U.S. Department of Homeland Security
Federal Emergency Management Agency
National Preparedness Directorate
Radiological Emergency Preparedness
500 C Street, S.W.
Washington, DC 20472

FEMA

October 23, 2007

Dr. John H. Marburger III
Director, Office of Science
and Technology Policy
Executive Office of the President
Washington, D.C. 20502

Dear Dr. Marburger:

The purpose of this letter is to convey to you the attached, "Interagency Technical Evaluation Paper for Section 127(f) of the Bioterrorism Act of 2002" prepared by the Potassium Iodide (KI) Subcommittee of the Federal Radiological Preparedness Coordinating Committee, at your request.

In your memorandum dated July 5, 2007, "Interagency Technical Evaluation Process for Section 127(f) of the Bioterrorism Act of 202," it was indicated that you would seek the assistance of the FRPCC to conduct a technical review and gather data on the impacts and effects of alternatives to the distribution of potassium iodide (KI) in the 10-20 mile zone around nuclear power plants. At the July 17, 2007, FRPCC meeting, Stan Sokul and Tammy Taylor of your staff formally requested the assistance of the FRPCC in this matter. The FRPCC membership agreed to provide the requested assistance and assigned the KI Subcommittee the task of conducting the technical review.

In drafting the paper, the Subcommittee honored the request of your office to gain specific "lead" agency review and approval of the chapters that encompass issues within each lead agency's particular area of expertise. Specifically, "lead" agency approval was obtained as follows:

- Most of Chapter 1, Basis for Emergency Planning, NRC lead;
- Section 1.12, entitled "Dose and Health Effects", HHS lead;
- Section 1.13, entitled "Reactor Accident Exposure Pathways, EPA and HHS lead;
- Section 1.14, entitled "Emergency Preparedness and Nuclear Power Plants, NRC and FEMA lead;
- Chapter 2, Basis for Iodine Prophylaxis, HHS lead;
- Chapter 3, Potassium Iodide as a Thyroid Blocking Agent, HHS lead; and,
- Chapter 4 (Emergency Preparedness) and Chapter 5 (State Plans and Programs), NRC and FEMA lead.

The initial draft of the technical evaluation paper developed by the KI Subcommittee was briefed to you and your staff by the KI Subcommittee co-chairs, Trish Milligan, NRC, and Dan Wilcox, FEMA, on September 5, 2007. Minor revisions were made based on your request for additional information and the draft was distributed to FRPCC members for their review and comment. It was then finalized and formally approved by the FRPCC during their last meeting on September 25, 2007.

Representatives from the departments and agencies listed on the front of the attachment provided their time and the technical expertise needed to develop this paper. I would be remiss if I did not specifically mention the hard work and effort put into this project by Trish Milligan, KI Subcommittee Co-Chair. Her technical knowledge and willingness to spearhead the overall coordination of this technical evaluation paper was invaluable.

If you have any further questions regarding this letter, or the attached technical evaluation report, please contact Dan Wilcox of my staff, 703-605-4211.

Sincerely,

Vanessa E. Quinn

Vanessa E. Quinn
Chair, Federal Radiological Emergency
  Preparedness Coordinating Committee

Attachment

cc: Dennis Schrader, Deputy Administrator for National Preparedness
    Trish Milligan, NRC
    Tammy Taylor, OSTP

Interagency Technical Evaluation Paper for Section 127(f) of the Bioterrorism Act of 2002

Prepared by the Federal Radiological Preparedness Coordinating Committee
Subcommittee on Potassium Iodide

DHS/FEMA, NRC, HHS, DHS, DOE, USDA, FDA, NIH, DOL, DOE/NNSA, DOD/Naval Reactors/AFFRI

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CHAPTER 1

BASIS FOR EMERGENCY PLANNING

1.1 Reactor Accidents, Source Terms, and Risk[1]

The Energy Reorganization Act of 1974 established the U.S. Nuclear Regulatory Commission (NRC) to regulate, among other things, civilian nuclear power plants. Under the 1974 Act and the Atomic Energy Act of 1954, the NRC has the authority to set such standards as it deems necessary to protect public health and safety and the common defense and security. Under this general authority, the agency issues orders, rules, policy statements, and guidance; conducts inspections; and enforces compliance with its standards. Among its standards are rules and orders that govern emergency planning at nuclear power plants.

The NRC's policy statement on "Safety Goals for the Operation of Nuclear Power Plants"[2] established goals that broadly define an acceptable level of radiological risk. The NRC established two qualitative safety goals, which are supported by two quantitative objectives. These two objectives are based on the principle that nuclear risks should not be a significant addition to other societal risks such that individuals living or working near nuclear power plants should be able to go about their daily lives without special concern because of their proximity to the plant, and that the risks of nuclear power plant operation should be comparable to or less than the risks from other viable means of generating the same quantity of electrical energy.

To determine the achievement of the qualitative safety goals, the NRC adopted two health effects as quantitative objectives—(1) the risk to an average individual who resides within 1 mile from the plant site boundary should not exceed 0.1 percent of the sum of prompt fatality risks from other general accidents (e.g., fatal automobile accidents), and (2) the risk to the population within 10 miles of the plant site should not exceed 0.1 percent of the sum of cancer fatality risks from other causes. The individual risk of a prompt fatality from all "other accidents" is about 5×10^{-4} per year, and the risk to the population from cancer from all "other causes" is about 2×10^{-3} per year. Using these data and the quantitative health objectives established by the NRC, the risk of prompt fatality and fatal cancer should be limited to 5×10^{-7} per year and 2×10^{-6} per year, respectively.[3]

A major element of the NRC's safety philosophy is to employ measures to prevent accidents or lessen the effect if an accident occurs at a nuclear facility (i.e., accident prevention and accident mitigation). Risk objectives for accident prevention (i.e., core damage frequency (CDF)) and accident mitigation (i.e., large early release frequency (LERF)) were established that also serve as surrogates for the NRC's two health objectives, cancer fatality and prompt fatality. These surrogate objectives include a CDF of 1×10^{-4} per year and an LERF of 1×10^{-5} per year. For currently operating U.S. nuclear power plants whose estimated CDF and LERF do not exceed these objectives, the NRC's quantitative health objectives would also not be exceeded.

The risk of an accident at U.S. nuclear power plants has not challenged the safety goals established by the NRC, and the risk has decreased over time. Although two plants, Peach

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[1] Public Law 107-188, "BioShield Act," Section 127, "Potassium Iodide," applies the consideration of the distribution of potassium iodide (KI) to populations within 20 miles of a nuclear power plant.

[2] http://www.nrc.gov/reading-rm/doc-collections/commission/policy/51fr30028.pdf

[3] ibid

Bottom and Surry, are used as examples below, the trend is similar for all U.S. nuclear power plants. The NRC and industry have made great strides in determining and understanding the risks from nuclear power plants. In 1975, the Reactor Safety Study (WASH-1400)[4] was completed. Its objective was "to try to reach some meaningful conclusion about the risk of nuclear accidents." This study examined the risk associated with (1) Peach Bottom, a boiling-water reactor (BWR), and (2) Surry, a pressurized-water reactor (PWR). The CDFs for Peach Bottom and Surry were estimated to be 5×10^{-5} per year and 1×10^{-4} per year, respectively, which is consistent with the latent cancer fatality objective. While the Reactor Safety Study advanced the understanding of the risk of nuclear power plants, it had shortcomings, such as a lack of nuclear data for component failure probability, simplified understanding of radionuclide behavior, and not addressing common-cause failures.

Since the completion of the Reactor Safety Study in 1975, substantial progress in developing probabilistic risk assessment (PRA) (e.g., tools and models) and in the accumulation of relevant data has been made. Programs were initiated, for example, to develop advanced methods to assess the frequency of accidents, to improve the means of collecting and using plant operational data, to develop advanced methods to assess the impact of human error and common cause failures, and to develop advanced methods and models to understand severe accident phenomena (e.g., interactions of molten core material with concrete).[5]

In 1989, the NRC issued NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants."[6] A major objective of this study was to update the estimates from the Reactor Safety Study and to provide realistic (versus conservative) risk estimates that reflect the plant design and operational characteristics. Based on the advancements since the Reactor Safety Study, the scope and level of detail of the analyses performed in NUREG-1150 substantially increased. For example, NUREG-1150 included dependencies among systems, loss-of-coolant accidents (LOCAs) from pump seal failure, loss of direct current power from battery depletion, and late iodine releases. In addition, improvements to nuclear power plants occurred since the Reactor Safety Study; examples include development of symptom-based emergency operating procedures, installation of safety-related hydrogen monitors, and installation of diverse reactor scram systems. Based on the NUREG-1150 results, a general conclusion can be drawn that the risks to the public from the operation of the plants analyzed are, in general, lower than those given in the Reactor Safety Study, and the risks from events occurring internal to the plant are well below the safety goals. NUREG-1150 estimated the CDF for Peach Bottom and Surry (from internal events) at approximately 5×10^{-6} per year and 4×10^{-5} per year, respectively. A reduction of approximately one order of magnitude is observed between the Reactor Safety Study and NUREG-1150 CDF estimates for internal events.

In 1988, the NRC issued Generic Letter 88-20, "Individual Plant Examination for Severe Accident Vulnerabilities,"[7] which requested that each existing plant perform a systematic examination to identify any plant-specific vulnerability to severe accidents and report the results to the Commission. The general purpose of this examination, defined as an Individual Plant Examination (IPE) [8], was for each utility (1) to develop an appreciation of severe accident behavior, (2) to understand the most likely severe accident sequences that could occur at its

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[4] http://www.nrc.gov/reading-rm/adams.html, under Agencywide Documents Access and Management System (ADAMS) Accession No. ML072350618

[5] http://www.nrc.gov/about-nrc/regulatory/research/soar/overview.html

[6] http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1150/

[7] http://www.nrc.gov/reading-rm/doc-collections/gen-comm/gen-letters/1988/gl88020.html

[8] In a supplement to Generic Letter 88-20, the NRC asked licensees to include external events (e.g., seismic events, high winds, floods).

plant, (3) to gain a more quantitative understanding of the overall probabilities of core damage and fission product releases, and (4) if necessary, to reduce the overall probabilities of core damage and fission product releases by modifying, where appropriate, hardware and procedures that would help prevent or mitigate severe accidents. It is expected that the achievement of these goals would help verify that severe core damage and large radioactive release probabilities at U.S. nuclear power plants are consistent with the NRC safety goal policy statement. Each licensee elected, in performing its IPE, to conduct a PRA and calculated CDFs and LERFs. The Commission received the results of these calculations and plant improvements resulting from the examination.

Based on the results of the IPEs, the CDFs at U.S. nuclear power plants are shown to be consistent with the NRC safety goals[9]; that is, the average CDF across the total nuclear power plants is on the order of $5x10^{-5}$ per year, which is below the risk surrogate of $1x10^{-4}$ per year. For Peach Bottom and Surry, the mean CDFs are approximately $5x10^{-6}$ per year and $7x10^{-5}$ per year, respectively. In addition, as a result of the IPE program, licensees identified and implemented plant improvements. These improvements included design, procedural, and maintenance changes. Examples include equipment and procedural changes to allow the use of alternative injection sources (e.g., fire protection system) to the reactor vessel and to the drywell spray in containment, replacing the o-rings in the reactor coolant pumps with a more temperature-resistant design, and installing hardened pipe vents to containment.

These plant improvements, as a result of the IPEs and for other reasons (e.g., increased monitoring of structure, system, and component performance to ensure their functionality), have resulted in decreases in the number of initiating events and the number of safety system failures. These improvements have contributed to the decrease in CDF and LERF. Current NRC analyses demonstrate this trend. Continuing from NUREG-1150, the NRC initiated further programs to advance PRA tools and methods. The NRC has been developing standardized plant analysis risk (SPAR) models for each U.S. nuclear power plant. These models take advantage of the improvements in PRA methodology, rely primarily on plant-specific data, represent the as-built and as-operated plant, and use more realistic calculations. In addition, the models reflect the plant improvements that have occurred in the industry. The CDFs estimated for Peach Bottom and Surry, using the NRC SPAR models, are $2x10^{-6}$ and $3x10^{-6}$ per year, respectively.

Starting with the Reactor Safety Study, then NUREG-1150, and now the current risk analyses, the frequency of core damage accidents has decreased, as shown below:

	Peach Bottom	Surry
1975	$5x10^{-5}$	$1x10^{-4}$
1989	$5x10^{-6}$	$4x10^{-5}$
1990s	$5x10^{-6}$	$7x10^{-5}$
Current	$2x10^{-6}$	$3x10^{-6}$

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[9] http://www.nrc.gov/reading-rm/doc-collections/commission/policy/50fr32138.pdf

This reduction is a result of changes in hardware and procedures, advances in PRA technology, accumulation of plant-specific data, and better understanding of plant performance and capabilities under upset conditions. Recent additional safety measures (including both equipment and procedures) that have been incorporated at all nuclear power plants, but not accounted for in the current frequency analyses, should achieve further reductions in CDF.

A similar trend has generally been observed with respect to the likelihood of a large early release. At the time of WASH-1400, containment failure modes would have included containment rupture caused by in-vessel steam explosions, called the α -mode failure. At the time of NUREG-1150, another containment failure mode, direct containment heating, was also considered possible. The NRC undertook extensive analytical and experimental research to specifically address these failure modes because of their potential to influence the likelihood of early containment failure. That research effectively resolved those issues and resulted in the elimination of their significant contribution to containment failure estimates. Additional research carried out domestically and internationally over the past 20 years has improved the characterization of the fission product source term released to the environment and addressed the magnitude and chemical form of fission products as well as their transport and deposition.

The cumulative knowledge gained from the NRC's severe accident phenomenological research of the last 25 years (together with research findings produced by the international reactor research community) has been incorporated into an integrated modeling tool, the MELCOR computer code[10], in order to consistently calculate accident progression and timing. These methods were not available for earlier risk assessments, which had to relay on simpler, often conservative treatment of accident progression and timing. In general, the much more detailed, integrated mechanistic modeling of the reactor coolant system and the containment afforded by use of the MELCOR code produces longer times to core damage, containment failure, and fission product release. For dominant scenarios, the offsite release of fission products may be delayed for 24 hours or longer from the start of an event. The more realistic evaluation of accident timing allows a greater opportunity for additional corrective action to prevent core damage or limit offsite release as well as ample time to carry out emergency preparedness activities such as public protective actions.

1.2 Consideration of Accident Mitigation

The following section discusses nuclear plant emergency preparedness programs more fully, but the purpose of these programs is to protect public health and safety in the event of an unlikely

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[10] MELCOR, as described in NUREG/CR-6619 "MELCOR Computer Code Manuals" ,is a fully integrated, engineering-level computer code whose primary purpose is to model the progression of accidents in light-water reactor nuclear power plants. Current uses of MELCOR include estimation of fission product source terms and their sensitivities and uncertainties in a variety of applications. Reactor plant systems and their response to off-normal or accident conditions include thermal-hydraulic response of the primary reactor coolant system, the reactor cavity, the containment, and the confinement buildings; core uncovering (loss of coolant), fuel heatup, cladding oxidation, fuel degradation (loss of rod geometry), and core material melting and relocation; heatup of reactor vessel lower head from relocated fuel materials and the thermal and mechanical loading and failure of the vessel lower head, and transfer of core materials to the reactor vessel cavity; core-concrete attack and ensuing aerosol generation; in-vessel and ex-vessel hydrogen production, transport, and combustion; fission product release (aerosol and vapor), transport, and deposition, behavior of radioactive aerosols in the reactor containment building, including scrubbing in water pools, and aerosol mechanics in the containment atmosphere such as particle agglomeration and gravitational settling, and impact of engineered safety features (ESFs) on thermal-hydraulic and radionuclide behavior.

severe radiological accident. This is accomplished in two ways—(1) protection of the public through protective actions, such as evacuation, and (2) through mitigation of the accident to prevent, reduce, or delay release of radioactive materials. The effectiveness of various protective actions is the topic of this paper and is discussed fully elsewhere. Mitigative actions may be contained in procedures or may be taken in an ad hoc manner. The emergency preparedness program includes drills and exercises in which response actions are practiced and refined. Drills often include the use of mitigative action procedures and provide an opportunity for discussion and simulation of ad hoc actions. In some important accident scenarios, such as a loss of electrical power, ad hoc mitigative actions that would prevent core damage include using a portable electric generator to recharge control system batteries or using a fire truck to pump water into a system. Ad hoc mitigative actions practiced in drills have resulted in procedural enhancements and enhancements to equipment available for emergency response.

In the aftermath of the terrorist events of September 11, 2001, the NRC ordered nuclear plants to make improvements to security, emergency preparedness, and accident mitigation capabilities. Oversight, review, and, in the case of emergency response, development activities in these areas continue, but enhancements to accident mitigation capability are currently being completed. These enhancements include equipment such as diesel powered pumps and electric generators to facilitate accident mitigation.

When an emergency is declared at a nuclear plant, the emergency response organization is activated and reports to its response centers to focus on the protection of public health and safety and the mitigation of accident consequences. The response organization includes many management and technical staff members such as licensed plant operators, engineers and health physicists. These personnel focus on preventing further degradation, ensuring that procedural actions are properly taken to mitigate the accident, and developing ad hoc actions where necessary.

The past assessments of reactor accident risk discussed above do not fully consider all mitigative actions or the efficacy of ad hoc actions. Furthermore, core damage estimates for some accidents are dependant on the assumption that successive operator errors will occur. While there may be a potential for error, the emergency response organization greatly diminishes that potential because of the increased expertise, management attention, and sheer numbers of technical and management staff examining issues and mitigative actions. Current analyses of severe accident progression show that accidents develop more slowly than previously thought. The potential for operator error is also diminished when operators and the supporting emergency response organization have a greater time period to evaluate actions to mitigate the accident. While the core damage estimates provided are sound estimates, it should be recognized that the analyses did not quantify all of the actions that the emergency response organization could take to mitigate the accident. Qualitatively, it is very probable that the contribution of the emergency response organization to reduce errors and develop ad hoc mitigative actions decreases even further the likelihood of serious radiological release.

1.2.1 Release Mitigation Measures

A number of release mitigation measures are available:

- Filters—The design of most currently licensed plants incorporates one or more ESF filtration systems. These systems are safety-grade systems and are generally subject to maintenance and testing requirements mandated by technical specification. Filters can exist in two broad configurations—(1) in systems intended to clean up the atmosphere in a particular area (e.g., containment recirculation filters) and (2) in ventilation systems exhausting to the environment. Although many of these filters were designed to minimize radioactivity releases during a design-basis accident, others were installed in the interest of keeping routine occupational exposures and routine effluent releases as low as is reasonably achievable.[11] The normal operating configuration may vary, with some filters always in service and others in a standby mode to be placed in service manually or automatically as needed.

A typical ESF filter bank includes an upstream high-efficiency particulate absorber (HEPA) filter, an activated charcoal absorber bed, and a downstream HEPA filter. The efficiencies of these filters vary as a function of design, but it is not unusual to see HEPA efficiencies of 99 percent or higher and charcoal filter bed removal efficiencies of 95 percent or higher for some chemical forms of radioiodine. A filter with a removal efficiency of 99 percent allows only 1 percent of the upstream contaminant to pass through—a reduction by a factor of 100. ESF filter systems generally incorporate upstream air dryers to remove excess moisture that would significantly degrade filter efficiency.

- Containment and Drywell Sprays—Spray systems can be highly effective in scavenging aerosols and elemental radioiodine. Spray nozzles high in the containment or the BWR drywell (and in some BWR wetwells) create an atomized mist of small water droplets that, as they fall through the sprayed volume, absorb contaminants with reduction factors on the order of 20 or greater per hour. Containment sprays as a means of atmosphere cleanup are part of the design of most PWRs. Although some BWRs have drywell and/or wetwell sprays for pressure suppression, these sprays could be effective in the atmosphere cleanup role as well.[12] (Insights from severe accident studies suggest that common fire suppression sprays can reduce aerosols and elemental radioiodine.)

- Overlaying Pool Scavenging—In this mitigation method, gaseous and aerosol contaminants are scavenged as the release stream rises through an overlaying pool. This mitigation can occur in several locations in a plant, including the spent fuel pool, flooded reactor cavity during refueling, suppression pools in BWRs, and steam generators in a PWR. The design of spent fuel pools provides for a minimum of 23 feet of water above the top of the fuel elements when stored, and fuel-handling accident analyses typically assume that the pool or reactor cavity water retains 99 to 99.5 percent of the radioiodine released from damaged fuel. Similarly, it is typically assumed that the steam generator bulk water will retain 99 percent of the radioiodine released by a primary-to-secondary leak (if the steam generator tubes are covered.) In a BWR, the suppression pool water can retain 80 percent or more of the aerosols and elemental radioiodine in the drywell atmosphere blowdown during a LOCA.

- Radioactive Decay—All radioactive material decays at a rate characteristic to that radionuclide, referred to as its radioactive half-life, defined as the time for 50 percent of the atoms present to decay. At the end of the first half-life, 50 percent remain; after the second, 25 percent remains; and so forth. Holding up a release in the containment or another vessel or building can reduce the environmental release significantly since it allows decay to occur.

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[11] http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-1101.html

[12] NUREG/CR-6042, "Perspectives on Reactor Safety," available at http://adamswebsearch2.nrc.gov/idmws/doccontent.dll?library=PU_ADAMS^PBNTAD01&ID=004069453

Although iodine-131 (^{131}I) has a half-life of about 8 days, the other dose-significant radioisotopes of iodine have much shorter half-lives ranging from seconds to hours.[13] A useful rule of thumb provides that shortly after shutdown the core inventory is reduced with an overall decay half-life of about 20–30 minutes for the first couple of hours. Once the short-lived radionuclides have decayed, the overall decay half-life lengthens.

- Plateout—Several naturally occurring phenomena can reduce the concentration of radionuclides within a vessel or system, including plateout and deposition. Plateout occurs when aerosols or elemental radioiodine in a vapor absorb onto surfaces with which the vapor is in contact. Deposition occurs when an aerosol, falling because of gravitation force, settles on a lower surface.

1.3 Core Damage and Containment Failure

The meaning of the terms "core damage" and "containment failure" may not be clear and tend to communicate a situation more severe than intended. Generally the onset of core damage is considered to occur when reactor coolant drops to the top of the active fuel (TAF). This is a conservative measure as nuclear fuel does not melt at this point, and adequate cooling to prevent core melt can be achieved with a much lower coolant level. Damage to the fuel cladding may occur, but this damage does not result in radiological releases of sufficient magnitude to cause protective actions to be appropriate at distance from the plant because there is no melting of the fuel. However, the coolant level is normally maintained well above TAF, and this level indicates a serious problem as there is a loss of level control. It is likely, although not certain, that the level will continue to decrease and lead to true core damage. For these reasons, TAF is used generally to indicate core damage.

The term "containment failure" is used to mean that the containment is leaking at a rate higher than its design leak rate. "Primary reactor containment" refers to the structure or vessel that encloses the components of the reactor coolant pressure boundary and serves as an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment. "Leakage rate" is that leakage that occurs in a unit of time, stated as a percentage of weight of the original content of containment air at the leakage rate test pressure that escapes to the outside atmosphere during a 24-hour test period. The design leak rate for nuclear reactor containments varies with containment design but is generally between 0.1 and 0.5 percent per day. The calculation example provided in Section 1.6 of this document assumes a 0.5-percent leakage rate per day and a containment volume of about 286,000 cubic feet. The leakage rate would vary with pressure and temperature and is rated at about 1430 cubic feet per day, at 56 pounds pressure and 281 °F. If a containment building fails, it is expected that it would fail at a penetration or closure fixture. While such a failure is important and would lead to a radiological release, the failure is not catastrophic, as might be communicated through the use of the term "containment failure." The areas where a failure might occur are usually enclosed by additional structures or buildings. Any radioactive release must travel through those areas before exiting to the environment. The significant radiological release, including radioactive iodine, is primarily an aerosol, which tends to adhere to surfaces and will diminish by deposition before entering the environment.

1.4 Updated Analyses

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[13] See Section 1.8, Table 1-2 "Fission Products Important to Offsite Consequences."

The NRC previously published studies predicting significant offsite consequences from very unlikely accidents (e.g., WASH-1400). These studies were performed using assumptions that are now known, as a result of extensive experimental research conducted since the accident at Three Mile Island, not to reflect actual nuclear accident behavior. In addition, plants improvements have been implemented by the industry, which improved plant capabilities to in preventing or mitigating the consequences of accidents that can potentially lead to offsite consequences. As a result, the NRC does not currently consider such consequence studies to represent the likely outcome of serious accidents. In order to improve on past-analyses, the NRC developed the MELCOR code, which uses the results from over twenty years of national and international severe accident and sources term research program. The MELCOR code has been used by the staff, to provide a more realistic evaluation of severe accident initiation and progression, radiological release, and offsite consequences for nuclear power plants.

As part of the ongoing refinement in severe accident and off-site consequence analysis, the NRC has begun the State-of-the-Art Reactor Consequence Analyses (SOARCA)[14] project. The SOARCA project is a combined effort of the Offices of Nuclear Regulatory Research (RES), Nuclear Reactor Regulation (NRR), and Nuclear Security and Incident Response (NSIR) to: (1) evaluate and update, as appropriate, analytical methods and models for realistic evaluation of severe accident progression and offsite consequences; (2) develop state-of-the-art reactor consequence assessments of severe accidents and replace such analyses as NUREG CR-2239, "Technical Guidance for Siting Criteria Development," dated December 1982; and (3) identify mitigative measures that have the potential to significantly reduce risk of offsite consequences.

To conduct the analyses, staff will use an improved understanding of source terms and severe accident phenomenology, and credit the use of severe accident mitigation strategies and procedures that were not in place when the 1982 study was performed. In addition to better understanding of accident phenomenology, the analyses will include design, operation, and emergency preparedness improvements to more accurately reflect plant performance and emergency response activities. The combined effect of code improvements, plant's improvements,and realistic consideration of mitigative actions results in substantial decrease in accident consequences.

The scenario analyzed for this paper uses the above mentioned MELCOR code and has a core damage frequency greater than or equal to one-in-a-million chance per year of reactor operation. This threshold value represents a risk which is about 10 times smaller than the NRC's safety goal. The criterion of one in million to discern de minimis risk is used elsewhere in Federal policy development.[15] Although normally used for the risk of a public fatality, in this case it represents the risk of core damage and a potential radiological release. This analysis uses the Peach Bottom nuclear plant as it has been analyzed in the past and is considered representative of BWR plants. This particular scenario involves the loss of electrical power, core damage, and eventually loss of containment and a radiological release. However, a large radiological release does not occur for more than 20 hours. This scenario was further refined and a second scenario analyzed that considers mitigative action that could be implemented to limit loss of containment. It should be noted that a similar mitigative action could prevent core damage itself, but that case was not presented as there would be little radiological release.[16]

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[14] http://www.nrc.gov/about-nrc/regulatory/research/soar/overview.html

[15] Travis, C.C., S.A. Richter, E.A.C. Crouch, R. Wilson, and E.D. Klema, " Cancer risk management: a review of 132 federal regulatory decisions," Environ. Sci. Technol. 21(5):415-420, 1987

[16] See footnote 10 regarding MELCOR.

While this scenario is representative of a credible severe accident, it is important to note, that there are other credible severe accident scenarios that would not result in containment failure for 2 or more days and with mitigative actions do not result in failure at all. Leakage would occur from the large containments surrounding a nuclear plant, but that leakage would not result in doses above protective action levels at distance from the plant.

1.5 Severe Accidents and Emergency Response Timeline

NRC regulations in Title 10, Section 50.47(b)(4), of the *Code of Federal Regulations* (10 CFR 50.47(b)(4)) and Appendix E, "Emergency Planning and Preparedness for Production and Utilization Facilities," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," require licensees to develop an emergency classification scheme whose purpose is to initiate a minimum set of onsite and offsite emergency response actions commensurate with existing plant conditions and the trend of those conditions. The licensee's classification scheme must describe the entire spectrum of emergency conditions that warrant alerting or activating progressively larger segments of the emergency response organization. Licensees must develop emergency action levels (EALs) that accurately and objectively define those conditions. These regulations do not specify a time requirement for the classification process itself, but they do imply that classification should be made without delay. In guidance to licensees[17], the NRC has stated that 15 minutes is a reasonable period of time for assessing and classifying an emergency once indications are available to control room operators that an EAL has been exceeded.

NRC regulations (i.e., Appendix E to 10 CFR Part 50) require that a licensee shall have the capability to notify responsible State and local governmental agencies within 15 minutes after declaring an emergency. The regulations require that the licensee shall demonstrate that the State/local officials have the capability to make a public notification decision promptly on being informed by the licensee of an emergency condition. The design objective of the prompt public notification system shall be to have the capability to essentially complete the initial notification of the public within the plume exposure pathway emergency planning zone (EPZ) within about 15 minutes. The use of this notification capability will range from immediate notification of the public (within 15 minutes of the time that State and local officials are notified that a situation exists requiring urgent action) to the more likely events where there is substantial time available for the State and local governmental officials to make a judgment whether or not to activate the public notification system.

It may be illustrative to generalize the timeline of emergency response to a severe accident.

Regardless of the initiating event, Federal law requires that a licensee notify the responsible State and local representatives with 15 minutes after declaring an emergency at a nuclear power plant. This is routinely practiced in drills and inspected in biennial exercises. A performance indicator[18] captures licensee success in this activity. The emergency notification would be one of the following four emergency classes[19]:

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[17] EPPOS-2, Emergency Preparedness Position on Timeliness of Classification of Emergency Conditions. http://www.nrc.gov/about-nrc/emerg-preparedness/regs-guide-comm/ep-generic-comm.html, EPPOS-2

[18] http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/index.html

[19] Each operating nuclear power plant is required to include in its emergency plans a standard emergency classification and EAL scheme. An EAL is a predetermined, site-specific, observable threshold for a plant condition that places the plant in an emergency class. See Regulatory Guide 1.101 (Revision 5), "Emergency Response Planning and Preparedness for Nuclear Reactors"; Appendix 1 to NUREG-

- Notification of Unusual Event (NUE)—Events are in process or have occurred that indicate a potential degradation of the level of safety of the plant or indicate a security threat to facility protection. No releases of radioactive material requiring offsite response or monitoring are expected unless further degradation of safety systems occurs.

- Alert—Events are in process or have occurred that involve an actual or potential substantial degradation of the level of safety of the plant or a security event that involves probable life-threatening risk to site personnel or damage to site equipment because of intentional, malicious, dedicated efforts or a hostile act. Any releases are expected to be limited to small fractions of the EPA Protective Action Guide (PAG) exposure levels.

- Site Area Emergency (SAE)—Events are in process or have occurred that involve an actual or likely major failure(s) of plant functions needed for protection of the public, or security events that result in intentional damage or malicious acts toward site personnel or equipment that could lead to the likely failure of or prevent effective access to equipment needed for the protection of the public. Any releases are not expected to result in exposure levels that exceed EPA PAG exposure levels beyond the site boundary.

- General Emergency (GE)—Events are in process or have occurred that involve actual or imminent substantial core degradation or melting with the potential for loss of containment integrity, or security events that result in an actual loss of physical control of the facility. Releases can reasonably be expected to exceed EPA PAG exposure levels off site for more than the immediate site area.

The Alert, SAE, and GE include activation of both the licensee and offsite emergency response organizations. The NUE is largely a notification process with little activation. The majority of declared emergencies are NUEs.

An event is likely to begin with the declaration of an Alert or SAE. In the case of a loss of all electrical power, an Alert is issued, followed shortly thereafter by an SAE. Emergency response organizations will activate and prepare to mitigate the accident and to recommend, consider, and implement public protective actions should they become necessary. In many locations, precautionary protective actions are taken at an SAE, including closing parks, stadiums, and other special facilities; evacuating schools to areas outside the EPZ; and preparations for general public evacuation should it become necessary. At this point in the timeline, there is little to no fuel cladding damage and no fuel melting. Any radioactive release is below the levels for which protective actions off site would be necessary. If accident conditions degrade, a GE would be declared. For a loss of electrical power, this occurs if the duration of a loss of all alternating current power exceeds the minimum time that control system batteries can last without recharging. The time selected will be between 2 and 8 hours depending on technical analyses of the site battery system. The actual time the batteries may last is very likely to be longer than this minimum time. However, the declaration criteria for emergency classification are conservative

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0654/FEMA-REP-1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants," November 1980; Nuclear Energy Institute 99-01, Revision 4, "Methodology for Development of Emergency Action Levels"; and Nuclear Utilities Management Council (NUMARC)/NESP-007, Revision 2, "Methodology for Development of Emergency Action Levels," January 1992. These documents can be accessed at http://www.nrc.gov/about-nrc/emerg-preparedness/emerg-action-level-dev.html.

and are designed to be anticipatory. In other scenarios, a GE is declared if the reactor coolant level has reached TAF. In both these cases, there is no fuel damage or core melt at this point, although core damage may subsequently occur.

As discussed above, at the declaration of a GE, regulations require that notification, including protective action recommendations, be provided to State and local officials within 15 minutes of declaration. Offsite response organization programs are required to have the capability to notify the public inside the EPZ within about 15 minutes of receiving notification of the need to take protective action. Should the officials decide that evacuation is the appropriate protective action, it is expected that evacuation of the public would begin within 15–30 minutes of their notification. If not already accomplished, schools and other special facilities would be also evacuated. In many scenarios, core damage would begin some hours after the GE is declared and a radioactive source term released into containment. Without mitigative actions, containment failure is possible, but it would be delayed for a period of time between several hours and 2 or more days depending on the containment design. If containment fails, delaying the radiological source term and its travel through buildings and other structures has the effect of reducing the source term through physical processes such as deposition, decay, and scrubbing.

1.6 Example Thyroid Dose Analyses

Dose calculations were performed by Sandia National Laboratories under contract to NRC, for two scenarios—(1) BWR loss of electrical power, including permanent loss of containment, and (2) the more likely case of mitigative actions limiting the containment integrity loss. The permanent loss of containment scenario has a probability in the range of one chance in one million per year, but because of the likelihood of successful mitigative actions qualitatively discussed above, the actual probability is likely to be lower. The case of mitigation of core damage is also a potential outcome, but it was not analyzed as there would be no significant radiological release.

Background

A set of calculations was performed to evaluate the effect of KI ingestion on thyroid doses between a 10- and 20-mile radius of a nuclear power plant. This study is based on MELCOR[20] calculations for Peach Bottom for two accident sequences. MACCS2[21] calculations were performed using the MELCOR-calculated source terms to evaluate the doses. This report presents the results for thyroid dose versus distance. It should be noted that the NRC staff continues to refine the MELCOR calculations of accident progression and source term, but these results were the most current at the time of this analysis and have been presented as illustrative examples.

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[21] NUREG/CR-4691, Volume 2, "MELCOR Accident Consequence Code System (MACCS): Model Description," Sandia National Laboratories, Albuquerque, NM. The principal phenomena considered in the MACCS2 code are atmospheric transport and deposition under time-varying meteorology, short- and long-term mitigative actions and exposure pathways, deterministic and stochastic health effects, and economic costs. No other U.S. code that is publicly available at present offers all these capabilities. MACCS2 was developed as a general-purpose tool applicable to diverse reactor and nonreactor facilities licensed by the NRC or operated by the U.S. Department of Energy or the U.S. Department of Defense.

Scenario Descriptions

The two scenarios considered in this study are variations of a long-term station blackout. They both treat design-basis containment leakage, which for Peach Bottom is 0.5 percent of the containment volume per day at nominal conditions. Containment leakage induces an early but very small release of fission products into the atmosphere. The difference between the two scenarios is that, in the second, operators are able to install equipment to implement containment sprays that knock down much of the suspended aerosols and prevent containment melt through. Of chief importance to the dose calculations are the magnitude and timing of the release of the source term. Table 1-1 compares the final iodine release fraction, timing of initial fission product release, and timing of subsequent containment failure, which induces a more substantial release. With the exception of the containment sprays, the timing of events is identical in the two scenarios.

Table 1-1 Source Terms for Peach Bottom Long-Term Station Blackout Scenarios

	Final Iodine Release Percent (%)	**Containment Failure (hr)***
Scenario 1	**6.6**	**21.1**
Scenario 2	**0.1**	**21.1**

*release from primary to secondary containment

MACCS2 Parameters and Assumptions

Many of the input parameters for this calculation were chosen according to current best practices for NRC calculations. This section describes the unique aspects of the input parameters chosen for this problem.

- Spatial Grid—The spatial grid for this calculation uses rings and sectors for distances between 10 and 20 miles. The angular resolution in this calculation was increased from the standard 16 sectors to 64 sectors.

- Dose Conversion Factors (DCFs)—This study used DCFs from Federal Guidance Report 13.[22] These are the most up-to-date DCFs that are currently available for MACCS2 calculations.

- Alarm Time—The alarm time was chosen to be the time at which a GE would be declared. This is 2 hours after the initiating event, the station blackout.

- Relocation Parameters—Relocation parameters were chosen so that individuals who did not evacuate were relocated 24 hours after plume arrival. Thus, the maximum exposure to any individual was 24 hours.

- Evacuation Delay Time—An evacuation delay time (i.e., the time from alarm to beginning of evacuation) was chosen to be 10 hours. This value was chosen to model evacuation

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[22] Federal Guidance Report 13 1999,, “Cancer Risk Coefficients for Environmental Exposure to Radionuclides,” U.S. Environmental Protection Agency (EPA)

of the 10- to 20-mile region, outside the normal EPZ. The combination of alarm time and evacuation delay time results in evacuation beginning 12 hours after accident initiation.[23]

- Evacuation Compliance—For the calculations that consider the impact of evacuation, it is assumed that 99 percent of the population evacuates as directed. Experience with evacuations that result from technological hazards (e.g., chemical fires) indicates a very high rate of compliance with evacuation orders.[24] Only a fraction of the population is in the pathway of the plume and would need to evacuate. The population outside of the plume pathway is not exposed to a radiation dose. Protective actions for those individuals may include instructions to shelter in place and listen to the emergency broadcast messages alerting them to any changes in protective action recommendations. Extensive traffic management plans have been prepared for the 10-mile EPZ. Real-life experience with ad-hoc evacuations has demonstrated good response by emergency response officials as well as good compliance by the public.[25]

- Evacuation Speed—Once evacuation begins, the evacuees are assumed to move radially outward from the plant at a uniform speed of 2.2 meters per second (5 miles per hour).

- KI Ingestion—The efficacy of KI as a prophylactic agent depends on the dose of the KI consumed and the timing of ingestion of the KI. To achieve maximum blockage of the thyroid gland by KI, the appropriate dose must taken 1 hour before the exposure. The efficiency of KI as a blocking agent decreases rapidly with time. Ingesting KI 3 hours after exposure, for example, reduces the efficacy to 60 percent. For the purposes of this calculation, in the cases that considered KI ingestion, the efficacy of the KI was chosen to be 70 percent, which represents about a 2.5-hour lag time from exposure to ingestion of KI. Experience from States with KI programs indicates that the percentage of the population with KI is relatively low[26], and it is assumed that it will take between 2 to 3 hours for the population to evacuate to a reception center and receive the KI dose. A reduction of 70 percent in thyroid dose was assumed to occur as a result of the ingestion of KI at that time. If KI is taken sooner (i.e., at the time of release), a reduction of 95 percent is possible. In the United States, there is sufficient dietary consumption of iodine so that the thyroid gland is effectively partially blocked at all times. The rate of uptake of iodine (radioactive or stable) by an iodine-sufficient thyroid gland is therefore reduced. In these examples, the biokinetic model for thyroid uptake of iodine does not consider the effects of iodine sufficiency. As a result, it is likely that the thyroid doses may be overestimated.

- Dose Predictions—Four cases are considered for each accident scenario as described below. These cases were selected to examine the effects of the administration of KI on thyroid dose. It should be noted that these analyses are for the response period.

    - Iodine Inhalation Only, No Evacuation, No KI—Doses to the thyroid are calculated assuming iodine was the only element released from the plant and, furthermore,

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[23] Doses were calculated for these scenarios for a peak individual dose without consideration of sheltering.

[24] NUREG/CR-6864, "Identification and Analysis of Factors Affecting Emergency Evacuations," January 2005

[25] ibid

[26] Section 4 3 provides further discussion of State experience with KI distribution. Chapter 5 presents a brief overview of State distribution plans and approximate percentages of predistributed KI.

that the only exposure pathway is inhalation. The population is assumed neither to evacuate nor take KI.

- All Pathways, No Evacuation, No KI—Doses to the thyroid are calculated assuming that all fission products are released from the plant and that all pathways are active. Again, the population is assumed to neither evacuate nor take KI. Comparing these results with those from the preceding case allows the fraction of the thyroid dose from inhalation of radioactive iodine to be determined.
- All Pathways, No Evacuation, With KI—Doses to the thyroid are calculated assuming that all fission products are released from the plant and that all pathways are active. In this case, members of the public do not evacuate but do take KI.
- All Pathways, With Evacuation, No KI—Doses to the thyroid are calculated assuming that all fission products are released from the plant and that all pathways are active. In this case, members of the public evacuate but do not take KI.

Figures 1-1 and 1-2 show the results for these four cases. Figure 1-1 is for the long-term station blackout without containment sprays; Figure 1-2 is for the same scenario but with containment sprays. The results are for mean, peak-sector doses to the thyroid. “Mean” indicates that the results are averaged over the set of weather trials; “peak-sector” indicates that the results are the peak value around the compass. Because the MACCS2 calculations accounted for wind shifts, a centerline dose is not available and, in fact, has no real meaning. The peak-sector dose is the maximum dose observed on the MACCS2 grid at each radial location. It is calculated on the fine grid. In this case, there are 64 course grid sectors, and each course grid is subdivided into 7 angular subintervals. Thus, the peak dose is calculated on a finer angular interval than 1 degree.

In these two scenarios, containment leakage of fission products begins about 1 hour before evacuation begins. Depending on windspeeds, the plume from containment leakage may overtake the evacuees and provide a very small dose. This accounts for the small doses shown in the plots for the case with evacuation. The curves in the plots terminate at about 18 miles. This is because the outermost grid element for which results are shown has an inner radius of about 16 miles and an outer radius of 20 miles. The values shown on the plot are at the radial midpoint of each grid element.

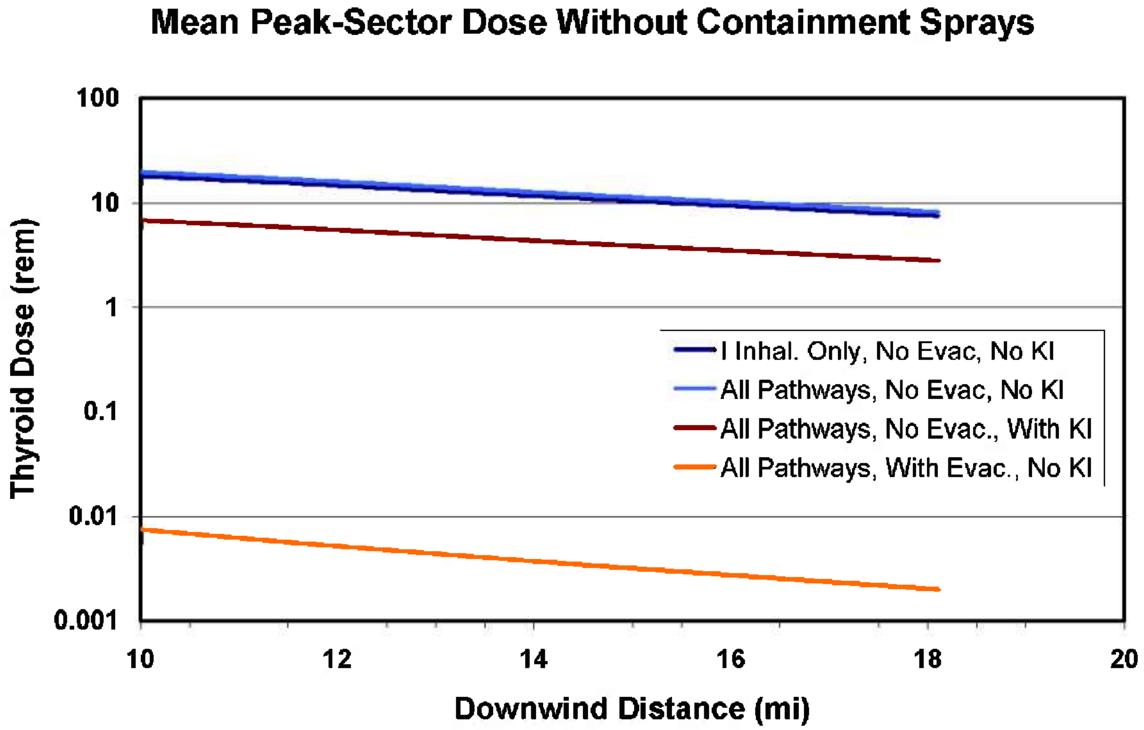
Mean Peak-Sector Dose Without Containment Sprays

Figure 1-1 Thyroid doses for a long-term station blackout at Peach Bottom without recovery of containment sprays

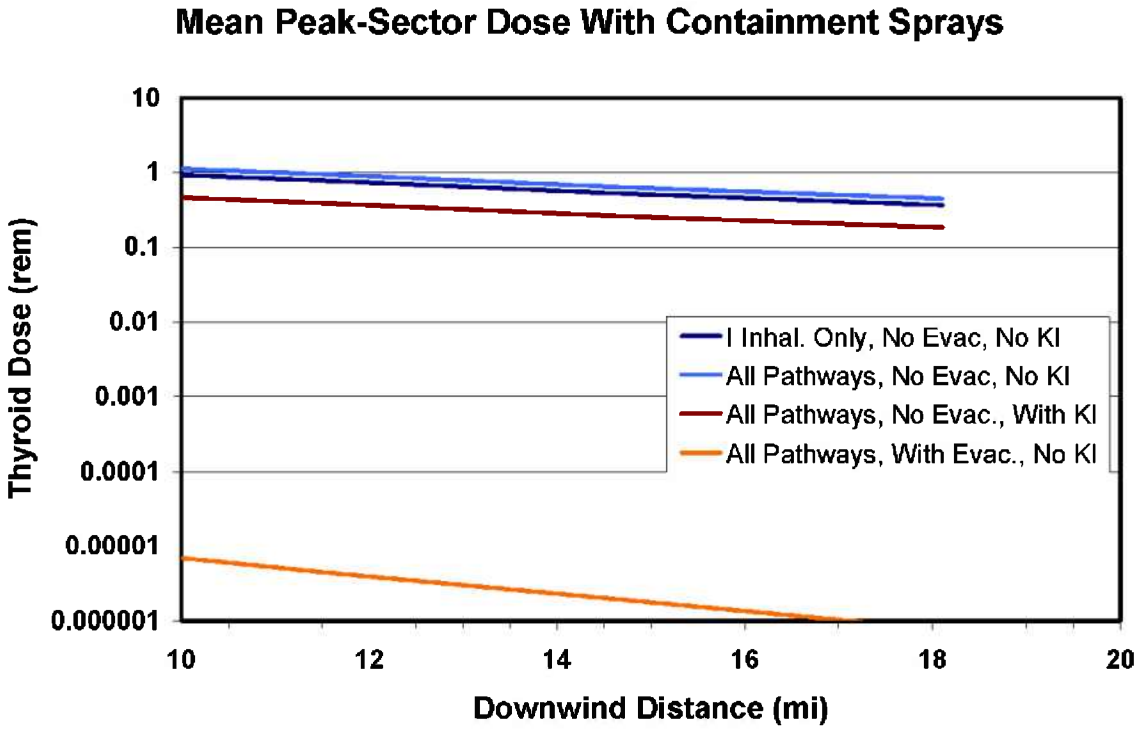

Figure 1-2 Thyroid doses for a long-term station blackout at Peach Bottom with recovery of containment sprays

As illustrated in Figure 1-1 above, ingesting KI within 10–20 miles from a commercial nuclear power plant during an environmental release of fission products reduces the projected thyroid dose to a member of the public by a factor of about three (from 20 rem to 7 rem at 10 miles; if KI were taken at the optimal time[27], dose reduction would be greater). However, evacuating the public in the area 10–20 miles from a commercial nuclear power plant during an environmental release of fission products reduces the projected thyroid dose to a member of the public by a factor of 1,000 to 10,000. Based on the NRC's conservative calculations of this highly unlikely but credible event, more than 24 hours would be available from the beginning of the event for members of the public within 10–20 miles of the plant to evacuate before a radioactive plume of sufficient concentration reaches 10 miles and delivers a dose of 5 rem to the thyroid. (It is estimated that the first 25 percent of the plume delivers 5 rem to the thyroid, and the mean windspeed is about 5 miles per hour at this site.)

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[27] Effective public education is paramount to success in the proper use of KI to ensure that KI is not used in place of evacuation and that the public does not delay evacuation while they seek out KI—a concern noted by the State of New Jersey in a recently published paper (Assessment of Potassium Iodide (KI) Distribution Program Among Communities Within the Emergency Planning Zones (EPZ) of Two Nuclear Power Plants," *Operational Radiation Safety Journal*, Health Physics Society, February 2007). Web sites such as http://www.ki4u.com have indicated that KI is an antiradiation drug, and many news articles have indicated the same (e.g., Boston Globe editorial, March 26, 2006, "Nuclear safeguard stalled"; Chattanooga Times Free Press, November 7, 2005, "Few neighbors of nuclear plants pick up anti-radiation tablets"; New York Times editorial, June 13, 2002, "Pills for Nuclear Plant Radiation"; and Washington Post, June 24, 2002, "Radiation Fears Spurs Sales of Iodide Pills").

1.7 Radioiodine Inventory

The approximate inventory of ^{131}I and other iodine radioisotopes in the core of a nuclear power plant depends on the size of the reactor core (megawatt-electric (MWe)) and the length of time the reactor has been in operation. For example, in the case of Three Mile Island, a 740-MWe reactor, the ^{131}I inventory at the time of the accident was equal to about 740 MWe × 85,000 curies per Mwe (Ci/Mwe) or 63 megacuries (MCi). Less than one-millionth of the inventory of radioiodine in the Three Mile Island core was postulated to have escaped to the environment (i.e., about 15 Ci) (Kemeny et al., 1979). Before radioactive iodine from the nuclear fuel of a nuclear power plant can reach the environment, extensive damage must occur to the fuel elements in the reactor core, with additional damage to the containment structure enclosing the reactor. Radioactive iodine (^{131}I) has a short half-life (8 days) and is of concern only with respect to the fuel in an operating nuclear power plant or with fuel from a reactor core that has recently been shut down.[28]

1.8 Other Radionuclides

Radioiodine is but one of many radionuclides presents in nuclear fuel or released when an atomic bomb detonates. A number of other radionuclides are important from the standpoint of public radiation dose. These include radioactive fission products such as gases (such as the radioactive noble gases of xenon and krypton), particulates (such as strontium), or volatile (can be readily evaporated) materials, such as radioiodine. Radioactive noble gases are, in general, not considered a threat to public health because they do not stay in the body if breathed in and they do not concentrate in the environment. While particulate radionuclides are of concern from a public health standpoint, they have a very low probability of being released to the environment as a result of an accident at a nuclear power plant. Under normal operating conditions, or even accident conditions, they do not escape nuclear reactor facilities in quantities of concern from a public health standpoint because they do not mix readily with air and because they are easily removed from a reactor facility's water and air by filters. Furthermore, the rigid nuclear power plant design features discussed above are designed to prevent particulate radionuclides from reaching the environment, even under accident conditions. Radioiodine is of particular concern because of the ease with which it can convert to a vapor state and because radioiodine taken into the body will concentrate in the thyroid gland if the thyroid is not saturated with nonradioactive iodine before the radioiodine reaches it. Under normal operating conditions, radioiodine is easily removed from the air and water of a nuclear power plant with highly effective filtration systems. A review of the nuclear accidents at Three Mile Island and Chornobyl illustrates how the design of reactors in the United States specifically addresses the nature of radioactive fission products and makes releases to the environment unlikely.[29]

Table 1-2 provides an overview of fission products that are important to offsite consequences; it is not an exhaustive list of all fission products produced. The fission process and resultant fission products are independent of reactor type (BWR versus PWR) and power; however, the quantity of fission products produced is a function of the power of the reactor. The table is presented as curies of fission product per megawatt (electric) of power. A large reactor (i.e., 1100 MWe) will have a greater quantity of fission products than a smaller reactor (i.e., 700 MWe).

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[28] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

[29] ibid

Table 1-2 Fission Products Important to Offsite Consequences

Fission Product	Half-Life	Inventory (Ci/MWe)
Kr 85	10.7 years	560
Kr 85m	4.5 hours	24,000
Kr 87	1.3 hours	47,000
Kr 88	2.8 hours	68,000
Sr 89	50.5 days	94,000
Sr 90	29.1 years	3,700
Sr 91	9.5 hours	110,000
Y 91	58.5 days	120,000
Mo 99	2.7 days	160,000
Ru 103	56.1 min	111,000
Ru 106	2.2 hours	25,000
Te 129m	33.6 days	5,300
Te 131m	1.4 days	13,000
Te 132	3.3 days	120,000
Sb 127	3.8 days	6,100
Sb 129	4.4 hours	33,000
I 131	8.0 days	85,000
I 132	2.3 hours	120,000
I 133	20.8 hours	170,000
I 134	52.6 min	190,000
I 135	6.6 hours	150,000
Xe 131m	11.9 days	1,000
Xe 133	5.2 days	170,000
Xe 133m	2.2 days	6,000
Xe 135	9.1 hours	34,000
Xe 138	14.1 min	170,000
Cs 134	2.1 years	7,500
Cs 136	13.2 days	3,000
Cs 137	30.2 years	4,700
Ba 140	12.8 days	160,000
La 140	1.7 days	160,000
Ce 144	284.6 days	85,000
Np 239	2.4 days	1.64×10^6

Adapted from NUREG-1228 Source Term Estimation of Severe Accidents, issued 1988, and WASH-1400

1.9 Three Mile Island Accident[30]

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[30] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

On March 28, 1979, a nuclear accident occurred at Three Mile Island Nuclear Power Station Unit 2, in south-central Pennsylvania. The accident began when the plant experienced a total loss of feedwater and a simultaneous tripping (shutting down) of the main turbine (USNRC, 1979, Nuclear Information Bulletin, 1990). Emergency feedwater pumps started, as designed, and the reactor continued to operate at full power. Unbeknownst to the operators, valves had been closed so that the emergency feedwater pumps could not discharge water from the auxiliary pumping system. When the reactor core cooling system temperature and pressure began to increase, the reactor scrammed (control rods were suddenly inserted into the reactor core). Simultaneously, a pilot-operated relief valve (PORV) opened to relieve pressure as the reactor's cooling water rapidly began to heat up. Once the pressure decreased to desired levels, the PORV stayed in the open position. That led to the loss of cooling water in the reactor vessel. Operators failed to recognize that the PORV had stayed open. That and other human errors caused the reactor core to be deprived of necessary cooling water, and an estimated 50 percent of the reactor core melted down (Langer et al., 1989).

As a result of the meltdown, an estimated 52 percent of the reactor core inventory of radiocesium and 40 percent of the radioiodine were released from the core into the reactor building (FDA, 1979), but no detectable amount of the radiocesium and only a minute proportion (0.00002 percent) of the radioiodine escaped to the environment. Considerable environmental monitoring followed the accident, and the maximum concentrations of ^{131}I found in milk were 41 picocuries per liter (pCi/L) (1.52 becquerels per liter (Bq/L)) in goat's milk and 36 pCi/L (1.33 Bq/L) in cow's milk (Weidner et al., 1980)—0.003 of the concentrations at which the Food and Drug Administration (FDA) would recommend removal of cows from contaminated pastures (FDA, 1978). Cesium-137 (^{137}Cs) in milk after the accident was comparable with that expected in milk from residual fallout from previous nuclear weapons testing.[31]

Within 3 days after the start of the accident, nearly 250,000 bottles of KI solution were obtained and rushed to the area (tablets were not available). It was decided that its use was not indicated, and none was distributed to the general public (Kemeny et al., 1979; Scranton 1980). Although megacurie (i.e., greater than 10^{15} Bq) quantities of radionuclides were released to the environment as a result of the accident (Kemeny et al., 1979), gamma-ray spectroscopy of collected samples indicated that radioactive noble gases were the only radionuclides detectable. It is estimated that 15 Ci (5.6×10^{11} Bq) of ^{131}I was released. The highest radiation dose recorded off site was 830 microgray (µGy) (83 millirad (mrad)) by thermoluminescent dosimeter reading (FDA, 1979), and the highest estimated dose to one person was 370 µGy (37 mrad) (FDA, 1979), less than half the annual dose from natural background radiation. In a 20-year follow-up study of mortality data for residents living within a 5-mile radius of Three Mile Island, researchers at the University of Pittsburgh's Graduate School of Public Health found no significant increase overall in deaths from cancer (Talbott et al., 2000).

1.10 Chornobyl Accident

The National Research Council[32] made the following observations regarding the Chornobyl accident:

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[31] EPA routinely monitors the environment for atmospheric radioactivity and posts the results quarterly at http://www.epa.gov/narel/radnet/erdonline.html.

[32] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

Most of our understanding of the consequences of exposure of a population to radioiodine in fallout comes from studies of the population in Belarus, northern Ukraine, and part of the Russian Federation exposed after the Chornobyl accident, in which large quantities of radioiodine were released and a large population was exposed. The incident, which occurred on April 26, 1986, resulted from a combination of an inappropriate experiment and human error and led to the release of about 8×10^{18} Bq of radioisotopes (UNSCEAR, 2000). The experiment involved a test at NPP unit 4 at Chornobyl to determine how long turbines would spin and supply power after a loss of main electrical power supply. When the control rods were inserted to reduce the reactor's power level, there was an initial drop to considerably below the desired power level. To compensate, the operators removed some control rods. That led to a sudden surge in the power level that the operators tried to compensate for by inserting control rods. The result was an erratic distribution of power throughout the reactor core. Damaged water lines in the bottom portion of the reactor, coupled with fuel damage, allowed escaping water to interact with hot fuel and flash to steam. That resulted in an explosion equivalent to that of 30–40 tons of TNT that destroyed the reactor building, which lacked secondary containment. Fires erupted, including fire in the graphite moderator in the reactor core. The result was that about 4% of the nuclear material in the core, particularly the volatile isotopes, was released to the environment.

The largest component released was Xenon-133, an inert gas, which did not form part of fallout. Iodine isotopes formed the second largest component and included ^{131}I, the most important, with a half-life of 8 days (about 1.8×10^{18} Bq); ^{133}I, with a very short half-life and therefore important only in the immediate vicinity of the reactor; and Tellurium-132, which decays to ^{132}I, another isotope with a short half-life. The iodine released to the environment amounted to about 50% of that present in the reactor, compared with the 0.00002% released after the Three Mile Island accident. The amount of activity of the iodine isotopes released was much greater than that of other isotopes that contributed to fallout, such as two cesium isotopes. Because of their short half-lives (up to 8 days with one minor exception), the iodine isotopes disappear rapidly from the environment and do not pose a long-term threat. The two cesium isotopes (^{134}Cs and ^{137}Cs), although present in much lower activity, have longer half-lives (2.1 and 30 years, respectively), are not concentrated or retained in any specific tissue and therefore pose a different problem.

The largest exposure to fallout, mainly iodine isotopes, occurred in the southern regions of Belarus (Gomel province) and immediately around the reactor in northern Ukraine and the neighboring provinces. The population of Pripyat, the town closest to the reactor, was evacuated about 2 days later, and the population of all the villages within 30 km of the site was evacuated later than that; return is still forbidden because of the ground contamination, mostly with cesium. In all, about 30,000 Km^2 was contaminated to more than 185 kBq/m^2, and this led to the evacuation of some 116,000 people. In the years after the accident, an additional 210,000 people were resettled into less-contaminated areas, and the initial 30 km radius exclusion zone (2,800 km^2) was modified and extended to a 37-km-radius exclusion zone (4,300 km^2).

Reactor designs in the United States are different from the Chornobyl design in that:

- Water is used as a moderator (material used to slow down neutrons) in US nuclear power plants (NPPs); Chornobyl type reactors use graphite (graphite is combustible, water is not).

- U.S. NPP designs prevent sudden, difficult to control increases in power level (sudden increases in the fissioning process).

- U.S. NPPs employ multiple layers of ("defense-in-depth") barriers to ensure that nuclear fuel and fission products cannot escape from the core. In the United States nuclear power plants have pressure vessels with walls that are about 187 mm (7.4 in.) thick (NUREG-1250) (USNRC, 1987). The Chornobyl Reactor had no reactor containment vessel.

- U.S. NPPs are designed on the basis of "full containment" or the complete enclosure of all reactor and primary support systems for the reactor in the event of a design basis accident (DBA) (NUREG-1250) (USNRC, 1987). In the United States, full primary containment is achieved by a thick steel reactor vessel and heavily reinforced concrete reactor building that surrounds all primary reactor systems. The containment can contain the peak pressure reached in DBAs or has sufficient pressure-suppression capacity to contain the worst-case peak pressure.

- In the case of the accident at Three Mile Island, ignition of accumulated hydrogen gas in the reactor containment building caused a pressure pike of 28 psi but, did not lead to a breach of the containment building or any apparent increase in the escape of radioactivity to the environment (USNRC, 1988). The thin metal of the Chornobyl reactor's building was easily breached by the explosion and fire that accompanied that accident. The breaching of the reactor building allowed the fire that consumed much of the reactor core to spew radionuclides, including radioiodine, directly to the atmosphere.

- In NPP licensing, the U.S. Nuclear Regulatory Commission subscribes to the "defense-in depth" (multiple layers) safety strategy, which includes: accident prevention, redundant safety systems, containment, accident management, siting, and emergency planning. U.S. NPPs have considerable redundancy in their design to prevent consequential releases of radioactive material to the environment. Thus, fission products in the reactor core of U.S. NPPs have to pass through several distinct fission-product barriers, including the fuel matrix, the fuel cladding,

  the reactor vessel and coolant system and the reactor building before reaching the environment.

1.11 Meteorology

The release of radioactive material into the atmosphere creates the greatest potential for offsite consequences. Meteorology is important because it determines where the offsite release (the plume) goes and the concentration of the radionuclides to which the downwind public is exposed.

Meteorological information includes wind speed, direction, persistence, and variability and vertical dispersion. Those factors describe the stability of the atmosphere and indicate how fast, far, and wide radionuclides would be transported in air. Under very stable atmospheric conditions, there is little dispersion of the plume and the radionuclide concentration is much greater than under very unstable atmospheric conditions that would disperse the plume and lower radionuclide concentrations in it. Stable conditions (unfavorable meteorology) are usually chosen for performing design-basis accident calculations, rather than the prevailing meteorological conditions.

Under normal meteorological conditions, the plume from a site moves away from the release point much as smoke moves away from a chimney. Only those in the direct path of the plume would be in immediate danger. Just as smoke dissipates as it moves away from a source, so does a radioactive plume. This dissipation quickly decreases the concentration of radioactive materials within the plume. If the quantities of radionuclides in the plume have public health significance for people in the path of the plume, authorities would consider such protective actions as sheltering (remaining indoors), evacuation, use of KI as appropriate, and, for areas beyond the 10-mile EPZ, interdiction of food supplies, relocation, and placing livestock on stored feed. Weather conditions that might prevent immediate evacuation, such as blizzards or torrential rainfalls, would remove radioactivity from the plume close to the point of release and actually help to protect people who are downwind.

Nuclear power plants must have the ability to obtain up-to-date meteorological information (e.g., windspeed, temperature differences between elevated and ground level to determine atmospheric stability class) and weather forecasts to consider the impact of shifting winds and variable weather on protective action recommendations.

1.12 Dose and Health Effects

Radiation effects can result from external radiation (from a source of radiation outside the body, such as x-rays) and from internal radiation (from a source of radiation in the body, such as radioisotopes absorbed from food or drink or absorbed from the air). The effects of internal radiation from iodine radioisotopes on the thyroid depend on the gland's ability to concentrate and store the isotopes, which together lead to a much higher radiation dose to the thyroid than to other tissues. Some other tissues (such as salivary glands, breast, and stomach) concentrate radioiodine but do not store it, so their dose, although more than that to most tissues, is much less than that to the thyroid.

Radiation from any source—including ingested or inhaled isotopes, medical or dental investigations with x-rays, and direct radiation from an atomic bomb—can damage DNA and thus pose a risk of tumors and, in high doses, cell death. The main expected consequences of exposure of the thyroid to radiation are an increase in the incidence of thyroid tumors and an increase in the occurrence of loss of thyroid function (hypothyroidism, myxedema). Tumors occur because DNA damage can lead, in a small minority of cells, to activation of genes that stimulate cell growth, to loss of function of genes that suppress cell growth, or to various other changes that give cells and their progeny the ability to multiply more rapidly than normal and to evade checkpoints that control cell proliferation. The chance of tumor development rises with increasing radiation dose up to a level that is high enough to kill all or most thyroid cells. Very high doses have a much *lower* likelihood of causing tumors, because cells that are fatally damaged cannot proliferate to produce tumors. However, such extensive damage can lead to hypothyroidism. In addition to tumors and cell death, a third possible thyroid-related consequence of radiation is autoimmune disease of the thyroid, in which the body's own lymphocytes become sensitized to thyroid cells and can destroy them and, in a small proportion of cases, lead to hypothyroidism. More rarely, the antibodies produced by the lymphocytes can react with the hormone-receptor switch that turns up thyroid function and thus lead to thyrotoxicosis (Graves's disease, or hyperthyroidism).

The external radiation from neutrons and gamma rays, unlike internal radiation from isotopes of iodine, does not irradiate the thyroid gland to a greater extent than the other tissues of the body, and KI will not prevent thyroid damage from external radiation. Studies of the survivors of the atomic bombs in Hiroshima and Nagasaki have shown increases (by a factor of about 2–3) in cancers of many different tissues in survivors who were close to the point of detonation (hypocenter) (Thompson et al., 1994). The approximately two-fold increase in thyroid cancer incidence was similar to that in many other cancer types—such as cancer of the colon, breast, ovary or bladder—and this suggests that it was a result of direct whole-body external radiation and that exposure to iodine isotopes made no observable contribution to the occurrence of thyroid cancer in the population studied.[33]

1.13 Reactor Accident Exposure Pathways

Radioiodine can exist in particulate form, such as cesium iodide (Cs ^{131}I) or sodium iodide (Na ^{131}I), as a radioiodine vapor, or as a solution with the radioiodine dissolved in water. In the environment, the different physical and chemical states of radioiodine provide several pathways for it to reach humans.

1.13.1 Exposure from Inhalation

Persons surrounded by the plume will inhale air containing the released radioactive materials, thereby introducing the radioactive material into the body. The behavior of this intake material depends on its chemical and physical form. Although exhalation would remove a large fraction of this inhaled material from the body, some material would deposit in the lungs and the upper and lower respiratory tracts. Radioiodine in the gaseous state can be inhaled into the lungs where it can dissolve and enter the blood. The blood then circulates through the body, including the thyroid gland. Under the condition of normal nutritional iodine supply, a normally functioning thyroid gland will take up and store between 15–30 percent of the iodine to which it is exposed, whether it is radioiodine or the chemically identical nonradioactive iodine (the thyroid does not recognize any difference between radioactive and nonradioactive iodine). Studies have shown that about 55 percent of radioiodine breathed in is absorbed into the blood in the lungs and transported throughout the body (Costa et al., 1982). However, the inhalation-exposure route was not the major contributor to the thyroid doses of the populations exposed to radioiodine released in the Chornobyl accident; rather, as previously discussed, it was estimated that most of the radioiodine taken into the thyroid entered the body in contaminated food or drink.[34]

1.13.2 Exposure from Contaminated Food and Water

The ability of radioiodine to exist in a particulate form or as a solution in water makes it possible for it to contaminate drinking water, soil, and plants used as food. Radioiodine on pasture grasses or on feed for cattle or goats can contaminate and concentrate in their milk. After

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[33] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

[34] ibid

Chornobyl, most of the dose to people's thyroids resulted from consumption of contaminated water and food, including milk.[35]

1.13.3 Exposure from External Radiation

Radiation dose that occurs from exposure to radiation emitted by radioactive materials located outside of the body is referred to as an external dose. Radiation doses caused by external exposure are predominantly associated with photon radiation and, with regard to the skin, beta particle radiation. Since the range of beta particles in air is limited, an individual must generally be submersed in the radioactive cloud, standing on contaminated ground, having contaminated skin, or wearing thin contaminated clothing in order to receive a skin dose. Exposure caused by elevated plumes will be from photon radiation. Radioactive iodine is a photon emitter and can be responsible, along with other radionuclides, for whole body radiation dose from an external source, either from a plume overhead or immersion in a plume. However, since the radioactive material is outside of the body, the external exposure ceases when the source is removed, or when the person is removed from the source.

1.14 Emergency Preparedness and Nuclear Power Plants

Each nuclear power plant in the United States has two EPZs—the plume exposure pathway EPZ and the ingestion exposure pathway EPZ. The plume EPZ is that area requiring immediate action to reduce risk to the public and is approximately 16 kilometers (10 miles) in radius. The ingestion EPZ is the area in which actions would be taken to protect the public from the consumption of foods contaminated with radioactive materials and for which there is considerable time to take action to reduce dose and therefore risk. The ingestion EPZ is about 80 kilometers (50 miles) in radius. The choice of the size of the EPZs represents a judgment on the extent of detailed planning that must be performed to ensure an adequate response by responsible authorities. In a particular emergency, protective actions might be restricted to a small part of the planning zones.

A joint NRC-EPA task force gave the technical basis for the size of the EPZs around nuclear power plants in NUREG-0396, EPA 520/1-78-016, "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants,"[36] issued December 1978. The purpose of the report was to provide a basis for Federal, State, and local government emergency response organizations to determine the appropriate degree of emergency planning efforts in the environs of nuclear power plants. The most important guidance for planning officials in the report was the introduction of the concept of EPZs, the plume exposure pathway EPZ and the ingestion exposure pathway EPZ, as a basis for the planning of predetermined response actions.

The findings and guidance expressed in NUREG-0396 were endorsed by the NRC in a policy statement on October 23, 1979 (44 FR 61123), and are reflected in the upgraded NRC and Federal Emergency Management Agency (FEMA) emergency planning regulations.[37] The NUREG-0396 Task Force considered various rationales for establishing a planning basis,

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[35] Chernobyl Forum Report, World Health Organization, et al, 2005

[36] Available via ADAMS at http://www.nrc.gov/reading-rm/adams.html, under Accession No. ML051390356.

[37] The severe accidents included in the emergency planning basis were those events with a very low probability of occurrence (less than 1×10^{-6}) at the time of publication. Further refinements in knowledge regarding accidents, source terms, mitigative actions, and radionuclide behavior suggest that the understanding of the probability of occurrence of these severe accidents and their characteristics has changed. The types of severe accidents included in the original emergency planning basis are considered unlikely today.

including risk, probability, cost effectiveness, and consequence spectrum. After studying the various approaches, the Task Force chose to base the rationale for the planning basis on a spectrum of consequences, tempered by probability considerations:

> With respect to the risk rationale, such an approach would establish 'planning guidance' that could be compared with the risks associated with non-nuclear accidents. This rationale would seemingly give a uniform basis for emergency planning and would clearly indicate the level of risk that could be mitigated by advanced planning. However, emergency planning for non-nuclear hazards is not based upon quantified risk analyses. Risk is not generally thought of in terms of probabilities and consequences, rather it is an intuitive feeling of the threat posed to the public. Reactors are unique in this regard: radiation tends to be perceived as more dangerous than other hazards because the nature of radiation effects are less commonly understood and the public generally associates radiation effects with the fear of nuclear weapons effects. In addition, a risk-related rationale might imply the determination of an acceptable level of risk which is outside the scope of the Task Force effort. Choosing a risk comparable to non-nuclear events, therefore, was not directly used as the rationale for an emergency planning basis.
>
> With respect to a probability rationale, one could arrive at 'planning guidance' by selecting an accident probability below which development of an emergency plan could not be justified. Factors favoring using this rationale center around providing a quantitative probability basis, which could be compared with the probabilities of other types of emergencies for which plans are prepared.
>
> Factors arguing against the probability rationale are similar to those against the risk approach. Emergency planning is not based upon quantified probabilities of incidents or accidents. On the basis of the accident probabilities presented in the Reactor Safety Study (nuclear and non-nuclear) society tolerates much more probable non-nuclear events with similar consequence spectrum without any specific planning. Radiological emergency planning is not based upon probabilities, but on public perceptions of the problem and what could be done to protect health and safety. In essence, it is a matter of prudence rather than necessity.
>
> A generic 'probability of an event' appropriate for planning has many implications felt to be outside the scope of the Task Force objective. However, the concept of accident probability is important and does have a place in terms of evaluating the range of the consequences of accident sequences and setting some reasonable bounds on the planning basis. The probability rationale was used by the Task Force to gain additional perspective on the planning basis finally chosen.
>
> With respect to a cost-effectiveness rationale, the level of emergency planning effort would be based on an analysis of what it costs to develop different levels of such a plan and the potential consequences that could be averted by that degree of development. The factor favoring the cost-effectiveness rationale is that an emergency plan could be developed on the basis of cost per potential health effect averted. Factors arguing against the cost-effectiveness rationale are the difficulty in arriving at costs of plan development and maintenance and considerations that general and radiological emergency response plans have already been developed. In addition, absent an actual accident, it would be very

> difficult to assign a dollar value to the effectiveness of the plan in terms of health effects averted.
>
> Lastly, the calculated consequences from a spectrum of postulated accidents were considered as the rationale for the planning basis. Such a rationale could be used to help identify desirable planning elements and establish bounds on the planning effort. Further, a planning basis could be easily stated and understood in terms of the areas or distances, time frames and radiological characteristics that would correspond to the consequences from a range of possible accidents. Consequence oriented guidance would also provide a consistency and uniformity in the amount of planning recommended to State and local governments. The Task Force therefore judged that the consequences of a spectrum of accidents should be the principal rationale behind the planning basis.[38]

In NUREG-0396, the NRC and EPA recommended a plume exposure pathway EPZ of about a 10-mile radius based on a consequence analysis of various reactor accidents[39] as follows:

- Projected doses from design-basis accidents would not exceed PAG[40] levels outside the zone.
- Projected doses from most core damage accidents would not exceed PAG levels outside the zone.
- For the worst core damage accidents, immediately life-threatening doses would generally not occur outside the zone.
- Detailed planning within the 10-mile zone would provide a substantial base for the expansion of response efforts in the event that this proved necessary.

NUREG-0396 recommended a radius of about 50 miles for the ingestion exposure EPZ for the following reasons:

- The downwind range within which contamination will generally not exceed the PAGs is limited to about 50 miles because of wind shifts during the release and travel periods.
- Iodine suspended in the atmosphere for long time periods may convert to chemical forms that do not readily enter the ingestion pathway.
- Much of any particulate material in a radioactive plume would have been deposited on the ground within about 50 miles from the facility.
- The likelihood of exceeding ingestion pathway PAGs at 50 miles is comparable to the likelihood of exceeding plume exposure pathway PAGs at 10 miles.

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[38] NUREG-0396, "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants"

[39] These accidents include those now considered to be highly unlikely in occurrence, as discussed in footnote 37.

[40] A PAG is a decision point at which it is considered prudent to take action, in this case the PAG refers to radiation dose levels from EPA-400 1992 "Protective Action Guidance Manual." The whole body dose PAG is 1–5 rem.

The NRC and FEMA regulations include 16 emergency planning standards against which the onsite licensee and offsite State and local emergency plans are evaluated to determine a plan's adequacy. The NRC emergency planning standards appear in 10 CFR 50.47(b), while the FEMA emergency planning standards are found in 44 CFR 350.5. The 16 standards address the (1) assignment of responsibilities for the response organizations, (2) responsibilities of on-shift licensee personnel, (3) arrangements for using offsite assistance resources, (4) use of a standard emergency classification scheme, (5) notification methods and procedures, (6) prompt communications to emergency personnel and the public, (7) public education and information, (8) emergency facilities and equipment, (9) assessment and monitoring of the consequences of a radiological emergency, (10) development of a range of protective actions, (11) control of exposures to emergency workers, (12) medical and public health support, (13) general recovery plans, (14) periodic drills and exercises, (15) emergency response training, and (16) responsibility for the planning effort. Evaluation criteria for each of the planning standards appear in the joint NRC-FEMA document NUREG-0654, FEMA-REP-1, Revision 1, "Criteria for the Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants," issued November 1980 (http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0654/).

Another important aspect of the planning basis is the timing of a release of radioactive materials following an accident, that is, the time between the initial recognition that a serious accident is in progress and the beginning of a release of radioactive material. NUREG-0396 reported that, depending on the type of accident, a wide range of timeframes for such release is possible, from one-half hour to as long as 30 hours after an initiating event. As a planning basis, NUREG-0396 established one-half hour as the time at which major releases may occur.

Subsequent studies (i.e., NUREG-1150) have shown the one-half-hour time for the start of major releases to be very conservative and highly unlikely. The NRC's emergency planning regulations in Section IV.D of Appendix E to 10 CFR Part 50 reflect the one-half-hour planning basis for the start of major releases in the requirement that licensees must have the capability to notify State and local governmental agencies within 15 minutes after declaring an emergency, and that State and local officials in turn have the capability to alert and notify the public in the plume exposure pathway EPZ within about 15 minutes. The NRC recognized in its rulemaking that the technical basis for the 15-minute requirement to notify the public is not without dispute and that there may never be an accident requiring the use of the 15-minute notification capability. However, the Commission concluded that the 15-minute notification capability is consistent with the essential rationale behind emergency planning to provide additional assurance for the public protection even during such an unexpected event.

With respect to the adequacy of emergency plans, the standard of reasonable assurance requires the NRC to make a predictive finding that there are no undue risks to the public health and safety. It does not require a finding of zero risk. In particular, the standard of reasonable assurance does not require an absolute demonstration that the population within the plume exposure pathway EPZ can be evacuated at all times or in all circumstances or within a specified time, or that a specific radiation dose can be prevented. There may, in fact, be circumstances (such as a severe winter storm, floods, or earthquakes) where, in the event of a radiological emergency, sheltering rather than evacuation would be the appropriate protective action because evacuation in severe offsite hazard conditions would pose greater risk to the public. Therefore, what constitutes reasonable assurance for a nuclear power plant is a finding that the plans are in conformance with the planning standards, that there are adequate staff and facilities to implement the plans, and that it has been demonstrated that the plans can be implemented.[41]

1.15 Consideration of Potential Terrorist Activities with Respect to Emergency Preparedness

The NRC has conducted and continues to conduct studies to determine the vulnerability of nuclear power plants and the adequacy of licensee programs to protect public health and safety in the threat environment after the terrorist attacks of September 11, 2001. Whether the initiating event is terrorist based or a nuclear accident, the emergency planning basis provides reasonable assurance that public health and safety will be protected. Emergency plans have always been based on a range of postulated events that would result in a radiological release, including the most severe.

The NRC has also conducted analyses of spent fuel pool[42,43] vulnerability. The calculations have shown that spent fuel pools are robust structures that are difficult to damage. Even under conditions in which fuel is damaged, current analyses predict that the time to begin and the magnitude of a release are consistent with those considered by the emergency preparedness planning basis. However, additional calculations continue to be performed to ensure that a reasonable spectrum of initial and boundary conditions is evaluated.

From the studies completed thus far, it is clear that current decommissioning plant emergency preparedness programs are adequate given the age of spent fuel contained in their pools. Modestly aged fuel will be air cooled under a loss of spent fuel pool water accident. The age of spent fuel dictates the time it would take to heat up the fuel, potentially releasing radioactive nuclides. All spent fuel at the current fleet of decommissioning plants is more than 5 years old and is therefore very slow to overheat even under these more challenging conditions. Regardless of the spent fuel age or configurations considered, the current analyses show that spent fuel heatup time is longer than previously estimated by the NRC in draft NUREG-1738[44], "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants,"

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[41] The NRC's ADAMS contains State plans. For example, at http://www.nrc.gov/reading-rm/adams.html, under Accession No. ML062790298 is "Southern Nuclear Operating Company AR-06-2295, List of Enclosures, Including State of SC Radiological Emergency Response Plan, State of SC Technical Radiological Emergency Response Plan & VEGP Site Specific Plant, Part 5."

[42] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/reducing-hazards-spent-fuel.html

[43] The National Academy of Sciences (NAS) published a report in 2004 that suggested some conclusions that differed from the NRC analysis of the event. This reference also includes a discussion of the NRC response to the NAS report as well as an overview of requirements to licensees and the NRC's ongoing work in this area. The document can be accessed at http://www.nrc.gov/reading-rm/doc-collections/congress-docs/correspondence/2005/domenici-03142005.pdf.

[44] The NRC withdrew NUREG-1738.

issued February 2001. Based on the analyses performed to date, the staff has not identified any spent fuel pool accident issues that would invalidate the emergency planning basis.

CHAPTER 2

BASIS FOR IODINE PROPHYLAXIS

2.1 Physiology of the Thyroid Gland

The thyroid gland is the largest gland in the neck.[45] It is situated in the front of the neck, attached to the lower part of the larynx and the upper part of the trachea. The thyroid gland has the shape of a butterfly—the two wings being the right and left lobes, which wrap around the trachea. Each lobe is about 4 centimeters (cm) (1.5 inches (in.)) long and 1 to 2 cm (0.65 to 0.78 in.) wide.[46] The sole function of the thyroid gland is to produce thyroid hormones. The thyroid gland is not critical to life, but the hormones it produces are necessary for normal growth and development, heat production, and the well-being of the individual. The most prominent effect of the thyroid hormones is their regulatory control of respiratory exchange and basal metabolic rate. The thyroid gland serves as the body=s metabolic thermostat by controlling the rate of oxidative metabolism of individual cells, which collectively produce heat and maintain body temperature. During childhood and puberty, thyroid hormones have a significant effect on the rate of body growth and development. A reduced hormone level during this time causes marked reduction in skeletal maturation and prevents full-body growth to adult dimensions. Thyroid deficiency during human fetal life and the postnatal period produces a significant depression in development and growth, including the central nervous system, with a negative impact on intellectual development.[47]

Thyroid hormones, thyroxine (T4) and triiodothyronine (T3), contain iodine. In addition to its role as the important component of these thyroid hormones, iodine is also important in their production. The synthesis of T4 and T3 takes place through a complex series of enzymatic steps on the interface between the thyroid follicular cell and the large protein thyroglobulin. Thyroid peroxidase is the major enzyme responsible for the oxidation (organification) of the iodine actively transported from the blood into the thyroid by the sodium-iodide symporter (NIS), the addition of the oxidized iodine to the amino acid tyrosine to generate mono- and diiodotyrosine (MIT and DIT, respectively), and the coupling of a MIT and a DIT to generate T3, and two DITs to generate T4. T4 and T3 are then secreted into the peripheral circulation where they are tightly bound to plasma proteins, primarily the thyroid-hormone binding globulin (TBG), an inter alpha globulin. Very small fractions of the circulating hormones are not bound to TBG, and these free or unbound hormones are available to enter all peripheral cells. It is generally recognized that T3, not T4, is the bioactive hormone and that the major source of T3 is not the thyroid but, in the peripheral tissues, the removal of an iodine from the outer or phenolic ring of T4 by a selenoenzyme, 5'-deiodinase. T3 binds to T3 nuclear receptors in the cells of the peripheral tissues and stimulates a wide variety of genomic events that result in enhanced protein synthesis and increased metabolism.[48]

Central nervous system control of thyroid function resides in the anterior hypothalamus, which synthesizes and secretes a tripeptide, thyrotropin-releasing hormone (TRH), into the hypothalamic-pituitary portal circulation. TRH binds to the TRH receptor on the beta cells of the anterior pituitary to stimulate and release into the peripheral circulation the glycoprotein, thyroid-stimulating hormone (thyrotropin or TSH), which consists of an alpha (α) subunit and a beta (β)

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[45] Surks, M., *The Thyroid Book*, Consumer Reports Books, 1999

[46] ibid

[47] ibid

[48] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

subunit. The β subunit binds to the TSH receptor on the basal cell surface of the thyroid cell, stimulates the synthesis of the iodine-rich thyroid hormones, T4 and T3, and releases them into the peripheral circulation.

It is evident that to maintain normal thyroid function (euthyroidism), the synthesis of the thyroid hormones and their release from the thyroid must be under tight control. That is accomplished by the classical negative-feedback system so typical of endocrine systems. Thus, a small rise in the circulating free thyroid hormones results in a decrease in the release of TSH from the anterior pituitary and, less so, TRH from the hypothalamus, thereby decreasing T4 and T3 synthesis and their release from the thyroid and maintaining euthyroidism. In contrast, a small decrease in circulating T4 and T3 concentrations enhances the release of TSH from the anterior pituitary and, less so, TRH from the anterior hypothalamus and results in stimulation of the thyroid to maintain serum T4 and T3 concentrations in the normal, euthyroid range. Changes in circulating T4 and T3 concentrations will result in far greater changes in the serum TSH concentration; this emphasizes the sensitivity of TSH secretion in maintaining euthyroidism. Overt hyperthyroidism is associated with increases in the serum free T4 and T3 concentrations and suppression of the serum TSH concentration. In contrast, overt hypothyroidism will result in decreases in the serum free T4 and T3 concentrations and an increase in the serum TSH concentration. Abnormalities in thyroid function may be mild and are usually diagnosed on the basis of low or high serum TSH and normal circulating free T4 and T3 concentrations; again, this emphasizes the use of serum TSH in diagnosing thyroid dysfunction.[49]

2.2 Physiologic Need for Iodine and Sources of Iodine[50]

It has been recognized for more than 50 years that iodine is an essential component of the thyroid hormones, T4 and T3, and that severe iodine deficiency (less than 50 micrograms (μg) iodine intake daily) is the major cause of mental retardation and endemic goiter and cretinism worldwide. Major efforts have been made over the last decade to eradicate iodine deficiency, and remarkable success has been achieved. However, much work remains, and careful continued monitoring of populations is necessary to confirm that proper iodine intake continues. The major and most efficient method to provide iodine to a population is the dietary use of iodized salt, but production and stability pose problems in many areas of the world. Other methods include the ingestion of iodized oil (lasts for about a year after a single dosage), iodination of the central water system (which is also antimicrobial), use of iodinated water to irrigate crops, and addition of iodine to animal feed. In the United States and other countries, dairy products, especially milk, are important sources of iodine because of the use of iodophors in the dairy industry. Fish is also an important dietary source of iodine.

Daily average iodine intake in the United States decreased from about 300 μg in 1971 –1974 to about 150 μg in 1988–1994 (Hollowell et al., 1998). Preliminary data from the current National Health and Nutrition Examination Survey (NHANES IV) suggests that daily iodine intake remains about 150 μg. This amount of iodine is appropriate for normal adult thyroid function, except for pregnant and lactating nursing women in whom 220 μg and 290 μg iodine daily, respectively, is recommended.

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[49] Section 2.2 is excerpted from "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, issued 2004.

[50] Section 2.3 is excerpted from "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, issued 2004.

The thyroid responds to dietary iodine deficiency by enlarging and more actively transporting iodine from the blood, thereby concentrating sufficient iodine to maintain normal function. In contrast, when iodine ingestion is excessive, the thyroid decreases the transport of iodine from the blood into the thyroid. The mechanism responsible for the adaptation of the thyroid to excess iodine is described below.

It has been recognized since the 1940s that excess iodine exposure causes a transient decrease in thyroid-hormone synthesis for about 48 hours—called the acute Wolff-Chaikoff (W-C) effect (Wolff et al., 1944)—and that normal thyroid-hormone synthesis resumes shortly thereafter despite continued ingestion of excess iodine (adaptation to or escape from the acute W-C effect) (Wolff et al., 1949). The transient inhibition of hormone synthesis most likely results from the generation of an iodinated lipid or an iodolactone that inhibits thyroid peroxidase activity and the oxidation of iodine, iodination of tyrosines, and the coupling of the iodinated tyrosines MIT and DIT to generate T4 and T3 (Pisarev and Gartner, 2000). The escape from the acute W-C effect was postulated to result from a decrease in the active transport of iodine from the blood to the thyroid that decreased intrathyroidal iodine and allowed normal thyroid hormone synthesis to resume (Braverman and Ingbar, 1963).

2.3 Radioactive Iodine[51]

2.3.1 Medical Uses

Radioactive iodine plays an important role in the diagnosis and treatment of various thyroid disorders. The two iodine isotopes used for those purposes are ^{123}I, primarily a gamma-emitter with a short physical half-life of 13 hours, and ^{131}I, a beta- and gamma-emitter with a longer physical half-life of 8 days. Since greater cellular damage or cell death is produced by the higher energy beta emissions of ^{131}I than by the gamma emissions of either isotope, ^{123}I is now the preferred choice for diagnostic studies of the thyroid. Its short half-life and its mainly gamma emission reduce potential radiation effects on the thyroid.

The ability of the thyroid to concentrate iodine permits the use of radioiodine to quantify the iodine-concentration activity of the thyroid because the isotope equilibrates with blood iodine and reflects the uptake of stable (nonradioactive) iodine into the thyroid. Thyroid radioiodine uptake is elevated in patients with hyperthyroidism, is usually low in hypothyroid patients, and varies inversely with iodine intake. Thus, the radioiodine uptake will be higher than normal in subjects with low iodine intake and lower in subjects with high iodine intake. The former probably occurred in Chornobyl because of dietary iodine deficiency, and the latter would occur in Japan, where iodine intake is high. The ability of the thyroid to concentrate radioiodine also permits visualization of the thyroid with appropriate imaging instruments to determine its location, configuration, and the functional status of thyroid nodules if they are present.

Radioiodine concentrated by the thyroid in large amounts can cause cell death primarily because of beta radiation from ^{131}I. Large doses of ^{131}I are, therefore, given to treat patients with hyperthyroidism; those who have large nodular goiters that are causing local compressive symptoms on the trachea and esophagus, and those who cannot tolerate thyroid surgery; and to ablate functioning residual normal or malignant thyroid tissue after definitive surgery for thyroid cancer. The very large doses used to treat thyroid cancer occasionally lead to radiation-induced salivary gland inflammation and loss of taste because iodine is also concentrated by the salivary glands.

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[51] Section 2.3 excerpted from "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, issued 2004.

2.3.2 Radioactive Iodine and Thyroid Disease

The 2005 report by the National Research Council of the National Academies, "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," makes the following observations:

> A large amount of ^{131}I delivered to the thyroid almost always leads to hypothyroidism because of permanent radiation-induced destruction of thyroid cells. Therefore, with a smaller population of vulnerable thyroid cells remaining, these large radiation doses from ^{131}I are much less likely to cause thyroid cancer. In contrast, a surprising number of children exposed to a relatively low radiation dose from ^{131}I and possibly other shorter-lived isotopes of iodine after the 1986 Chornobyl accident developed thyroid cancer within a few years. There are several potential reasons for the differences between the medical use of radioactive iodine and exposure to radiation fallout in causing thyroid cancer.
>
> - As noted above, large amounts of ^{131}I can result in thyroid-cell death. In contrast, low-dose exposure damages but does not kill thyroid cells and can induce nuclear damage and mutations, which can result in thyroid cancer.
> - Radioiodine released to the atmosphere may likely include a number of shorter-lived isotopes of iodine in addition to ^{131}I, which are also potentially carcinogenic.
> - Because their thyroid cells divide more frequently than in adults, children are at far greater risk of nuclear mutations and thyroid cancer when exposed to low level radiation to the thyroid. The higher uptake of iodine by infants and children is discussed below in Section 2.3.5.
> - As noted earlier, the presumed low dietary iodine intake in the Chornobyl area probably resulted in an increased uptake of radioactive iodines.

Acute radiation thyroiditis generally occurs within 2 to 3 weeks after an internal exposure to radioiodine and is characterized by inflammation and necrosis of thyroid tissue (Maxon et al. 1977). The symptoms are generally mild but in some instances may be made worse by the rapid release of stored thyroid hormones (thyroid storm) (Shafer, 1971). In most instances, this syndrome abates within several weeks of onset.

Hypothyroidism is a metabolic state in which the thyroid produces an insufficient quantity of the thyroid hormone for normal physiologic function. For radiation-induced hypothyroidism, it must be assumed that a substantial number of cells are either killed or rendered nonfunctional, because of the large reserve capacity of the normal thyroid. Thyroid doses of 600 Gy (60,000 rad) could be expected to result in a 100 percent probability of hypothyroidism. The latency period between exposure and symptoms of hypothyroidism ranges from less than 1 year to several decades and increases with decreasing doses.

2.3.3 Thyroid Nodules

Single or multiple nodules of sufficient size may cause obvious enlargement of the thyroid and may be seen as bumps on the neck. Usually a nodular thyroid is without symptoms, but with continued growth there may be a visible enlargement in the neck and compression of the trachea, which results in a sensation of choking or coughing and hoarseness. The incidence of nodules is 10 to 20 times as great in women as in men, and since it develops and progressively increases in size during life, it is most frequently found in females 50 to 70 years of age. It is very common for nodules to remain undetected during a person's life and only be detected upon autopsy.

2.3.4 Thyroid Cancer

The thyroid gland, like other body tissues, can develop cancer. The incidence of thyroid cancer is relatively uncommon; about 33,550 cases were diagnosed in 2007. Of these, about 25,480 will occur in women and 8,070 in men.[52]

In "normal" populations, the incidence of clinically diagnosed thyroid cancers ranges from less than 0.5 per 100,000 persons (in the United States and Central Europe) to 8 per 100,000 in Chinese people. Thyroid cancers are often hidden or "occulted" and remain so during the lifetime of the patient. Often they are not discovered until the patient's death from other causes. The incidence of occulted thyroid cancers in normal populations is a thousand times higher and ranges from 5,600 per 100,000 in Colombia to 35,000 per 100,000 in Finland. In the younger age group (0–15 years), the incidence of occult cancers in Finland is lower, 2,400 per 100,000.[53]

Thyroid cancers are generally classified on the basis of cell origin, such as (1) papillary, (2) follicular, (3) medullary, and (4) anaplastic carcinomas. Radiation is generally considered a causative agent for the induction of papillary and follicular carcinomas.

Radioiodine uptakes from inhalation or ingestion or both could result in acute, chronic, and delayed thyroid effects. For very high doses, acute effects include thyroiditis induced within 2–3 weeks after exposure. Following a latency period of years to decades, chronic and delayed thyroid effects may involve the gradual insufficiency of thyroid hormone production (hypothyroidism) or the appearance of thyroid nodules and cancer.

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[52] American Cancer Society, http://www.cancer.org/docroot/CRI/content/CRI_2_4_1X_What_are_the_key_statistics_for_thyroid_cancer_43.asp?sitearea=

[53] Fransilla, K.O., and H.R. Harach, "Occult papillary carcinoma of the thyroid in children and young adults. A systematic study in Finland," Cancer 58:715-719, 1986, and Harach, H.R., K.O. Fransilla, and V.M. Vasenius, "Occult papillary carcinoma of the thyroid. A 'normal' finding in Finland. A systematic autopsy study," Cancer 56:531-538, 1985

Radiation-induced thyroid cancers are essentially confined to the papillary and follicular types. Nearly 80 percent of all thyroid carcinomas (and about 90 percent of radiation-induced thyroid carcinomas) are papillary tumors.[54] Papillary lesions are frequently very small. Tumor growth tends to be partially dependent on TSH and is less aggressive in individuals under the age of 40. The 10-year survival rate with various forms of therapy is about 90 percent.

Follicular thyroid cancers (about 10 percent of the radiation-induced thyroid cancers) tend to metastasize early by way of the blood stream to the lungs and bones. The tumors are TSH responsive and tend to pick up and metabolize iodide and to form the thyroid hormone. This is not a common type of thyroid cancer. This type of cancer has a lower survival rate than papillary carcinomas, typically a 10-year survival rate of 50 percent.[55]

2.3.5 Age-Related Factors in the Development of Thyroid Disease[56]

Children

One observation that is central to the understanding of the consequences of exposure to iodine isotopes in Chornobyl fallout concerns age-related sensitivity of the thyroid to carcinogenesis. Early studies showed that the age of incidence of thyroid carcinoma in exposed children was changing—the peak age of exposed children diagnosed with thyroid carcinoma in 1992 was about 7 years, but the peak age of children diagnosed in 1994 was about 9 years. It soon became apparent that the difference was caused by a rapid decrease in the risk of developing thyroid cancer with age at the time of exposure to radioiodine; children who were youngest at exposure were carrying an increased risk that continued as they aged (Williams, 1996). Children who were newborn at the time of Chornobyl are now 17 years old, and the exposed population continues to show an increased risk of developing new cases of thyroid cancer.

Calculations suggest that the relative risk in children who were 0–1 year old at exposure to the Chornobyl fallout is 40 or more times that of children who were 10 years old or older at exposure (Cardis et al., 1999), but this ratio may change with study over a longer period. It appears that the risk in those exposed as adults is extremely small. The thyroid gland of the fetus begins to concentrate iodine at about the 3-month stage of pregnancy; those who were in utero at the time of the accident show an increase in thyroid cancer, but much less than those who were newborn. Those who were born more than 6 months after the accident show no increase in thyroid cancer; because of the short half-life of the iodine isotopes, they would not have had appreciable exposure.

Three factors contribute to the high sensitivity of very young children to the risk of thyroid cancer after exposure to iodine isotopes—(1) a high intake of isotopes mainly through milk, (2) the high uptake of radioiodine by the infant thyroid, and (3) increased biologic sensitivity. The intake of milk is important as an exposure pathway because in the absence of precautions it is the main route through which radioiodine reaches individuals. Grazing animals collect fallout from a considerable area of ground, and iodine, including radioactive iodine, is concentrated in milk (goats concentrate radioiodine approximately 10 times more than cows). Other foods, such as green vegetables, may also be contaminated. If a nursing mother consumes contaminated food, in particular milk from cows or goats exposed to fallout, she will pass the radioactivity on to her child through breastfeeding. The relatively high breathing rate of children will increase the amount of radioiodine absorbed through inhalation, although this is only a small proportion of the total. The radiation dose to the infant thyroid is therefore higher than that to older children or

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[54] Practice Guidelines in Oncology – v.1.2001 Thyroid Carcinoma

[55] ibid

[56] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

adults because infants take in relatively more iodine radioisotopes, have a smaller thyroid gland, and have a higher uptake by the thyroid, leading to a thyroid dose estimated to be up to 5 times that of adults (IAEA, 1991). Infants are also more sensitive to the risk of carcinogenesis, probably because of the way the thyroid develops—growing rapidly during the early years of life but hardly at all during adult life. Although thyroid cancer has been the main thyroid consequence of exposure to fallout from Chornobyl, benign thyroid tumors also appear to be increasing in frequency; this is similar to the findings after exposure to x-rays (Shore et al., 1993).

The long-term incidence of hypothyroidism in those exposed to fallout from Chornobyl is not known. One study reported higher levels of TSH in children from the more heavily exposed areas than in those from the less exposed areas (Yamashita et al., 2002); this suggests that some degree of thyroid damage occurred. An alternative explanation could be iodine deficiency, but the main exposed areas do not appear to have more iodine deficiency than the rest. Juvenile hypothyroidism was found in about 0.1 percent of a large population of children exposed to fallout from Chornobyl; the evidence that it was exposure related depended on correlation with the body burden of ^{137}Cs (Goldsmith et al., 1999). Radiation may also lead to an increase in circulating antibodies to the thyroid; this has been demonstrated to occur after treatment of thyrotoxicosis with high doses of radioactive iodine. The same study also examined circulating thyroid antibodies in more and less exposed areas and found no correlation. A separate study compared circulating thyroid antibodies in villages with different levels of fallout exposure and concluded that there was a relationship between radiation exposure and the development of autoimmune disease of the thyroid (Yamashita et al., 2002). The clinical significance of those observations is uncertain but is likely to be small.

Adults 20 to 40

The studies also suggest that there was no appreciable risk of thyroid cancer in those who were adults at the time of exposure to radiation from radioiodine, although reliable information on the risk to those who were adults at the time of exposure to fallout from Chornobyl is not available, and future work in this area is needed. Studies from external radiation show no significant risk above the age of 20 years (Thompson et al., 1994), although there might be a very small risk between the ages of 20 and 30 years.

Adults over 40

People more than 40 years old appear to be more resistant to the thyroid-cancer-causing effects of ^{131}I exposure as well as to the underlying thyroid disorders that predispose a person to iodine-induced thyroid dysfunction later in life. Therefore, people over 40 probably should not take KI tablets after a nuclear incident unless they receive a large internal radiation dose to the thyroid (more than 500 centiGray) as they are at virtually no risk of developing thyroid cancer from the radiation and are more likely than younger people to develop side effects from the KI.

In summary, a review of experience with thyroid cancer in populations exposed to the consequences of nuclear events shows the following:

- Exposure to external radiation or internal radiation from radioactive iodine is linked to a dose-dependent increase in thyroid cancer incidence.
- Young children are by far the most sensitive to the carcinogenic effect of radiation on the thyroid, especially after exposure to radioactive iodine in fallout.

- The risk of thyroid carcinoma in adults exposed to radioactive iodine in fallout is very low and can be assumed to be absent for adults over 40 years old, although at very high doses there is a risk of hypothyroidism.

- The probability of a large release of radioactive iodine from the type of reactor used in the United States is much lower than the chance of a large release in countries that use reactors of the type used at Chornobyl. Therefore, the risk of thyroid carcinoma in the U.S. population in the event of a nuclear accident is likely to be considerably less than the risk after Chornobyl both because of the level of dietary iodine and because of the use of precautionary measures.

- The concentration of stable iodine intake in the diet is probably relevant. In experimental studies, fewer tumors develop when radioiodine is administered to animals that have a high iodine intake than in animals that have a low-iodine diet. The population around Chornobyl had a low iodine intake; in the United States, dietary stable iodine is 3–5 times higher than in much of the area around Chornobyl. The greater dietary iodine is associated with a smaller thyroid gland and also with a lower uptake of radioiodine than in areas that have iodine deficiency. The population around Chornobyl would therefore be predicted to take up more radioiodine into their thyroids than a U.S. population exposed to similar levels of contamination measures.

CHAPTER 3

POTASSIUM IODIDE AS A THYROID BLOCKING AGENT

3.1 How Potassium Iodide Works

KI is a salt, similar to table salt; in fact, KI is the ingredient that is routinely added to table salt to make it "iodized." KI will be taken up by the thyroid gland and, if taken in large enough quantities and at the appropriate time, will effectively saturate the thyroid gland and thus can prevent the uptake of radioactive iodine that may be released in the unlikely event of a severe nuclear reactor accident.[57]

The National Research Council[58] stated the following about the distribution of KI to populations within 20 miles around nuclear power plants:

> …under normal circumstances, excess iodine decreases the sodium-iodide symporter (NIS) on the thyroid-cell surface, thereby inhibiting the further entrance of iodine into the thyroid. Excess iodide administration at the appropriate time decreases the thyroid radioactive iodine uptake (RAIU) by decreasing NIS and by increasing the amount of nonradioactive iodine available for binding to thyroid cells. In the event of release of radioiodine from a nuclear incident, a marked decrease in thyroid RAIU could be achieved by the timely administration of stable iodine that would be extremely useful in reducing internal radiation to the thyroid caused by exposure to iodine radioisotopes from inhalation or by consumption of radioiodine-contaminated foods, especially milk, other dairy products, and leafy vegetables. The concentration of stable iodine intake in the diet is likely relevant. In experimental studies, fewer tumors develop when radioiodine is administered to animals that have a high iodine intake than in animals that have a low-iodine diet. The population around Chornobyl had a low iodine intake; in the United States, dietary stable iodine is 3–5 times higher than in much of the area around Chornobyl. The greater dietary iodine is associated with a smaller thyroid gland and also with a lower uptake of radioiodine than in areas that have iodine deficiency. The population around Chornobyl would therefore be predicted to take up more radioiodine into their thyroids than a U.S. population exposed to similar levels of contamination.
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> In healthy volunteers, thyroid uptake of radioactive iodine has been reported to be essentially blocked for at least 24 hours by administration of 30–200 mg of stable iodine, administered in the form of KI, just before and minutes after exposure. If KI is given one to three hours after exposure to radioactive iodine, further thyroid radioiodine uptake (that is, beyond what is already in the thyroid) is blocked for at least 24 hours. The inhibitory effect on the thyroid RAIU of a single dosage of 130 mg of iodine as KI lasts for about 48 hours. Even if KI is given 8 hours after

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[57] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

[58] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

exposure to radioiodine, the normal uptake of 28% of the radioiodine would be reduced by about 40% to an uptake of about 16% (see Table 3-1). However, it should be noted that if KI is given first 2 to 3 days after ^{131}I exposure, there is some concern that the retention of the ^{131}I would be slightly prolonged, theoretically enhancing the radiation effect of the retained ^{131}I. Because of normal prolonged retention of radioiodine by the thyroid (half-life of stable iodine is 80–120 days, 7.8 days is the effective half-life of radioactive iodine; a factor of the radiological half-life and the biological half-life) further slowing of thyroid discharge by subsequent KI is likely to be small. If ^{131}I continues to be detected in the air at concentration capable of producing a thyroid dose of 5 Gy (500 rad) or more, then KI should be given.

Table 3-1 Percent Thyroid Protection from ^{131}I after a Single 130 mg Dosage of KI

Time of KI with Respect to ^{131}I Exposure (hours)	Protection Afforded KI Ingestion (% of control)
-96	Very little
-48	~80
-1	~100
0	98
2	80
3	60
8	40
24	16

Data at 0 and 3 hours come from experimental observations (Blum and Eisenbud, 1967, Sternthal et al., 1980, Ramsden et al., 1967); other data are derived from models of iodine metabolism (Zanzonico and Becker, 2000).

3.2 Potassium Iodide Products in the United States

Currently, FDA has approved the KI products Iosat, Thyrosafe, and ThyroShield for over-the-counter use. ThyroShield is marketed as a pediatric oral solution, and the other two products are available as 130-milligram (mg) and 65-mg tablets, respectively. KI is inexpensive and stable, and it has a long shelf-life if tablets are stored in a blister package to prevent exposure to light and moisture (Iosat shelf-life is 7 years; Thyrosafe shelf life is 6 years).

The FDA issued guidance[59] to Federal agencies and to State and local governments on testing to extend the shelf-life of stockpiled KI tablets. This guidance presents the FDA recommendations on the requisite testing that would allow holders of stockpiled KI to retain these supplies beyond the originally labeled expiry date.

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[59] http://www.fda.gov/cder/guidance/5353dft.htm

3.3 Food and Drug Administration Recommendations on Potassium Iodide Use for Nuclear Incidents

Table 3-2 provides the FDA recommendations[60] on KI use for a nuclear incident.

Table 3-2 Threshold Thyroid Radioactive Exposures and Recommended Doses of KI for Different Risk Groups

	Predicted Thyroid Gland Exposure (cGy)	KI Dose (mg)	Number or Fraction of 130-mg Tablets	Number or Fraction of 65-mg Tablets	Milliliters (mL) of Oral Solution, 65 mg/mL
Adults over 40 years	≥ 500	130	1	2	2 mL
Adults over 18 through 40 years	≥ 10	130	1	2	2 mL
Pregnant or Lactating Women	≥ 5	130	1	2	2 mL
Adolescents, 12 through 18 years*	≥ 5	65	½	1	1 mL
Children over 3 years through 12 years	≥ 5	65	½	1	1 mL
Children 1 month through 3 years	≥ 5	32	Use KI oral solution**	½	0.5 mL
Infants birth through 1 month	≥ 5	16	Use KI oral solution**	Use KI oral solution**	0.25 mL

* Adolescents approaching adult size (more than 70 kilograms) should receive the full adult dose (130 mg).

** KI oral solution is supplied in 1-ounce (30-mL) bottles with a dropper marked for 1, 0.5, and 0.25 mL dosing. Each mL contains 65 mg KI.

These recommendations are meant to provide States and local authorities as well as other agencies with the best current guidance on the safe and effective use of KI to reduce thyroidal radioiodine exposure and thus the risk of thyroid cancer. FDA recognizes that, in the event of an emergency, some or all of the specific dosing recommendations may be very difficult to carry out given their complexity and the logistics of implementing a program of KI distribution. The recommendations above should be interpreted with flexibility to allow for optimal KI dosing during a population emergency.

In the interest of pediatric emergency preparedness, FDA published emergency home preparation instructions[61] for laypersons to convert solid oral dosage forms to palatable liquid

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[60] http://www.fda.gov/cder/guidance/4825fnl.htm

forms of KI using commonly found foodstuffs in the home. However, following the more recent approval by FDA of ThyroShield (KI oral solution), it is anticipated that home preparation instructions will be less necessary.

The lactating woman presents a unique situation since the breast removes iodine from the blood, and the iodine is then transported into breast milk. Approximately one quarter of the iodine ingested by the mother is secreted into breast milk. An excess of stable iodine can partially decrease the transport of radioiodine into the breast. Thus, the mother must minimize her potential thyroid exposure to radioiodine by taking the recommended adult dosage of KI and ensure that the nursing infant be given KI as recommended for infants. Both mother and infant must take KI for both to be protected from thyroid radioiodine exposure. Assuming an alternative food source is available for the infant, the mother should stop breastfeeding the infant to prevent the infant from ingesting radioiodine concentrated in breast milk.

3.4 Adverse Effects of Potassium Iodide

The use of KI in Poland after the Chornobyl accident provided useful information regarding its safety and tolerability in the general population. Approximately 10.5 million children under age 16 and 7 million adults received at least one dose of KI. Of note, among newborns receiving single doses of 15 mg KI, 0.37 percent (12 of 3214) showed transient increases in TSH and decreases in free thyroxine (FT4). The side effects among adults and children were generally mild and not clinically significant. Side effects included gastrointestinal distress, which was reported more frequently in children (up to 2 percent, felt to be caused by the bad taste of SSKI (super saturated potassium iodide) solution), and rash (approximately 1 percent in children and adults). Two allergic reactions were observed in adults with known iodine sensitivity (Nauman and Wolff, 1993).

Extremely rare disorders reported to be aggravated by excess iodine ingestion include dermatitis herpetiformis Duhring, ioderma tuberosum, hypocomplementemia vasculitis, and myotonia congenital.[62]

The potential nonthyroidal side effects of KI include the following:[63]

- Gastrointestinal side effects include nausea, vomiting, diarrhea, and stomach pain.
- Allergy-related side effects include andioedema (generalized swelling), arthralgia (joint pains), eosinophilia (abnormal white blood cells), lymphadenopathy (enlarged lymph nodes), urticaria (itching), and skin rashes.

People with underlying thyroid disease—such as autoimmune thyroiditis or nontoxic nodular goiter, both of which are more prevalent in the elderly and may occur in approximately 25 percent of older individuals, especially women—are at risk for iodine-induced thyroid dysfunction. People who develop iodine-induced hypothyroidism do not escape from the acute W-C effect described in Section 2.2. Underlying thyroid disorders and other clinical situations that would predispose a person to iodine-induced thyroid dysfunction are listed below. In contrast with iodine-induced hypothyroidism, excess iodine ingestion may induce hyperthyroidism or Iod Basedow disease, especially in regions of iodine deficiency, including many countries in Western Europe.

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[61] http://www.fda.gov/cder/drugprepare/kiprep.htm

[62] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

[63] ibid

The National Research Council[64] identified the following groups, classified below as to the existence of underlying thyroid disease, as at risk for iodine-induced hypothyroidism:

- No underlying thyroid disease
    - fetus/neonate, mostly preterm
        - secondary to transplacental passage of iodine or exposure of neonate to topical or parenteral iodine-rich substances
    - infant
        - occasionally reported in infants drinking iodine-rich water (China)
    - adult
        - in Japanese subjects with high iodine intake where Hashimoto's thyroiditis has been excluded
    - elderly
        - reported in elderly subjects with and without possible defective organification and autoimmune thyroiditis
    - chronic nonthyroidal issues
        - cystic fibrosis
        - chronic lung disease
        - chronic dialysis treatment
        - thalassemia major
        - anorexia nervosa
- Underlying thyroid disease
    - Hashimoto's thyroiditis
    - euthyroid patients previously treated for Graves' disease with I-131, hyroidectomy, or antithyroid drugs
    - subclinical hypothyroidism (especially in elderly)
    - after transient postpartum thyroiditis
    - after subacute painful thyroiditis
    - after hemithyroidectomy for nodules
    - euthyroid patients with previous episode of amiodarone-induced destructive thyrotoxicosis

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[64] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

  - euthyroid patients with a previous episode of interferon-alpha-induced thyroid disorders
- patients receiving lithium therapy

The National Research Council[65] also identified the following, categorized below as to existence of underlying thyroid disease, as risk groups susceptible to iodine-induced hyperthyroidism:

- Underlying thyroid disease
  - iodine supplementation for endemic iodine-deficiency goiter
  - iodine administration to patients with euthyroid Graves' disease, especially those in remission after antithyroid drug therapy
  - nontoxic nodular goiter
  - autonomous nodules
  - nontoxic diffuse goiter
- No underlying thyroid disease
  - iodine administration to patients with no recognized underlying thyroid disease, especially in areas of mild to moderate iodine deficiency

Iodine may also be useful in some clinical situations other than a need to prevent iodine deficiency. The National Research Council[66] has identified the following medical uses of stable iodine:

- treatment and prevention of iodine deficiency goiter
- thyroid storm
- preoperative preparation of toxic goiter
- post-^{131}I therapy of Graves' disease
- as sole therapy of Graves' disease (when sensitive to antithyroid drugs)

3.5 Alternative Prophylaxis or Preventive Measures

Other antithyroid drugs have been proposed to block the entrance of iodine into the thyroid, including thiocyanate and perchlorate. The former is too toxic, and the latter may not be acceptable because of concerns over the unproven adverse thyroid effects of the trace amounts of perchlorate that are in ground water in at least 14 States (Engell and Lamm, 2003). KI is the only drug approved by FDA as a thyroid blocking agent in the event of radioiodine exposures.[67]

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[65] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

[66] ibid

[67] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

It is important to note that a release of radioactivity from a nuclear power plant is not limited only to radioiodine but is composed of a mix of radioisotopes of varying energies and half-lives. Radiation dose to the thyroid gland resulting in notable increases in thyroid cancer can occur as a result of exposure to external radiation from a passing plume in the absence of significant quantities of radioiodine. Ingestion of KI does not block the external radiation dose to the thyroid, nor does it block internal exposure to the thyroid from other radionuclides circulating or resident in the body. Therefore, evacuation and sheltering are the preferred methods of protecting populations from direct exposure to radioactive materials (including radioiodine) in a nuclear emergency.[68,69,70,71]

Sheltering offers considerable, but time-limited, protection when a radioactive plume is passing. To achieve greater protection through sheltering, air-handling systems that bring outside air into buildings must be shut off and windows and doors must be closed. Additional protection can be gained by moving to areas of buildings that provide the most shielding from radiation coming from radionuclides in outside air (for example, if occupants move inward and downward within the building). However, sheltering is effective for only a limited period of time; after a number of hours, the air inside the building becomes more concentrated with radioactivity than the external air. Evacuation before or as soon as possible after plume passage is the preferred way of moving people out of harm's way and ensuring that they are not exposed to released radionuclides.

As discussed in earlier sections of this document, the thyroid can also be exposed internally from radioiodines taken in through the consumption of contaminated milk or leafy vegetables, commonly known as the ingestion pathway. The milk pathway is particularly important because radioiodines deposited on pasture grass are effectively transferred to the milk of grazing animals (particularly, cows, goats, and reindeer). Studies of the Chornobyl accident show that the dominant pathway for exposure to children (who were later afflicted with thyroid cancer) was predominately from consumption of contaminated milk. Interdiction of food products is a very important protective action for the prevention of and reduction in incidence of thyroid cancer.

Food products are routinely interdicted in the United States, and the public routinely modifies consuming behavior to adjust to product recalls. In 2006, a massive recall of potentially contaminated spinach occurred. The public was notified of potential bacterial contamination of

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[68] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

[69] In "10 CFR Part 50, Consideration of Potassium Iodide in Emergency Plans, Final Rule," U.S. Nuclear Regulatory Commission, *Federal Register,* Vol. 66, No. 13, page 5430, the NRC states the following:

> The use of KI is intended to supplement, not to replace, other protective measures. This amendment represents no change in the NRC's view that the primary and most desirable protective action in a radiological emergency is evacuation of the population before any exposure to radiation occurs.

[70] In 10 CFR 50.47(b)(10), the NRC states the following:

> A range of protective actions has been developed for the plume exposure pathway EPZ for emergency workers and the public. In developing this range of actions, consideration has been given to evacuation, sheltering, and, as a supplement to these, the prophylactic use of potassium iodide (KI), as appropriate. Guidelines for the choice of protective actions during an emergency, consistent with Federal guidance, are developed and in place, and protective actions for the ingestion exposure pathway EPZ appropriate to the locale have been developed.

[71] "Federal Policy on Use of Potassium Iodide," *Federal Register*, Vol. 67, No. 7, page 1355

the spinach and warned not to consume bagged spinach products. Section 4.2 further discusses public awareness and response to food product recalls.

CHAPTER 4

EMERGENCY PREPAREDNESS AND THE ROLE OF POTASSIUM IODIDE

4.1 The Role of Evacuation and Sheltering in Emergency Preparedness

Large-scale evacuations occur on average about once every 3 weeks in the United States.[72] These occur for a number of different reasons, including wildfires, hurricanes, severe weather, earthquakes, and other natural phenomena; chemical spills; and malevolent events. A recent study examined large-scale evacuations that occurred within the United States from 1990 to June 2003. From these evacuations, researchers identified 230 for additional study before further reducing this sample to 50 case studies. Details regarding the 50 case studies came from a literature search as well as interviews from emergency management officials, emergency responders, local and State officials, and others. The researchers identified a number of variables and analyzed these variables. From this analysis, the study, published by the NRC in January 2005 as NUREG/CR-6864, "Identification and Analysis of Factors Affecting Emergency Evacuations," concluded that evacuation is effective and prevents injuries and saves lives.[73] This study was continued after the recent hurricane evacuations to gain insights into large-scale evacuations. It examined a total of 10 evacuations; 5 hurricanes and a mix of wildfires and technological hazards. This second study has not yet been published, but it also shows the effectiveness of evacuation in preventing injury and death. Both studies show that the rate of compliance by the public was good[74] and that evacuations were effective in saving lives. According to "A Failure of Initiative: The Final Report of the Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina," issued by the U.S. House of Representatives, "The failure of complete evacuations led to preventable deaths, great suffering, and further delays in relief."

In the 230 evacuations examined for NUREG/CR-6864, only one resulted in a fatality from the actual evacuation as opposed to fatalities caused by the hazard. The evacuation of Houston and the surrounding Texas coast region (approximately 3.7 million people) resulted in 113 deaths in contrast to the 7 deaths attributable directly to Hurricane Rita. However, in this evacuation, authorities did not initiate the traffic management plans, including contraflow, until the second day of the evacuation when traffic was already gridlocked. The failure to implement the existing emergency plans contributed to the problems during this evacuation.

Traffic management plans, including evacuation time estimate studies, are a part of the emergency plan for each nuclear power plant site.[75] These plans are reviewed and updated routinely. Each nuclear power plant site participates in a Federally graded exercise with State and local emergency officials, hundreds of local volunteers, first responders, and local law enforcement.

As seen in other hazard evacuations, and emphasized by the U.S. House of Representatives report on Hurricane Katrina, early evacuation is the most effective protective action. This is also

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[72] NUREG/CR-6864, "Identification and Analysis of Factors Affecting Emergency Evacuations," January 2005, **http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6864/**. Large scale evacuations are defined as those involving more than 1000 people and evacuating from more than one building

[73] NUREG/CR-6864, "Identification and Analysis of Factors Affecting Emergency Evacuations," January 2005, http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6864/

[74] The rate of compliance was good as judged by emergency responders and State and local officials as well as based on the number of deaths from the primary hazard and from evacuations.

[75] Attachment 1, "Evacuation Time Estimate for the Indian Point Energy Center"

true for nuclear power plant accidents. Plant operators are expected to recommend prompt evacuation to offsite authorities without waiting for a release of radioactive materials. Removing the public before the arrival of the plume is always more effective than waiting for a release to begin and then ordering evacuation. Plant operators base their recommendations on current and expected plant conditions.

In some cases, sheltering may be the appropriate protective measure. If travel conditions present an extreme hazard, public officials may initially decide to shelter (rather than evacuate) the nearby population until conditions improve. Sheltering may also be the appropriate initial action for people requiring assistance with transportation. In addition, sheltering may be the appropriate protective action for controlled releases of radioactive material from the containment if there is assurance that the release will be of short duration and if the area near the plant cannot be evacuated before the plume arrives. However, evacuation should begin after the plume has passed in order to realize dose savings from evacuation.

After performing the initial early evacuation near the plant, licensee and offsite officials could modify the protective action recommendations, as appropriate, on the basis of (1) dose projections indicating that the EPA PAG doses may be exceeded in areas beyond those that have been evacuated, and (2) field monitoring results that have located areas with high levels of contamination. On the basis of this information, plant and offsite officials may expand the evacuations to encompass other areas in the plume EPZ.

4.2 Interdiction of Contaminated Food Products[76]

The NRC and FEMA require that plans be in place for a distance out to 50 miles from a nuclear power plant that provide for the interdiction of potentially contaminated food products as well as the placement of livestock on stored feed. These plans are tested at least once every 6 years as part of the State's ingestion pathway exercise.[77]

During an incident at a nuclear power plant that may result in an offsite release of radioactive materials, specific guidance would be given on foods and drinks that should not to be consumed by humans because of the presence of radioiodine or other radionuclides. It is expected that there would be good consumer compliance with public health directives not to consume products identified as potentially contaminated. The American public receives warnings about possible contamination in the food supply up to several times per year. The recent E. coli contamination of spinach in 2006 is a good example of public compliance with food product recalls. According to the Perishables Group, a market researcher, for the week ended December 23, 2006, "packaged spinach sales were down 37% from the same period a year earlier...while bulk spinach sales, a smaller market, were off 22%."[78] Dramatic reduction in sales is directly correlated to consumer awareness of the spinach recall, according to a Rutgers University national survey. The survey showed that nearly 9 out of 10 consumers had heard about the recall, about 1 in 5 who were aware of the recall also stopped eating other bagged produce, and more than 75 percent of respondents with spinach in their home threw it out.[79] FDA is

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[76] The category of food products includes beverages such as milk.

[77] Appendix E to 10 CFR Part 50, NUREG-0654/FEMA-REP-1

[78] http://www.usatoday.com/money/industries/food/2007-01-29-spinach-usat_x.htm

[79] http://ur.rutgers.edu/medrel/viewArticle.html?ArticleID=5588

conducting a 6-month pilot program to educate and assist consumers in identifying recalled food products that may pose a significant health risk.[80]

4.3 The Role of Potassium Iodide in Emergency Preparedness

KI is a supplement to evacuation and sheltering under specific local conditions for very specific nuclear power plant incident scenarios where there is a potential for significant release of radioactive iodine.

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[80] http://www.fda.gov/oc/po/firmrecalls/pilot.html

For optimum benefit, KI should be administered just before, concurrent with, or within 3 to 4 hours after the release. FDA concluded that prevention of thyroid uptake of ingested radioiodines, once the plume has passed and radiation protection measures (including KI) are in place, is best accomplished by food control measures and not by repeated administration of KI.

Previously, KI was considered primarily for administration to nuclear power plant workers and emergency workers. Thyroid blocking for emergency workers was recommended because (1) the emergency response responsibilities of these individuals may not permit them to evacuate, (2) the number of individuals involved at any site is relatively small and requires a limited supply of KI that can be readily distributed, (3) the storage, distribution, and administration of KI can be readily controlled, (4) the known sensitivity to iodide of this limited number of individuals can be reviewed, and (5) these individuals can be readily monitored for adverse side effects by medical personnel. In certain situations, KI may also be appropriate for institutionalized individuals for similar reasons.

The studies following the Chornobyl accident support the etiologic role of relatively small doses of radioiodine in the increase in thyroid cancer among exposed children. Furthermore, it appears that the increased risk occurs with a relatively short latency. Finally, the Polish experience supports the use of KI as a safe and effective means by which to reduce the risk of thyroid cancer caused by internal thyroid irradiation from inhalation of contaminated air or ingestion of contaminated food and drink when exposure cannot be prevented by evacuation, sheltering, or food and milk control.[81]

The use of KI is intended to supplement, not replace, other protective measures. One of the challenges of adding KI as a supplement to the range of public protective actions is ensuring that evacuation is not delayed. In a survey conducted by the State of New Jersey, many members of the public believed that they would be able to obtain KI at the time of need from local hospital emergency rooms, personal physicians, and pharmacies. These types of actions could impede successful evacuation as members of the public seek out KI rather than follow evacuation instructions. It is important to recognize that a nuclear incident of such magnitude as to require the prophylactic administration of KI is likely to be accompanied by the release of other nuclides such as noble gases (e.g., xenon, krypton) and particulates (e.g., strontium, cesium), and KI provides no protection against these other nuclides nor does it provide any protection to the thyroid or whole body from external radiation dose.

A large number of States have reported very limited success in the distribution of KI tablets to the general public. Many States that conducted some predistribution to the population report that less than 20 percent of the population obtained KI tablets from State or county distribution centers. The New Jersey Department of Health and Senior Services conducted an assessment of its KI distribution program and published the results in the *Operational Radiation Safety Journal* of the Health Physics Society. Overall, the department's predistribution of KI tablets was variable for the two nuclear power plant sites in the State, and approximately 46 percent of the population surveyed about KI was able to answer questions on its use correctly. The paper stated that "These data also showed that KI pill distribution requires a significant education and outreach component for it to be effective."[82]

4.3.1 Analysis of the Implementation of Potassium Iodide as a Supplemental Protective Action by State and Local Officials

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[81] "Guidance on Use of Potassium Iodide," FDA, 2002

[82] "Assessment of Potassium Iodide (KI) Distribution Program Among Communities Within the Emergency Planning Zones (EPZ) of Two Nuclear Power Plants," *Operational Radiation Safety Journal*, Health Physics Society, February 2007

It is the State's responsibility to provide for the health and safety of the public in the State. KI has been available since 1978 as an over-the-counter product to individuals and States and local officials desiring to have KI for their personal protection or as part of a larger emergency preparedness effort. Therefore, since 1978, States have been able to include KI as part of their radiological emergency plans. However, until the NRC's offer to supply KI tablets to requesting States, only 3 out of 33 States included the use of KI in their radiological emergency plans. Tennessee was the only State to implement a program to distribute KI directly to the public, and Alabama and Arizona maintained stockpiles for postevent distribution. This report includes the experience of Tennessee because of its long experience with distributing KI directly to the public.

Tennessee

Tennessee began its program to distribute KI to populations near nuclear facilities in 1981 with a pilot project to assess door-to-door predistribution of KI to households within a 5-mile radius of the Sequoyah Nuclear Power Plant near Chattanooga, operated by the Tennessee Valley Authority (TVA) (Fowinke et al., 1983). The decision to predistribute KI was made after emergency drills that simulated distribution after an emergency had been declared revealed that distribution was too slow to protect the public effectively. Because the pilot door-to-door distribution program was expensive, it was replaced with a system of community stockpiles that would be moved to mass shelters for administration to the evacuating population. In addition, since the early 1980s, the Tennessee Department of Health has publicized KI and made it available to those who wished to pick it up and store it at home. That continues, although only about 5 percent of the population near the facility takes advantage of the offering.

Fowinkle et al. (1982) describes the pilot door-to-door distribution of KI, which took place from November 16 to December 11, 1981. After a 1-day training session, 38 employees of county health departments attempted to distribute KI to the 5591 households within 5 miles of the power plant. The households were identified from addresses on TVA meter-reader sheets. Those distributing were local health professionals with experience in communicating with the public. They were prepared to answer general questions about the response plan for a nuclear accident. Some 3022 households accepted the KI at the door. A letter left if residents were not at home indicated that they could pick up KI at two local health centers at specific times on three designated Saturdays; an additional 682 residents availed themselves of this opportunity. A few more residents arranged to pick up KI later. In total, 66 percent of the targeted households received KI. The KI was packaged in a dark clear glass vial wrapped in the manufacturer's package insert. To discourage indiscriminate use, this was placed in a childproof brown plastic vial. The glass vial contained 14 130-mg tablets. Before the distribution, a letter from the commissioner of public health was mailed to the targeted households. News media also attended the training sessions given to those distributing KI. In the expectation that people would consult their physicians regarding the distribution, a program to inform local physicians through the local medical society was conducted before the distribution. As a partial indication of cost, it took 166 person-days to visit the 5591 households.

Because of the costliness of the pilot program, in 1983 the State established a program of stockpiling, supplemented with voluntary pickup, and it remains in place. The program has been described by Hagstrom (2003). KI is stored at central community stockpiles and will be distributed to mass shelters in the event of an emergency. At the shelters, public health nurses would administer the KI to the evacuated public. The Tennessee Department of Health decided not to make KI available to schools or day-care centers, because the facilities would not have health-care professionals available at the time of an emergency to oversee the administration of

KI. The State plans to relocate schoolchildren by bus to schools outside the 10-mile radius around a nuclear facility immediately on declaration of an onsite emergency at the power plant.

The amount of KI in the stockpile is sufficient to cover all those living within a 2-mile radius of the power plant and 20 percent of the population living within 2–10 miles. The KI is packaged in blister packs of 14 130-mg tablets. Dosages would be administered as recommended in the 2001 FDA guidelines. As part of the communication strategy for the stockpiling program, the State mails calendars yearly to all living within a 10-mile radius of the power plant. The calendars contain instructions for parents of schoolchildren, information on evacuation routes and sectors, details on the location of shelters, and other information related to nuclear power plant emergencies.

Anyone living within 10 miles of a nuclear facility can pick up KI from the few health department offices near the power plants. The Tennessee Department of Health states that it continues to publish the availability of KI for home storage. In the early 1990s, about 20 percent of those affected picked up KI. That proportion has declined, and now only about 5 percent of those affected pick up KI for their household. As a supplement to information made available in packaging, through calendars, and in publicizing the availability of KI for pick up, the State plans to have the mass media play a role in advising the public on dosing and possible side effects during an emergency.[83]

When the U.S. Department of Health and Human Services (HHS) offered for comment its draft guidelines for distribution of KI to those within 20 miles around nuclear power plants and then published them in the *Federal Register*, 20 States responded with comments. Of these, 14 States rejected the expanded distribution of KI citing the potential negative impact of expanding distribution of KI to 20 miles, questioned the scientific basis for expansion, cited economic concerns with the increased costs of reaching out to an area that is four times larger than the 10-mile ring, and expressed the fear that such expansion of KI distribution would lead to an expansion of the plume EPZ.[84] Several private citizens as well as two professional societies and law firms representing the manufacturers of some KI products commented favorably upon the draft guidelines and the efforts to expand KI to 20 miles. These respondents stated that this protection is needed based on the increase in thyroid cancers seen in children after the Chornobyl accident and cited the risk of terrorism as an initiating event at a nuclear power plant that could lead to a release of radioactive materials.

HHS has contracted for the delivery of 4.8 million bottles of ThyroShield—a liquid KI pediatric formulation—using the BioShield Special Reserve Fund. This procurement addresses the needs of children who do not easily accept the tablet formulation. The U.S. Government has taken possession of approximately 3 million bottles. Delivery of the remainder of the bottles procured under the contract is expected between August and December 2007. (FDA licenses this product with a 5-year expiry.) The NRC has worked cooperatively with HHS since 2005 to offer liquid KI to States with populations within the 10-mile EPZ. To date, 12 States have requested and

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[83] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

[84] State and county emergency plans for nuclear power plants are well established. Many States and counties have been a part of the current emergency planning for nuclear power plant events for more than 28 years. These plans and planning zones are well known to emergency management officials who practice plan implementation in a rigorous, Federally evaluated, full-participation exercise with the nuclear power plant at least every 2 years. These emergency plans and evaluations address topics including relocation centers, siren and public alert systems, school evacuation planning, use of KI, emergency alert messaging, evacuation planning, and public education.

received liquid KI to supplement existing stockpiles of KI tablets. Some States have expressed concerns regarding the addition of liquid formulation to their existing stores, as the State of South Carolina explained in a July 23, 2007, correspondence[85] with the NRC:

> After much discussion and consideration, the state has determined that the liquid KI available could not meet the states' needs,…accepting this form of liquid KI would pose several major financial, logistic and potentially legal issues. Among the concerns we have, the most pressing is the financial and logistical issues involved with liquid KI storage…acceptance of liquid KI would prompt severe financial burdens associated with pre-distributing and storing the liquid doses in our regional and county offices. In our state, 13 (thirteen) of our counties are designated host counties. Taking into account our pre-distribution needs, each of these 13 offices would be required to rent climate-controlled space and/or facilities to store the liquid KI being offered. In addition, our agency members voiced concerns over individual distribution/dispensability control of liquid KI. The vials of liquid KI contain enough for 15 (fifteen) adult doses, but are not distributed in a form that is easily divisible for families with fewer than 15 members. Safe distribution, of the appropriate amount of liquid KI, to each interested family would require health officials to break the seals of the bottles and separate the liquid into additional containers. The issue here is two-fold: cost of the additional vials and "custody controls." If a health official divides the liquid KI, or removes it, from the original packaging they have—potentially—violated the manufacturer's storage instructions because the integrity of the original vial has been compromised. However, not dividing the dosage could also result in families having enough liquid KI at their disposal to—potentially—cause an overdose to one or more family members.

The NRC and HHS staff members continue to discuss concerns raised by the States.

4.4 Other Considerations[86]

Although the qualitative results after Chornobyl are valuable, the quantitative results cannot be transposed to the situation in the United States without many caveats. First, the reactor design greatly influences the risk of an accident involving a large release of radioactive iodine. The type of reactor in the four units at Chornobyl contained a number of design flaws, particularly the lack of secondary containment.

Second, even if an event in the United States did involve large-scale releases, nuclear power plant operators and State and local officials are required to provide prompt notification to the American public. This did not occur during the Chornobyl accident. After Chornobyl, the population at risk was not informed of the nature of the accident, or of the precautions that should be taken, until long after the precautions would have been effective. Milk with a high radioiodine content continued to be used, as did contaminated food; the population was not told to take shelter; stable iodine was not immediately distributed or used; and even limited evacuation was not started until about 36 hours after the accident. If contaminated milk and food had been avoided, most of the resulting thyroid cancers would almost certainly have not occurred. If KI had been effectively distributed within the appropriate time, the numbers of

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[85] Email from Chris Staton (STATONCD@dhec.sc.gov) to P. Milligan, NRC, July 23, 2007 (http://www.nrc.gov/reading-rm/adams.html, under ADAMS Accession No. ML072070220)

[86] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

resulting thyroid cancers would have been even more greatly reduced.

Third, the concentration of stable iodine intake through the diet is probably relevant. In experimental studies, fewer tumors develop when radioiodine is administered to animals that have a high iodine intake than in animals that have a low-iodine diet. The population around Chornobyl had a low iodine intake; in the United States, dietary stable iodine is 3–5 times higher than in much of the area around Chornobyl. The greater dietary iodine is associated with a smaller thyroid gland and also with a lower uptake of radioiodine than in areas that have iodine deficiency. The population around Chornobyl would therefore be predicted to take up more radioiodine into their thyroids than a U.S. population exposed to similar levels of contamination.[87]

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[87] "Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident," National Research Council of the National Academies, National Academies Press, 2004

CHAPTER 5

STATE PLANS AND PROGRAMS

5.1 NRC and FEMA Radiological Emergency Preparedness Requirements Related to Potassium Iodide

In the United States, public health and safety are State responsibilities. However, States generally have delegated some authority for responding to incidents to local public officials and local responders. Local responders generally arrive first at the scene of an accident or incident and have the best knowledge of local conditions that might affect response decisions. If the situation overwhelms the response capability of local responders, State and then Federal resources may be called on to assist. In general, incidents that overwhelm local resources affect large geographic areas or large populations.

States have developed response plans to guide them through the decisionmaking process in connection with an incident to mitigate the consequences of large events. The emergency preparedness plans include predetermined actions related to credible scenarios that enable quick responses to ensure public safety with limited initial information. Emergency response plans take into consideration such items as general types of incidents, general traffic conditions, evacuation estimates[88], the locations of different types of fixed facilities, predominant weather for different times of year, population densities, available State and local resources, prearranged contracts for services with private industries, and other relevant observations. Planning allows for quick decisionmaking in the face of sparse information to ensure public health and safety.

Emergency preparedness for nuclear power plant incidents is a cooperative effort involving the nuclear power plant facility and local, county, State, and Federal governments.[89] Since the emergency preparedness plans must be capable of initially addressing several possible incidents, they must be based on simple and consistent assessment methodologies, and the agencies involved must be capable of implementing their assigned actions. To ensure that plans developed on the local, county, and State level will protect public health and safety, the NRC and FEMA evaluate emergency preparedness at and around nuclear power plants. Evaluation takes place regularly to ensure that adequate protective measures will be taken in the event of a nuclear power plant incident.

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[88] See Attachment 1 for an example of an evacuation time estimate plan.

[89] For an example plan, see "Southern Nuclear Operating Company AR-06-2295, List of Enclosures, Including State of SC Radiological Emergency Response Plan, State of SC Technical Radiological Emergency Response Plan & VEGP Site Specific Plant, Part 5," available in the NRC's ADAMS at http://www.nrc.gov/reading-rm/adams.html under Accession No. ML062790298. See the NRC regulations in 10 CFR 50.47, "Emergency Plans, at http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0047.html and in Appendix E to 10 CFR Part 50 at http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appe.html. See also NUREG-0654/FEMA-REP-1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants," at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0654/, and FEMA/Department of Homeland Security regulations in 44 CFR Part 350, "Review and Approval of State and Local Radiological Emergency Plans and Preparedness," at http://www.access.gpo.gov/nara/cfr/waisidx_06/44cfr350_06.html.

5.2 Eligible and Participating States

In the United States, 33 States and 1 Tribal Nation have populations within the 10-mile plume EPZ. Table 5-1 shows which entities have KI programs. Expanded distribution of KI would include at least 2 States that presently are not part of the 10-mile plume exposure pathway planning but are included in the ingestion zone planning out to 50 miles. According to data from the 2000 census, the resident population within the 10-mile EPZ is approximately 5 million. This does not count transient populations included in a community's emergency planning. The resident population from 10 to 20 miles around nuclear power plants is approximately 18 million. This figure does not reflect transient populations such as tourists, day workers, visitors, and college students.

Table 5-1 KI Programs by State/Tribal Nation

State	KI	Liquid KI
Alabama	Y	N
Arkansas	N	N
Arizona	Y	Y
California	Y	N
Connecticut	Y	N
Delaware	Y	Y
Florida	Y	Y
Georgia	N	N
Illinois*	Y*	N
Iowa	N	N
Kansas	N	N
Louisiana	N	N
Maryland	Y	Y
Massachusetts	Y	N
Michigan	N	N
Minnesota	Y	Y
Missouri	N	N
Mississippi	Y	Y
Nebraska	N	N
New Hampshire	Y	N
New Jersey	Y	Y
New York	Y	Y
North Carolina	Y	Y
Ohio	Y	N
Pennsylvania	Y	N
Prairie Island Indian Community**	N	N
South Carolina	Y	N
Tennessee	Y	N
Texas	N	N
Vermont	Y	Y
Virginia	Y	Y

West Virginia	Y	Y
Washington	N	N
Wisconsin	N	N

*Illinois did not participate in the NRC KI program but obtained its own supply.

**The Minnesota KI request included the Prairie Island Indian Community.

5.3 Overview of Existing State Plans

Predistribution typically includes one dose per individual, with one dose held at the reception center/KI distribution center. Table 5-2 summarizes existing State plans.

Table 5-2 Existing State Plans

State	Predistribute (Yes/No)	% of Population that Has KI	Other
Tennessee (Liz)	No. KI is stockpiled by the county public health departments. Yearly public information campaigns direct the public on what to do in an emergency. Media partners will help spread the word. Members of the public can pick up KI if desired, but otherwise county public health nurses will take doses to mass care shelters in an event.		
Mississippi (BJ Smith)	No. KI is only given by order of the State Public Health Officer. It is stockpiled at county public health offices. Once ordered, it is delivered and distributed at reception centers.		
Florida (Charles Adams)	No. KI is stored at county sites near reception centers. It is only issued by order from State public health authorities.		

California (Ben Tongs)	Yes. However, distribution of KI is a very costly and time-intensive process. Since KI is classified as a "drug," it cannot be mailed at random. The State prints and mails brochures with self-addressed stamped envelopes to EPZ residents. If they want KI, they just complete and return the cards. The State must then purchase Bubble envelopes to mail the KI as it would be crushed in regular envelopes. The process costs more than $300,000 and requires 1300 hours of donated labor, and could cost as much as $1 million without the free labor.	The State mailed 154,000 brochures and received requests for KI from 38 percent of recipients. 52 percent of recipients around the San Onofre Nuclear Generating Station and 28 percent of recipients around the Diablo Canyon plant requested KI.	
New Hampshire (Mike Nawoj)	The State maintains an ongoing program to distribute KI to the public upon request. Emergency information calendars and State homeland security and public health Web sites contain information on KI and applications for obtaining KI from the State. The State also provides information on how citizens may obtain/ purchase KI over the counter if they want more than the State provides. The Division of Public Health Services serves as the point of contact and is responsible for mailing out KI to those who request KI and qualify to receive it.	To date, the State has distributed about 3 or 4 percent of the tablets. Two of the six school districts in the Seabrook EPZ and none of the school districts in the Vermont Yankee EPZ have requested KI for their students and staff. Those two districts received about 4500 tablets.	The remaining tablets are stored in the Division of Public Health Services warehouse in Concord and are available for distribution as required.

Minnesota (Kevin Leuer)	Yes. The State does redistribute KI.		The State established a partnership with Target Pharmacies so people could pick up KI locally at any time. Once a year, the State mails vouchers for KI to everyone in the EPZ for redemption at the local Target store. The State does not distribute KI at the reception centers.

Massachusetts (Christine Packard of the Massachusetts Emergency Management Agency, answering on behalf of the Massachusetts Department of Public Health)	No. The State used to predistribute KI in a limited fashion. When the Massachusetts Department of Public Health first received KI, it distributed it at pharmacies in the EPZ for a period of time. The department no long distributes KI via its Web site. The boards of health in the towns within the EPZ will distribute the new batch of KI received from the NRC directly to their residents on demand. EPZ residents can obtain additional KI after a power plant accident at either the reception centers or the KI dispensing sites.	The percentage of those who obtain KI via predistribution methods is very low. To date, about 11 percent of the eligible EPZ residents have requested KI. Therefore, the State has a plan in place to distribute KI during an emergency. KI is not generally offered at reception centers so that the centers are not overwhelmed with people who only seek KI. In addition, those who are monitored and do not show contamination do not need to take it anyway.	The State does have a small stockpile at its reception centers so that individuals who are found to be contaminated can take KI if they have not already done so on their own. Otherwise, the Massachusetts Department of Public Health has established KI dispensing sites, which are a type of "drive-through" model at various location (such as large parking lots) outside of the EPZ and past reception centers. Evacuating populations who choose not to go to a reception center can still go to a KI dispensing site to get KI for themselves and their family. Persons who go to reception centers and are found to be "clean" but still want KI can also go to dispensing sites to access it.
Arizona (Aubrey Godwin)	No.		The State distributes KI through public health nurses at the reception centers when directed by the local health officer.
Connecticut (Deborah Ferarri)	Yes. The State uses a layering effect for distribution of KI. In 2002, it conducted a mass mailing to all citizens in the EPZ. During the 2007 KI distribution, the State is predistributing KI packages (two-pill pack with information) in the towns within the EPZ, usually at the town halls. The State has placed three advertisements in the newspapers to let people know that KI is available in their town for them to pick up.	The State has been offering it to the towns for about a month as of the preparation of this report and did not yet have figures on the percentage of people who have picked up KI.	KI is also available to visitors, seasonal residents, and workers in the EPZ. The State has also made it available to colleges (soon the schools), big business, State agencies involved in the Radiological Emergency Preparedness Program, nursing homes, daycares, and hospital in the EPZ. KI is available in host communities, should evacuation ever be ordered.

Alabama (Tonya Appleyard)	No. The KI is stockpiled at the health departments in risk counties and remains in the possession of the county health nurse who has been trained on the distribution of KI.		Plans for the distribution of KI are written and reviewed each year and signed by the State Health Officer. During a nuclear emergency at one of the plants in the State, the nurses will follow these plans, which instruct them to either go to the forward command to distribute KI to the emergency workers or to the reception centers to prepare to distribute to the public. For emergency workers, KI is issued as a piece of equipment and workers are instructed not to take it until a health order has been issued for KI for emergency workers. For the public and reception centers, KI will only issued to the public from designated sectors that have been so ordered by the State Health Officer and listed in the KI health order.

Maryland (Mike Griffen)	Yes. The Maryland Department of Health and Mental Hygiene, in cooperation with local emergency operations centers and local county health departments, was to see to either storage, or predistribution of KI to the public through the department's network of local health officers. Typically, the county health officer announces an availability date and members of the public come to a local health department office, reception center, or clinic to pick up individual supplies. It is not known whether all five counties predistributed all of their KI supplies, or if they held some in reserve to have available at reception centers in case of emergency.	The State undertook several deliveries of KI to local governments. Delivery 1: 45,980 units of 130-mg adult dose KI tablets; 9,372 units of 65-mg half-dose KI tablets; and 937 unit doses of KI liquid to the Harford County Emergency Operations Center. Delivery 2: 11,000 units of 130-mg adult dose KI tablets; 1,236 units of 65-mg half-dose KI tablets; and 124 unit doses of KI liquid to the Cecil County Health Department. Delivery 3: 82,500 units of 130-mg adult dose KI tablets; 14,339 units of 65-mg half-dose KI tablets; and 1,434 unit doses of KI liquid to the Calvert County Health Department for Calvert County and 1,100 units of 130-mg adult dose KI tablets; 120 units of 65-mg half-dose KI tablets; and 60 unit doses of KI liquid to the Calvert County Health Department for Dorchester County. Delivery 4: 27,500 units of 130-mg adult dose KI tablets; 6,279 units of 65-mg half-dose KI tablets; and 628 unit doses of KI liquid to the St. Mary's County Health Department. The State keeps all of the remaining doses in a climate-controlled room, up on a high shelf in case of flooding.	
Delaware (Janet Chomiszak)	Yes. The Delaware Emergency Management Agency staff predistributes KI on designated days. The State will distribute KI on September 13, September 29, October 3, and October 27, 2007, and will provide more details on percentage of citizens covered after that time.	More than 60 percent of Delaware citizens have the expired KI.	Delaware will also have a pharmacist at the reception center for citizens who did not previously receive the KI.

Ohio (Steve Helmer)	No. Ohio has decided to no longer predistribute KI.	Ohio attempted to predistribute KI in 2002, and the expiration for this KI has been extended to 2009. This effort resulted in the following rates of participation: Residents: ~23.9% Businesses: ~22.5%	The Ohio Department of Health recommends stockpiling excess stocks of KI at designated monitoring/ decontamination and reception centers. However, after an emergency alert notification is made, the department recommends that KI only be made available at designated facilities outside of the 10-mile EPZ, such as the monitoring/ decontamination and reception centers for evacuees, and on a priority basis to people contaminated by the plume, children, and pregnant women. Counties should consider providing KI to individuals demonstrating exposure to the radioactive plume upon entrance to a monitoring/ decontamination center.

Pennsylvania (Meghan Treber, Benjamin Seiber, David Allard, Brian Moyer)	The State predistributes KI through several different means. In accordance with the Governor's acceptance of KI from the NRC, distribution will involve the populations that reside within the 10-mile EPZ of the State's five nuclear power plants (Beaver Valley, Limerick, Susquehanna, Three Mile Island, and Peach Bottom). The Department of Health district offices are responsible for coordinating with county emergency management agency officials to make KI available to residents living and working within the 10-mile EPZ surrounding the nuclear power plants, realizing that evacuation is still the primary protective action. The predistribution of KI occurs on an annual basis for all five EPZs and is preceded by public announcements. In addition, transients and residents who live in the EPZ can obtain KI through the district and local health offices at any time throughout the year. Arrangements will be made on an individual basis for delivery of KI tablets to persons with special needs by reason of disability. The department also distributes KI to employers located with the 10-mile EPZ for their employees. Public health nurses will handle all distributions of KI tablets to persons. These nurses will have received instruction in advance on the correct use of KI and will be able to answer medical questions from the public. The State also uses participating school districts to predistribute KI. Distribution through the school system receives highest priority since children are much more sensitive than adults to the ill effects of radioactive iodine. Upon approval by local school boards, the Health Department will distribute KI to the school districts located in the EPZ and orient school nurses in the correct use of KI. The school system will mail a letter to parents residing within the protective zone using a passive consent approach. The State also provides a cache of KI pills at the power plants, local fire stations, Pennsylvania Emergency Management Agency offices, and a few other locations for emergency workers and first responders who will be within the 10-mile EPZ in the event of an incident.	The department does not have an exact percentage of eligible residents who have received KI through predistribution. To date, the State has distributed approximately 951,235 KI tablets (259,203 tablets to businesses; 556,468 tablets to residents; and 135,564 tablets to schools).	

CHAPTER 6

SUMMARY

KI is an effective medical countermeasure to reduce the risk of radiation-induced thyroid cancer and thyroid dysfunction following ingestion of ^{131}I. The risks of these medical conditions are not high. The large majority of the radiation-induced thyroid cancers are papillary tumors that have a very high long-term survival rate with appropriate management. Hypothyroidism is another primary risk; the condition is manageable medically but also requires long-term management. Consequently, avoiding ^{131}I ingestion and uptake by the thyroid reduces the likelihood of thyroid-related medical problems, which can be long term and of significant consequence to a small number of people. In comparing populations in the United States and in the areas around the Chornobyl nuclear power plant, the relatively low iodine content of the Chornobyl diet probably increased uptake of ^{131}I and, therefore, long-term consequences.

The release of radionuclides including ^{131}I from a reactor is a time-dependent process, whether it results from an accidental or intentional event. Because of the construction of nuclear power plants in the United States, the release of radioactive materials including ^{131}I as a result of either a highly unlikely successful terrorist attack or failure of multiple reactor safety systems would be a very rare event and would evolve over many hours or days, allowing time for notification of the public and the implementation of predetermined protective actions for the populations potentially at risk, such as sheltering, evacuation, and interdiction of the food supply

The release and subsequent transport and dispersion of radioactivity, including radioactive iodine, from a nuclear power plant is dependent on many factors, such as radioactive decay rate of the isotope, its chemical form, the efficacy of partitioning inside the reactor vessel and containment, whether it is an elevated or ground-level release, the buoyancy of plume (i.e., plume rise), terrain effects, atmospheric stability, windspeed and direction, and humidity/precipitation. Many of these factors, such as the meteorology, are known, and others can be predicted from various monitor readings and later from sample analysis. Knowledge of these factors and the length of time from the core damage event to the possible release to environment allow offsite emergency officials to implement the appropriate protective actions (evacuation, interdiction of food supply, KI use (if part of the State plan)) for those populations within the keyhole (i.e., the 2-mile ring around the plant and 5 to 10 miles downwind in the affected and two adjacent sectors) for the projected plume path. If the conditions dictate that protective actions are necessary beyond the 10-mile EPZ, time would be available for projecting, organizing, and implementing the appropriate response for the identified population beyond 10 miles.

Young people are at increased risk for problems related to the ingestion of ^{131}I because of the high metabolic activity of their thyroids. To be most effective, KI must be administered promptly (i.e., just before or within 4 to 6 hours of release) because of the rapid uptake of iodine by the thyroid gland. KI is the only form of iodine approved by FDA. However, other antithyroid drugs have been proposed to block the entrance of iodine into the thyroid, including thiocyanate and perchlorate. The former is too toxic, and the latter may not be acceptable because of concerns over the unproven adverse thyroid effects. As with any medical condition, avoidance is superior to subsequent drug mitigation or treatment. However, should a subpopulation be identified to remain at risk to potential exposure to ^{131}I through ingestion, that group would benefit from appropriate treatment with KI. This would require proper timing, dose, and scheduling of a nonexpired drug and its time-sensitive availability.

ATTACHMENT 1

EVACUATION TIME ESTIMATE

FOR THE

INDIAN POINT ENERGY CENTER

ATTACHMENT 1
EVACUATION TIME ESTIMATE
INDIAN POINT ENERGY CENTER

KLD Associates, Inc.
Rev. 1

EXECUTIVE SUMMARY

This brief summary should be viewed as a preamble of the report. The reader is encouraged to review the entire report.

This report describes the analyses undertaken and the results obtained by a study to update the existing Evacuation Time Estimates (ETE) for the Indian Point Energy Center (IPEC) located in Buchanan, New York. Evacuation time estimates provide State and local governments with site-specific information helpful for Protective Action decision-making.

In the performance of this effort, all available prior documentation relevant to Evacuation Time Estimates was reviewed. Other guidance is provided by documents published by Federal Government agencies. Most important of these are:

- Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plans, NUREG 0654/FEMA-REP-1, Rev. 1, November 1980.
- Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones, NUREG/CR-1745, November 1980.
- State of the Art in Evacuation Time Estimate Studies for Nuclear Power Plants, NUREG/CR-4831, March 1992.

Overview of Project Activities

This project began on May 1, 2002 and extended over a period of one year. The major activities performed are briefly described in chronological sequence:

- Attended "kick-off" meetings with Entergy Nuclear Northeast (ENN) personnel, then with emergency management personnel of the four counties within the Emergency Planning Zone (EPZ) of IPEC.
- Reviewed prior ETE reports prepared for IPEC and accessed U.S. Census Bureau data files for the years 2000 and 1990. Studied large-scale highway maps of the area in the vicinity of IPEC, then conducted a detailed field survey of the highway network.
- Synthesized this information to create an analysis network representing the highway system topology and capacities within the EPZ, extending to the four bounding Interstate Highways: (1) I-87 on the west; (2) I-87/287 on the south; (3) I-684 on the east; and (4) I-84 on the north.
- Designed and sponsored a telephone survey of residents within the EPZ to gather focused data needed for this ETE study that were not contained within the census database. The

survey instrument was reviewed and modified by State and county personnel prior to the survey.

- Conducted additional mail and telephone surveys and accessed county and State data files to quantify estimates of employment within the EPZ, identifying that portion who lived outside the EPZ. Other surveys obtained information on transit-dependent and transient populations, and of available transit resources. In addition, the populations of "special facilities" (i.e., schools, health-related) were ascertained.
- The traffic demand and trip-generation rate of evacuating vehicles were estimated from the gathered data. The trip generation rate reflected the estimated mobilization time (i.e., the time required by evacuees to prepare for the evacuation trip) that was computed using the results of the telephone survey of EPZ residents.
- Following federal guidelines, the EPZ is subdivided into 51 Emergency Response Planning Areas (ERPAs). These are the same ERPAs used in the prior ETE studies. These ERPAs are then grouped to form circular areas or "keyhole" configurations (circles plus radial sectors) that define a total of 35 Evacuation Regions.
- The time-varying circumstances are represented as Evacuation Scenarios, each described in terms of the following factors: (1) Season (Summer, Winter, Autumn, Spring); (2) Day of Week (Midweek, Weekend); (3) Time of Day (Midday, Evening); and (4) Weather (Good, Rain, Snow). Two special scenarios involving activities at West Point were considered: Football Games and Commencement. A total of 14 scenarios are considered.
- The Planning Basis for the calculation of ETE is:
    - A rapidly escalating accident at IPEC that quickly assumes the status of General Emergency such that the Advisory to Evacuate is virtually coincident with the siren alert.
    - While an unlikely accident scenario, this planning basis will yield ETE, measured as the elapsed time from the Advisory to Evacuate until the last vehicle exits the impacted Region, that represent "upper bound" estimates. This conservative Planning Basis is applicable for all initiating events including the prospect of a terrorist attack.
- If the emergency occurs while schools are in session, the ETE study assumes that the children will be evacuated by bus directly to specified school reception centers located outside the EPZ. Parents, relatives, and neighbors may pick up their children at school prior to the arrival of the buses dispatched for that purpose. The ETE for school children are calculated separately.
- Evacuees who do not have access to a private vehicle will either ride-share with relatives, friends or neighbors, or be evacuated by buses provided as specified in the county evacuation plans. Those in special facilities will likewise be evacuated with public transit, as needed: bus, van, or ambulance, as required. Separate ETE are calculated for the transit-dependent evacuees and for those evacuated from special facilities.

Computation of ETE

A total of 490 ETE were computed for the evacuation of the general public. Each ETE quantifies the aggregate evacuation time estimated for the population within one of the 35 Evacuation Regions to completely evacuate from that Region, under the circumstances defined for one of the 14 Evacuation Scenarios (35 x 14 = 490). Separate ETE are calculated for transit-dependent evacuees, including school children for applicable scenarios.

Except for Region R3, which is the evacuation of the entire EPZ, only a relatively small portion of the people within the EPZ would be advised to evacuate. That is, the Advisory to Evacuate applies only to those people occupying the specified impacted region. It is assumed that 100 percent of the people within the impacted region will evacuate in response to this Advisory. The people occupying the remainder of the EPZ outside the impacted region may be advised to take shelter.

The computation of ETE assumes that a portion of the population within the EPZ but outside the impacted region will elect to "voluntarily" evacuate. These voluntary evacuees could impede those others who are evacuating from within the impacted region. The impedance that could be caused by voluntary evacuees is considered in the computation of ETE for the impacted region.

The area outside the EPZ but within the bounding interstate highways identified earlier is identified as the Shadow Region. This study assumes that a portion of the population occupying the shadow region will also elect to travel away from IPEC over the same time frame as those evacuating from within the impacted region. This "shadow evacuation" could also impede the movement of evacuees from within the impacted region. This potential impedance of evacuees is also considered in the computations of ETE.

The computational procedure is outlined as follows:

- A link-node representation of the highway network is coded. Each link represents a unidirectional length of highway; each node usually represents an intersection or merge point. The capacity of each link is estimated based on the field survey observations and on established procedures.
- The evacuation trips are generated at locations called "zonal centroids" located within the EPZ and within the Shadow Region. The trip generation rates vary over time reflecting the mobilization process, and from one location (centroid) to another depending on population density and on whether a centroid is within, or outside, the impacted area.
- The computer models compute the routing patterns for evacuating vehicles that are compliant with federal guidelines (outbound relative to the location of IPEC), then simulate the traffic flow movements over space and time. This simulation process estimates the rate that traffic flow exits the impacted region.
- The ETE statistics provide the elapsed times for 50 percent, 90 percent, 95 percent and 100 percent, respectively, of the population within the impacted region, to evacuate from within the impacted region. These statistics are presented in tabular and graphical formats.

Traffic Management

This study includes the development of a comprehensive traffic management plan designed to expedite the evacuation of people from within an impacted region. This plan is also designed to control access into the EPZ after returning commuters have rejoined their families.

The plan takes the form of detailed schematics specifying: (1) the directions of evacuation travel to be facilitated and other traffic movements to be discouraged; (2) the equipment needed (cones, barricades) and their deployment; (3) the locations of these “Traffic Control Points” (TCP); (4) the priority assigned to each traffic control point indicating its relative importance and how soon it should be manned relative to others; and (5) the number of traffic control personnel required.

Over the coming months this plan will be reviewed with State and local law enforcement personnel. The Traffic Management Plan will incorporate revisions made as a result of this review.

Selected Results

A compilation of selected information is presented on the following pages in the form of Figures and Tables extracted from the body of the report; these are described below.

- Figure 3-1 displays a map of the IPEC site showing the layout of the 51 Emergency Response Planning Areas (ERPAs) that comprise, in aggregate, the Emergency Planning Zone (EPZ).
- Table 3-2 presents the estimates of permanent resident population in each ERPA based on the 2000 Census data. Extrapolation to the year 2003 reflects population growth rates in each county derived from census data.
- Table 6-1 defines each of the 35 Evacuation Regions in terms of their respective groups of ERPAs. The tabulation also identifies the azimuths of the underlying sectors associated with the keyhole configurations of Regions R4 through R35.
- Table 6-2 lists the 14 Evacuation Scenarios.
- Table 7-1D is a compilation of Evacuation Time Estimates (ETE). These data are the times needed to *clear the indicated regions* of 100 percent of the population occupying these regions. These computed ETE include consideration of mobilization time and of estimated voluntary evacuations from other regions within the EPZ and from the shadow region.
- Tables 8-9, 8-10 and 8-11 present ETE for school evacuation, transit-dependent evacuees and evacuees from special facilities, respectively. All these evacuees will be transported by bus, van or ambulance, as appropriate.

We wish to express our appreciation to all the directors and staff members of the Orange, Putnam, Rockland, and Westchester County Emergency Management Offices, the various county planning offices, New York State Emergency Management Office (SEMO), and local and state law enforcement agencies, who provided valued guidance and contributed information contained in this report.

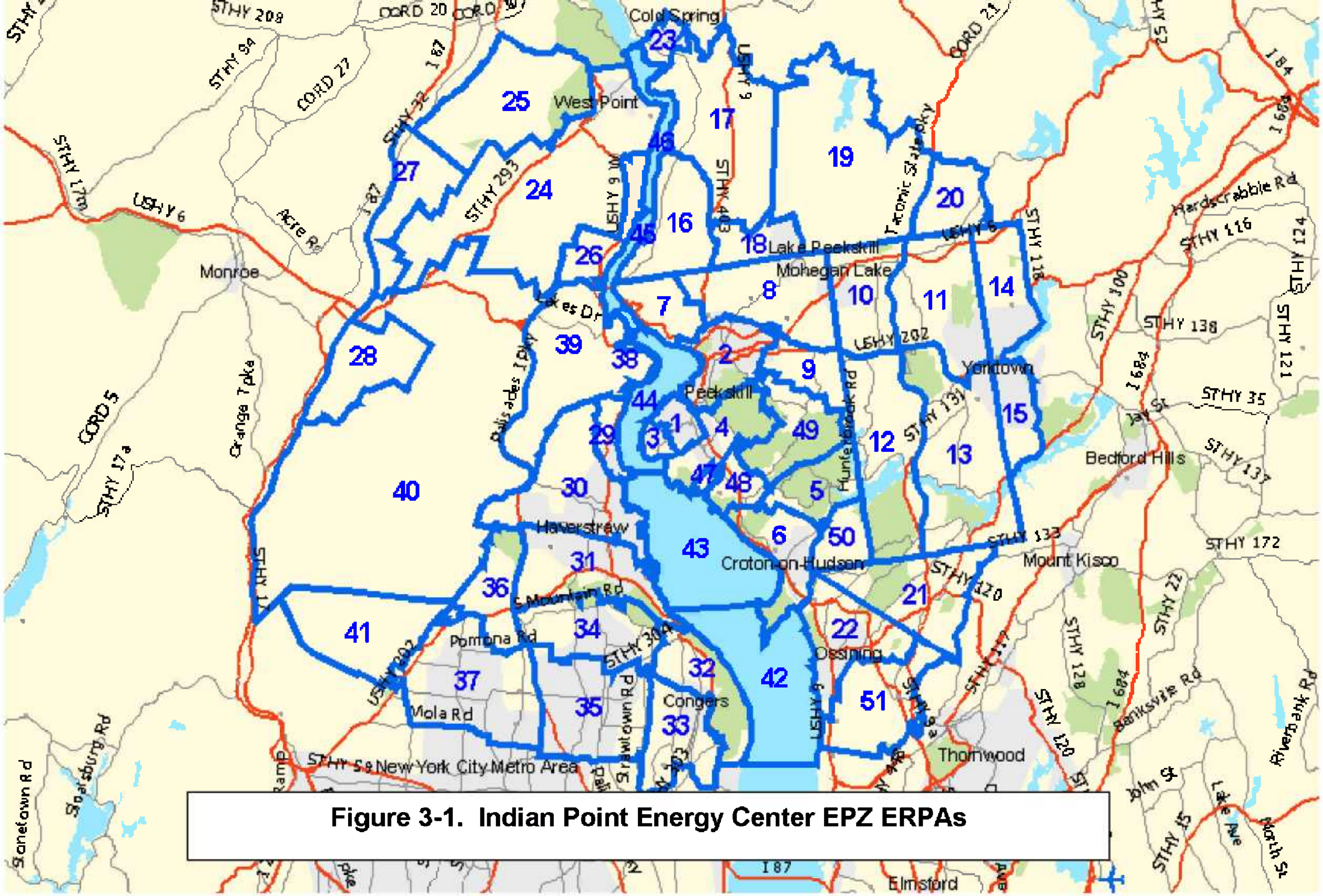

Figure 3-1. Indian Point Energy Center EPZ ERPAs

Table 3-2. EPZ Permanent Resident Population Growth

	Population			Population	
ERPA	**2000**	**2003**	**ERPA**	**2000**	**2003**
1	2,171	2,206	**27**	2,200	2,270
2	22,459	22,826	**28**	52	54
3	1,273	1,294	**29**	1,143	1,170
4	3,534	3,592	**30**	12,968	13,271
5	957	973	**31**	31,314	33,267
6	7,589	7,713	**32**	4,973	5,089
7	185	188	**33**	10,616	10,864
8	11,156	11,338	**34**	7,428	7,602
9	4,486	4,559	**35**	23,681	24,235
10	8,021	8,152	**36**	2,601	2,662
11	18,086	18,382	**37**	23,220	23,763
12	3,102	3,153	**38**	60	61
13	7,124	7,240	**39**	19	20
14	2,688	2,732	**40**	561	579
15	1,284	1,305	**41**	174	178
16	532	553	**42**	-	-
17	1,927	2,005	**43**	-	-
18	3,533	3,675	**44**	-	-
19	6,851	7,127	**45**	-	-
20	4,110	4,275	**46**	-	-
21	4,785	4,863	**47**	332	337
22	29,454	29,936	**48**	3,483	3,540
23	2,523	2,625	**49**	2,820	2,866
24	7,134	7,360	**50**	471	479
25	932	962	**51**	8,277	8,412
26	5,353	5,523	TOTAL	297,642	305,276

Table 6-1. Definition of Evacuation Regions

REGION	ERPAs IN ORANGE COUNTY	ERPAs IN PUTNAM COUNTY	ERPAs IN ROCKLAND COUNTY	ERPAs IN WESTCHESTER COUNTY	DESCRIPTION OF REGION	ERPAs IN REGION
R1	39	NONE	29, 38, 39	1-4, 7, 44	Entire 2 mile ring	1-4, 7, 29, 38, 39, 44
R2	26, 39, 40	16, 18, 45	29-31, 38-40	1-9, 43, 44, 47-49	Entire 5 mile ring	1-9, 16, 18, 24, 26, 29-31, 38-40, 43-45, 47-49
R3	24-28, 39, 40	16-20, 23, 45, 46	29-41	1-15, 21, 22, 42-44, 47-51	Full EPZ	1-51
2 Mile Ring and Sector to 5 Miles						
R4	26, 39, 45	16, 18, 45	29, 38, 39	1-4, 7, 8, 44	N	1-4, 7, 8, 16, 18, 26, 29, 38, 39, 44, 45
R5	39, 45	16, 18, 45	29, 38, 39, 44, 45	1-4, 7-9, 44, 45	NNE	1-4, 7-9, 16, 18, 29, 38, 39, 44, 45
R6	39	16, 18	29, 38, 39, 44	1-4, 7-9, 44, 49	NE	1-4, 7-9, 16, 18, 29, 38, 39, 44, 49
R7	39	NONE	29, 38, 39, 44	1-4, 7-9, 44, 49	ENE	1-4, 7-9, 29, 38, 39, 44, 49
R8	39	NONE	29, 38, 39, 44	1-5, 7-9, 44, 48, 49	E	1-5, 7-9, 29, 38, 39, 44, 48, 49
R9	39	NONE	29, 38, 39, 44	1-7, 9, 44, 47-49	ESE	1-7, 9, 29, 38, 39, 44, 47-49
R10	39	NONE	29, 38, 39, 43, 44	1-7, 43, 44, 47-49	SE	1-7, 29, 38, 39, 43, 44, 47-49
R11	39	NONE	29-31, 38, 39, 43, 44	1-7, 43, 44, 47-49	SSE	1-7, 29-31, 38, 39, 43, 44, 47-49
R12	39	NONE	29-31, 38, 39, 43, 44	1-4, 6, 7, 43, 44, 47, 48	S	1-4, 6, 7, 29-31, 38, 39, 43, 44, 47, 48
R13	39	NONE	29-31, 38, 39, 43, 44	1-4, 7, 43, 44	SSW	1-4, 7, 29-31, 38, 39, 43, 44
R14	39, 40	NONE	29-31, 38-40, 43, 44	1-4, 7, 43, 44	SW	1-4, 7, 29-31, 38-40, 43, 44
R15	39, 40	NONE	29-31, 38-40, 44	1-4, 7, 44	WSW	1-4, 7, 29-31, 38-40, 44
R16	39, 40	NONE	29, 30, 38-40, 44	1-4, 7, 44	W	1-4, 7, 29, 30, 38-40, 44
R17	24, 26, 39, 40, 45	45	29, 30, 38-40, 44, 45	1-4, 7, 44, 45	WNW	1-4, 7, 24, 26, 29, 30, 38-40, 44, 45
R18	24, 26, 39, 40, 45	16, 45	29, 38-40, 44, 45	1-4, 7, 44, 45	NW	1-4, 7, 16, 24, 26, 29, 38-40, 44, 45
R19	24, 26, 39, 40, 45	16, 45	29, 38, 39, 40, 44, 45	1-4, 7, 8, 44, 45	NNW	1-4, 7, 8, 16, 24, 26, 29, 38, 39, 40, 44, 45
R1	39	NONE	29, 38, 39	1-4, 7, 44	Entire 2 mile ring	1-4, 7, 29, 38, 39, 44
R2	26, 39, 40	16, 18, 45	29-31, 38-40	1-9, 43, 44, 47-49	Entire 5 mile ring	1-9, 16, 18, 24, 26, 29-31, 38-40, 43-45, 47-49
R3	24-28, 39, 40	16-20, 23, 45, 46	29-41	1-15, 21, 22, 42-44, 47-51	Full EPZ	1-51
2 Mile Ring and Sector to 5 Miles						
R4	26, 39, 45	16, 18, 45	29, 38, 39	1-4, 7, 8, 44	N	1-4, 7, 8, 16, 18, 26, 29, 38, 39, 44, 45
R5	39, 45	16, 18, 45	29, 38, 39, 44, 45	1-4, 7-9, 44, 45	NNE	1-4, 7-9, 16, 18, 29, 38, 39, 44, 45

Table 6-1. Definition of Evacuation Regions

REGION	ERPAs IN ORANGE COUNTY	ERPAs IN PUTNAM COUNTY	ERPAs IN ROCKLAND COUNTY	ERPAs IN WESTCHESTER COUNTY	DESCRIPTION OF REGION	ERPAs IN REGION
R6	39	16, 18	29, 38, 39, 44	1-4, 7-9, 44, 49	NE	1-4, 7-9, 16, 18, 29, 38, 39, 44, 49
R7	39	NONE	29, 38, 39, 44	1-4, 7-9, 44, 49	ENE	1-4, 7-9, 29, 38, 39, 44, 49
R8	39	NONE	29, 38, 39, 44	1-5, 7-9, 44, 48, 49	E	1-5, 7-9, 29, 38, 39, 44, 48, 49
R9	39	NONE	29, 38, 39, 44	1-7, 9, 44, 47-49	ESE	1-7, 9, 29, 38, 39, 44, 47-49
R10	39	NONE	29, 38, 39, 43, 44	1-7, 43, 44, 47-49	SE	1-7, 29, 38, 39, 43, 44, 47-49
R11	39	NONE	29-31, 38, 39, 43, 44	1-7, 43, 44, 47-49	SSE	1-7, 29-31, 38, 39, 43, 44, 47-49
R12	39	NONE	29-31, 38, 39, 43, 44	1-4, 6, 7, 43, 44, 47, 48	S	1-4, 6, 7, 29-31, 38, 39, 43, 44, 47, 48
R13	39	NONE	29-31, 38, 39, 43, 44	1-4, 7, 43, 44	SSW	1-4, 7, 29-31, 38, 39, 43, 44
R14	39, 40	NONE	29-31, 38-40, 43, 44	1-4, 7, 43, 44	SW	1-4, 7, 29-31, 38-40, 43, 44
R15	39, 40	NONE	29-31, 38-40, 44	1-4, 7, 44	WSW	1-4, 7, 29-31, 38-40, 44
R16	39, 40	NONE	29, 30, 38-40, 44	1-4, 7, 44	W	1-4, 7, 29, 30, 38-40, 44
R17	24, 26, 39, 40, 45	45	29, 30, 38-40, 44, 45	1-4, 7, 44, 45	WNW	1-4, 7, 24, 26, 29, 30, 38-40, 44, 45
R18	24, 26, 39, 40, 45	16, 45	29, 38-40, 44, 45	1-4, 7, 44, 45	NW	1-4, 7, 16, 24, 26, 29, 38-40, 44, 45
R19	24, 26, 39, 40, 45	16, 45	29, 38, 39, 40, 44, 45	1-4, 7, 8, 44, 45	NNW	1-4, 7, 8, 16, 24, 26, 29, 38, 39, 40, 44, 45

Table 6-2. Evacuation Scenario Definitions

Scenario	Season	Day of Week	Time of Day	Weather	Special
1	Summer	Midweek	Midday	Good	None
2	Summer	Midweek	Midday	Rain	None
3	Summer	Weekend	Midday	Good	None
4	Summer	Weekend	Midday	Rain	None
5	Summer	Midweek, Weekend	Evening	Good	None
6	Winter	Midweek	Midday	Good	None
7	Winter	Midweek	Midday	Rain	None
8	Winter	Midweek	Midday	Snow	None
9	Winter	Weekend	Midday	Good	None
10	Winter	Weekend	Midday	Rain	None
11	Winter	Weekend	Midday	Snow	None
12	Winter	Midweek, Weekend	Evening	Good	None
13	Autumn	Weekend	Midday	Good	West Point Football
14	Spring	Midweek	Midday	Good	West Point Graduation

Table 7-1D. Time To Clear The Indicated Area of 100 Percent of the Affected Population (Page 1 of 2)

	Summer		Summer		Summer		Winter			Winter			Winter		Autumn	Spring
	Midweek		Weekend		Midweek Weekend		Midweek			Weekend			Midweek Weekend		Weekend USMA Football	Midweek USMA Graduation
Scenario:	(1)	(2)	(3)	(4)	(5)	Scenario:	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Scenario:	(13)	(14)
Region	Midday		Midday		Evening	Region	Midday			Midday			Evening	Region	Midday	Midday
	Good Weather	Rain	Good Weather	Rain	Good Weather		Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather		Good Weather	Good Weather
Entire 2-Mile Region, 5-Mile Region, and EPZ																
R1	4:55	5:30	4:50	5:25	4:45	R1	5:15	5:15	6:50	4:55	5:30	5:55	4:30	R1	5:30	5:15
R2	6:20	7:10	5:55	6:45	5:25	R2	6:20	7:00	8:00	5:55	6:25	7:20	5:25	R2	6:30	6:20
R3	9:25	10:30	8:50	9:50	7:15	R3	9:30	10:55	12:00	7:55	8:50	10:10	7:10	R3	8:45	9:30
2-Mile Ring and Keyhole to 5 Miles																
R4	5:45	6:20	5:10	5:35	4:50	R4	5:45	6:25	7:30	5:15	5:30	6:35	4:45	R4	5:55	5:45
R5	6:00	6:45	5:25	5:50	5:15	R5	6:10	7:00	8:00	5:25	5:45	7:10	5:15	R5	5:55	6:10
R6	6:00	6:45	5:25	5:50	5:15	R6	6:10	7:00	8:00	5:25	5:45	7:10	5:15	R6	5:55	6:10
R7	6:10	6:40	5:20	5:50	5:10	R7	6:10	6:45	8:00	5:20	5:40	7:05	5:15	R7	6:00	6:10
R8	6:10	6:35	5:20	5:50	5:10	R8	6:05	6:45	8:00	5:20	5:45	7:10	5:15	R8	6:00	6:05
R9	5:55	6:25	5:55	6:40	4:35	R9	6:00	6:30	7:35	5:10	5:30	6:45	4:35	R9	6:00	6:00
R10	5:25	5:45	5:55	6:40	4:25	R10	5:20	5:55	6:45	4:40	5:25	5:55	4:25	R10	5:30	5:20
R11	6:20	6:55	5:55	6:40	5:25	R11	6:20	6:55	7:45	5:55	6:20	7:20	5:25	R11	6:30	6:20
R12	6:20	6:55	5:55	6:40	5:25	R12	6:20	6:55	7:45	5:55	6:20	7:20	5:25	R12	6:30	6:20
R13	6:20	7:10	5:55	6:45	5:25	R13	6:20	6:55	7:40	5:55	6:25	7:15	5:25	R13	6:30	6:20
R14	6:20	7:10	5:55	6:45	5:25	R14	6:20	6:55	7:40	5:55	6:25	7:15	5:25	R14	6:30	6:20
R15	6:20	7:10	5:55	6:45	5:25	R15	6:20	6:55	7:40	5:55	6:25	7:15	5:25	R15	6:30	6:20
R16	5:25	5:40	4:50	5:10	4:25	R16	5:10	5:45	6:45	4:45	5:30	5:55	4:25	R16	5:30	5:10
R17	5:25	5:40	4:50	5:10	4:25	R17	5:10	5:45	6:45	4:45	5:30	5:55	4:25	R17	6:50	5:10
R18	5:20	5:40	4:50	5:15	4:25	R18	5:15	5:50	6:45	4:45	5:30	5:50	4:25	R18	6:50	6:00
R19	5:40	6:20	4:55	5:30	4:45	R19	5:40	6:35	7:30	5:15	5:30	6:35	4:45	R19	5:55	5:40

Table 8-9. School Evacuation Time Estimates

County	ETE to Leave EPZ			ETE to Reception Center		
	Good Weather	Rain	Snow	Good Weather	Rain	Snow
Orange	2:55	3:05	3:40	3:25	3:35	4:20
Putnam	2.45	2:50	3:25	3:30	3:35	4:25
Rockland	2:55	3:05	3:40	4:25	4:35	3:30
Westchester	3:05	3:30	4:05	4:05	4:30	5:20

Table 8-10. Transit-Dependent Evacuation Time Estimates

County	Region Extends			Region Extends to EPZ Boundary			Second Wave Completion (if needed)		
	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Rain	Snow
Orange	4:35	4:50	5:25	5:05	5:20	5:55	7:30	7:55	9:35
Putnam	4:15	4:50	5:00	4:40	4:50	5:25	6:50	7:10	8:05
Rockland	4:35	4:50	5:25	5:05	5:20	5:55	8:00	8:10	9:10
Westchester	4.50	5:30	6:05	5:20	6:15	6:50	8:25	9:40	10:35

Table 8-11. Ambulatory Evacuees from Special Facilities Evacuation Time Estimates

County	ETE to Leave EPZ		
	Good Weather	Rain	Snow
Orange	3:50	4:00	4:35
Putnam	3:40	3:45	4:20
Rockland	3:50	4:00	4:35
Westchester	4:00	4:25	5:00

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