Become a Nuclear Safety Expert

Rev. 2

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ABOUT THE AUTHOR

Herschel Specter, President of Micro-Utilities, Inc., holds a BS in Applied Mathematics from the Polytechnic Institute of Brooklyn and a MS from MIT in Nuclear Engineering. He is a Licensed Professional Engineer in the State of New York. He has had a long association with the Indian Point nuclear power plants starting as a member of the Atomic Energy Commission (now the Nuclear Regulatory Commission) where he was the Licensing Project Manager for the original licensing of the Indian Point 3 nuclear plant in the 1970s. In the 1980s the New York Power Authority hired Mr.Specter to manage the defense of Indian Point 3 in a federal adjudicatory trial in the wake of the Three Mile Island nuclear accident in Pennsylvania. Prior to joining NYPA, Mr. Specter served at diplomat rank for 5 years at the International Atomic Energy Agency in Vienna, Austria where he headed up an international effort writing design safety standards for nuclear power plants.

Mr. Specter has been Chairman of two national committees on emergency planning and was a guest lecturer for several years on emergency planning at Harvard's School of Public Health. He led an effort as a consultant to Entergy analyzing emergency responses during a hypothetical terrorist attack on Indian Point. Mr. Specter has presented testimony at the National Academy of Sciences on the Fukushima accident and on other nuclear safety matters and has been a guest speaker at many universities on matters of energy policy. Today he is one of 14 Topic Directors in Our Energy Policy Foundation, a group of about 1500 energy professionals who seek to bring unbiased and comprehensive energy information to our political leaders and members of the public.

Mr. Specter was born in White Plains, NY and lives there now.

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1.0 Executive Summary

You too can become a nuclear safety expert and it should take you less than an hour. Becoming a nuclear safety expert does not require an advanced college degree. Further, you may learn aspects of nuclear safety that many, even some in the nuclear energy field, are unaware of. All you need to do is read the first three pages of this report.

Large quantities of carbon-free electricity will be necessary if we are to have a low carbon future, and nuclear power plants reliably do this. However, many people fear nuclear power plants and radiation in general. Therefore it is important for the public and governmental leaders to understand that the radiological and economic risks to the public from nuclear power plants are extremely small and certainly far smaller than many think. There are multiple reasons for this, but one that has not received sufficient attention is the protective role of natural forces. In addition to man-made engineered safety systems, natural forces like gravity, changing wind direction, human biology, weathering, and several others, greatly reduce the consequences of nuclear accidents. These natural forces do not need electric power or actions by plant operators or emergency workers to reduce radiological consequences. These natural forces are always there and no act of terrorism or anything else can prevent them from protecting the public. Because of these man-made and natural protective features, the benefits of using nuclear power to reduce the challenges of climate change greatly outweigh its risks.

Two other areas that are poorly understood are the significant safety importance of the containment buildings and the simplicity and high effectiveness of a modern emergency plan. In order to clarify the safety benefits of natural forces, containment buildings, and a modern emergency plan, this report examines four major nuclear accidents and two advanced accident analyses by Sandia National Laboratories to highlight the roles that these features play in protecting the public and off-site property.

Insights from Sandia's advanced computer analyses reveal that nuclear accidents release far less radioactive material into the environment than thought before, that these more limited releases enter the environment much later than thought before, and that these releases are much more gradual. These three characteristics are all beneficial in protecting the public. A review of the Fukushima accident in Japan, provided in this report, supports all three of these Sandia insights.

The bottom line of all this is: In US designs, and those of many other countries, severe nuclear power plant accidents are rare and extremely unlikely to cause any near term off-site radiation fatalities or radiation sicknesses. Long term effects, **if any,** would be too small to be detected. We also know today that the risk of contaminating land areas from a nuclear accident is far less than thought before because only very small amounts of cesium would be released and because natural "weathering" effects rapidly reduce cesium dose rates. Extreme claims about nuclear accident consequences are not supported by advanced analyses or by actual nuclear accidents.

Nuclear power plants operating today do not represent a significant threat to society. Future nuclear plant designs will do even better as many new designs will avoid reactor meltdowns altogether. Carbon-free electricity from nuclear power plants is essential in dealing with climate change.

2.0 Key Points

A. Nuclear accidents that could release radioactive material into the environment are very rare, about one chance in a one hundred thousand per year to one chance in a million per year per nuclear power unit.

B. Nuclear power plants are designed to have, and to operate within, well defined safe operating envelopes.

C. If something goes awry there will be no reactor core damage if the reactor fuel is adequately cooled. There are multiple safety systems designed to cool the reactor fuel. Fuel heat rates drop quickly once the reactor is shut down, which would happen immediately.

D. If the reactor fuel can not be adequately cooled because there has been a total loss of off-site and on-site electric power, i.e., a station blackout situation, the passive containment building would still provide extensive public protection. For pressurized water reactors (PWRs) like Indian Point and Diablo Canyon, at least 24 hours would be available in a station blackout situation before significant containment leakage would begin. During this time period natural forces like gravity, plating out on metal surfaces, and being trapped in wet surfaces and in pools of water generated by the accident, would greatly reduce airborne radioactive material within the containment building well before significant containment leakage would occur, leaving little to be released to the environment.

E. Even without an emergency response, the limited released radioactive material would be unlikely to cause off-site near term fatalities or detectable long term radiological fatalities. Off-site economic losses and contaminated areas would be **far less than thought before.**

F. Nonetheless, nuclear safety philosophy requires a *defense-in-depth* approach. As such, an off-site emergency response would be put into action if there were an impending release of radioactive material. Guidance from the Environmental Protection Agency calls for emergency plans to balance radiological and non-radiological risks. A modern emergency plan would minimize both radiological and non-radiological consequences. This would be accomplished by a combination of in-close evacuation (innermost two miles from the site) prior to the release of radioactive material, then downwind sheltering after the release began, and even later, relocations if there were hot spots, including any hot spots that were beyond the ten mile Emergency Planning Zone (EPZ). Modern emergency plans would be far simpler and much safer than massive evacuations.

G. In a nuclear accident, the range of the radiation-caused near term (early) fatality risk is between **zero to one mile** from the point of release and the range of radiation sicknesses is between **zero to two miles.** By evacuating the innermost two miles prior to the release of radioactive material all near term radiation effects from an accident are expected to be eliminated. There is ample time to achieve this focused evacuation and it involves less than 4% of the EPZ area. Downwind sheltering reduces long term radiation effects, if any, and minimizes the non-radiological risks of over-evacuation. While a total evacuation of the whole EPZ would eliminate near term radiation consequences, it would add to the non-radiological risks. Thus a total evacuation of the whole EPZ is not an optimum response. Extreme evacuations out to 50 miles, as some have suggested as necessary, are dangerous, have no basis in science, and must be avoided.

H. See TABLE A-1 for a compilation of consequences from four actual nuclear accidents.

TABLE A-1 Radiological Consequences from Four Nuclear Accidents

Power Plant	Number of **on-site** near term fatalities	Number of **off-site** near term fatalities	Long term fatalities	Comments
Browns Ferry	0	0	0	Reactor fuel never damaged, no releases to the public.
Three Mile Island	0	0	0	Reactor meltdown, no significant leakage from the containment building.
Fukushima	0	0	Would be too small to be detected, even when conservatively calculated.	3 Reactor meltdowns, containment leakage after 12 hours. Containment building and emergency diesels survive magnitude 9 earthquake. Tsunami causes station blackout. Only small releases of iodine and cesium, consistent with modern accident analyses.
Chernobyl	28	0	No observed cases of leukemia, even after 30 years. Thyroid cancers among children in Belarus, Russia, and the Ukraine.	Rapid power excursion, burning graphite, no containment building -only a very limited confinement building. Contamination of nearby land and property, some of which still kept off-limits. However, dose rates from widespread release of cesium have decreased rather rapidly from “weathering” effects. Thyroid cases caused by drinking contaminated milk, 99+% successfully treated. This consequence would not happen in the US or elsewhere (e.g. Japan) because of contaminated food interdiction programs.

3.0 Insights From Four Actual Nuclear Accidents and Advanced Accident Studies

3.1 Introduction

This section starts out with normal operating conditions and then reviews four actual nuclear power plant accidents that range from no damage to the plant to extensive damage with large releases of radioactive material into the environment. These actual accident analyses are supplemented with insights gained from advanced accident analyses performed by Sandia National Laboratories. It will be shown that the accident at Fukushima, Japan is supportive of the general conclusions reached by Sandia National Laboratories analyses. The Fukushima accident also provided insights on how to develop a modern emergency plan. The importance of natural forces, the containment building, and the benefits of a modern emergency plan are woven into the discussions below.

3.2 Nuclear Accidents are Rare

Everyone has an interest in having a low likelihood of a severe accident at any nuclear power plant. Nuclear regulators, in their role of protecting the public, want to keep the chances of having a release of radioactive material into the surrounding environment to a very small number. Utilities that own/operate nuclear plants share this concern for public safety and also seek to avoid the very large economic penalty of losing a major asset, the considerable cost of cleaning up a damaged power plant, and off-site costs. The design of nuclear plants includes a variety of instruments, such as temperature, pressure, flow rate, and water level gages, that continuously measure the status of the power plant to keep the plant in its well defined operating envelope. Should something go awry, all kinds of engineered safety equipment - pumps, valves, emergency electric diesels, batteries, sprays and the like - are rapidly activated to prevent damage to the reactor and the containment building while returning the plant to a safe condition. In addition to automatic safety equipment at a nuclear plant, there are operators who have been trained to return the plant to a safe condition if a nuclear power plant strays outside of its well defined operating envelope. As a result of these operator actions and engineered safety features, the chances of having a core melt situation is between one chance in 10,000 to one chance in 100,000 per year per nuclear power plant. Core melt sequences do not necessarily lead to a release of radioactive material into the environment. The frequency of releases of radioactive material into the environment is in the range of one chance in 100,000 to one chance in 1,000,000 per year per nuclear power plant, or smaller.

3.3 The Containment Buildings

US nuclear containment buildings are very robust structures. They have withstood category 5 hurricanes, tornadoes, external flooding, and earthquakes. A measure of the great strength of US containment designs occurred in Japan in March, 2011 when a magnitude 9 earthquake struck. All the containment structures in Japan’s 50+ nuclear power plants withstood this extreme seismic event.The damage done to the Fukushima plant was due to the tsunami that followed the seismic shock. Not only can these containments withstand very large external forces, they have considerable margins to withstand high internal pressures. For example, nuclear power plants with large dry containment buildings can withstand internal pressures up to about 220% of their design pressure before significant leakage would begin. For station blackout accident scenarios, it would take between 25 to 45 hours before such leakage would begin with this type of containment building.

3.4 The Browns Ferry Accident

A fully mitigated nuclear accident with an intact containment

In 1975 there was a serious fire at Unit 1 of the Browns Ferry Nuclear Plant in Alabama. All during this fire adequate cooling of the reactor fuel was maintained and therefore there was no fuel damage or any leakage from the containment. Because there was no fuel damage, there was no release of radioactive material into the environment. Therefore this was a fully mitigated accident. Even though there was no fuel damage and the public was never in danger, lessons were learned which led to fire protection upgrades.

3.5 The Three Mile Island Accident

A partially mitigated nuclear accident with an intact containment

In 1979 the accident that occurred at the Three Mile Island in Pennsylvania was caused by a series of operator errors and a stuck open relief valve that led to large amounts of reactor cooling water being dumped into the containment building. This, and a lack of adequate core cooling because of other operator errors, led to damage of the reactor fuel and a melt down. This was a partially mitigated accident because the containment building was never overpressurized and only miniscule amounts of radioactive material entered the environment. Again, although the public was never in danger, this accident was extensively reviewed and additional safety upgrades, along with additional operator severe accident training and procedures, were implemented.

3.6 The SOARCA Analysis

Two hypothetical accidents with no mitigation, followed by leakage from the containment building.

The source term is the amounts and types of radioactive material in the nuclear reactor core that calculated to be released into the environment from a nuclear accident. The smaller the amount, the smaller the off-site effects. An early estimate of a severe accident source term (called the SST1 source term) was presented in 1982 by Sandia National Laboratories. Many years later, in 2012, Sandia National Laboratories published[1] NUREG-1935 “State -of-the-Art Reactor Consequence Analyses (SOARCA) Report” which reflected great advances in accident analysis technology since its 1982 report.

TABLE A-2 compares the 1982 Sandia SST-1 source term to the SOARCA results for a Pressurized Water Reactor (PWR) with a large dry containment building, like the Indian Point, Diablo Canyon power plants and others. The SOARCA analyses presented here[2] examined two different station blackout scenarios, one short term and one long term. These hypothetical station blackout

[1] A companion document is NUREG-7110, Volume 2.

[2] See NUREG-1935, TABLE 7-1.

scenarios assumed that all engineered safety features were inoperable. The differences in source terms between the 1982 report and these SOARCA analyses are profound, with the modern calculated source terms much smaller than the 1982 estimates. TABLE A-2 also shows that the calculated times for releases to begin to enter the environment of 25.5 to 45.3 hours, are far longer than the 1982 number of 1.5 hours. These much longer time delays provide (1) many more hours for natural forces to reduce airborne radioactive material in the containment air space, (2) ample time to evacuate the innermost two miles near the reactor site prior to the release of radioactive material, and (3) more time for plant operators to end the core melt sequence before releases to the environment begin.

TABLE 7-1 of NUREG-1935 also compared the SST-1 and SOARCA release fractions of other fission products, but they were not included in TABLE A-2 because they are comparatively unimportant for calculating off-site health and economic consequences[3]. Radioactive iodine-131 and to a lesser extent radioactive tellurium, dominate early health effects. Cesium-137 dominates long term health effects and land contamination issues. Reactor cores have initial inventories of radioactive fission products. A release fraction is that portion of an initial radioactive inventory that enters the environment.

TABLE A-2 SST-1 and SOARCA Release Fractions

	Core damage frequency, events/yr	Tellurium release fraction	Iodine release fraction	Cesium release fraction	Release start, hours	Release end, hours
SOARCA in 2012, Short term station blackout in a large dry PWR	$2x10^{-6}$	0.006	0.006	0.001	25.5	48.0
SOARCA in 2012, Long term station blackout in a large dry PWR	$2x10^{-5}$	0.006	0.003	0.000	45.3	72.0
SSTI in 1982	$1x10^{-5}$	0.640	0.450	0.670	1.5	3.5

3.6.1 What are the Major Insights from SOARCA?

There are three dominant differences between the 1982 SST-1 source term and the 2012 SOARCA source terms:

1. The amounts of radioactive material calculated to be released to the environment are much smaller in the SOARCA analysis than the 1982 SST-1 source term,

[3] NUREG-1935 TABLE 7-1 also included release fractions for Xe, Ba, Ru, Mo, Ce, and La.

2. The time that these releases begin to enter the environment is much later in the SOARCA analysis,
3. The duration of these releases is much longer in the SOARCA analysis.

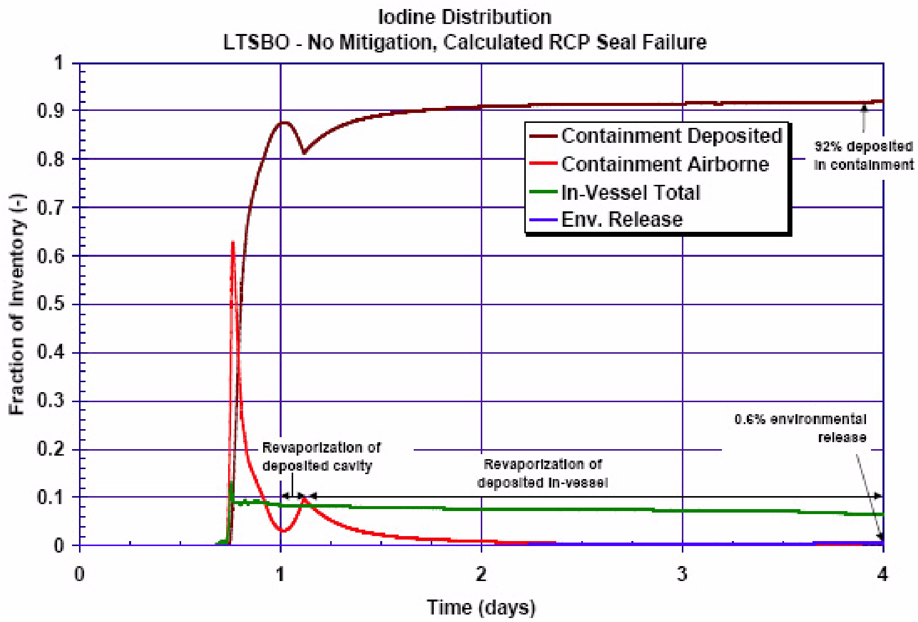
All three of these insights are supported by the analyses shown in TABLE A-2 and by an analysis of the Fukushima accident. All three of these differences reduce calculated off-site radiological health effects, as discussed in Section 4 of this report.

3.6.2 Why are the SOARCA Calculated Release Fractions so Small?

Even though the SOARCA analyses assumed that no engineered safety systems were operable because of a total station blackout and that leakage from the containment began after 25.5 to 45.3 hours, the calculated releases of iodine and cesium, and others, were very small. This is because natural forces like gravity, plating out on metal surfaces, and being trapped in wet surfaces and within pools of water created by the accident greatly reduce airborne concentrations of radioactive material in the time period before containment leakage becomes significant.

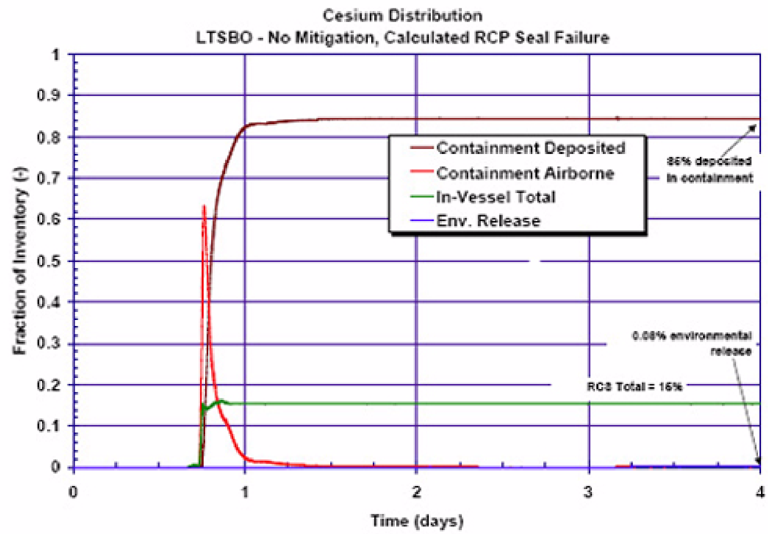
FIGURE A-1 which depicts the airborne iodine concentration as a function of time for a large dry PWR containment for a long term station blackout sequence where significant containment leakage does not begin until 45.3 hours after accident initiation. Note that the iodine concentration in the containment air space reaches high levels around the time of reactor vessel failure. However, these airborne iodine concentrations rapidly decrease after their peak because of the above natural removal processes. This rapid drop off in iodine airborne concentrations occurs before there is significant containment leakage. Airborne concentrations in the containment air space for cesium and other fission products have profiles similar to that of iodine. See FIGURE A-2.

FIGURE A-1 Iodine Distribution, Long Term Station Blackout (Sandia)



Unmitigated LTSBO iodine fission product distribution history

FIGURE A-2 Cesium Distribution, Long Term Station Blackout (Sandia)



Unmitigated LTSBO cesium fission product distribution history

3.7 The Fukushima Daiichi Accident

<u>An unmitigated accident with significant containment leakage after 12 hours</u>

On March 11, 2011 the Great East Japan Earthquake of magnitude 9 struck Japan. This earthquake was so powerful, portions of the seafloor were moved 17 feet. Tsunamis up to about 50 feet were generated and the human death toll from this extraordinary event took the lives of about 19,000 people. By way of contrast, there were no fatalities caused by radiation from the three simultaneous reactor meltdowns at Fukushima.

In spite of the great forces generated by this extraordinary earthquake, none of the containment buildings and none of the engineered safety features failed in any of Japan's 50+ reactor units. The earthquake did cause a widespread loss of the electric grid, immediately causing nuclear plants to turn to their emergency diesels for electric power. All operating nuclear plants automatically shut down when this huge seismic event struck.The three Fukushima Daiichi meltdowns were not caused by this powerful earthquake directly, but by the towering tsunami that followed that flooded out an electric panel that controlled the electric diesels and components used for water circulating functions. Until the arrival of this towering tsunami inundated the diesel generator control panel, the emergency diesels at Fukushima Daiichi operated as they were designed to do.

Once all electric power was lost at Fukushima the reactor fuel could not be cooled and core melt sequences were initiated. At that moment the containment buildings with their suppression pools stood as the final barriers between the public and the reactor melt downs. Much of the radioactive material was captured within the plants' suppression pools and elsewhere within the containments.

3.7.1 Fukushima and SOARCA comparisons

TABLE A-3 shows that the three general characteristics of nuclear accidents derived from the SOARCA analyses (See Section 3.5) are supported by observations from the accident at Fukushima.

TABLE A-3 SOARCA and Fukushima Comparisons

Fraction of Reactor Core Inventory	Iodine	Cesium
1982 SST-1 source term	0.450	0.670
Fukushima (average of three meltdowns)	0.017-0.083 Smaller than thought before	0.009-0.029 Smaller than thought before
N/A	Start of release after shutdown	Duration of release
1982 SST-1 source term	1.5 hours	Two hours
Fukushima	> 12 hours, longer than thought before	~13 days, more gradual than thought before

3.7.2 Fukushima Emergency Response History

TABLE A-4 provides a history of the evacuations and sheltering for the Fukushima accident.

TABLE A-4 Fukushima Evacuation and Sheltering History

Time in year 2011	Distance from site, km	Action
March11,@ 14:46	N/A	Magnitude 9 earthquake
March 11@ 15:42	N/A	Units 1,2, and 3 lose power
March11@ 20:50 and@ 21:23	2,3	Two pre-emptive evacuations
March 12@ 05:44	10	Compulsory evacuation
March 12@18:25	20	Compulsory evacuation
March 15	20-30	Shelter in home
March 25	20-30	Self evacuation
April 22	Areas with dose rate > 20 mSv/year	Evacuation within a month
June 16	Hot spots with dose rate > 20 mSv/year	Recommended for evacuation (relocation)

3.7.3 Evacuation Lessons Learned

The emergency response to the simultaneous three meltdowns at Fukushima was a radiological risk success, but a non-radiological risk failure. The World Health Organization (WHO) and the US National Academy of Sciences have concluded that there were no early fatalities due to exposure of radiation and that long term effects, even when conservatively calculated, would be too small to be detected.

Once the two pre-emptive evacuations were completed, the near term fatality and radiation sickness risks were eliminated. Unfortunately, additional ordered and voluntary evacuations out to 30 km took place. Over 100,000 people were evacuated, some very hastily before they could even take their medications with them. Many were placed in crowded shelters and the stresses of this, plus fears of having been irradiated plus stresses from the assumed loss of long held homes, farms, and family burial grounds resulted in non-radiological deaths. Over 1000 deaths are attributed to this over-evacuation response. Years after the accident some people in government shelters still refused to return to their homes even though these homes were safe, having once been told that they had to evacuate. Fear is a powerful force.

Had the emergency response to the Fukushima accident been one of downwind sheltering once the pre-emptive evacuation had been completed, many of these non-radiological deaths might have been avoided.

3.7.4 Other Lessons Learned

All nuclear accidents and operating events, even if they do not lead to core damage or releases of radioactive material into the environment, are carefully scrutinized to learn lessons from them. The Fukushima accident was no exception to such safety re-examinations. In the United States addition safety equipment and procedures have been added. These safety additions differ from past responses. The emphasis here was to give plant operators additional capability and flexibility to deal with unexpected conditions. A major goal was to prevent reactor fuel damage, even in a station blackout condition. Among the post-Fukushima safety enhancements was the placement of portable electricity generators at different locations within a nuclear power plant and additional means to deliver cooling water at different plant locations.

3.8 The Chernobyl Accident

<u>An unmitigated accident without any containment building protection</u>

The largest release of radioactive material into the environment from a nuclear accident occurred at Chernobyl in April, 1986 because of a flawed design and inappropriate actions taken by the plant operators that initiated this accident.

In US designs a loss of cooling water, perhaps through a pipe break, immediately shuts the reactor down because the chain reaction can not be sustained. No operator actions or insertion of control rods would be necessary, although this would happen automatically. However, the physics design the Chernobyl reactor was different from US designs and the loss of water had the opposite effect. The power level spiked 100 fold in just 4 seconds. The Chernobyl plant did not have a containment building. Instead, a confinement building with only a one psi pressure capability was used. A typical large dry containment building in the US has a design pressure around 45 psi but, because of a significant margin, can reach about 100 psi before extensive leakage would begin. There seems to be a hundred fold more pressure protection in US large dry containments compared to Chernobyl's confinement building.

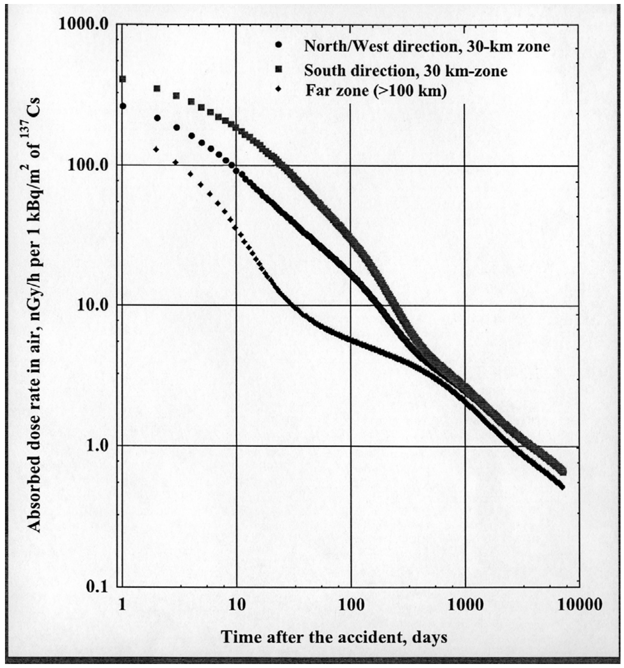
The Chernobyl design also had a large, very hot, block of graphite within its reactor vessel. Once outside oxygen came into contact with this graphite a fire ensued. So the Chernobyl accident released both energy from the nuclear power excursion plus chemical energy from the graphite fire. Since there was only a very limited confinement building, radioactive material from the accident entered the environment very rapidly. There was no time for various natural removal processes, described before, to reduce these releases.

The intense heat of this accident caused the radioactive plume to rise vertically from the damaged plant. This had two effects. First, three people who flew through this highly radioactive plume in a helicopter later died from this exposure. Second, radiation levels in the public areas surrounding the plant were actually quite low because of the vertical rise of the plume. **No member of the public at Chernobyl became a near term fatality.** There was a total of 28 deaths from Chernobyl, all of which were due to **on-site** exposure. Three of these 28 deaths were the people exposed in the helicopter and the rest were on-site emergency workers, like firemen putting out the blaze.

3.8.1 More Natural Forces

The Chernobyl accident released far more cesium-137 than would be possible with a design that met US specifications. Cesium-137 has a long half life, about 30 years. Because of the long half life of cesium-137, people have been concerned that areas where the radioactive plume deposited cesium-137 would be contaminated for very long periods of time. As it turns out, **natural forces** like rainfall, soil covering ground shine from cesium, etc., rapidly reduce dose rates from cesium-137. FIGURE A-3 presents above-ground, post Chernobyl, radiation level measurements. The decrease in dose rates over time is significantly more rapid than what would be expected if radioactive decay were the only mechanism for reducing doses. Since the dose rate from released cesium-137 decreased far more rapidly than thought before, projections of the size of contaminated areas and the long term health effects of people who reoccupy affected areas are far less than thought before. FIGURE A-3 was presented at the Beebe Symposium hosted by the National Academy of Sciences, held in recognition of 30 years after the Chernobyl accident.

FIGURE A-3 Decrease in Dose Rate from Cesium Released by Chernobyl Accident



4.0 Off-Site Near Term Health Consequences

It was previously stated that the range of the early fatality risk from nuclear power plant accidents is expected to be between zero and one mile. The range of radiation sickness is expected to be zero to two miles. Several natural forces combine to achieve this. First there is human biology which requires very high doses to cause a fatality. This is shown in FIGURE A-4[4], at below about 1.5 Grays (Gy), or 150 rads, of exposure there is essentially no chance of becoming a near term fatality, assuming minimal medical treatment. In other words, human biology establishes a radiation exposure threshold below which there is effectively no chance of causing an early fatality. An exposure of 150 rads may not be achievable with the kind of very small radioactive releases that SOARCA calculates. If there were supportive medical treatment, the threshold is higher where exposures below around 2 Grays (200 rads) should not lead to an early fatality. Additionally, the chances of causing a near term fatality are also dependent on the dose rate. At slower dose rates it would take a larger exposure to cause a near term fatality. The more gradual releases of radioactive material predicted by SOARCA and observed in the Fukushima accident should increase the threshold level somewhat.

There are multiple ways of reducing a person’s dose in addition to evacuation and sheltering. Two natural process that would reduce doses are diffusion and wind direction changes. Diffusion is a natural process that is easily observable. Plumes thin out and widen as they move away from their points of release. This means that a person under a radioactive plume that is further away from the point of release would get a smaller dose, i.e., distance reduces the dose rate.

Because of the decreasing dose rate with distance, distance alone from a damaged nuclear power plant is sufficient to limit the range of the early health effects. Regardless of the size of the radioactive release, there is always some distance at which radiation exposures fall below the threshold of becoming a near term fatality. Reviews of different accident analyses and actual accidents place this limiting distance between zero and one mile for near term fatalities and zero and two miles for radiation sicknesses.

In addition to the dilution effects of distance, lower downwind doses would occur if there are wind shifts during the long duration of the release of a radioactive plume from a nuclear accident. If a wind shift ended up with the radioactive plume covering <u>twice</u> the area compared to the area covered by plume with a steady wind direction, exposed individuals would get only <u>half</u> the dose. FIGURE A-4 can be used to illustrate the importance of thresholds to wind shifts. Assume that a person experiencing a steady wind direction received a very high dose of 3 Grays. In this hypothetical situation, according to FIGURE A-4 with minimal medical treatment, there would be about a 50% chance that this very exposed individual would become an early fatality. Now take another hypothetical case where the wind has shifted so that two individuals each receive half the dose, 1.5 Grays, of the first individual who received 3.0 Grays. Figure A-4 indicates that these two individuals with half the dose each would be below the threshold for near term fatalities. In this hypothetical example the chances of causing a near term fatality from exposure to radiation decreased from 50% for one individual to 0% for two individuals. Even though the same amount

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[4] Figure 3.1 of “Health Effects Models for Nuclear Power Plant Accident Consequence Analysis”, NUREG/4214, Rev.2, Part 1, ITRI-14, October, 1993.

of radioactive material was released into the environment in these two hypothetical cases, wind shifts can significantly lower calculated early health risks from nuclear accidents.

Actual meteorological data taken at the Indian Point nuclear power plant provide more insights. At this site, on average, there is about a 50% chance that the wind will shift one sector (22.5 degrees) in just one hour. Every four hours, on average, there is a 50% chance the wind will shift the wind will shift three sectors (67.5 degrees). Considering the very long times now calculated for the gradual release of radioactive material (See TABLE A-2), changing wind directions make it less likely that anyone can acquire high doses. As a further layer of protection, a pre-emptive evacuation of the innermost two miles by itself should eliminate all near term radiation risks.

FIGURE A-4 Risk of Mortality Versus Radiation Exposure

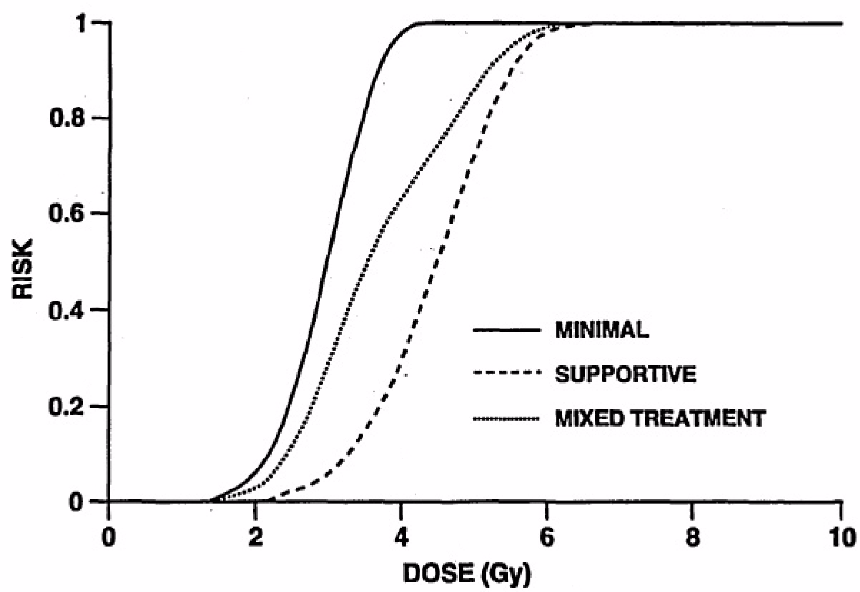

Figure 3.1 **Risks of mortality from the hematopoietic syndrome for minimal, supportive, and mixed treatments: central estimates for exposure at a high dose rate.**