond successfully to extreme events like fires and flood. This work will include analysis to identify any potential that equipment functions could be lost during seismic events appropriate for the site, and development of strategies to mitigate any potential vulnerabilities.

- TVA owns the Browns Ferry plant with three BWR units featuring Mark-1 type containments, similar to the Fukushima-Daichii plant design. TVA stated that the plants already have explosion-resistant pipes to vent hydrogen from the containment, fire-hoses pre-placed to fill spent fuel pools in case of loss of cooling, and hardened diesel rooms, including 7-day supply of fuel, behind water-tight doors. The diesel switchgear is located within the reactor building, and thus is protected from flooding. Also, as a result of Fukushima, TVA bought diesel-driven fire pumps. Most U.S. plants also have battery carts located throughout the reactor building to provide power for critical valves and instruments, should AC power be lost for a few hours (i.e. their coping time, as defined above).

Finally, we note that right after the Fukushima accident operators of nuclear power stations in Japan were urged by the Japanese government to ensure their facilities have back-up emergency power sources. The government told utility companies they should have *mobile* generators on hand to cool their nuclear reactors as an added safety measure. The utilities have been asked to confirm the steps they have taken and conduct drills within a month or stop operating their nuclear facilities.