

**UPDATE ON RADIOLOGICAL EMERGENCY PREPAREDNESS  
ENHANCEMENT ACTIVITIES RESULTING FROM LESSONS  
LEARNED FOLLOWING SEPTEMBER 11, 2001, AND OTHER  
RECENT NATURAL DISASTERS**

**A Report for the  
Senate Committee on Environment and Public Works and the  
House Committee on Energy and Commerce**



**By the U.S. Nuclear Regulatory Commission**

Enclosure

## **INTRODUCTION**

The U.S. Nuclear Regulatory Commission (NRC) developed this report in accordance with Section 105 of the Nuclear Energy Innovation and Modernization Act (NEIMA), which requires the NRC to submit to the appropriate congressional committees a report describing the actions the Commission “has taken, or plans to take, to consider lessons learned since September 11, 2001, Superstorm Sandy, Fukushima, and other recent natural disasters regarding directed or spontaneous evacuations in densely populated urban and suburban areas.” Section 105 also requires the NRC to discuss a number of specific topics in this report, including its actions as a result of the State-of-the-Art Reactor Consequence Analyses (SOARCA) project, the results of its examination of emergency planning zones (EPZs) for small modular reactors and advanced nuclear reactors, its monitoring of international reviews, potential shadow evacuations in response to a disaster, and expected levels of self-evacuation from populations outside of the 10-mile EPZ.

For each topic, addressed in this report, the NRC describes the results of any agency actions taken, lessons learned, and plans for future action. The report concludes that the NRC’s approach to evacuations as part of the NRC’s emergency planning programs for currently operating power reactors remains valid, and that the NRC’s understanding of evacuations can help risk-inform future power reactor emergency planning programs.

In accordance with Section 105 of NEIMA, the NRC prepared this report after consulting with the Federal Radiological Preparedness Coordinating Committee, State emergency planning officials from affected States, and experts in analyzing human behavior and probable responses to a radiological emission event.

## **BACKGROUND**

The NRC is an independent regulatory agency with the mission to license and regulate the Nation’s civilian use of radioactive materials to provide reasonable assurance of adequate protection of public health and safety, to promote the common defense and security, and to protect the environment. In fulfilling its mission, the NRC emphasizes the integration of safety, security, and emergency preparedness (EP) and response. The NRC EP regulations and guidance enable licensee emergency personnel to rapidly identify, evaluate, and react to a broad spectrum of emergencies, including those arising from terrorism or natural events. The NRC’s incident response program integrates the agency’s overall capabilities for the response to, and recovery from, radiological incidents and emergencies involving facilities and materials regulated by the NRC or an Agreement State.<sup>1</sup> Under the National Response Framework, the NRC coordinates with other Federal, State, and local emergency organizations in response to various types of domestic events.

## **EVACUATION (Sec. 105(a))**

The NRC’s regulations on evacuation originated, in large part, because of lessons learned from the March 1979 accident at the Three Mile Island Unit 2 reactor. The NRC has updated its regulations, conducted, and published studies on emergency evacuations and issued guidance for licensees and State and local authorities on methodologies for evacuation time estimate studies. The emergency planning basis for commercial nuclear power plants (NPPs) includes a technical analysis to determine the size of EPZs, which are planning areas for the protective actions that make up an important part of emergency planning. The NRC considers evacuation

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<sup>1</sup> An Agreement State is a state that has entered into an agreement with the NRC authorizing the State to regulate certain quantities of radioactive materials within the State.

and sheltering to be the two primary protective actions implemented for the protection of public health and safety in the unlikely event of a severe NPP accident. The NRC also finds that potassium iodide is a reasonable, prudent, and inexpensive supplement to evacuation and sheltering for the public in specific local conditions. Evacuation is widely used as a protective measure for many different types of disasters, including flooding, hurricanes, wildfires, malevolent events, natural gas explosions, chemical accidents, and hazardous materials transport accidents. The Federal Emergency Management Agency (FEMA) recognizes that “[e]ven though each hazard’s characteristics (e.g., speed of onset, size of affected area) are different, the general tasks for conducting an evacuation and shelter operations are the same” (Ref. 1).

The Environmental Protection Agency (EPA) issued guidance in the form of a Protective Action Guide (PAG) Manual (Ref. 2) in 1992 and updated the PAG Manual in 2017 (Ref. 3), to state the criteria upon which protective actions should be based when the doses from radiation resulting from a radiological incident are expected to exceed 1 rem.<sup>2</sup> The 1 rem dose criterion is not based upon immediate and harmful effects to an individual. Rather, it is based upon the potential for an increase in the risk of a fatal cancer balanced against the risk of taking a protective action, such as evacuation. Federal radiation protection criteria, including the EPA PAG Manual, are based upon the linear no-threshold hypothesis, which assumes that any exposure to ionizing radiation may linearly increase the risk of developing cancer at some point in the future. This hypothesis assumes that the hypothetical risk of “radiation-induced” cancers is low at low doses. Because studies with low doses (<10 rem) almost inevitably have relatively low statistical power, the findings for radiation and solid cancer incidence are often not statistically significant and cannot therefore be distinguished from the natural incidence of cancer in the population (Ref. 4).

Following the terrorist attacks of September 11, 2001, the NRC staff reviewed the EP planning bases in the context of the new threat environment and concluded that they were still valid. However, the staff recognized that some enhancements could be made to the NRC’s EP regulations to address the newly identified threats. In addition, the staff determined that other aspects of the EP regulations could be enhanced, such as updating requirements for evacuation time estimates (ETEs). The ETE is a calculation of how long it would take to evacuate the EPZ of a nuclear power plant.

In December 2004, the NRC staff informed the Commission of its intent to conduct a review of the NRC’s EP regulations and guidance to assess the need for regulatory enhancements (Ref. 5). The staff identified and reviewed several emergency planning issues. Each item was assigned a priority based on the analysis of the issue’s relationship to reactor safety, physical security, EP, the NRC’s strategic goals of openness and effectiveness, and stakeholder impact. As part of the EP review, the staff met with internal and external stakeholders, including representatives of FEMA, on many occasions to discuss the elements of the EP review and plans to update EP regulations and guidance. The NRC staff provided the results of the review and a recommendation to the Commission for its consideration in SECY-06-0200, “Results of the Review of Emergency Preparedness Regulations and Guidance,” (Ref. 6). In its Staff Requirements Memorandum (SRM) SRM-SECY-06-0200 (Ref. 7), the Commission approved the staff’s recommendation and directed the development of a rulemaking plan and guidance changes to enhance the EP regulations and guidance. As a result, the staff identified several

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<sup>2</sup> A rem is a measure of effective dose that accounts for the energy absorbed by human tissue and its medical effects given the type of radiation. To put this in context, an average person in the United States receives about 0.3 rem per year due to naturally occurring sources, including radiation from soil and rocks, space, and naturally occurring elements within the human body.

high priority issues that were the subject of the subsequent rulemaking in SECY-09-0007, "Proposed Rule Related to Enhancements to Emergency Preparedness Regulations (10 CFR Part 50) (RIN 3150-A110)," dated January 9, 2009 (Ref. 8). The EP rule was finalized in 2011 (Ref. 9).

The final EP rule included requirements on updating ETEs, which help to inform evacuation strategies. The NRC requires power reactor licensees and applicants for certain other facilities to prepare ETEs under Section 50.47(b)(10) of Title 10 of the *Code of Federal Regulations* (10 CFR) and Section IV of Appendix E to 10 CFR Part 50, covering transient and permanent residents of the 10-mile EPZ using the most recent U.S. Census Bureau data. The ETE also considers the impact of "shadow evacuation" of populations beyond the 10-mile EPZ, as discussed later in this report. Licensees and offsite response organizations (OROs) use ETEs to inform protective action decisionmaking during an emergency. Licensees and OROs also use ETEs in advance of an emergency to develop traffic management plans to minimize delays during an evacuation. Since the ETE is used as an information tool and not as a "go/no-go" basis for a licensing decision, the rule does not set a required maximum evacuation time.

In addition to rulemaking, the NRC commissioned two studies of evacuations and emergency planning for a variety of disasters with different causes that had occurred within the United States. The first study followed the September 11, 2001, terrorist attacks and examined the efficacy of evacuation as a protective measure (Ref. 10). Specifically, the efficiency and effectiveness of public evacuations of 1,000 or more people in response to natural disasters, technological hazards, and malevolent acts occurring in the United States between January 1, 1990, and June 30, 2003 were studied. A set of 230 evacuation incidents was identified, with a subset of 50 incidents selected for case study analysis. The criteria for case study selection were designed to identify evacuation incidents of sufficient complexity to challenge the local and regional emergency response capabilities. Planning officials and first responders were the primary participants in the study. Statistical methods, including regression and correlation analyses, were used to identify factors contributing to evacuation efficiency. The study revealed that large-scale evacuations in the United States, whether pre-planned or ad hoc, safely evacuated people from the area, saved lives, and reduced the potential number of injuries from the hazard.

The second study, following Hurricane Katrina (Ref. 11), assessed Hurricanes Katrina, Rita, and Wilma, and eight other events that triggered large-scale evacuations that occurred primarily after the concluding date of the prior study. The study set out to determine whether the emergency planning activities were effective in managing the response effort. The 11 incidents occurred across a wide geographical area<sup>3</sup> and affected EPZs of 14 NPPs. Researchers engaged in discussions with emergency response personnel to determine the scope of the planning and compared the plans to the NRC emergency planning standards located in 10 CFR 50.47(b). Many of the standards developed for the NPP EPZs had been incorporated into the planning for these 11 incidents. Evacuations related to these events identified issues not previously encountered during large-scale evacuations, such as specific considerations associated with the evacuation of vulnerable populations, including the homeless, the elderly, people with physical and mental disabilities, people with chronic illnesses, children, and non-English speakers. Importantly, this study also found that emergency planning for NPPs had substantially anticipated and addressed these issues.

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<sup>3</sup> None of the evacuations were related to NPP operations.



An understanding of the public's knowledge of, and confidence in, protective actions can improve regulatory decisions about protective actions. Therefore, in 2008, the NRC undertook a third study to examine residents' understanding of protective action strategies within the 10-mile EPZs around NPPs (Ref. 12). To accomplish this, a national telephone survey of residents living within NPP EPZs (in both higher density population areas and lesser populated rural areas) was conducted to obtain data needed to develop an understanding of public attitudes towards EP.

The survey data indicated the following:

- Residents are generally well-informed about what to do in the event of an NPP emergency.
- Most residents remembered receiving emergency response information from the NPP's operator and kept it readily accessible.
- Most residents recalled receiving information regarding evacuation and sheltering.
- Most residents stated that they would evacuate, shelter, or monitor for more information, if so directed.
- Most residents stated that they would support a staged evacuation order (i.e., shelter while others evacuated).
- Many parents stated that they would go to schools to pick up children, even if they were told that their children are already being evacuated.
- Most special needs persons who are not in specialized facilities had not registered for evacuation assistance.

Subsequently, the NRC and FEMA have worked together to revise NUREG-0654/FEMA-REP-1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants." Enhancements identified from the NRC telephone survey and focus group study are included in the forthcoming revision. For example, the study showed that many individuals with special needs are hesitant to release personal information to emergency response officials. State and local officials have undertaken efforts to identify and register these individuals who do not reside in specialized facilities. Since these studies were published, there has been greater awareness of all-hazards EP and planning for schools, and significant outreach and education has been undertaken by school districts and individual schools on evacuation of students and family reunification. FEMA has prepared the "Multi-hazard Emergency Planning for Schools Toolkit" website (Ref. 13) to assist school, local, and State officials with the development of effective all-hazards response plans.

As discussed above, the NRC's regulatory framework regarding evacuation has evolved over many years and incorporated numerous lessons learned and study results. That framework, developed in cooperation with FEMA and EPA, has been demonstrated to be effective. The following sections of this report provide additional information and address specific subjects identified in Section 105 of NEIMA.

### **LARGE-SCALE URBAN EVACUATION (Sec. 105(a))**

Large-scale urban evacuations are not uncommon in the United States. They occur with some predictability because of mandatory evacuations in advance of large-scale hurricanes. For example, Hurricane Katrina, in 2005, resulted in the evacuation of over one million people from the Gulf Coast with more than 150,000 people evacuating from New Orleans. Hurricane Rita, in 2005, resulted in the evacuation of almost 2 million residents from Houston/Galveston. Hurricane Gustav, in 2008, resulted in the evacuation of over 200,000 residents from New Orleans; and Hurricane Harvey, in 2017, forced thousands of residents of Houston to leave.

The NRC staff has studied many of these evacuations for lessons learned that could be applied to NPP evacuations. These studies were published as NUREG/CR reports, as discussed above.

There are notable differences between evacuations triggered by natural disasters such as hurricanes, storms, wildfires, and flooding and an evacuation triggered by a radiological event at an NPP. For example, the area for which an evacuation may be ordered for an NPP accident would have a smaller footprint than a hurricane evacuation—a 10-mile EPZ for the NPP compared to potentially hundreds of miles for hurricanes, storms, and large wildfires. Another difference is the nature of the threat to public health and safety. During a hurricane, wildfire, or chemical disaster, the public is evacuating due to an immediately dangerous threat to life or health. On the other hand, during an NPP accident, the public is evacuating to reduce the potential for any radiation exposure (and thus any potential future health effects). There are similarities in planning for all of these disaster scenarios that include protective action decisionmaking. For almost all disasters and technological events, including radiological events at NPPs, protective action decisionmaking considers windspeed and direction.

The evacuation that occurred because of the terrorist attack at the World Trade Center complex in New York City on September 11, 2001, provided unique data to consider.<sup>4</sup> Five hundred thousand people were stranded south of the collapsed towers at the lower end of Manhattan Island with no way to leave on their own. An ad hoc evacuation occurred to get these individuals to either New Jersey or Staten Island. The U.S. Coast Guard supported the ad-hoc effort but did not lead or direct this evacuation. Because of this ad hoc effort, 500,000 people were safely transported off the island in approximately 9 hours. Evacuees were met by volunteer staff to provide medical care and to decontaminate them (i.e., chemically/biologically clean them). Buses then moved the evacuees to transit centers or other safe destinations. The NRC discussed the findings and lessons learned from this ad hoc evacuation with researchers from the University of Delaware Disaster Research Center, who studied this evacuation in detail (Ref. 14). The researchers found that the people who responded to provide help were not aware at the time of the magnitude of the event or that their own lives could be in peril. They responded because “they had to help.” The researchers believe, based on their analysis of this event and experience in this field of study, that people will respond in this same manner regardless of the nature of a threat, the size of the communities, or the extent of involvement by Federal authorities.

The NRC considers this event illustrative of the expectation that large-scale evacuations are viable even in the absence of detailed planning and even in densely populated areas.

### **SUPERSTORM SANDY (Sec. 105(a))**

As Superstorm Sandy approached the east coast of the United States in 2012, the NRC focused on the safety of NPPs in the storm’s path. Additional inspectors were sent to augment the resident inspectors assigned to the potentially affected sites to provide for 24-hour coverage. In addition, the NRC shifted to an elevated response mode that involved the activation of the Incident Response Centers in NRC Regions I and II (in King of Prussia, PA and Atlanta, GA, respectively) and the Operations Center at the NRC Headquarters office in Rockville, MD.

Throughout the event, the NRC also worked closely with State, county, and Federal partners, including FEMA. As the storm struck, the plant closest to the eye of the hurricane, Oyster Creek Nuclear Generating Station in New Jersey, was already shut down for non-storm-related

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<sup>4</sup> This evacuation was not included in prior NRC studies.

reasons but had to cope with flooding conditions and a temporary loss of offsite power. Three other reactors shut down due to the storm's effects.

Superstorm Sandy assumed different forms during its brief but destructive course. At different times it was a hurricane, a tropical storm, or a post-tropical cyclone. Many response officials believe that, due to the rapidly changing nature of the storm and downgraded warnings, residents of vulnerable communities may have been confused about the risk of the storm or had a false sense of security (Ref. 15). The number of New York City residents who evacuated in response to orders, at any point in time, was less than 50 percent (Ref. 16). Similar numbers were reported for coastal New Jersey populations that were ordered to evacuate.

According to one author, an important reason for the refusal to evacuate was that, in the prior year, New York residents had been warned to evacuate due to Hurricane Irene, but this hurricane did not have the predicted impact (Ref. 16). As a result, some residents displayed an attitude of nonchalance when Superstorm Sandy was approaching that was reinforced by the frequently changing forecasts regarding the storm track and intensity. Furthermore, most New York residents had little experience responding to hurricanes. As a result, many misjudged the appropriate response, and many disregarded the evacuation orders (Ref. 15). This human factor plays an essential role during evacuation processes, as people often measure the risks against their past experiences (Ref. 17). In addition to this psychological element, a significant obstruction to the efficiency of evacuations turned out to be the lack of knowledge of the evacuation zones<sup>5</sup> (Ref. 15).

A number of lessons learned from Superstorm Sandy have been addressed as part of the long-standing EP plans for offsite populations around NPPs. For example, NRC regulations require the development of evacuation plans, traffic management plans including pre-determined evacuation routes, and periodic public education regarding the evacuation plans and routes for populations within the 10-mile EPZ. Evacuation routes are also included in the prepared messages that would be distributed through various emergency broadcast media. To ensure timely actions, licensees are required to promptly notify State officials of problems at the NPP, and offsite officials are required to promptly issue protective action decisions to the public. These notifications are made by various means, including sirens, social media, tone alert radios, and route alerting.

The Superstorm Sandy experience highlights the value of a culture of preparedness, and it indicates the importance of evaluating hazards applicable to the community and designing EP plans capable of an appropriate protective response to the hazards.

#### **EVACUATION TIME ESTIMATES AND SHADOW EVACUATIONS (Sec. 105(b)(1)(B) and Sec. 105(b)(2))**

ETEs provide a tool for planning and protective action decision-making for each NPP site. Licensees are required to estimate the time needed to evacuate the public from the plume exposure pathway. ETE analyses are conducted to accomplish several objectives. First, they provide data to emergency decision-makers that indicate whether evacuation can be implemented in time to reduce any potential radiation exposures significantly. Second, they can be used to determine whether ETEs are significantly affected by events such as adverse weather. Third, they indicate whether traffic management actions would significantly reduce evacuation times and provide information relevant to the development of effective traffic

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<sup>5</sup> "Evacuation zones" are geographical areas that define the potential area of impact and allow prioritizing protective action activities, including evacuation, based on proximity of the populations at risk to the hazard.

management plans. Also, there are ETEs for evacuating different segments of the EPZ and the entire 10-mile EPZ under various conditions and scenarios, including those unique to each NPP site.

The NRC's regulations in 10 CFR Part 50, Appendix E, Section IV require that licensees update the ETEs every 10 years (to coincide with the frequency of the U.S. Census Bureau reports) or when there are significant population changes. The most recent update to the guidelines for licensees to use when developing ETEs addresses shadow evacuation criteria (Ref. 18). Shadow evacuation is defined as evacuation by persons outside of any officially declared evacuation zone. A shadow evacuation of 20 percent of the permanent resident population, based on U.S. Census Bureau data, is assumed to occur in areas outside of the evacuation area extending out to 15 miles from the NPP. The 20 percent value is a generic assumption across all NPP sites to support a standardized assessment. The NRC conducted a telephone survey and focus groups to assess the likely response of EPZ residents to a radiological incident and gained extensive knowledge regarding the expected response of EPZ residents (Ref. 12). From this research, the NRC determined that approximately 20 percent of the resident population in the area out to 5 miles beyond the EPZ would likely self-evacuate. A shadow evacuation would likely occur in a diminishing manner, with the highest potential for a 20 percent shadow evacuation to occur from the areas that are closer to the ordered evacuation area and the potential decreasing as the distance increases from the NPP.

The NRC recently commissioned an independent review of its draft ETE guidance. The ETE study's insights will help to inform the NRC staff's efforts to enhance existing guidance in support of the next required ETE update (consistent with the 2020 census) and to test the validity of the NRC's 20 percent shadow evacuation metric. This applied research, performed by evacuation experts at Louisiana State University, examined various aspects of ETE studies. Evacuation models were built to represent small, medium, and large population EPZs. Analyses were then conducted to examine the modeling of traffic movement during evacuations, including the impact of shadow evacuations, and effectiveness of manual traffic control.

In this study, shadow evacuation rates were modeled to range from 0 to 100 percent in the small population site and from 0 to 40 percent in both the medium and large population models. Prior evacuation time estimate studies had shown that shadow evacuation has minimal impact on ETEs for the small population site, and the 100 percent participation assumption in this study was for research purposes only. The medium and large population models considered a maximum of 40 percent participation in shadow evacuation.

There are difficulties in accurately quantifying a shadow evacuation (Ref. 19 and Ref. 20). Several assumptions are made regarding the population in the shadow evacuation area. Typical scenarios for many NRC consequence analyses include a winter, weekday, and daytime evacuation. Under these conditions, in the shadow evacuation area, people are working, children are at school, and government, commercial, and retail establishments are open for business. Most residents would therefore not be available to participate in a shadow evacuation. Schools and government facilities would likely not evacuate, unless they were ordered to do so; thus, they would likely not be a contributor to the shadow evacuation. A small percentage of parents may choose to leave work and remove their children from school, but this would be done at the individual decision level, not as an organized response. Considering these and other factors, approximately 60 percent of the population within the defined shadow evacuation zone would likely not be available to participate in a shadow evacuation.



In addition, throughout an NPP emergency, State and local officials would continuously update the public. A supplement to the planning guidance intended for use by both licensees and OROs directs that OROs should inform populations in areas beyond the EPZ that they are not under official orders to evacuate to reduce the potential for shadow evacuation (Ref. 21). Although it is possible that some small businesses may choose to close and allow employees to leave, large businesses are not expected to close in areas where no evacuation order has been issued. To the contrary, in past (non-nuclear) emergencies, commercial and service industries outside of designated evacuation areas have often been observed staying open and providing for the needs of the evacuating public.

The analyses showed no significant increase in ETEs at the medium population site because of shadow evacuations. An increase of more than 30 minutes in the 10-mile "90 percent ETE"<sup>6</sup> was observed in the large population site model when the shadow evacuation was increased to 40 percent from the 20 percent assumption. However, the increase did not affect the 2-mile and 5-mile ETEs. That is, shadow evacuation is not an impediment to those most at risk.

In summary, the NRC staff concluded that the current regulatory guidance of a 20 percent shadow evacuation participation in the 10-to-15-mile ring is adequate to capture the impact of shadow evacuation. As noted above, shadow evacuation may lead to increased evacuation time estimates for larger population EPZs. However, shadow evacuation is not an impediment to those most at risk. The ETE study's insights will help to inform NRC staff efforts to enhance ETE guidance in support of the next required ETE update (consistent with the 2020 census). Figure 1 illustrates the consideration of shadow evacuation in the 10-to-15-mile ring around Indian Point Energy Center in Westchester County, New York, as indicated by the star. The nodes (dots) on the roadway network represent traffic control points, intersections, origin points, or destination points. The solid green lines are the roads that were modeled in the forthcoming ETE study. The roadway network greatly expands as the distance from the plant increases allowing for shadow evacuees to move out and away without causing significant delays to the population evacuating from closer to the NPP.

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<sup>6</sup> The "90 percent ETE" is the time required to evacuate 90 percent of the total population in the 10-mile EPZ.

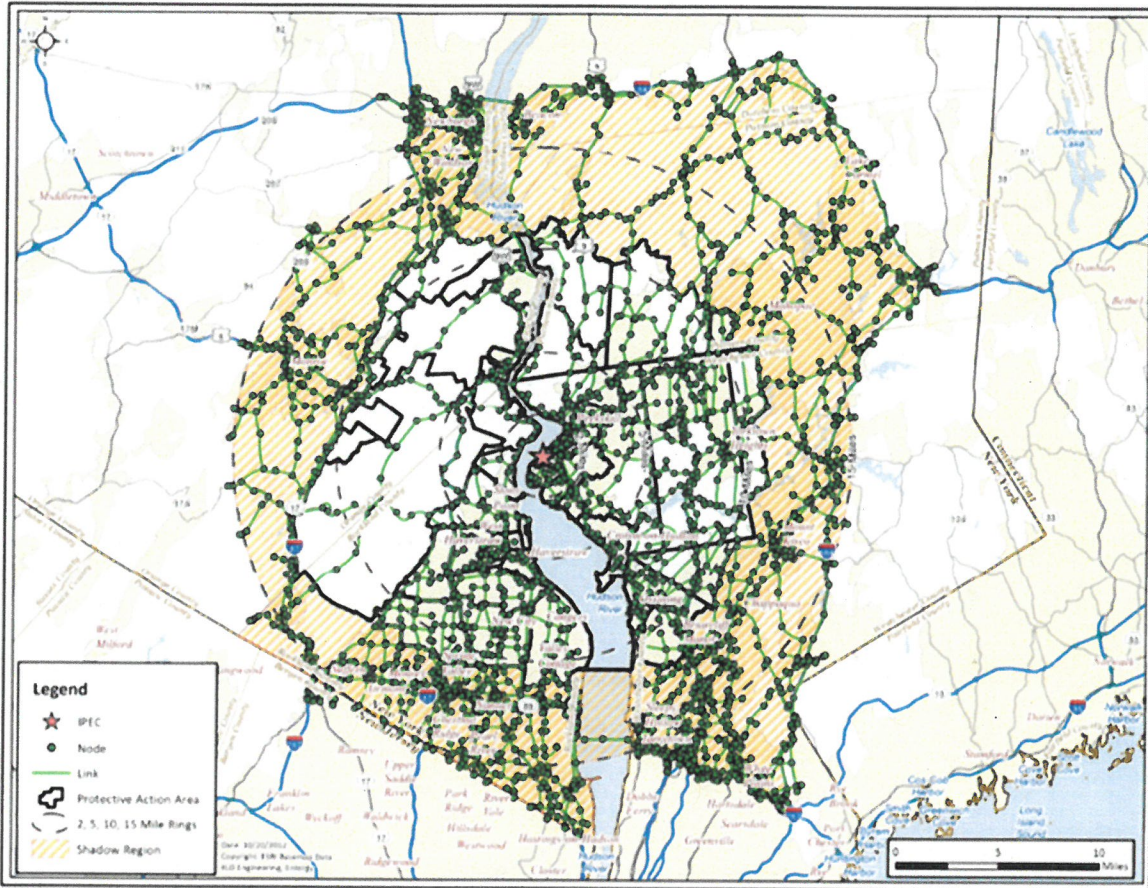


Figure 1 Indian Point Energy Center Development of Evacuation Time Estimates  
p. 1-8, Figure 1.2

**STATE-OF-THE-ART REACTOR CONSEQUENCE ANALYSES PROJECT (Sec. 105(b)(1)(A)(i))**

The NRC initiated the State-of-the-Art Reactor Consequence Analyses (SOARCA) project to develop best estimates of the offsite radiological health consequences for potential severe reactor accidents. The SOARCA project analyzed the potential consequences of severe accidents at representative NPPs (Surry Power Station and Peach Bottom Atomic Power Station). The project began in 2007 and combined up-to-date information about the plants' layout and operations with local population data and EP plans. This information was then analyzed using state-of-the-art computer codes that incorporate decades of research into severe reactor accidents. The results of the analyses of the Surry and Peach Bottom stations are documented in NUREG-1935 (Ref. 22).

The SOARCA project's main findings fall into three basic areas: (1) how a reactor accident progresses; (2) how existing systems and emergency measures can affect an accident's outcome; and (3) how an accident would affect the public's health.

Findings from the SOARCA project include:

- Existing resources and procedures can stop an accident, slow it down, or reduce its impact before it can affect public health. Even if accidents proceed uncontrolled, they take much longer to happen and release much less radioactive material than earlier analyses suggested; and
- The analyzed accidents involving the release of radioactive effluents would cause essentially zero immediate deaths and only a very small increase in the hypothetical risk of long-term cancer effects.

The SOARCA project accounted for changes to plant hardware and operational practices that were not reflected in earlier NRC publications such as improvements in plant systems, power uprates, training, emergency procedures, offsite emergency response, and security-related enhancements. The project used state-of-the-art computer modeling with the MELCOR code for accident progression analyses and the MELCOR Accident Consequence Code System, Version 2, for offsite consequence analyses.

Several accident scenarios were analyzed in the SOARCA project. The weather patterns selected for the analyses in the SOARCA project were intentionally selected so as to be neither overly optimistic nor pessimistic. This was done to provide the best, most realistic estimate of the risk to the public. If worst-case weather or worst-case accidents had been chosen, it would have reduced the probability of the event; the SOARCA project attempted to identify the more important accident scenarios based on a frequency-of-occurrence perspective. This boundary condition allowed the study to analyze in detail the phenomena of these accidents.<sup>7</sup>

The SOARCA project considered aspects of emergency response, including relocation from areas of relatively high potential for exposure, as well as variations of evacuation and sheltering of population groups outside the 10-mile EPZ to 20 miles from the plant in determining impacts to public health. This step of the SOARCA process also recognized that OROs will take necessary actions as detailed in their offsite emergency plans to reduce the risk to the public in the unlikely event of an accident. The NRC used site-specific information from OROs to support protective action timelines used in the models. The licensees provided ETEs and other relevant information. The analyses for the SOARCA project showed no early fatalities due to the slower-developing accidents, lower source terms than had been assumed in previous analyses, and the effectiveness of EP when plans are implemented as written, approved, practiced, and inspected.

While SOARCA models are not used as a basis for emergency planning regulations, insights from the studies, with the inclusion of EP actions in the modeling, indicate that the current EP regulatory structure provides reasonable assurance of adequate protection of the public health and safety in the unlikely event of a severe NPP accident (Ref. 23).

#### **INTERNATIONAL SCIENTIFIC ORGANIZATIONS (Sec. 105(b)(1)(B) and Sec. 105(c))**

The NRC staff maintains awareness of, and involvement with, international scientific organizations that continue to monitor the health and environmental impacts of the radioactive releases from the Chernobyl and Fukushima Dai-ichi reactor sites. These organizations include, for example, the International Atomic Energy Agency (IAEA), the United Nations

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<sup>7</sup> A full-scope probabilistic risk analysis is underway at the NRC to address a full range of accidents, including those even less likely than the highly unlikely accidents analyzed in the SOARCA project.



Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the World Health Organization (WHO). The NRC staff reviews new information as it is released from health studies on the affected populations at Fukushima and Chernobyl, including the Fukushima Health Management Survey. To date, the results of these ongoing studies agree with the NRC basis for EP. NRC staff members participate regularly in international committees with UNSCEAR and IAEA. This routine participation ensures that the NRC staff is up to date on current findings and thinking regarding the impacts of these accidents.

### **BEHAVIORAL RESPONSES TO RADIOLOGICAL EMISSION EVENTS (Sec. 105(b)(1)(B) and Sec. 105(c)(3))**

Many of the health impacts from radiological emission events have resulted, not from direct effects of radiation, but from the stresses of evacuation, relocation, and the perception of being a radiation victim. The NRC staff participates in both international and national level committees examining the behavioral responses to radiation events. Fortunately, these events have been few. Consequently, there has been limited opportunity to study behavioral responses to radiation events. At both Chernobyl and Fukushima, the impacted public followed the guidance issued by officials and evacuated or relocated when directed. The NRC's studies of evacuations have shown that the public generally responds to directions issued by emergency management officials to evacuate.

The European Organisation for Economic Co-operation and Development's Nuclear Energy Agency Working Party on Nuclear Emergency Matters (NEAWPNEM) is working with the WHO on a report that examines psychosocial impacts of radiation events. The NRC staff actively participates on the NEAWPNEM and is engaged in the development of this report and an upcoming workshop scheduled for 2020. The staff also closely follows the scientific literature for papers that discuss behavioral responses to Fukushima as well as studies of the impacts on the public in the United States from hypothetical significant radiation events such as radiation dispersal devices and improvised nuclear devices. Additionally, the NRC staff works closely with other Federal agencies in the development of radiation risk communication tools and strategies, and public education materials, through its participation on the Federal Radiological Preparedness Coordinating Committee (FRPCC).

### **SMALL MODULAR REACTORS (SMR) AND OTHER NEW TECHNOLOGIES (Sec. 105(b)(1)(A)(ii))**

In the early 2000s, the NRC anticipated that future small modular reactor (SMR) and other new technology (ONT) applications would reflect a wide range of potential designs with smaller source terms than the current fleet of large light-water reactors and inherently incorporate EP considerations into the design. The Commission's 2008 Policy Statement on the Regulation of Advanced Reactors (Ref. 24) stated that the Commission "expects that advanced reactors will provide enhanced margins of safety and use simplified, inherent, passive, or other innovative means to accomplish their safety and security functions."

The NRC has a long-standing practice of licensing facilities (including certain NPPs) that have smaller EPZ sizes than large light-water reactors as well as facilities for which there is no mandated offsite radiological EP plan. Lower-risk, smaller power reactors such as Big Rock Point and Ft. St. Vrain were licensed with a 5-mile EPZ.<sup>8</sup> Research and test reactors and most fuel facilities are not required to have offsite radiological EP plans due to the lower risk of offsite

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<sup>8</sup> Both plants are now permanently shut down.



impacts to public health and safety. While the current EP requirements in 10 CFR 50.47(c)(2) allow for licensees to request exemptions, these regulations did not consider advances in designs and safety research and their applications to the future operation of SMRs and ONTs. Rather than regulating by exemptions, the Commission is considering a draft proposed rule that would amend regulations and develop implementing guidance to create an alternative EP framework for SMRs and ONTs (Ref. 25).

The NRC staff's objective behind the draft proposed rule for SMRs and ONTs is to establish a set of EP requirements that would (1) continue to provide reasonable assurance that adequate protective measures can and will be implemented by an SMR or ONT licensee; (2) promote regulatory stability, predictability, and clarity; (3) reduce expected requests for exemptions from EP requirements; (4) recognize technology advancements embedded in design features; (5) credit safety enhancements in evolutionary and passive systems; and (6) credit the potential benefits associated with postulated accidents, including slower transient response times and relatively small and slow release of fission products, for smaller-sized reactors and non-light-water reactors.

The draft proposed rule and draft implementing guidance would adopt a consequence-oriented, risk-informed, performance-based, and technology-inclusive approach. The draft proposed rule would consider the risks posed by operation of the reactor, would include a scaling approach for determining the size of the plume exposure pathway EPZ, and would increase regulatory predictability and flexibility in the development of an alternative generic approach that designers, vendors, and applicants could use to determine the appropriate plume exposure pathway EPZ for SMRs and ONTs that emergency planning would otherwise need to be addressed on a case-by-case basis.

The planning basis for the existing EPZ requirements in 10 CFR Part 50 was established in NUREG-0396, "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light-Water Nuclear Power Plants," (Ref. 26) and was based on the objective that emergency response plans should provide dose savings for a spectrum of accidents that could produce offsite doses in excess of the EPA early-phase Protective Action Guides (PAGs). In the PAG Manual (Ref. 3), EPA provided recommended numerical PAGs for the principal protective actions available to public officials during a radiological accident, including guidance for early phase protective actions for projected doses ranging from 1 to 5 rem during the first 96 hours of an accident.

As described in the regulatory basis (Ref. 26), the draft proposed rule would establish a plume exposure pathway EPZ boundary that provides public protection from dose levels above a 10 mSv (1 rem) threshold over a 96-hour period. The primary purpose of the plume exposure pathway EPZ is to provide an area where predetermined protective actions are implemented that result in dose savings and a reduction in potential health effects. The EPA identified the 1-rem PAG dose as the threshold above which consideration of offsite radiological protection is appropriate. At doses below that limit, NRC's understanding is that the EPA determined that there was a greater risk to public health of implementing the PAG compared to the possible health benefits. This determination was based on evacuation traffic accident deaths compared to the hypothetical increase in risk of developing a fatal cancer.

In determining this boundary under the draft proposed rule, the applicant would consider plume exposure doses from a spectrum of credible accidents for the facility. The proposed rule would apply the same dose standard for predetermined protective actions to SMRs or ONTs as is required of the current operating large NPPs. By maintaining this consistency, the regulations

described in the proposed 10 CFR 50.33(g)(2) would afford the same level of protection of the public health and safety as the current regulatory framework. Because the dose criteria under which predetermined protective actions would be taken (e.g. evacuation, sheltering) would be similar under both rules, the dose consequence to the public would be similar and therefore human health impacts would be similar. In practice this means that, in the draft proposed rule, the PAG dose would become a bounding parameter for the EPZ size. For a new, lower-risk facility, if the PAG dose would not be exceeded at a distance from the facility that is less than the 10-mile EPZ for large light-water reactors, then the EPZ for the new facility could be smaller than 10 miles. Under this approach, if the PAG dose would not be exceeded at the site boundary, then the EPZ size could be limited to the site boundary, and formal radiological EP planning would be an on-site requirement only.

In summary, in the draft proposed rule, the NRC staff has proposed to align SMR and ONT EP requirements according to the risk posed by the facility. Under the proposed rule, for facilities of very low risk (i.e., the PAG dose would not be exceeded at the site boundary), formal offsite EP would not be required. In such cases, the NRC staff believes that all-hazards EP is adequate to ensure that required protective actions are taken to protect public health and safety. Therefore, the NRC staff has proposed to the Commission a consequence-oriented, performance-based, and technology-inclusive rule that would continue to provide for reasonable assurance of adequate protection of public health and safety.

#### **CONSULTATION WITH THE FEDERAL RADIOLOGICAL PREPAREDNESS COORDINATING COMMITTEE (FRPCC) AND STATES (Sec. 105(c)(1) and Sec. 105(c)(2))**

The NRC staff shared a draft of this report with FEMA and the FRPCC, which is composed of representatives from 20 Federal agencies (including FEMA) that have an interest in radiological matters. The role of the FRPCC is to assist FEMA in providing policy direction for the program of Federal assistance to State and local governments in their radiological emergency planning and preparedness activities (Ref. 27). Representatives from FEMA and the FRPCC provided comments on this report in a teleconference followed up by a letter (Ref. 28). Some general themes emerged during member and NRC staff discussions of the draft. Several FRPCC members expressed concern that the unique aspects of radiological offsite preparedness do not receive adequate consideration when forced into an all-hazards response framework. FEMA had previously addressed this type of concern in its Comprehensive Preparedness Guide (CPG) (Ref. 1), which recognizes that characteristics of emergency events may be unique, but the general tasks for implementing protective measures are the same across events. The CPG recognizes that some jurisdictions participate in special preparedness programs that publish their own planning guidance. These include the Chemical Stockpile Emergency Preparedness Program and the Radiological Emergency Preparedness Program. The CPG directs the participating jurisdictions to ensure that they meet the special planning requirements for these programs either by incorporating the requirements across functional annexes or by developing a hazard-specific annex or program.

To consult with State EP officials, the NRC staff engaged the Conference of Radiation Control Program Directors (CRCPD). The CRCPD's primary membership is made up of radiation professionals in State and local governments that regulate the use of radiation sources. As with the FRPCC, a follow-up teleconference was held with the CRCPD to discuss the document and their comments. CRCPD expressed concern with the possible licensing of NPPs without formal and evaluated offsite radiological EP plans.

## CONCLUSION

Emergency planning is a dynamic process. The NRC staff remains active and engaged in studying events that may not involve NPPs but could impact EP and planning. The NRC SOARCA report insights on accident progression and the reviews of NRC EP regulations and guidance following the lessons learned from the terrorist attacks of September 2001, Hurricanes Katrina and Rita in 2005, the tsunami and accident at the Fukushima Nuclear Power Station, and Superstorm Sandy reaffirm that the NRC emergency planning bases for the current fleet of large light-water NPPs remain valid. The NRC staff has proposed a rule to align EP with risk to support the potential for a reduced-size EPZ or eliminating formal offsite radiological emergency preparedness for the licensing of SMRs and ONTs. Importantly, the studies show that, even in those areas without formal planning, ad-hoc evacuations as a protective action can be effective should an evacuation be necessary. The NRC remains confident that people can be evacuated successfully from the designated evacuation areas around NPPs, including relatively densely populated areas, in the unlikely event of a severe radiological accident.

### Acronyms

ADAMS	Agencywide Documents Access and Management System
CFR	Code of Federal Regulations
CPG	Comprehensive Planning Guide
CRCPD	Conference of Radiation Control Program Directors
EP	Emergency Preparedness
EPA	Environmental Protection Agency
EPZ	Emergency Planning Zone
ETE	Evacuation Time Estimate
FEMA	Federal Emergency Management Agency
FRPCC	Federal Radiological Preparedness Coordinating Committee
IAEA	International Atomic Energy Agency
NEA\WPNEM	Nuclear Energy Agency Working Party on Nuclear Emergency Matters
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
ONT	Other New Technology
ORO	Offsite Response Organization
PAG	Protective Action Guide
Rem	Roentgen equivalent man (unit)
SOARCA	State-of-the-Art Reactor Consequence Analyses
SMR	Small Modular Reactor
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

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