

Public Use of Respiratory Protection from Nuclear Power Plant Accidents and Terrorist Attacks

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ABSTRACT

Of great interest today are the possible offsite health effects of a terrorist attack on a nuclear power plant. This is particularly important for two nuclear power plants, located about 24 miles north of New York City at Indian Point in Westchester County, New York. This is the most populated nuclear site in the United States where about 367,000 people live/work within the surrounding 10 mile Emergency Planning Zone (EPZ). Nearby road systems are often congested and the feasibility of an effective emergency plan has been a source of contention for decades. Entergy, owner of these two plants, has applied to the Nuclear Regulatory Commission for 20 year license extensions for these two plants, but a number of people and their elected officials oppose these extensions. In order to address public concerns a multi-year study, now nearing completion, evaluated hypothetical terrorist-caused offsite consequences and those from postulated accidents to determine offsite risk levels and to look for ways to improve the emergency plan. The purpose of this paper is to provide the results of this extensive analysis and indicate where further joint research conducted by the nuclear community and those in the respiratory protection community could be beneficial.

It was assumed that one of these Indian Point nuclear power plants was attacked by terrorists who breached its massive reinforced concrete containment building and then caused a reactor meltdown. It was determined that near zero early fatalities and a small number of early injuries would be expected, even under these extreme conditions. Long term cancer fatalities, at most, would be a very small fraction of the normal background cancer rate.

A number of consequence-reducing strategies were investigated. Among these strategies was the public's use of wet handkerchiefs or face masks to reduce inhalation doses from radioactive material. It was shown that a 10-fold reduction in inhalation doses could be very valuable in reducing health consequences, provided that such a reduction factor can be achieved. If no additional steps were taken to reduce consequences, five early fatalities and 203 early injuries would be expected out of the 367,000 people surrounding the site, assuming very poor weather conditions. Emergency traffic controls would reduce these consequences to four early fatalities and 80 early injuries. With both traffic controls and a 10-fold reduction in the inhalation dose these consequences become zero and 10, respectively. With traffic controls the mean number of latent fatalities is 114 people. With an inhalation dose reduction factor of 10 the calculated mean number of latent fatalities would decrease from 114 to 22. Normal background non-nuclear cancer fatalities in this EPZ area are expected over time to be around 80,700.

This paper identifies joint tasks for the nuclear and respiratory communities that would be necessary in order to verify the effectiveness of wet handkerchiefs and face masks in reducing inhalation doses from releases of radioactive material. The nuclear community would have to determine the gas/particle ratio in the postulated radioactive plumes from nuclear reactors during a large release. The respiratory community would then use this gas/particle ratio to determine the effectiveness, i.e., the reduction factors, of wet handkerchiefs and face masks for this kind of radiological event.

Keywords: Terrorism, emergency planning, nuclear, Indian Point, traffic, consequences, face masks

INTRODUCTION

A multi-year analysis of the health risks from a hypothetical successful terrorist attack on one of the two nuclear power plants at Indian Point, about 24 miles north of New York City, is now nearing completion (Specter, 2007). The purpose of this lengthy study was to determine the early fatality, early injury, and latent fatality health risks, should a major release of radioactive material occur from one of these nuclear plants. This study was also used to evaluate the feasibility of evacuation at this crowded site and to identify specific consequence-reducing actions that could be taken. Among these possible consequence-reducing actions was the public's use of wet handkerchiefs or face masks to reduce their inhalation doses. The use of wet handkerchiefs, or face masks of the type often available at local drug stores, is appropriate for a public response since it is unlikely that the public would have access to the superior kinds of masks utilized by professionals in hazardous areas.

A series of sensitivity studies were made to determine the impact on the above health effects if a factor of 10 reduction in the inhalation dose could be achieved. It was found that an inhalation dose reduction of this magnitude would be particularly valuable under two conditions: where evacuation was not possible for several hours and people first took shelter before evacuating and in reducing latent cancer fatalities for both sheltering and evacuation responses. However, it remains to be shown for wet handkerchiefs and face masks what the actual inhalation dose reduction factor would be for the type of gas/particle mix that would be characteristic of a release of radioactive material from a nuclear reactor meltdown. A joint effort by the nuclear and respiratory protection communities would be needed to quantify such a dose reduction factor.

It is useful to understand why some people are anxious about the continuing operation of these two nuclear power plants. On September 11, 2001 American Airlines flight 11 flew down the Hudson Valley in New York on its way to crashing into one of the towers in the World Trade Center. It flew near the site of the two operating Indian Point nuclear power plants. Some time later documents seized overseas in battles with terrorists revealed that nuclear power plants were among the targets under their consideration. Then there was the tragic emergency response to Hurricane Katrina.

Because of the high population surrounding the Indian Point nuclear power plants and a congested road system, the feasibility of an effective emergency plan has been a source of contention for decades. In the early 1980s there was a federal court case where people sought to shut down these two plants in the aftermath of the accident at the Three Mile Island nuclear plant. Emergency planning was a central issue in that court case. After federal judges found in favor of allowing these plants to continue to operate, emergency planning objections subsided. However, recent events have caused a groundswell of new objections to these important sources of electricity. Several representatives in Congress and one Senator have responded to this public outcry and have pressed the Department of Homeland Security and the Nuclear Regulatory Commission to justify their approval of the Indian Point emergency plan. Their actions follow a lengthy report by James Lee Witt who, at the request of the past Governor of New York, examined the Indian Point emergency plan (Witt, 2003). Mr. Witt, former director of the Federal Emergency Management Agency, concluded that it was not feasible to have an effective emergency plan at Indian Point. However, the past Governor did not act on the Witt report.

Others point to the economic importance of the approximately 2000 megawatts of electricity produced by these plants. The Indian Point plants are the lowest cost producers of electricity in the area. As reported in the New York Times, a study by the National Academy of Sciences concluded that while it was theoretically possible to replace the two Indian Point nuclear power plants, as a practical matter it could put the surrounding region at economic risk (Wald, 2006). Even with the Indian Point plants operating, there is a projected shortfall of several thousand megawatts in the Indian Point service area in the near future. Further, nuclear power plants do not produce greenhouse gases and one of New York State's environmental objectives is to reduce its carbon footprint. This would rule out using coal or natural

gas to replace Indian Point's electricity production and the use of renewables in sufficient quantity and with acceptable reliability is thought to be too far off.

Because of the great importance of this issue, both locally and nationally, a study was initiated over three years ago under the sponsorship of Entergy, owner of the Indian Point plants, to quantify offsite health risks and to look for opportunities to improve the emergency plan at Indian Point. Unlike most other emergency planning studies which focus on unintended accidents, this effort assumed that terrorists purposefully set out to cause enormous numbers of fatalities and injuries by having a large release of radioactive material at this highly populated site. Note that a successful terrorist attack at Indian Point is extremely unlikely. Not only are there substantial security forces both on and off the site, breaching the massive containment which is made of reinforced concrete three or more feet thick, would be very difficult. Even if the containment were breached, many further acts of destruction would have to be performed to cause a reactor meltdown. If this were a ground attack, all these destructive acts would have to be accomplished in a short time frame before the site would be swarming with security forces.

However, for purposes of this study, it was assumed that the terrorists were successful. The challenge then was, given a breached containment and a reactor meltdown, could the goals of the terrorists to inflict great harm at this crowded site be thwarted? The very small numbers of early health effects and the short ranges of these health effects described here is consistent with information recently published by the Centers of Disease Control (Donnelly et al., 2007).

METHODS

Two technical disciplines have been merged to determine the consequences of a successful terrorist attack. One of these technical disciplines is advanced traffic analysis and the other is advanced consequence analysis. The merging of these two advanced technologies, followed by applying this capability to the nation's most densely populated nuclear site, is unique and yielded many new insights.

Traffic analysis is essential when analyzing crowded sites (KLD, 2004). In order to determine how much radiation exposure people might receive, one has to know where these people are at any given time. This information is merged with an analysis of where the radioactive plume is and its strength, both of which vary with time. In this effort the traffic analysis divided the 10 mile area surrounding Indian Point into 112 smaller areas, and some 357 locations were used as the starting points of the evacuations of various population groups. The size and makeup of these population groups were determined by updating the most recent national census and by using imagery from Google Earth. These groups include permanent residents, employees, and transients. The locations of schools and special needs facilities, like hospitals and retirement homes, were identified and the number of buses and ambulances needed in an evacuation were accounted for, as well as the distances of these facilities from Indian Point. Detailed measurements were made of the road network in the EPZ such as road capacity, direction of flow, traffic lights, etc. Some 14 different traffic scenarios were examined. Among the scenarios considered were evacuations during the day or night, weekday or weekend, the season of the year, if there was clear weather, rain, or snow, and during special sports events in the area. Surveys were conducted to determine the number of people without vehicles as well as the number of vehicles per family for different sized families. Sensitivity studies were run to determine the impact of different times it took for people to mobilize and start their evacuations and the impact of voluntary evacuation, i.e., evacuations in excess of those that government leaders would recommend. The results of these numerous scenarios were examined and the scenarios most likely to impede evacuation from the inner four miles from Indian Point were then selected for further traffic analysis. KLD Associates, Inc., who conducted traffic analyses of Indian Point in the past, won a national engineering award in 2007 for their advanced Indian Point traffic analyses. The KLD advanced traffic analysis code was also used as a search tool to locate specific road segments which, if temporarily made one-way and outward bound, would materially improve vehicular evacuation speeds.

Polestar Applied Technology, Inc. performed the consequence analysis in this effort. They too advanced the technology in their area of expertise. With regard to consequence analyses, the starting

point was an analysis of the source terms. Source terms are the amounts of different radioactive species that might enter the environment from a reactor meltdown if containment integrity was lost. Two major classes of terrorist related reactor meltdown sequences were investigated. One class of sequences is station blackouts (SBO) where it is assumed that the terrorists breached the containment building and also disabled all sources of offsite and onsite electrical power so that the pumps that push cooling water through the reactor core would no longer work and all electricity-driven emergency reactor core cooling pumps would also be rendered inoperable. It would take over four hours after reactor scram in a SBO reactor meltdown sequence before the radioactive material would enter the environment. The other class of scenarios is called loss of coolant sequences (LOC). Here it is assumed that the terrorists were able to cause a huge hole in the containment building, sever one of the large pipes that carries cooling water into the reactor core and disable all the emergency reactor core cooling systems. This too would lead to a reactor core meltdown. LOC events are calculated to release radioactive material into the environment in about two hours after reactor scram. The terrorists would also have to disable both Indian Point containment spray systems, otherwise the release of radioactive material to the environment would be very small.

The time between a reactor scram and the onset of a release of radioactive material into the environment is a very important consideration in emergency planning. During such a time delay people would start to evacuate and since the range of the early fatality risk is about a mile, many of the people closest to the site would be beyond this distance prior to the radioactive material entering the environment. Even though evacuation speeds at Indian Point would be very slow, sometimes slower than typical walking speeds, advanced traffic analyses indicate that some 39% of the inner one mile population would have evacuated in their vehicles beyond one mile at the onset of a LOC release. Over 95% of this population would be beyond one mile for the slower acting SBO release.

Another major consequence consideration is the observation that natural chemical and physical processes would cause much of the radioactive material to stick to surfaces inside the open containment or remain dissolved in water there. Even in the extreme SBO and LOC sequences investigated here, 73% and 89% of the radioactive iodine would be trapped in the open containment, respectively. A comparison was made between the LOC and SBO radioactive releases to those that were calculated for accidents in the Probabilistic Safety Assessment for Indian Point (Entergy, 2007). It was determined that the frequency weighted accident source term is considerably smaller than the LOC and SBO source terms. Therefore, the consequences provided here for terrorist events exceed those that would be calculated for accident scenarios. Table I provides a comparison of the fractions of the reactor core's inventory of iodine, cesium, and tellurium that would enter the environment for accidents and the two classes of terrorist events. Isotopes of radioactive iodine, cesium, and tellurium are the dominant contributors to offsite health and economic consequences. The core fractions listed in Table I for accidental releases were determined by examining the calculated releases for a spectrum of accidents and then weighting these releases by their frequencies.

Table I. Comparison of Accident Source Terms to Terrorist Caused Source Terms

	Accidents	LOC	SBO
Iodine	0.022	0.111	0.274
Cesium	0.015	0.101	0.188
Tellurium	0.015	0.121	0.182

Neither the trapping of radioactive material in the open containment nor the time delay between reactor scram and the onset of a release of radioactive material into the environment requires any engineered safety system to work or actions by the plant operators. Further, these naturally occurring protective actions can not be defeated by terrorist acts.

These source terms and the results of the traffic analyses were part of the input to a consequence computer code, MACCS2 (Chanin,1997). The MACCS2 consequence code calculated early fatality and early injury consequences. It was necessary to run multiple MACCS2 calculations for each source term/traffic scenario investigated, one per initial starting location within four miles of the site. For each source term/ traffic scenario the results of these multiple MACCS2 calculations were summed to give the overall consequences for that scenario. Then these results for different scenarios were compared.

The MACCS2 consequence code was developed by Sandia National Laboratories and is used by the U.S. Nuclear Regulatory Commission, the nuclear industry, various national laboratories, and various public interest groups. Other important data that are input to MACCS2 analyses are the frequency of different weather conditions, the number and location of the surrounding populations, shielding characteristics of buildings like those in the Indian Point area where people might take shelter, and evacuation speeds and pathways for those people that do evacuate.

RESULTS

Without face masks

A number of emergency responses were investigated. The slowest emergency response would be a midday, midweek evacuation where everyone in the EPZ evacuated and no traffic control strategies were implemented. The resultant calculated number of early fatalities would be five and the number of early injuries 203, at the 95% exceedence level. The 95% exceedence level means that 95% of the time weather conditions are more favorable and calculated consequences would be smaller. If traffic controls were implemented, the number of calculated early fatalities would decrease to four and the number of early injuries would decrease to 80, both at the 95% exceedence level. If traffic controls were implemented and if a 10-fold decrease in the inhalation dose could be achieved, the calculated number of early fatalities would be zero and early injuries would be 10, at the 95% exceedence level.

It is unlikely that everyone in the EPZ would evacuate, especially since it has been determined that sheltering beyond four miles is sufficient to prevent any latent cancer fatalities and, at four miles, one is well beyond the range of the early fatality and early injury health risks. Therefore a basic emergency response that would avoid massive evacuation was developed for Indian Point, although it could be used at any nuclear site. The basic emergency response assumed evacuation of everyone within two miles of Indian Point, then evacuation of everyone from two to four miles in an 170 degree downwind "wedge" area. Beyond four miles downwind people should take shelter. In this analysis 65% of the population was assumed to take shelter with the remaining 35% voluntarily evacuating, contrary to government instructions for all people beyond four miles to take shelter. If the one-way outward bound traffic controls identified by the KLD search analysis were put in place, calculations indicate that two early fatalities and 33 early injuries might occur, both at the 95% exceedence level and both without the benefit of a reduction in the inhalation dose. All of these results are very small compared to the EPZ population of 366,866 people. The number of early injuries for the basic response divided by the EPZ population is 0.00009 and the ratio of early fatalities to the EPZ population is effectively zero. If a basic emergency response were implemented, the need for further inhalation dose reductions is minimal for early health effects.

With face masks

According to the National Council on Radiation Protection and Measurements "A reduction by up to a factor of 10 may be afforded by advising people to use *ad hoc* respiratory protection through wet handkerchiefs, towels, frequent showering, etc." (NCRP, 2000). Because of this NCRP statement a factor of 10 was used in various sensitivity studies discussed below.

There may be situations where evacuation is not immediately possible and people would then be advised to first take shelter and then evacuate as soon thereafter as possible. Assuming an initial response of three hours of sheltering, later followed by an evacuation, the 95th percentile calculated number of early fatalities was 39, with 141 early injuries. However, if a 10-fold reduction in the inhalation dose could be achieved these numbers would decrease to 5 and 56, respectively. Therefore, in terms of early health effects, reducing the inhalation dose is considerably more important for sheltering responses than for responses that utilize a prompt evacuation.

Table II below summarizes the importance of a 10-fold reduction in the inhalation dose on the early fatality and early injury health effects.

Table II. Impact of 10-Fold Reduction in the Inhalation Dose on Early Health Effects, 95% Exceedence Level, LOC Release

Emergency Response	Early Fatalities	Early Injuries
A. 100% evacuation of Indian Point EPZ, no traffic controls.	5	203
B. Same as A, but with traffic controls.	4	80
C. Same as B, but only 35% of the people beyond 4 miles evacuate, the other 65% beyond four miles takes shelter.	2	33
D. Same as B, but with the inhalation dose reduced by a factor of 10.	0	10
E. Three hours of sheltering, then evacuation.	39	141
F. Same as E, but with the inhalation dose reduced by a factor of 10.	5	56

Having analyzed early health effects, attention then focused on latent health effects. Here an advanced version of MACCS2 was used, but with a simplified evacuation model that used much of the sophisticated KLD traffic analyses. For the basic emergency response described above, a mean value of 114 latent fatalities was calculated. This can be compared to a background number of latent cancer fatalities of about 80,700 expected over time in the 10 mile population surrounding Indian Point. The 114 figure was calculated for the very slow midday, midweek time period. Whereas these 114 latent fatalities were calculated for a highly unlikely successful terrorist event, the figure of 80,700 background cancer fatalities has a probability of occurring close to 1.0. Since both the consequences and the frequencies of cancer fatalities from radioactive releases at Indian Point are small compared to natural background figures, the risk, the product of consequence and frequency, of becoming a latent fatality from an accident at Indian Point over the next 20 years is about 23 million times smaller than becoming a latent fatality from natural background causes. If the release occurred at nighttime, evacuation speeds would be much faster than those at midday, midweek conditions, and no early or latent health effects would be expected.

With regard to the number of latent fatalities expected when the basic emergency response is used, a 10-fold reduction in the inhalation dose would reduce the mean number of latent fatalities from 114 to 31. At the 95% exceedence level the number of calculated latent fatalities with a 10-fold reduction in the inhalation dose would decrease from 405 to 117. Table III below compares mean values of the latent fatality consequences at Indian Point to the EPZ population for a number of different emergency responses. These data are for the LOC release.

Table III. Comparison of Mean Latent Fatality Consequences to EPZ Population

Type of emergency response	Mean number of latent fatalities	Fraction of EPZ population
No response	770	0.00210
Basic response	114	0.00031
Basic response plus 10-fold reduction in the inhalation dose	32	0.00009
Nighttime Evacuation	0	0.0

DISCUSSION

Two types of concerns have been raised about the effectiveness of face masks when used by the public. One issue relates to how well the face mask must fit on a person in order to be effective. The other issue is more fundamental. The 10-fold inhalation dose reduction identified by the NCRP for wet handkerchiefs may be applicable to nuclear emergency situations where the great majority of the released radionuclides are transported as particles, not gases. It is contended that the particle/gas mix may have different characteristics in reactor release scenarios than the radiological releases analyzed by the NCRP. Further research would be necessary to resolve these two questions. Even though the inhalation dose reduction factor for face masks appropriate for reactor events is unknown at this time, it is clear that there would be some benefit in their use because some fraction of a release is likely to be in particle form. If, after all, a 10-fold inhalation reduction factor could be achieved with face masks, this would be a significant benefit for situations where a prolonged sheltering response preceded evacuation. It would also be useful in reducing the latent fatality health effects.

There are many other benefits to the public's use of face masks. They are also effective against other terrorist and non-terrorist attacks involving dangerous particles including chemical attacks, biological attacks, and airborne threats like SARS and avian flu. Unlike the development of flu vaccines, face masks are available in large quantities now and would be effective even if flu strains or other airborne pathogens differed from year to year. These non-nuclear applications of face masks may be far more important than issues related to terrorism at Indian Point because the probability of a release of radioactive material and its consequences are so small. Face masks of the type that are locally available to the public are inexpensive. They are portable so they could be stored in a car's glove compartment, on school buses, in trains, in emergency vehicles, in briefcases, etc. They have a long shelf life and can be used by most people. The multiple uses of face masks provide justification for their distribution, independent of nuclear power plant issues. If a person could not use a face mask or find one, then the *ad hoc* use of a wet handkerchief might still be beneficial.

CONCLUSIONS

Health consequences from accidents and terrorist acts at any nuclear power plant would be very small even if its containment building were breached, followed by a reactor meltdown. If no additional steps were taken to reduce consequences, five early fatalities and 203 early injuries would be expected out of the 367,000 people surrounding the site, assuming very poor weather conditions. Emergency traffic controls would reduce these consequences to four early fatalities and 80 early injuries.

For sites like Indian Point with a large in-close population additional protective measures can be taken to achieve still lower health consequences. Among these additional protective measures is the possible use of wet handkerchiefs or face masks to reduce inhalation doses. With both traffic controls and a 10-fold reduction in the inhalation dose these consequences become zero and 10, respectively. With traffic controls the mean number of latent fatalities is 114 people. With an inhalation dose reduction factor

of 10 the calculated mean number of latent fatalities would decrease from 114 to 22.

Further research is needed to quantify the inhalation reduction factors of wet handkerchiefs and face masks under reactor core release scenarios.

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