

Nuclear Power Plant Emergencies and Thyroid Cancer Risk

What New Jersey Physicians Need to Know

LAURA H. KAHN, MD, MPH, AND FRANK VON HIPPEL, PHD

LEARNING OBJECTIVES

- I. To define what protective measures can be put in place that will protect the public from radioactive iodine in the event of a nuclear power plant accident.
- II. To identify the risks and benefits, the most effective time to administer, and the dosage of potassium iodide (KI) to be given in the event of a nuclear power plant accident.
- III. To identify the group of people who received potassium iodide (KI) distributed by the state of New Jersey to be taken in the event of a nuclear power plant accident.

Al Qaeda terrorists initially plotted to attack U.S. nuclear facilities on September 11, 2001, but decided to defer these targets for future strikes.¹ Despite successful regime changes in Afghanistan and Iraq, the risks of future terrorist strikes within U.S. borders still exist.² These developments underscore the need for physicians to be aware of the civil defense strategies available to mitigate the health effects resulting from terrorist attacks against, or unintentional events within, nuclear facilities. This issue is particularly pertinent for New Jersey physicians, since virtually the entire state is within a fifty-mile radius of a nuclear power plant.

New Jersey has four commercial nuclear reactors and six others within fifty miles of its borders in Pennsylvania and New York. Three of the four New Jersey nuclear power plants are located in Salem County, on an artificial island in the Delaware River. The fourth is located in Ocean County. New York has two operating reactors located in Westchester County, approximately fifteen miles from the New Jersey border. Pennsylvania has seven reactors: the closest two are in Limerick, approximately twenty miles from the New Jersey border. Two more are located at Peach Bottom, which is approximately forty-eight miles from the New Jersey border.³

If any of these nuclear facilities had a melt-down accident and its containment walls were breached, then radioactive cesium (Cs^{137}) and radioactive iodine (I^{131}) could be released into the atmosphere. Cesium-137 has a half life of thirty years and emits penetrating gamma rays; heavily contaminated areas would require evacuation. Iodine-131 has a half life of eight days and would primarily affect the thyroid gland with its short-range radiation. Exposure to iodine-131 would be through inhalation and potentially through ingestion of contaminated foods, particularly milk.

Children are especially vulnerable to the effects of radioactive iodine because of their growing thy-

LAURA H. KAHN, MD, MPH, an internist, is a research staff member in the Program on Science and Global Security in the Woodrow Wilson School of Public and International Affairs at Princeton University. FRANK VON HIPPEL, PHD, a physicist, is a professor of public and international affairs at Princeton University. He organized the American Physical Society's Study Group on Light-water Reactor Safety, which first recommended (in 1975) to the Nuclear Regulatory Commission the use of KI to mitigate the consequences of reactor accidents.

DISCLOSURE STATEMENT: LAURA H. KAHN, MD, MPH, and FRANK VON HIPPEL, PHD, have no relationships to disclose.

roid glands. Thyroid cancer risk from radioactive-iodine exposure can be reduced by blocking thyroid radioactive-iodine uptake using stable potassium iodide (KI) and decreasing exposure through contaminated milk. Feeding cattle stored hay until the iodine-131 decays away keeps the milk from becoming contaminated. This paper will discuss the history of thyroid radiation exposures and the risks and benefits associated with KI use. New Jersey's plans for potassium iodide distribution will be discussed in the context of a possible nuclear reactor emergency.

HISTORICAL EVIDENCE

Historical exposures have provided evidence that irradiation of the thyroid increases cancer risk. Hiroshima and Nagasaki atomic-bomb survivors who were less than ten years of age at the time of exposure had a thyroid cancer risk three times greater than survivors who were ten to nineteen years of age at the time of exposure.⁴

Between 1926 and 1957, infants were treated with high doses of X-rays to shrink their supposedly enlarged thymus glands. At the time, enlarged thymus glands were believed to increase the risk for sudden infant death syndrome. An increased frequency of benign and malignant thyroid tumors was found in these children subsequently.⁵

Marshall Islanders, particularly children, exposed to radioactive iodine from a 1954 nuclear test, subsequently were shown to have excess rates of thyroid tumors, hypothyroidism, and resulting growth retardation.⁵

On April 26, 1986, an explosion in one of the nuclear reactors at Chernobyl spewed radioactive products into the atmosphere for nine to ten days. The areas most heavily affected were in Ukraine and nearby Belarus. In Belarus, the incidence of childhood thyroid cancer increased to almost one hundred children per year, a hundred-fold increase compared to the pre-accident rate.⁶ In the Gomel region, which has about twice the area of New Jersey, the average dose, largely from ingested milk, to the thyroids of children under eighteen years of

age was about 0.4 Grays (Gy).⁷ [The Gray is the international physical unit of exposure to ionizing radiation: one Gray corresponds to the deposition of one joule of ionizing energy per kilogram of tissue. For scale, one plain chest film (posterior-anterior and lateral) has a radiation dose to the bone marrow of approximately 0.03 to 0.1 milliGrays (mGy)⁵].

Three hundred and thirty-three children living in Ukraine were evaluated and surgically treated for thyroid cancer from 1986 to 1998.⁸ During the first four years after the accident, there was a twenty-fold increase in childhood thyroid cancers, particularly in the areas with the greatest radiation exposures. This trend increased to over one hundred and forty fold during the years 1991 to 1995 compared to the pre-accident baseline years. The children who were younger than eight at the time of the Chernobyl accident accounted for over 80% of the total cases. Upon presentation, the children were frequently found to have aggressive thyroid tumors with regional metastases.⁸ For children less than age fifteen at the time of exposure, the increased incidence of thyroid cancer is consistent with that from X-ray doses, about 4.4 per Gy per 10,000 person-years (i.e., approximately a 2% chance per Gy in fifty years).⁷ A detectable increase in the incidence rate of childhood thyroid cancer has been documented as far as five hundred kilometers from the accident site, with estimated thyroid doses as small as 0.05 to 0.1 Gy.⁶

POTASSIUM IODIDE: RISKS AND BENEFITS

Potassium iodide is a salt that works by saturating the thyroid with stable iodine (I^{127}). Once saturated, the thyroid will not take up radioactive iodine. KI is absorbed in the stomach and primarily excreted by the kidneys.

To be maximally effective, KI must be given before the exposure to radioactive iodine; however, it would still have some protective effect if taken within 3–4 hours after exposure.⁹ Its protective effect lasts approximately twenty-four hours, so it should be administered daily as long as the risk of

Table 1 Recommended Doses of KI for Different Age Groups

AGE	EXPOSURE (Gy)	KI DOSE (MG)
Pregnant/Lactating women	> 0.05	130
Birth-1 mon.	> 0.05	16
1 mon.-3 yrs	> 0.05	32
Child 4-18*	> 0.05	65
Adults 18-40	> 0.1	130
Adults >40	> 5	130

*Adolescents approaching adult size (> 70 kg) should receive the full dose (130 mg).

SOURCE: Food and Drug Administration, Center for Drug Evaluation and Research (CDER). Available at www.fda.gov/cder/guidance/4825fnl.htm.

exposure to I^{131} persists, especially if the release of radioactive iodine into the atmosphere is protracted.⁹ In these circumstances, evacuation and sheltering of pregnant and lactating women and neonates should be a priority, since repeat dosing of KI to these populations is not recommended.⁹

KI can either be administered as a saturated solution (SSKI) or as a tablet. It is available over-the-counter and can be ordered on the Internet. The tablets have a shelf-life of at least five years. KI should be taken after food to minimize stomach upset. Since infants and small children cannot swallow tablets, KI tablets can be dissolved in different liquids according to taste. The Food and Drug Administration (FDA) provides instructions on how to prepare the tablets; raspberry syrup, milk, chocolate milk, and orange juice reportedly hide KI's salty taste well.¹⁰

The FDA recommends different KI dosages according to age and estimated exposures. Pregnant and lactating women should be given KI. However, as mentioned above, repeated dosing should be avoided if possible. Neonates are likely to be the most critical group of concern, since within the first few days after birth, they have a dramatic increase in thyroid activity that is critical for brain development. They are also at a special risk for exposure to potassium iodide (KI). The World Health Organization (WHO) recommends that KI solution should be available in all maternity hospitals, which would

enable a rapid response with an exact dosage.⁶ These neonates should be closely monitored with thyroid stimulating hormone (TSH) measurements (and free T4 measurements, if indicated) for hypothyroidism after being given KI. If hypothyroidism develops, then they should be treated with thyroid hormone therapy.⁹ For children up to sixteen years of age, it is recommended that KI be used if the projected thyroid dose is expected to be above 0.05 Gy.⁹

Studies of atomic bomb survivors in Hiroshima and Nagasaki indicate that there is little risk of subsequent thyroid cancer in radiation-exposed individuals over age twenty and virtually no risk in people ages forty and older.⁶ Consequently, the FDA recommends higher thresholds of exposure for these less susceptible populations: 0.1 Gy for adults between eighteen and forty years of age and 5.0 Gy for adults over forty to prevent hypothyroidism.⁹ (See table 1).

The threshold exposures for children could be incurred quite far downwind at distances that make evacuations of large populations impractical. A 1980 study for the National Regulatory Commission (NRC) found that, for a median release fraction of about 20% of a reactor's inventory of radioactive iodine to the atmosphere, the probability of an adult inhalation thyroid exposure exceeding 0.10 Gy would be about 80% at a distance of 100 miles downwind and 50% at 200 miles.¹¹ The doses to

children at the same distances would be at least as large.

RISKS

SIDE EFFECTS

The risk of severe side effects from single KI doses in children and young adults is extremely low, approximately 10^{-7} and 10^{-6} , respectively.⁶ Older adults are at an increased risk.

Common *acute* side effects include: nausea, vomiting, diarrhea, and stomach pain.¹² Symptoms of iodism (iodine toxicity) such as metallic taste, sore mouth, ulcerated mucous membranes, headache, acute rhinitis, allergic reactions, minor rashes, and eye irritation with eyelid swelling develop after *prolonged* use and generally disappear within a few days of KI discontinuation. Potentially serious side effects from *prolonged* KI use include: iododerma (a rare, but potentially fatal cutaneous eruption), hypersensitivity reactions, fetal and neonatal goiter, hypothyroidism, hyperthyroidism, potassium toxicity, cardiac irritability, pulmonary edema, angioedema, periarteritis nodosa, thrombotic thrombocytopenic purpura (TTP), pustular psoriasis, and vasculitis.¹² Patients with systemic diseases such as rheumatoid arthritis, multiple myeloma, lymphoma, polyarteritis nodosa, and subacute glomerulonephritis may be predisposed to developing iododerma since this condition has been reported with a higher frequency in these individuals.¹² The vast majority of individuals with these conditions will be older adults. Many of the severe side-effects will diminish after KI's discontinuation, and, if necessary, corticosteroids can be used to control the symptoms.¹²

CONTRAINDICATIONS

Potassium iodide should not be given to individuals with known iodine allergy, hypocomplementemic vasculitis, and dermatitis herpetiformis. Patients with these rare conditions are at an increased risk of severe iodine hypersensitivity.⁹ Patients with past or present thyroid disorders should

also avoid KI since they are at an increased risk of side effects.¹³

DRUG INTERACTIONS

Thyroid function should be closely monitored in patients taking sulfonamide derivatives, lithium salts, phenazone, and amiodarone concurrently with KI. Potassium iodide taken with potassium-sparing diuretics, such as spironolactone, or with potassium retaining agents, such as angiotensin-converting enzyme (ACE) inhibitors, increases the risk for potassium toxicity.¹²

BENEFITS

THE POLISH EXPERIENCE

Despite the potential risks, the Polish experience with KI during the Chernobyl accident revealed few adverse effects. Over ten million children, sixteen years of age and under, and approximately seven million adults received at least one dose of KI prophylaxis in Poland. Side effects were primarily minor gastrointestinal distress and skin rashes. Only 0.37% (12 of 3,214) newborns receiving single 15mg doses of KI showed transient increases in TSH and decreases in free T4.⁹ Two severe adverse reactions occurred in adults with known iodine allergies. Nauman and Wolff conducted a preliminary four-year follow-up study on a sample of 52,092 individuals from this Polish population (0.09% of the total population of Poland) with a 66% response rate. They found that two children had thyroid nodules, but no thyroid cancers developed in the 12,641 children ages sixteen and under who were part of the sample.¹⁴ Long-term follow-up is needed to assess the development of any future thyroid cancers.

ADDITIONAL MEASURES

Beyond the use of KI, Polish officials implemented additional protective measures to reduce radioactive iodine exposure. Cows were not allowed to feed in pastures until twenty days after the accident. Children and pregnant or lactating women were

forbidden to drink radioactive milk. The government provided powdered milk to all children under the age of four through numerous distribution centers. Children and pregnant or lactating women were also advised to eat a minimum of fresh vegetables until twenty days after the accident.¹⁴

NEW JERSEY'S KI DISTRIBUTION PLAN

New Jersey received a total of 722,000 KI pills from the NRC in April 2002.¹⁵ New Jersey officials distributed approximately seventy-five thousand pills to individuals who volunteered to receive them and who live or work within a ten-mile radius of a nuclear power plant. These individuals received a one day supply (i.e., one tablet) to use in the event of a release of radioactive iodine. The state provided KI recipients with education on the proper use and storage of these tablets.¹⁶

Most of the KI tablets received from the NRC have been stockpiled in the region within ten miles of New Jersey nuclear power plants and at select locations (including schools and day care centers) outside the 10-mile radius to which the people inside might be evacuated. Individuals living outside of the ten-mile radius would need to purchase their own KI. However, in 2002, Congress passed the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (Public Law No: 107-188) which instructs the secretaries of Health and Human Services and Veteran's Affairs to make KI available to those living within twenty miles of nuclear power plants.¹⁷ Action on this legislation is on hold until the National Academy of Sciences study on the best strategy for distribution is assessed.¹⁸

What should New Jersey physicians recommend to their patients living outside the ten- to twenty-mile radius of a nuclear power plant?

Based on United States experience, the likelihood of a large release of radioactive iodine from a power reactor in or near New Jersey is low. One hundred power reactors have operated in the United States for an average of about twenty years each without such a release. In the 1979 accident

at the Three Mile Island unit outside Harrisburg, Pennsylvania, about half of the radioactive iodine was released from the reactor core, but very little leaked from the containment unit.

On the basis of past experience, therefore, in New Jersey, the risk over the next five years of an exposure caused by a nuclear power plant accident is estimated to be less than 2%. If such a release were to occur, only those downwind would be at risk. In a steady wind, more than 90% of the population at a given distance would be outside the plume.¹⁹

In summary, KI is a relatively safe and effective salt that protects only the thyroid from exposure to radioactive iodine that might be released during a nuclear reactor emergency. To be effective, it must be taken either immediately before, concurrently with, or within three to four hours after the radiation exposure. Neonates, within the first few days of life, are a critical group that would require exact dosing of KI and careful monitoring for subsequent hypothyroidism. Infants, small children, and adolescents up to eighteen years of age are at high risk of thyroid cancer from radioactive iodine exposure, and reassuringly, are the groups least likely to have serious side effects from KI. Other important countermeasures include evacuation and sheltering for regions near a reactor accident, feeding cows stored hay, and providing uncontaminated, powdered milk for infants, children, and pregnant or lactating women. *NJM*

REFERENCES

1. BBC World News "Al-Qaeda plotted nuclear attacks," available at http://news.bbc.co.uk/2/hi/middle_east/2244146.stm.
2. P. Shenon. "Ridge Warns Iraq War Could Raise Terror Threat," *New York Times*, March 4, 2003. Available at <http://www.nytimes.com/2003/03/04/politics/04HOME.html>.
3. Nuclear Reactors Operating in the United States, 2000. Available at http://www.eia.doe.gov/cneaf/nuclear/page/at_a_glance/reactors/states.html.
4. D. Thompson, et al. "Cancer Incidence in Atomic Bomb Survivors, 1958-1987," *Radiation Research* 137 (1994): s17-s67.
5. L. F. Fajardo, M. Berthrong, and R. E. Anderson. *Ra-*

diation Pathology (New York: Oxford University Press, 2001): 9, 27-30, 139.

6. World Health Organization. "Guidelines for Iodine Prophylaxis following Nuclear Accidents, Update 1999," available at www.who.int/environmental_information/Information_resources/documents/Iodine/guide.pdf.

7. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Report to the General Assembly. *Sources and Effects of Ionizing Radiation* (New York: United Nations Publications, 2000), Annex J, "Exposures and Effects of the Chernobyl Accident," tables 39 and 40: 499.

8. S. J. Rybakov, et al. "Thyroid Cancer in Children of Ukraine after the Chernobyl Accident," *World Journal of Surgery* 24 (2000): 1446-1449.

9. Food and Drug Administration. "Guidance Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies." Available at <http://www.fda.gov/cder/guidance/4825fnl.htm>.

10. Food and Drug Administration. "Home Preparation Procedure for Emergency Administration of Potassium Iodide Tablets to Infants and Small Children." Available at <http://www.fda.gov/cder/drugprepare/kiprep.htm>.

11. D. C. Aldrich and R. M. Blond. *Examination of the Use of Potassium Iodide (KI) as an Emergency Protective Measure for Nuclear Reactor Accidents* (Albuquerque, N. M.: Sandia National Laboratory, 1980), NUREG/CR-1433, Fig. 5. The authors considered *Reactor Safety Study* PWR 1-5 accident scenarios for which the fractional releases of radioiodides range from 3% to 70% (RSS, table VI 2-1).

12. J. B. Sterling and W. R. Heymann. "Potassium Iodide in Dermatology: A 19th-Century Drug for the 21st Century-Uses, Pharmacology, Adverse Effects, and Contraindications," *Journal of the American Academy of Dermatology* 43 (2000): 691-697.

13. K. Shaver. "Potassium Iodide for Nuclear Exposure," *Prescriber's Letter* 8 (2001): 171-214.

14. J. Nauman and J. Wolff. "Iodide Prophylaxis in Poland

After the Chernobyl Reactor Accident: Benefits and Risks," *American Journal of Medicine* 94 (1993): 524-532.

15. New Jersey Department of Health and Senior Services News Release. "State Unveils Potassium Iodide Distribution Plan," June 19, 2002. Available at <http://www.state.nj.us/health/news/p20619a.htm>.

16. Joseph Kolakowski, Coordinator, Office of Emergency Response, New Jersey. Department of Health and Senior Services, personal communication. April 29, 2003.

17. United States Congress. Section 127 (Potassium Iodide) of H.R. 3448, the Public Health Security and Bioterrorism Preparedness and Response Act of 2002. Enacted June 12, 2002. Available at <http://thomas.loc.gov/>. Search for Bill Number "HR 3448" in the 107th Congress. Choose Version 3 ("HR 3448.ENR"). Once in the bill, choose "Sec. 127, Potassium Iodide."

Additional important national and international documents about potassium iodide are available on the American Thyroid Association web site at http://www.thyroid.org/publications/statements/ki/02_04_09_ki_links.html.

18. National Research Council of the National Academy of Science. *Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident* (Washington, D.C.: National Academies Press, 2003). Available at <http://www.nap.edu/catalog/10868.html>.

19. U.S. Nuclear Regulatory Commission. Reactor Safety Study (Washington, D.C., 1975), NUREG-75/014, table VI-5 and figure.

20. American Cancer Society. "What are the Key Statistics for Thyroid Cancer?" Available at http://www.cancer.org/docroot/CRI/CRI_2_3x.asp?dt=43.

21. J. Kaiser. "How Much Are Human Lives and Health Worth?" *Science* 299 (2003): 1836-1837.

22. American Medical Association CPT Code/Value Search. Available at webstore.ama-assn.org/index.jhtml.

23. Drugstore.com. Prices based on a thirty day supply of Synthroid®. Available at <http://www.drugstore.com/pharmacy/prices/drugprice.asp?ndc=00048113003&trx=1Z5006>.

CME EXAMINATION DEADLINE DECEMBER 31, 2005

To take this test online go to <http://ccoe.umdnj.edu/online> or turn to page 97.

71. In the event of a nuclear facility melt-down, human exposure to radioactive iodine¹³¹ would be through:
 - A. Inhalation
 - B. Ingestion of contaminated foods, particularly milk
 - C. Both of the above
 - D. None of the above
72. The risk of thyroid cancer following an exposure to radioactive products is greatest among:
 - A. The elderly
 - B. Infants and children
 - C. Teens
 - D. Middle-aged adults
73. Potassium iodide (KI) is a salt that protects against thyroid cancer by:

- A. Saturating the thyroid with stable iodine so that there will not be an uptake of radioactive iodine
 - B. Displacing radioactive iodine already in the thyroid
 - C. Interfering with the action of thyroid stimulating hormone (TSH)
 - D. All of the above
74. The maximum protective effect of KI is achieved:
- A. If taken 24 hours following exposure to radioactive iodine
 - B. If taken immediately before, concurrently with, or within 4 hours after exposure to radioactive iodine
 - C. If taken 48 hours before exposure to radioactive iodine
 - D. If taken 36 hours following exposure
75. Neonates are a group of concern in the event of a nuclear accident because:
- A. Thyroid activity is critical for brain development and hypothyroidism needs to be watched for after giving KI
 - B. KI is lethal in this age group
 - C. KI is unable to be absorbed and metabolized in the newborn
 - D. KI is likely to cause hyperthyroidism
76. The risk of severe side effects from single KI doses in children and adults is:
- A. High
 - B. Medium
 - C. Low
 - D. None existent
77. In addition to giving KI and evacuating and sheltering the population, other countermeasures to protect exposure to radioactive fallout include:
- A. Feeding cows stored hay and substituting non-contaminated powdered milk, especially to all children and lactating women
 - B. Keeping fresh vegetables, grown in the area of fallout, out of the food supply for twenty days after the accident
 - C. None of the above
 - D. A and B
78. New Jersey officials distributed potassium iodide (KI) pills to:
- A. Individuals who volunteered to receive them and live or work within a ten-mile radius of a nuclear power plant
 - B. All individuals living within 100 miles of a nuclear power plant
 - C. Only children living within 50 miles of a nuclear power plant.
 - D. All individuals living within 50 miles of a nuclear power plant.
79. Potassium iodide (KI) should not be given to:
- A. Individuals with known iodine allergy, hypocomplementemic vasculitides, and dermatitis herpetiformis
 - B. Individuals with past or present thyroid disorders who are at increased risk of side effects
 - C. Both of the above
 - D. None of the above
80. Patients should be watched for drug interactions with KI if:
- A. They are taking sulfonamide derivatives, lithium salts, phenazone, and amiodarone
 - B. They are taking potassium-sparing diuretics or with potassium retaining agents
 - C. Both of the above
 - D. None of the above