# Fukushima and Emergency Planning

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# Fukushima and Emergency Planning, Executive Summary

## Executive Summary

One of the major lessons to be learned from the Fukushima accident is the need to minimize overall public risks from nuclear incidents by modernizing emergency planning in the United States. This modernization should take place on an accelerated basis.

This report discusses emergency responses during the first few days after the start of a nuclear accident. Other emergency responses, such as the protection of food stuffs, are not included in this report.

In 1992 the Environmental Protection Agency (EPA) issued guidelines[1] on responding to nuclear incidents. A fundamental principle of emergency planning was laid out in this EPA report on page 1-1: “The decision to advise members of the public to take an action to protect themselves from radiation from a nuclear incident involves a complex judgement in which the risk avoided by the protective action must be weighed against the risks involved in taking the action.”

The need to balance the risks from exposure to radiation against the risks of taking a protective action to reduce radiation exposure appears to have been forgotten, with dire consequences at Fukushima. There were zero early fatalities at Fukushima due to radiation based on measurements and analyses[2] performed by the World Health Organization (WHO), yet over 1,100 excess deaths at Fukushima are attributed to over-evacuation[3] and long term sheltering. Further, this basic EPA principle to strike a balance between competing risks to achieve the lowest overall risk, also seems to be forgotten in the United States.

This report pulls together a number of source term and emergency planning studies that were made before and after the Fukushima accident and demonstrates that the WHO finding of no early fatalities is consistent with earlier severe accident consequence predictions and the consequences of actual nuclear power plant accidents.

1. “Manual of Protective Action Guides and Protective Actions for Nuclear Incidents”, Office of Radiation Programs, Environmental Protection Agency, Second Printing, May, 1992
2. “Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami based on a preliminary dose estimation”.World Health Organization, February, 2013
3. “Commentary on Fukushima and Beneficial Effects of Low Radiation’ Dr. Jerry M. Cuttler, Canadian Nuclear Society Bulletin 34(1):27-32 (2013)

With zero or near zero early fatalities the expected result from severe nuclear accidents, in order to achieve a much smaller overall risk, efforts must be made now to reduce the non-radiological risks associated with taking protective actions, especially the risks attributed to over-evacuation.

Finally, a generic emergency response to nuclear incidents, both accidents and willful acts of terrorism and for both reactor core and spent fuel pool incidents, is suggested. This generic response takes into account near term and long term health effects from exposure to radiation. This modern approach to emergency planning appears to strike a much better balance between radiological and non-radiological emergency response risks.

Implementation of this generic emergency response is consistent with the NRC's purpose to minimize the health risks of the public from nuclear power plants, even including those risks that arise out of fear rather than facts.

**Fukushima and Emergency Planning**

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# Main Report

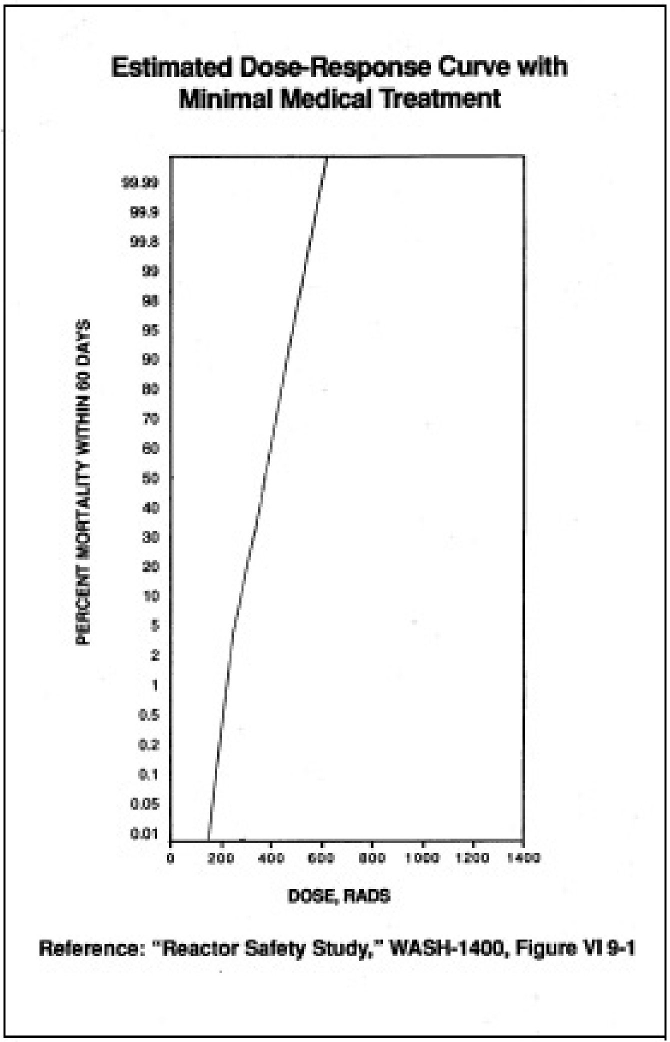
## 1.0 Source Term Studies

### 1.1 Basics

Offsite health consequences due to the release of radioactive material into the environment are often divided into near term and long term effects. The most important near term health effect would be acute (or early) fatalities, i.e., fatalities that might occur within 60 days of exposure to radiation. Of lesser health significance are a variety of near term effects from exposure to radiation that may cause early injuries. Both early fatalities and early injuries due to exposure to radiation have threshold values. Radiation exposures below these thresholds should not lead to these early health effects. The probability of causing an early fatality decreases rapidly with decreasing exposure[1]. As shown in Figure 1, at a whole body exposure of 400 rads there is about a 70% chance of causing a fatality within 60 days, assuming minimal medical treatment. However, if the whole body exposure was half as much, 200 rads, the chance of becoming a fatality within 60 days, assuming minimal medical treatment, decreases to about 0.3%. A two fold decrease in exposure, in this example, decreases the chances of becoming an early fatality by about a factor of 250.

1. "Estimated Dose-Response Curve with Minimal Medical Treatment", Reactor Safety Study, WASH - 1400, Figure VI 9-1

### Figure 1: Estimated Dose-Response Curve




Normal atmospheric diffusion processes generally cause plumes, including radioactive plumes, to spread out as they move away from the point of release. Because the plume becomes less concentrated as it moves away from a damaged nuclear power plant, individual exposures also decrease with distance and the chances of becoming an early fatality decreases rapidly with distance. As a result of normal human biological responses to exposure to radiation and because natural physical processes like diffusion cause radioactive plumes to become less concentrated with increasing distance from the point of release, the range of the early fatality risk is inherently short, less than two miles in almost all situations.

Evacuating areas near the point of release would decrease individual early health risks for people living near a damaged nuclear power plant. Further, there are additional ways to reduce exposures to radiation from a nuclear incident. A major consideration is the amount of radioactive material, particularly Iodine- 131, that enters the environment during a nuclear incident. The smaller the amount of radioactive iodine that enters the environment, the shorter the range of the early fatality risk. If the release of Iodine-131 is small enough, the range of the early fatality risk will shrink to zero. This means that the number of early fatalities would be expected to be at or near zero even if no evacuation took place. Another consideration is the time between the initiation of a core melt accident and the time when radioactive material first enters the environment. Longer time differences between accident initiation and the time when radioactive material enters the environment also decreases radiological early health effects. This is because people who live or work close to a nuclear power plant would have more time to take protective actions, like evacuating beyond the innermost two miles. Finally, if the radioactive releases enter the environment gradually, this too would decrease calculated early health consequences as there would be less exposure to evacuating people leaving the inner two miles.

The history of source term technology for US light water reactor designs reveals that calculated source terms are smaller, more delayed in entering the environment, and evolve more slowly than thought before. Because of all three of these factors, the justification for massive evacuations, such as evacuating the whole ten mile Emergency Planning Zone (EPZ) has decreased considerably over the years. With the additional information that has come out on the non-radiological health effects of offsite responses to the Fukushima accident, it has become clear that massive evacuations must be avoided. With many nuclear power plants in operation, the need to modernize their emergency plans on an accelerated basis has become imperative.

People understandably are also concerned about long term health effects from a release of radioactive material into the environment. Long term health effects have two components: (1) health effects due to exposure during the time that the radioactive plume exists, and (2) exposure to radiation should people occupy or reoccupy land/ buildings that were in the plume pathway and may have long half life radioisotopes like Cesium -137 deposited on them. Such occupation of contaminated areas would only occur if radiation levels were kept below strict occupation limits. In this report on emergency planning emphasis is placed on minimizing early health effects and the contribution to long term health effects as discussed in (1), above. Issues like re-occupation of exposed property, protecting food and water supplies and compensating people for their economic losses are important, but are not part of the emergency response issues discussed here.

This report concentrates on Iodine -131 and Cesium-137 as the most important isotopes in determining the health effects from nuclear incidents. Tellurium has a lesser role and is dealt with in Section 1.4.

### 1.2 Fukushima source terms and release times

Table 1, below, includes information supplied by Sandia National Laboratories[2] on the initial inventories of Iodine-131 and Cesium -137 in the three reactor cores at Fukushima that experienced core damage. Table 1 also includes analyses and measurements conducted by Kobayashi[3], et al, on the quantities of Iodine-131 and Cesium -137 released from the three damaged Fukushima plants. Sandia also provided the time between the reactor scram caused by the initial magnitude 9 earthquake and the beginning of releases of iodine and cesium to the atmosphere for each of these three nuclear power plants. Table 2 lists, for I-131 and Cs-137, the fraction of the total initial inventory from Units One, Two, and Three at Fukushima that was estimated to be released to the environment. As can be seen in Table 2, only a small fraction of the initial inventories of I-131 and Cs-137 were released to the environment, the rest was trapped inside of these plants or at the site.

2. Personal communication from Dr. R. O.Gauntt, Sandia National Laboratory
3. "Source term estimation of atmospheric release due to the Fukushima Dai-ichi Nuclear Power Plant accident by atmospheric and oceanic dispersion simulations", Takuya Kobayashi, et al, Journal of Nuclear Science and Technology, Volume 50, Issue 3, 2013

**Table 1: Fukushima Megacuries Iodine-131 and Cesium-137**

| | Unit One, Initial Inventory (Sandia) | Unit Two, Initial Inventory (Sandia) | Unit Three, Initial Inventory (Sandia) | Total inventory of all three units | Released from the three plants (Kobayashi) |
|---|---|---|---|---|---|
| Iodine -131 | 36.72 | 62.95 | 63.45 | 163.12 | 5.4 |
| Cesium-137 | 5.53 | 6.88 | 6.45 | 18.86 | 0.35 |
| Time of release to environment after scram, hours | ~13 | ~70-80 | ~42 | N/A | N/A |

**Table 2: Fraction of the three unit initial inventory released to the environment**

| | |
|---|---|
| Iodine-131 | 5.4/163.12 = 0.033 |
| Cesium -137 | 0.35/18.86 = 0.019 |

## 1.3 SOARCA analysis of the Peach Bottom plant

In 2007 the NRC initiated the State-of-the -Art- Consequence-Analysis (SOARCA) project to develop best estimates of the offsite radiological health consequences for potential severe reactor accidents for two pilot plants: the Peach Bottom Atomic Power[4] Station in Pennsylvania and the Surry Power station in Virginia.

The Peach Bottom analysis is particularly relevant to the Fukushima accident. Peach Bottom is generally representative of U.S. operating reactors using the General Electric boiling- water reactor (BWR) with a Mark-I containment, which is similar to plants that were damaged at Fukushima. Further, a number of the accident

4. "State-of-the-Art- Reactor- Consequence- Analyses Project, Volume 1: Peach Bottom Integrated Analysis" NUREG/CR-7110 Volume 1, January, 2012

scenarios examined with the MELCOR computer code in the SOARCA effort were station blackout scenarios, the same class of scenarios that occurred at Fukushima. These scenarios all sometimes referred to as unmitigated accident scenarios in that many of the engineered safety systems become inoperable because of the loss of both offsite electric power and onsite emergency diesel generators (EDGs).

Figures 2 and 3, below, are reproduced from NUREG/CR- 7110, Volume 1 and show iodine releases and cesium releases to the environment, respectively, for unmitigated accident scenarios. These figures show strikingly smaller releases of iodine and cesium compared to the 1982 Sandia Siting Study's [NUREG/CR-2239] SST-1 source term. Not only are the SOARCA's MELCOR calculated source terms much smaller, the times of their releases to the environment are much later. The 1982 Sandia Siting Study's SST-1 source term utilized an iodine release of 45 percent and a cesium release of 67 percent of the core inventory. The 1982 Sandia Siting Study's SST-1 source term was assumed to enter the environment after just 1.5 hours after reactor scram. As seen in these figures, SOARCA's MELCOR analyses calculate a much later entry of radioactive material into the environment, eight hours for the most rapid of the SOARCA Peach Bottom analyses. This later entry of radioactive material into the environment would provide more time for offsite people to take protective actions and for plant operators to attempt plant recovery actions that might prevent a release of radioactive material into the environment. The SOARCA analyses of the Peach Bottom plant show essentially a zero early fatality risk, according to NUREG/CR- 7110, Volume 1.

In addition to Figures 2 and 3, NUREG/CR-7110,Volume 1 provides a detailed comparison of MELCOR calculated source terms for unmitigated scenarios from the Peach Bottom plant to the SST-1 source term used in the Sandia Siting Study. This comparison is reproduced in Table 3, below, including the times at which the radioactive material is calculated to start to enter the environment and when such releases end, relative to the time when reactor scram would occur [at t = 0].

**Table 3: Comparison of Peach Bottom source terms to SST-1**

| Events per year | Xe | Cs | Ba | I | Te | Ru | Mo | Ce | La | Start (hr) | End (hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.978 | .005 | .006 | .020 | .022 | .000 | .001 | .000 | .000 | 20 | 48 |
| B | 0.979 | .004 | .007 | .013 | .015 | .000 | .001 | .000 | .000 | 16.9 | 48 |
| C | 0.947 | .017 | .095 | .115 | .104 | .000 | .002 | .007 | .000 | 8.1 | 48 |
| SST-1 | 1.000 | .670 | .070 | .450 | .640 | .050 | .050 | .009 | .009 | 1.5 | 3.5 |

Event A is a long term station blackout scenario at Peach Bottom which has a mean frequency of 3 $(10)^{-6}$ per year.

Event B is a short term station blackout with RCIC (Reactor Core Isolation Cooling) with black start capability scenario at Peach Bottom which has a mean frequency of $3(10)^{-7}$ per year.

Event C is a short term station blackout without RCIC black start capability scenario at Peach Bottom with a mean frequency of $3(10)^{-7}$ per year.

With the recent introduction of FLEX equipment and procedures, the frequency of events A, B, and C should be even smaller than those calculated in NUREG/CR-7110,Volume 1.

A comparison of the Fukushima to the data in Table 3 show similarities that are important to emergency planning. Both the measured releases at Fukushima and the calculated releases from the MELCOR analyses of Peach Bottom show long time periods between the reactor scram and radioactive releases to the environment. As stated before, this provides more time to take offsite protective actions. Both Fukushima and the Peach Bottom analysis had release times much longer than those assumed in the Sandia Siting study. Iodine and cesium releases for Peach Bottom events A, B, and C in Table 3 for and the Fukushima accident in Tables 1 and 2 are far smaller than the SST-1 source term and are in the few percent of the initial core inventory range. Iodine and cesium releases in the few percent range are unlikely to cause offsite early health effects.

**Figure 2: Iodine releases to the environment**

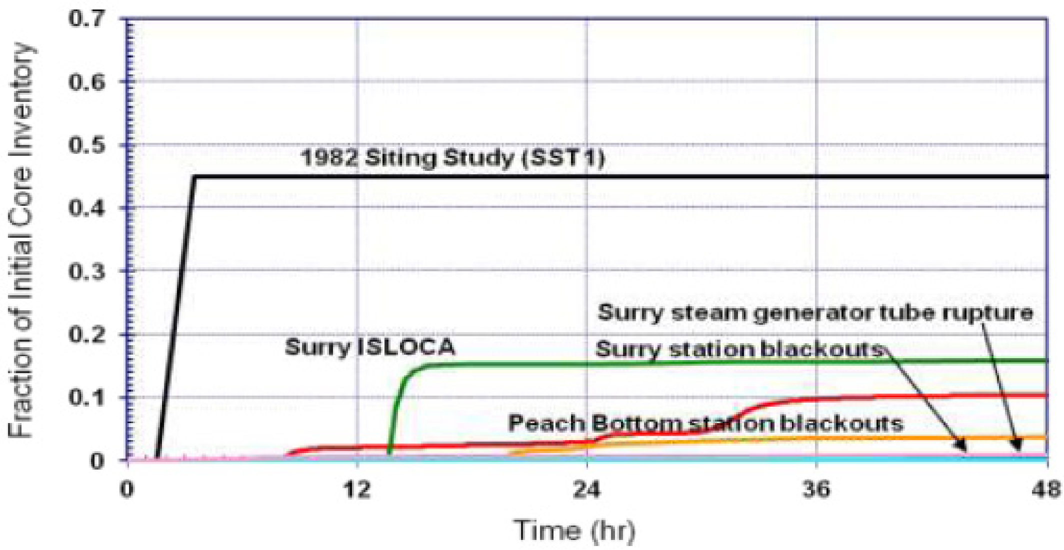
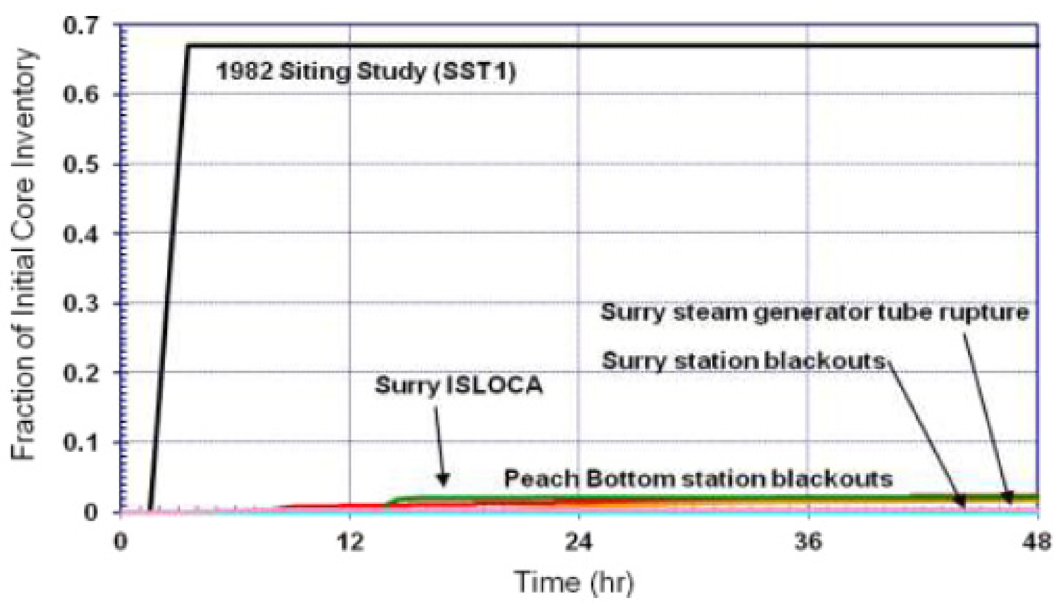


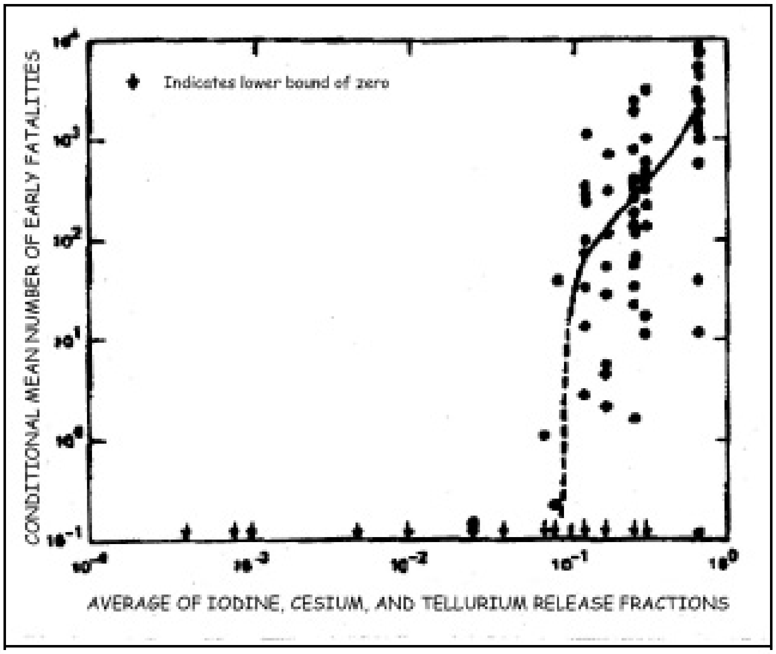

**Figure 3: Cesium releases to the environment**



### 1.4 Sensitivity of early fatalities to the source term

A number of years ago a sensitivity study was performed by Kaiser[5] who examined the relationship between the size of the source and the conditional mean number of early fatalities. The MACCS code was used and an evacuation speed of 10 miles per hour was assumed. Kaiser's results are provided in Figure 4, below.

**Figure 4: Sensitivity of early fatalities to source term**




Kaiser plotted the conditional mean number of early fatalities versus the average of the iodine, cesium, and tellurium release fractions for a single nuclear power plant. In Table 2 an estimate of the Iodine- 131 and Cesium -137 release fractions, averaged over Fukushima Units One, Two, and Three were given as 0.033 and 0.019, respectively. In order to estimate the tellurium release for Fukushima, use is made of the data in Table 3. There the ratio of the tellurium to iodine release fraction for Event A was 0.022/0.020 = 1.1. Using this 1.1 factor, the estimated average tellurium release from the three damaged plants at Fukushima is about 0.036 of the initial core inventory. Averaging the iodine, cesium, and tellurium release fractions,

5. "Implications of Reduced Source Terms for Ex-Plant Consequences Modeling and Emergency Planning", G.D. Kaiser, Nuclear Safety, Volume 27, No.3, July-September, 1986

one gets 0.029. Based on Kaiser's sensitivity study, zero or near zero early fatalities would be expected for such a limited release of radioactive material, if this averaged release fraction came from a single nuclear power plant. However there were three nuclear power plants that released radioactive material into the environment. It is assumed that this multi-unit release can be approximated by considering this as an accident at a single nuclear plant whose average release fraction of its I-131, Cs-137, and Tellurium was 3(0.029) = 0.087. Even if a single power plant had an average release fraction of 0.087 this would still place the number of early fatalities at or near zero according to Kaiser.

### 1.5 The Indian Point terrorist attack emergency planning study

The two active Indian Point nuclear power stations located in Buchanan, New York are in the nation's most populated site with about 366,000 people within the ten mile Emergency Planning Zone. As such, they represent an extreme challenge to emergency planning since vehicular evacuations would, in most cases, be quite slow. These nuclear power plants were also along the pathway taken by one of the airplanes that struck the World Trade Center in the terrorist attack of September 11, 2001. Because of this, a special emergency planning analysis[6] was made to examine the consequences a hypothetical successful terrorist attack on one of these nuclear power plants.

This hypothetical successful terrorist attack at Indian Point represented a situation that would be much more serious than the Fukushima accident. The nearby population at Indian Point is larger than that at Fukushima and the source terms used in the Indian Point analysis are significantly larger and are assumed to enter the environment much more rapidly.

In the Indian Point hypothetical terrorist study it was assumed that the attack created a 3 square foot hole in the containment. Larger holes would not have caused larger radioactive releases to the environment. Two core melt sequences, a loss-of-coolant incident and a station blackout incident, were analyzed. Each sequence was assumed to be initiated in just one half hour after the containment was assumed to be breached.

6. "Enhanced Emergency Planning", RBR Consultants, Inc., December, 2007 [Already submitted to the NAS Committee on Lessons Learned From the Fukushima Accident.

The Indian Point study's calculated source terms were both larger and released earlier than the SOARCA analysis of the Surry Plant, a pressurized water reactor similar to Indian Point. Source term comparisons for both BWRs and PWRs for actual accidents and hypothetical studies are compiled in Table 4, below.

In addition to the conservative assumptions that a terrorist attack was attempted and succeeded in spite of all the security measures in place at Indian Point, and that it only took one half hour after a large hole was created in the containment to initiate a core melt incident, several other highly conservative assumptions were made:

(1) There was vehicular evacuation of 100% of the peak population in the ten mile Emergency Planning Zone and 35% of the population out to neighboring interstate highways. This is a group larger than 360,000 people and this evacuation process was assumed to not get underway for an hour after the containment was breached. No credit was given for people evacuating on foot which would have reduced the vehicular traffic. No credit was given to alerting the public to start to evacuate prior to the breach of the containment.

(2) Peak populations were assumed.The peak population was calculated to be at midweek, midday conditions. Evacuations beyond the nearest interstate highways beyond the EPZ have no significant effect on overall evacuation speeds. The assumption of evacuating this very large population leads to the slowest evacuation speeds and the largest number of calculated early health effects.

(3)Weather conditions were very unfavorable. The weather condition that was chosen was the 95% weather condition. This means that 95% of the time other weather conditions would result in lower calculated consequences.

In spite of the above string of conservative assumptions, the number of calculated offsite early fatalities from an assumed successful terrorist attack at Indian Point **was limited to 5 persons, all within one mile of the power plant.** Almost any other set of circumstances, would likely reduce the calculated number of early fatalities **to zero**.

**Table 4: Comparisons of source terms**

| Event | Cs | I | Te | Start of release after scram (hr) | End of release (hr) |
|---|---|---|---|---|---|
| Peach Bottom, long term SBO [SOARCA]-BWR | .005 | .020 | .022 | 20 | 48 |
| Peach Bottom, short term SBO, with RCIC black start | .004 | .013 | .015 | 16.9 | 48 |
| Peach Bottom, short term SBO, without RCIC black start | .017 | .115 | .104 | 8.1 | 48 |
| Fukushima-BWR | .019 | .033 | ~.036 | 13-80 | N/A |
| Surry, long term SBO, [SOARCA]-PWR | .000 | .003 | .006 | 45.3 | 72.0 |
| Surry, short term SBO, | .001 | .006 | .005 | 25.5 | 48.0 |
| Surry, with thermally induced steam generator tube rupture | .004 | .009 | .007 | 3.6 | 48 |
| Surry, ISLOCA | .020 | .154 | .132 | 12.8 | 48 |
| Indian Point, loss of coolant, assumed terrorist attack-PWR | .101 | .111 | .121 | 2.0 | 15 |
| Indian Point, SBO | .180 | .274 | .182 | 4.4 | 18.0 |

Such a limited number of calculated number of early fatalities may seem counterintuitive, especially since the site specific traffic analysis confirmed that vehicular traffic speeds would be very slow. However, what separates this emergency planning analysis from others is joining of a detailed treatment of the traffic flow away from the assumed stricken plant with MACCS2 analyses that replicate this traffic flow by using both radial and tangential evacuation pathways. Most consequence analyses using the MACCS2 computer code rely on a very simple evacuation model where people are assumed to travel at a constant speed radially away from the point of release. However, the plumes that emanate from a damaged plant are also represented by a radial type of motion, but where changing wind directions are accounted for. This means that there are times when the radial motion of the evacuees and the location of the radially moving plume coincide. When weather conditions create a very narrow plume the concentration of the radionuclides in the plume are maximized. Almost all of the MACCS2 calculated early health effects come from a situation where a highly concentrated narrow radially moving plume is assumed to coincide with a radially evacuating group of people.

However, in real life, people around Indian Point could not evacuate using their cars along a radial pathway because the road system would not permit this. Much of the actual road system near the Indian Point power plants is similar to a rectangular grid array. Evacuees in this in-close area would be turning left and right as dictated by the actual road system. This means that evacuees would be crossing perpendicular to the plume some of the time. When plumes are at their most concentrated they are most narrow and closest to the stricken power plant. Because the plumes are so narrow, the time to cross through them is short, a matter of a few minutes even at very slow evacuation speeds, and therefore the exposure to radiation is limited. Wider plumes, which would occur under different weather conditions or further from the point of release, take longer to cross through, but they are not as concentrated.The Indian Point emergency planning analysis was based on a very detailed, street by street, traffic analysis which is described in the report referenced in footnote 9. The MACCS2 analysis of Indian Point did not use the traditional constant velocity radial model for evacuation but rather used a series of radial and tangential segments that matched the actual road system and used the calculated traffic speeds for each of these segments. The exposures of the evacuees were calculated for each segment that passed through the radioactive plume and all such exposures were added together and converted to health effects. This process was repeated over many weather scenarios and a time distribution, based on actual experience at previous evacuations, of when people start to evacuate was represented in these analyses by a series of cohorts of people starting their evacuations at different times.

A comparison was made between the much more precise evacuation analysis in this Indian Point study to the simple, radially only, single velocity, one group type of evacuation normally used in MACCS2 consequence analyses. One of the Indian Point loss-of-coolant terrorist attack scenarios that was studied was used in this comparison. Although the Indian Point terrorist caused loss-of-coolant source term is smaller than the Indian Point terrorist caused SBO source, it is calculated to cause more health effects because it would enter the environment sooner, thereby affecting more people earlier in their evacuation. See Table 5, below.

**Table 5: Importance of a more precise evacuation analysis**

| Weather condition | Simple MACCS2 Radial Evacuation | | Precise Traffic Analysis Based Evacuation | |
|---|---|---|---|---|
| | Early Injuries | Early Fatalities | Early Injuries | Early Fatalities |
| Mean | 43 | 17 | - | - |
| Worst 90% | 171 | 69 | - | - |
| Worst 95% | 221 | 124 | 33 | 2 |

The overall conclusion of the Indian Point analyses was that even for very large and early releases of radioactive material into the environment and very slow evacuations, the calculated number of early health effects are quite limited for Indian Point because evacuees would naturally be taking pathways that limit their exposures. As pointed out before, even small reductions in the exposure level greatly reduce the probability of becoming an early fatality. This Indian Point study also implies that the analyses by Kaiser (See section 1.4) are conservative in that the simpler MACCS2 radial evacuation model was used.

## 1.6 The Chernobyl and Three Mile Island Accidents

Some 31 early fatalities are attributed to the Chernobyl accident. However, these fatalities did not occur among the general public but were limited to emergency workers who went on site and others in a helicopter that flew through an intense radioactive plume that arose from the explosion and graphite fire at Chernobyl. The plume from the Chernobyl accident apparently rose vertically from the damaged plant to significant heights because of the heat from the rapid power excursion experienced by the damaged reactor core and the burning graphite. It has been stated, but the author has not been able to reconfirm, that members of the public near Chernobyl did not immediately evacuate or take other protective actions and that high radiation readings were not measured in the immediate vicinity of the stricken plant. The explanation offered for this is that the highly buoyant plume carried the released radioactive material away from the public. This would have to be reconfirmed.

The possibility of significant plume heating could be a consideration in estimating the radiological effects of hypothetical terrorist attacks, such as through strikes on containment buildings by large aircraft. Burning the onboard airplane fuel might be sufficient to cause a vertical plume, as was the case when the World Trade Center was hit by large airplanes. The greater the lofting of a radioactive plume, the smaller the offsite radiological early health effects.

The Three Mile Island accident did not release significant amounts of radioactive material to the environment in spite of significant core damage. This can be attributed to an intact containment building. Nuclear accidents are unlikely and those that could lead to releases of radioactive material into the environment are quite unlikely. The fact that the majority of possible nuclear accidents would not lead to a significant release of radioactive material into the environment should be a consideration when developing an emergency plan that has a goal to balance radiological risks and non-radiological risks. This thought is implemented in Section 2 of this report where a staged evacuation is recommended, rather than ordering all evacuees to start to leave at the same time. If a nuclear accident is brought under control before the second stage of evacuation would be ordered, this would reduce the non-radiological risks of evacuation.

### 1.7 Further insights

The ten events listed in Table 4 could be expanded to include the Three Mile Island (TMI) accident and the Chernobyl accident. These two accidents are effectively opposites. In the TMI accident the containment maintained its integrity and the releases of radioactive material to the environment were extremely small. The Chernobyl accident, the world's worse nuclear accident, did not have a containment building but rather used a low pressure capability confinement building. The physics design of the Chernobyl reactor led to a power excursion. As cooling water was lost the power level in this reactor increased by a factor of about 100 in just 4 seconds, based on UN reports. Because of this power excursion and the very limited pressure retaining capability of the confinement building, the source term from the Chernobyl accident was very large.

It may be possible to rank the TMI and Chernobyl accidents and the ten entries in Table 4 according to a figure of merit, delta T where delta T is the time difference between reactor scram and the time radioactive material first enters the environment. For TMI, delta T is infinite since effectively no radioactive material entered the environment. For Chernobyl, delta T is essentially zero. The ten entries in Table 4 those sequences may also lend themselves to a delta T ranking. Those scenarios that had large holes in the containment boundary, such as the hypothetical Indian Point terrorist attack with a 3 square foot hole in the containment and only an assumed half hour between containment breach and the start of a core melt accident and the Surry Containment bypass accident (ISLOCA), would have comparatively small delta T figures of merit. Those accident sequences which had small leakages from the containment that would occur long after reactor scram would have larger delta T figures of merit. The Fukushima accident would be a member of this group.

Using this delta T concept in terms of ranking how serious an accident sequence is, the following approximate ranking was obtained, where the least serious is TMI and Chernobyl is the most serious:

1.TMI

2.Surry, long term SBO

3.Surry, short term SBO

4. Peach Bottom, long term SBO

5. Peach Bottom with RCIC black start

6. Fukushima

7.Peach Bottom without RCIC black start

8. Surry, with thermally induced steam generator tube rupture

9. Surry, ISLOCA

10. Indian Point, loss of coolant

11. Indian Point, SBO

12. Chernobyl

Note that even though the rankings listed above cover a very wide range of conditions, none of thee events have or would have led to offsite early fatalities.

### 1.8 Conclusions

Section one of this report examined the source terms for a wide range of accidents and analyses for both BWRs and PWRs. From an offsite radiological health consequence point of view, using the source terms summarized in Table 4, none of these events would lead to early fatalities either because the source terms were too small or the radioactive releases were so delayed that in-close evacuation (innermost two miles) would have resulted in people being located beyond the range of the early fatality risk at the time at which the release into the environment began, or both.

This conclusion is consistent with the findings of the World Health Organization's (WHO) examination of the Fukushima accident: "Some health effects of radiation, termed deterministic effects, are known to occur only after certain radiation dose levels are exceeded. The radiation dose levels in Fukushima prefecture were well below such levels and therefore such effects are not expected to occur in the general population."

With regard to radiological health effects other than early fatalities or early injuries WHO concluded "The health risk assessment concludes that no discernible increase in health risks from the Fukushima event is expected outside Japan. With respect to Japan, this assessment estimates that the lifetime risk for some cancers may be somewhat elevated above the baseline rates in certain age and sex groups that were in the areas most affected."

Further thought has been given to circumstances even more extreme than the scenarios presented earlier in this report. One possibility that was examined in the Indian Point study was a situation where vehicular evacuation was not possible, along with the source terms used in the Indian Point analysis as described in Table 4. Vehicular evacuation might not be possible if there were some extreme natural event that also severely damaged the nuclear plant. However, even this may not result in significant radiologically caused health effects if people within two miles of a damaged plant can evacuate on foot. Further, any extreme natural event that prevented evacuations near a damaged plant might also have, itself, caused many early fatalities and injuries so that the radiological increment, if any, might be very small. Another possibility is that the same terrorist event that is hypothesized to breach the containment and quickly start a core melt sequence would also directly imperil the public near the power plant, preventing a safe evacuation. If that were the case, people could take shelter until security forces ended the terrorist threat. Extended sheltering, combined with large source terms, are predicted to have early radiological health consequences that exceed the near zero levels associated with evacuations, even very slow ones. Substituting sheltering for evacuation in the two mile region closest to the Indian Point site was analyzed and results are provided in the referenced report. Such an unusual scenario is not an emergency planning scenario as much as it is a plant security issue.

Lastly, the Indian Point plants have the largest number of people within two miles of the site. Most other sites have a much smaller in-close population. As such, they are already pre-evacuated.

## 2.0 A Generic Emergency Plan

The goal of a generic emergency plan for nuclear power plant sites is to strike a better balance between radiological and non-radiological risks so that the overall risk to the public is minimized.

A combination of three protective actions is recommended: a staged evacuation, downwind sheltering, and selective relocations.

With regard to evacuation, it is recommended that the innermost one mile around a nuclear power plant be evacuated if conditions at the site reach the General Emergency level. Declaration of a General Emergency should be vested in the Site Manager. This limited evacuation is to start before any reactor damage might have occurred. Simultaneously, the public and all levels of government associated with dealing with such an event would be alerted that a General Emergency had been declared. At Indian Point the one mile population is 4,402 people, about 1.2 percent of the whole EPZ population.

There likely would be many hours between the declaration of the General Emergency and any release of radioactive material into the environment. Based on the information in Table 4 it is suggested that further evacuations not be ordered until about another four hours have elapsed and if plant conditions continued to deteriorate. If a second evacuation is ordered, it would be limited to a radius of about two miles from the site. At Indian Point about 15,623 people live in the one to two mile ring around the plant.Some emergency plans use ERPAs, Emergency Response Protection Areas, whose shapes are often influenced by geographic, school districts, political boundaries and the like. When this is the case, those ERPAs that approximate a two mile radius area would be used for the second and final evacuation process.The emergency plan would identify these ERPAs.

Pre-evacuations not only reduce the possibility of an early health effect, they also reduce exposures to radiation that might lead to long term health effects. If evacuation was ordered for the innermost two miles around Indian Point some 4, 402 +15, 623 = 20,025 people would be evacuated. This represents about 5.4% of the EPZ population.

Downwind sheltering would be ordered if there was an actual release of radioactive material. Since wind shifts are frequent, downwind sheltering should not be ordered too soon because the wind may be blowing in a different direction when the radioactive release begins and because sheltering can be implemented quickly. As the wind direction changes the public would be made aware of this and additional areas may be ordered to take shelter if a release is underway. Those areas already in a sheltered protective mode would remain that way, even if wind directions changed, until they were advised otherwise. The order to shelter in place would extend from the inner two miles to the edge of the Emergency Planning Zone (EPZ) and should be broadcast on television to the public, if such a communication system is operable during this event.

The third protective action is selected relocations. Emergency workers would look for “hot spots” in the downwind areas. If it is discovered that there might be “hot spots” beyond the EPZ, they should be looked for and the public should be so advised if any are found. Once at a “hot spot” emergency responders should alert the sheltered people there to relocate to a predesignated sheltering facility. The ordering of such relocations would depend on local radiation level measurements and determinations made by the emergency responder on the shielding capability of the structure near where “hot spot” radiation levels have been detected.

As part of creating such an emergency plan, a relocation criterion would have to be developed and uniformly used by all emergency responders. An example of such a criterion might be that locally measured radiation levels near where people are taking shelter would, over the next 24 hours, likely exceed some rather familiar dose people get in medical procedures. For example, a Cranial CT, multiple scan average dose, is about 50 mSv [50 miliSieverts]. If the emergency responder estimated that sheltered people might exceed this level during the next 24 hours, he/she should direct these sheltered people to relocate to a public sheltering facility. The NRC should establish a projected dose relocation criterion for emergency responders to advise sheltered people in “hot spot” locations.

This generic emergency plan concentrates on those members of the public who are most at risk if there is a nuclear incident. By concentrating on those who are most at risk, excess evacuations should be avoided. In the case of Indian Point implementing such a plan should eliminate all early health effects and reduce exposures to radiation that might lead to long term effects.Yet, these low radiological consequences could be accomplished without having to evacuate more than about 6% of the EPZ population. Such evacuations would take place over many hours and should be orderly. It is believed that this simple plan strikes the right balance between radiological and non-radiological risks. Further, this same generic emergency plan would be applicable to incidents involving the spent fuel pools.

## 3.0 A Task for the Nuclear Regulatory Commission

The over-evacuation at Fukushima is another example of the fear of radiation has a much larger health effect than the radiation itself. This is not a new issue. It has been reported that numerous abortions were performed on women in the wake of the Chernobyl accident because they incorrectly feared that their unborn had been harmed by this accident. At Fukushima some evacuated people refuse to return to their homes in spite of assurances by the Government that it would be safe to do so.

Implementation of the Generic Emergency Response Plan described in Section 2 may be somewhat helpful in reducing such fears. First, far fewer people would be ordered to evacuate. Those people who evacuated on their own without being ordered to do so by a governing body, may be more comfortable in returning to their homes when low dose rates are reported.

Use of the relocate from “hot spots” protective action, as described above, may put some people more at ease.This “hot spot” relocation process is not limited to the EPZ but would be implemented wherever dose rate levels and the type of construction people are taking shelter in. This may bring comfort to some people who live beyond the ten mile EPZ. Some citizens have expressed deep concerns that present ten mile EPZ emergency plans leave them out because they live beyond the ten mile radius of the EPZ.

Local governments may be supportive of the Generic Emergency Response Plan because it would reduce the costs of providing shelter to much larger numbers of evacuees. It would also reduce the costs for transporting evacuees who do not own a vehicle.

The bulk of the population in the EPZ would be free to move around prior to the release of radioactive material into the environment. For some, this would permit them to gather up their children at nearby schools. It would also ease the issue of parents who work outside the EPZ and have a home inside the EPZ. In such cases many could regroup with their families prior to taking shelter, if they are downwind from a plant that is releasing radioactive material into the environment.

There are several messages the NRC needs to communicate to the public and their government officials about severe nuclear accidents and there are several messages that the NRC needs to stop conveying. Among the messages the NRC has to communicate to the public are that severe nuclear accidents are far “weaker” than thought before, that almost always there are many hours between the start of a severe accident and the time when radioactive material might enter the environment, and that the best overall response to a severe nuclear accident is to limit evacuation to the innermost two miles, with downwind sheltering and selective relocations, even beyond the EPZ, if necessary. The public needs to hear that severe accidents can happen, but they are very rare and that only a small fraction of these severe accidents go on to produce a release of radioactive material to the environment.

The messages that the NRC will want to stop are those that imply that evacuation of the whole EPZ is an acceptable response to an actual or a potential severe accident. It is suggested that the NRC stop calling for periodic Evacuation Time Estimates that are modeled after a full EPZ evacuation. Evacuation Time Estimates should concentrate on the time to evacuate the innermost two miles, assuming a staged evacuation. Periodic emergency drills should test the Generic Emergency Plan, not some full EPZ massive evacuation scenario. Finally, some senior NRC Officials refer to the EPZ as the Evacuation Protective Zone, whereas EPZ is an acronym for Emergency Protective Zone.

The NRC's role is to protect the public from undue risks associated with nuclear energy. Taking actions to inform the public and their elected officials about how small the health risks from nuclear power plants are and how modernized emergency plans would be both simpler and more protective, is consistent with the purpose of this regulatory body.