The Science of Responding to a Nuclear Reactor Accident: Summary of a Symposium

ISBN
978-0-309-31659-0

52 pages
8.5 x 11
PAPERBACK (2014)

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The Science of Responding to a Nuclear Reactor Accident

SUMMARY OF A SYMPOSIUM

Ourania Kosti, *Rapporteur*

Nuclear and Radiation Studies Board

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS **500 Fifth Street, NW** **Washington, DC 20001**

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The symposium was sponsored by the National Institutes of Health through a subcontract from RTI International (Subcontract 15-312-0212208) and the Environmental Protection Agency, Radiation Protection Division (Grant EP-14-M-000026). Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-31659-0
International Standard Book Number-10: 0-309-31659-6

Additional copies of this report are available for sale from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu/ .

Printed in the United States of America

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Reviewer Acknowledgement

This symposium summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this symposium summary:

Armin Ansari, Centers for Disease Control and Prevention
Vincent Covello, Center for Risk Communication
Scott Davis, Fred Hutchinson Cancer Center
Barbara Hamrick, University of California, Irvine
Jill Lipoti, New Jersey Department of Environmental Protection (retired)
Steve Simon, National Cancer Institute
Harold Swartz, Geisel School of Medicine at Dartmouth

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the symposium summary before its release. The review of this summary was overseen by Paul Locke, Johns Hopkins Bloomberg School of Public Health. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the author and the institution.

Preface

This document provides a summary of the presentations and discussions that took place during the May 13, 2014, Gilbert W. Beebe Symposium titled *The Science and Response to a Nuclear Reactor Accident*. The symposium, dedicated in honor of the distinguished National Cancer Institute radiation epidemiologist who died in 2003, was organized by a committee of five members with expertise in emergency preparedness, radiation epidemiology, radiation dosimetry, and risk communication.[1] The symposium was cohosted by the Nuclear and Radiation Studies Board of the National Academy of Sciences and the National Cancer Institute and sponsored by the National Institutes of Health through a subcontract from RTI International and by the Environmental Protection Agency.

The symposium topic was prompted by the March 2011 accident at the Fukushima Daiichi nuclear power plant that was initiated by the 9.0-magnitude earthquake and tsunami off the northeast coast of Japan. This was the fourth major nuclear accident that has occurred since the beginning of the nuclear age some 60 years ago. The 1957 Windscale accident in the United Kingdom caused by a fire in the reactor, the 1979 Three Mile Island accident in the United States caused by mechanical and human errors, and the 1986 Chernobyl accident in the former Soviet Union caused by a series of human errors during the conduct of a reactor experiment are the other three major accidents. The rarity of nuclear accidents and the limited amount of existing experiences that have been assembled over the decades heighten the importance of learning from the past.

This year's symposium promoted discussions among federal, state, academic, research institute, and news media representatives on current scientific knowledge and response plans for nuclear reactor accidents. The symposium addressed the following statement of task:

> *This Beebe symposium will explore how experiences from past nuclear plant accidents can be used to mitigate the consequences of future accidents, if they occur. More specifically, the symposium will address lessons learned regarding:*
>
> - *Offsite emergency response (e.g., shelter, prophylactic medicine, evacuation) and long-term management of the accident consequences (e.g., cleanup of contaminated areas, resettlement).*
> - *Estimating radiation exposures of affected populations.*
> - *Health effects (e.g., mental distress, cancer, other diseases) and population monitoring.*

[1] See the summary's front matter for the organizing committee membership.

- *Other radiological consequences (e.g., land and water contamination, disruption of food distribution, disruption of the economy).*
- *Communication among plant officials, government officials, and the public and the role of the media.*

The symposium will not address the causes of nuclear accidents or examine lessons learned regarding nuclear power plant design, operations, or regulations.

The symposium featured a range of expert briefings[2] on the topics listed above. These briefings and discussions are summarized in Chapter 2.

Chapter 1 of this summary is based on a White Paper distributed to symposium participants to provide background information on the symposium topics. The White Paper describes some federal and state responsibilities and introduces the nomenclature related to protective action guidance during different phases of a nuclear reactor accident. The chapter is also informed by a symposium presentation about nuclear reactor accidents by Dr. Steven Simon, head, Dosimetry Unit, Radiation Epidemiology Branch, National Cancer Institute (NCI).

This symposium summary was prepared by Dr. Ourania Kosti, who is a staff member of the Nuclear and Radiation Studies Board, National Academy of Sciences. She is responsible for the overall quality and accuracy of the report as a record of what transpired at the symposium. This report is primarily a narrative description of the individual symposium participants' perspectives. It does not provide findings or recommendations or represent a consensus reached by the symposium participants or the symposium planning committee.

[2] See Appendix A for the symposium agenda and Appendix B for short biographic information on the symposium speakers and moderators.

Contents

Abbreviations

AFRRI	Armed Forces Radiobiology Research Institute
AMS	Aerial Measuring System
ASPR	Assistant Secretary for Preparedness and Response
CBRN	Chemical, Biological, Radiological, or Nuclear
CDC	Centers for Disease Control and Prevention
CRCPD	Conference of Radiation Control Program Directors
DHS	Department of Homeland Security
DILS	Derived Intervention Levels
DoD	Department of Defense
DOE	Department of Energy
DTRA	Defense Threat Reduction Agency
EPA	Environmental Protection Agency
EPZ	Emergency Planning Zone
ERDS	Emergency Response Data System
ESF	Emergency Support Function
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FRMAC	Federal Radiological Monitoring and Assessment Center
HHS	Department of Health and Human Services
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMAAC	Interagency Modeling and Atmospheric Assessment Center

KI	Potassium Iodide
NARAC	National Atmospheric Release Advisory Center
NCRP	National Council on Radiation Protection and Measurements
NNSA	National Nuclear Security Administration
NRC	Nuclear Regulatory Commission
NRF	National Response Framework
PAGs	Protective Action Guides
PHEMCE	Public Health Emergency Medical Countermeasures Enterprise
POD	Points of Dispensing
REAC/TS	Radiation Emergency Assistance Center/Training Site
SNS	Strategic National Stockpile
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USDA	Department of Agriculture

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Introduction

This introduction is based on a White Paper distributed to the participants of the May 13, 2014, symposium titled *The Science and Response to a Nuclear Reactor Accident*. It is intended to provide factual background information on federal and state responsibilities related to responding to a nuclear reactor accident and nomenclature related to protective action guidance at the different phases of a nuclear reactor accident. Some information in this chapter was distilled from introductory remarks made at the symposium by organizing committee member Dr. Steven Simon, National Cancer Institute (NCI).

NUCLEAR REACTOR ACCIDENT RESPONSE IN THE UNITED STATES

There are 100 nuclear reactors in the United States operating at 62 sites in 31 states. These plants are regulated by the Nuclear Regulatory Commission (NRC). After the 1979 Three Mile Island accident, the NRC required that each site have onsite and offsite emergency response plans to protect the plant workers and members of the public from radiation exposure in the event of a nuclear reactor accident.[1] In the case of a nuclear reactor accident that results in release of radioactive materials to the atmosphere, possible means of exposure to radiation are direct external exposure from the plume and deposited material and internal exposure resulting from the inhalation or ingestion of radioactive material. Offsite response, the focus of this symposium, includes evacuation, sheltering in place, use of potassium iodide (KI), food interdictions, or other protective actions.[2]

The NRC has defined two emergency planning zones (EPZs) around nuclear power plants. According to the NRC, EPZs are designated as "the areas for which planning is recommended to assure that prompt and effective actions can be taken to protect the public in the event of an accident."[3] The actual size and shape of the EPZs vary from plant to plant and depend on the site layout, geographical features of the surrounding area, political subdivisions, and characteristics of the surrounding community such as land use. However, typically:

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[1] Dr. Steven Simon, NCI, provided the following definition for a nuclear accident: "It is an unpredictable, unusual, and unwanted event involving radiation and/or radioactive materials which result in occupational or public exposure and contamination of structures, property, or persons." A nuclear reactor accident is a type of a nuclear accident.

[2] For example, an action that may be undertaken to protect agricultural interests is to place dairy animals on stored feed.

[3] Nuclear Regulatory Commission and Environmental Protection Agency, 1978, Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants, NUREG-0396/EPA 520/1-78-016, http://pbadupws.nrc.gov/docs/ML0513/ML051390356.pdf.

- The EPZ region designated for protection from the plume exposure has a radius of about 10 miles (~16 km). Protective action plans in this region that may call for evacuation, sheltering in place, and use of KI are in place to protect populations from potential exposures to radiation.
- The EPZ region designated for protection from ingestion of radioactive materials has a radius of about 50 miles (~80 km). Protective action plans in this region that may call for restrictions in the consumption of contaminated food and water or on land use are in place to prevent or reduce exposure from potential ingestion of radioactive materials.

Plant personnel are at all times responsible for onsite accident response and for limiting the consequences of the accident by preventing radioactive releases offsite.

The offsite response to a nuclear reactor accident starts with the plant personnel, among other response actions, notifying state and local authorities and the NRC about the occurrence of the accident. If the accident is likely to result in a radiation dose that reaches federal government protective action guides (PAGs), plant personnel make protective action recommendations to the state and local authorities.[4] The Environmental Protection Agency (EPA) defines a PAG as the projected radiation dose from an unplanned radioactive release at which a protective action to minimize or avoid that dose and therefore risk from that dose is recommended.[5]

STATE RESPONSIBILITIES

States and counties where nuclear reactors are located are responsible for the preparation of radiological emergency response plans.[6] The purpose of these plans is to organize and coordinate actions taken by the plant owner, federal and state agencies, local governments, and support groups and to allocate and deploy resources and personnel in response to an emergency.

State and local authorities are responsible for making decisions and issuing orders for protective actions. These decisions are based on the status of the plant, prognosis for the accident, and meteorological conditions. Other responsibilities of state and local authorities include independent plume modeling and dose projection, offsite tracking of radioactive releases, sampling of the environment and the food supply for contamination, establishing and operating reception centers that provide radiation monitoring and decontamination for members of the general public, and providing recommendations to the agricultural community.

FEDERAL RESPONSIBILITIES

Several federal agencies provide guidance to state and local governments during a nuclear reactor accident. These agencies and state and local authorities coordinate the responses to the accident through an individual or joint Incident Command System. Dissemination of accident-related information to the news media and members of the public is coordinated by a Joint Information Center.

The President of the United States is kept informed about all aspects of the emergency and has the authority to accelerate federal emergency response in the absence of a specific request from state officials.[7]

Some of the roles and responsibilities of eight federal agencies during a nuclear reactor accident are discussed here. A comprehensive listing is provided in federal planning documents such as the National Response Framework (NRF)[8] and radiation-specific documents such as the NRF's Nuclear/Radiological Incident Annex. These docu-

[4] Federal Emergency Management Agency, 2008, Nuclear/Radiological Incident Annex, http://www.fema.gov/pdf/emergency/nrf/nrf_nuclearradiologicalincidentannex.pdf.

[5] Environmental Protection Agency, 2013, PAG Manual: Protective Action Guides and Planning Guidance for Radiological Incidents, http://www.epa.gov/rpdweb00/docs/er/pag-manual-interim-public-comment-4-2-2013.pdf.

[6] In many jurisdictions, municipalities (cities and towns) also have that responsibility.

[7] Robert T. Stafford Disaster Relief and Emergency Assistance Act, Public Law 93-288, as amended, 42 U.S.C. § 5121 et seq.

[8] Department of Homeland Security, 2014, National Response Framework, http://www.fema.gov/media-library-data/20130726-1914-250451246/final_national_response_framework_20130501.pdf. The NRF contains 15 Emergency Support Function (ESF) Annexes that include protocols for communications (ESF #2), Public health and Medical Services (ESF # 6), Long-Term Community Recovery (ESF # 14), and External Affairs (ESF #15).

ments also define the process and structure for coordinated delivery of federal assistance should federal assistance be requested by the state and local governments.

Department of Homeland Security (DHS)

Pursuant to the Homeland Security Act of 2002,[9] DHS has the overall responsibility for coordinating the federal response to a domestic nuclear reactor accident. If a state requests federal assistance, DHS reviews the situation and determines whether to assume federal leadership for the overall response in accordance with the NRF. DHS also leads the Interagency Modeling and Atmospheric Assessment Center (IMAAC), which provides interagency coordination of atmospheric dispersion modeling capabilities for producing and disseminating predictions of the effects from radiological releases.[10]

The Federal Emergency Management Agency (FEMA) is responsible for coordinating the provision of federal assistance to state and local government agencies during a nuclear reactor accident. FEMA is also responsible for overseeing offsite preparedness of state and local authorities through its Radiological Emergency Preparedness program.[11]

Nuclear Regulatory Commission (NRC)

The NRC is responsible for monitoring and providing assistance to plant personnel to mitigate the consequences of a nuclear reactor accident. This includes assessing the status of the plant, accident progression, and onsite activities. It may also provide technical assistance to state and local governments for source-term, plume-dispersion, and dose-assessment calculations to supplement those of the plant and offsite response organizations.

Environmental Protection Agency (EPA)

One of EPA's roles prior to an emergency is to provide PAGs to assist emergency responders with their recommendations on protective actions.

During a response, EPA supports environmental radiological monitoring and assessment, as well as participates on the Advisory Team for Environment, Food, and Health.[12] This team develops coordinated recommendations on environmental, food, and health matters and assists in the development and implementation of a long-term plan for monitoring radioactivity in the environment. It also assists in the development and implementation of a long-term recovery plan.

Department of Health and Human Services (HHS)

HHS is responsible for providing guidance to state and local authorities on health effects from exposure to radiation following a nuclear reactor accident and how to minimize physical and psychological adverse health effects from exposure to radiation. HHS also provides medical guidance to individuals exposed to radiation and

[9] http://www.dhs.gov/xlibrary/assets/hr_5005_enr.pdf.

[10] IMAAC participating agencies are the Nuclear Regulatory Commission, Department of Defense, Department of Energy, Environmental Protection Agency, Department of Health and Human Services, National Oceanic and Atmospheric Administration (Department of Commerce), and National Aeronautics and Space Administration. The Defense Threat Reduction Agency (DTRA) serves as the technical operations hub of the IMAAC. As such, DTRA coordinates the requests for atmospheric dispersion modeling, performs modeling, and distributes the modeling products to the requestors. See http://www.ofcm.gov/homeland/gmu2013/Presentations/IMAAC%20Fact%20Sheet%20-%20GMU.pdf; communication with Dr. Daniel Blumenthal, Department of Energy/National Nuclear Security Administration.

[11] Nuclear Regulatory Commission and Federal Emergency Management Agency, 1980, Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, NUREG-0654/FEMA-REP-1, http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0654/.

[12] The Department of Agriculture (USDA), the Food and Drug Administration (FDA), and the Centers for Disease Control and Prevention (CDC) are also part of the Advisory Team for Environment, Food, and Health.

may assist with laboratory bioassays to assess human exposures. Additionally, it provides guidance on conducting surveillance of exposed populations for potential long-term health effects.

Within HHS, the Office of the Assistant Secretary for Preparedness and Response[13] is responsible for preparing for and responding to the public health and medical effects of natural and man-made disasters.

Food and Drug Administration (FDA)

As noted previously (see note 12), FDA participates in the Advisory Team for Environment, Food, and Health. It provides laboratory capabilities and Derived Intervention Levels (DILs)[14] for possible embargo of contaminated foodstuffs.

Department of Energy (DOE)

DOE's National Nuclear Security Administration (NNSA) coordinates federal environmental radiological monitoring and produces predictive plume models and dose assessments. This information is provided to decision makers at the federal, state, and local levels to assist with making protective action decisions and communicating them to the public.

NNSA has a variety of emergency response assets to map the probable or actual spread of radioactivity in the environment. They include the National Atmospheric Release Advisory Center (NARAC) for plume and deposition modeling,[15] the Aerial Measuring System for measurements of actual ground deposition with aircraft-mounted detectors, and the Radiation Emergency Assistance Center/Training Site (REAC/TS)[16] to provide specialized assistance, training, and dose assessment related to the medical management of radiation injuries. NNSA can establish a Federal Radiological Monitoring and Assessment Center (FRMAC)[17] to help integrate consequence management resources and coordinate the development of a common operating framework.

Department of Agriculture (USDA)

The USDA may assist with the collection and assessment of agricultural samples within the ingestion exposure pathway EPZ to determine the effect of radioactive materials released during a nuclear reactor accident on agriculture. Also, in conjunction with HHS, USDA monitors the production and distribution of food through wholesale channels to ensure that the levels of contamination in the product are below the DILs.

Department of Defense (DoD)

Subject to the approval of the Secretary of Defense, DoD provides Defense Support of Civil Authorities in response to requests for assistance during incidents that happen within the United States. DoD also provides immediate assistance under Immediate Response Authority for any civil emergency that may require immediate action to save lives, prevent human suffering, or mitigate great property damage.

[13] www.phe.gov.

[14] FDA has adopted DILs as guidance levels for radionuclide activity concentration to help determine whether domestic or imported food presents a safety concern. See Compliance Policy Guides, § 560.750, Radionuclides in Imported Foods —Levels of Concern, http://www.fda.gov/ICECI/ComplianceManuals/CompliancePolicyGuidanceManual/ucm074576.

[15] NARAC is one of the assets that support IMAAC requests.

[16] http://orise.orau.gov/reacts/.

[17] EPA takes over management of the FRMAC when the emergency response phase of the incident is over and the recovery phase has begun. See http://www.nnsa.energy.gov/aboutus/ourprograms/emergencyoperationscounterterrorism/respondingtoemergencies-0-1.

NUCLEAR REACTOR ACCIDENT EVENT PROGRESSION AND RESPONSE

Federal agencies define three phases in structuring the response to a radiological emergency in the United States: early (or emergency), intermediate, and late (or recovery) phase. These phases are represented by the activities performed rather than by precise time periods; some overlap between phases may exist.

The early phase lasts from several hours to days from initiation of the nuclear reactor accident. During this phase, the ability to assess radiological conditions is often limited, but immediate decisions for protective actions may be required to protect populations from exposure to direct radiation and inhalation from an airborne plume. Such actions are generally based on plant conditions and projected doses and include evacuation and sheltering in place (possibly supplemented by KI) and are prompted by comparing expected radiation levels to a PAG. Restrictions on the consumption and use of potentially contaminated food and water may be initiated during this phase.

The intermediate phase may last from weeks to months. During this phase the nuclear reactor has been brought under control and there are no further significant radioactive releases that would exceed the PAGs. During this phase, environmental measurements of radioactivity are made available for use as a basis for decisions on additional protective actions. Doses may accrue in this phase from deposited, resuspended, and ingested radioactive material. The protective actions issued during this phase are relocation[18] and decontamination to reduce radiation levels in the environment. Similar to the emergency phase, protective actions are prompted by comparing radiation levels to a PAG.

The late phase can last from months to years. It begins when actions have been initiated to remediate contaminated areas and allow relocated populations to reoccupy or resettle.[19] Recovery ends when all actions have been completed.

[18] Relocation is frequently issued during the intermediate and recovery phases. It involves the removal or continued exclusion of people from areas deemed contaminated to avoid low-level, chronic radiation exposure.

[19] The term *reoccupancy* refers to moving back to the area that was evacuated at the time of the nuclear emergency. The term *resettlement* refers to living in a new area after being permanently relocated.

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Symposium Summary

This chapter provides the rapporteur's summary of the presentations and discussions that took place at the May 13, 2014, symposium titled *The Science and Response to a Nuclear Reactor Accident*. The summary does not provide findings and recommendations or represent a consensus reached by the symposium participants or the symposium planning committee.

OPENING REMARKS

The symposium planning committee invited Dr. Nicole Lurie, Assistant Secretary for Preparedness and Response, Department of Health and Human Services (HHS), to help set the stage for the symposium discussions.

Dr. Lurie began her remarks by noting that despite significant enhancements to public health preparedness over the years, there are gaps in knowledge and practice for responding to public health emergencies including nuclear reactor accidents. There is a limited number of experts available to provide scientific advice, communicate messages, and conduct research rapidly and in real time. In addition, there is currently no system in place to locate those experts and appropriate research facilities. Research during an emergency, she said, would benefit and inform improved response and recovery. Dr. Lurie called for a formalized system for conducting scientific research (including social science) in response to public health emergencies and having a prioritized research agenda on which to act. In her view, this system would inform preparedness in the next disaster if it were integrated into the formal structure of how a disaster is managed.

The Office of the Assistant Secretary for Preparedness and Response (ASPR)[1] in HHS has initiated a program to provide for the inclusion of scientific research into the health and medical response to a disaster (including a nuclear disaster),[2] coordinated alongside lifesaving response activities. This program includes rapid review mechanisms for human subjects, administratively simple ways to get funding to investigators without having them write grants, and create the registries and networks to allow for a rapid and flexible research response. As the program evolves, ASPR will continue to lead interagency efforts to enhance public health preparedness, response, and recovery through innovative and achievable approaches to rapid science research before, during, and after a disaster.

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[1] The office was formed in 2007 as a lesson learned from Hurricane Katrina in an effort to coordinate public health response to emergencies.

[2] Lurie N., Manolio T., Patterson A.P., Collins F., Frieden T., 2013, Research as a part of public health emergency response. N Engl J Med, 368(13):1251-1255.

HEALTH AND OTHER EFFECTS OF A NUCLEAR REACTOR ACCIDENT

The committee invited two presenters to discuss the health and other effects of a nuclear reactor accident. Dr. Alina Brenner, staff scientist, Radiation Epidemiology Branch, National Cancer Institute (NCI), provided an overview of the physical health effects of nuclear reactor accidents based on knowledge gained from previous accidents. Dr. Steven Becker, professor of community and environmental health, College of Health Sciences, Old Dominion University, discussed the range of community impacts that can occur following a nuclear reactor accident and highlighted research needs to improve the community's recovery.

Physical Health Effects

Dr. Brenner, NCI, said that of the four major nuclear accidents that have occurred to date (Windscale, UK, 1957; Three Mile Island, U.S., 1979; Chernobyl, former Soviet Union, 1986; and Fukushima Daiichi, Japan, 2011), most knowledge about the health consequences of nuclear reactor accidents was obtained from studies of the Chernobyl accident, the most severe nuclear reactor accident in history in terms of radioactive material releases.[3]

Dr. Brenner first discussed the acute radiation physical health effects of the Chernobyl accident. One hundred thirty-four plant and emergency workers received high whole-body doses resulting in acute radiation syndrome; 28 of these workers died within 4 months and their deaths were directly attributed to high radiation doses.[4] No acute health effects were reported among evacuees or the general population.

Dr. Brenner also described the late physical health effects of the Chernobyl accident and focused on three outcomes that in her view are strongly and consistently linked with radiation exposure from the accident. These were:

- Thyroid cancer in children:[5] Residents of the Chernobyl area received substantial radiation doses to the thyroid from consumption of milk contaminated with iodine-131. A dramatic increase in the incidence of thyroid cancer among those exposed in childhood was observed as early as 1991 and was attributed to iodine-131 exposure. Epidemiological studies reported that radiation risk estimates for thyroid cancer associated with primarily internal radiation were comparable to thyroid cancer risk estimates from external radiation based on systematic assessment of studies focusing on external radiation and thyroid cancer risk.[6] There is no convincing evidence of radiation-related increase in thyroid cancer among residents exposed in adulthood or other health outcomes in the general population.
- Leukemia in cleanup workers:[7] Over 500,000 workers from the former Soviet Union were involved in recovery operations following the Chernobyl accident. The main pathway of their exposure was external gamma radiation from contaminated material deposited on the ground and building surfaces. The most

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[3] Dr. Steven Simon, NCI, tabulated the amounts of radionuclides presented in emissions from nuclear power plant accidents ($\times 10^{15}$ Bq). For iodine-131, these were 0.6 from Windscale, 0.0001 from Three Mile Island, 1,800 from Chernobyl, and 160 from Fukushima Daiichi.

[4] United Nations Scientific Committee on the Effects of Atomic Radiation, 2011, Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2008 Report to the General Assembly with Scientific Annexes (Volume II: Scientific Annexes C, D, and E), New York: United Nations, April, www.unscear.org/docs/reports/2008/11-80076_Report_2008_Annex_D.pdf.

[5] Stezhko V.A., Buglova E.E., Danilova L.I., Drozd V.M., Krysenko N.A., Lesnikova N.R., Minenko V.F., Ostapenko V.A., Petrenko S.V., Polyanskaya O.N., Rzheutski V.A., Tronko M.D., Bobylyova O.O., Bogdanova T.I., Ephstein O.V., Kairo I.A., Kostin O.V., Likhtarev I.A., Markov V.V., Oliynik V.A., Shpak V.M., Tereshchenko V.P., Zamotayeva G.A., Beebe G.W., Bouville A.C., Brill A.B., Burch J.D., Fink D.J., Greenebaum E., Howe G.R., Luckyanov N.K., Masnyk I.J., McConnell R.J., Robbins J., Thomas T.L., Voilequé P.G., Zablotska L.B., Chornobyl Thyroid Diseases Study Group of Belarus, Chornobyl Thyroid Diseases Study Group of Ukraine, Chornobyl Thyroid Diseases Study Group of the USA, 2004, A cohort study of thyroid cancer and other thyroid diseases after the Chornobyl accident: Objectives, design and methods, Radiat Res, 161:481-492.

[6] Ron E., Lubin J.H., Shore R.E., Mabuchi K., Modan B., Pottern L.M., Schneider A.B., Tucker M.A., Boice J.D., Jr. 1995, Thyroid cancer after exposure to external radiation: A pooled analysis of seven studies. Radiat Res, 141(3):259-277.

[7] Kesminiene A., Evrard A.S., Ivanov V.K., Malakhova I.V., Kurtinaitis J., Stengrevics A., Tekkel M., Anspaugh L.R., Bouville A., Chekin S., Chumak V.V., Drozdovitch V., Gapanovich V., Golovanov I., Hubert P., Illichev S.V., Khait S.E., Kryuchkov V.P., Maceika E., Maksyoutov M., Mirkhaidarov A.K., Polyakov S., Shchukina N., Tenet V., Tserakhovich T.I., Tsykalo A., Tukov A.R., Cardis E., 2008, Risk of hematological malignancies among Chernobyl liquidators, Radiat Res, 170:721-735.

consistent health effect in cleanup workers is increased risk of leukemia. Some studies also reported elevated risks of chronic lymphocytic leukemia, previously considered unrelated to radiation exposure.

- Cataracts in cleanup workers:[8] Lens opacity in cleanup workers occurs at substantially lower doses than then-existing radiation protection guidelines.

No incidents of acute radiation syndrome or deaths attributed to radiation have been reported following the Fukushima Daiichi accident due to protective actions taken (prompt evacuations, sheltering in place, control of milk consumption) by the Japanese government. Radiation dose estimates currently available for residents and recovery workers are substantially lower than those observed during the Chernobyl accident.[9] Therefore, the magnitude of radiation-related health consequences is also expected to be considerably lower. Various health programs in Japan are currently in progress, including a thyroid ultrasound survey, to help ensure the well-being of residents and recovery workers and extend knowledge about physical health effects of nuclear reactor accidents.

Dr. Brenner briefly described preliminary findings of a thyroid ultrasound survey among children in Japan. Out of the 250,000 children examined, 75 have suspected thyroid cancer and 32 have confirmed thyroid cancer.[10] This translates to 1-3 cases of thyroid cancer per 10,000 people, a rate higher than expected.[11] Dr. Brenner cautioned, however, that the ultrasound equipment used in this screening program is sensitive and therefore able to detect small thyroid cancers that may have little clinical relevance.

Social, Psychological, and Behavioral Impacts

Dr. Becker, Old Dominion University, noted that one of the primary lessons from research and experience in the field over the past several decades is that social, psychological, and behavioral impacts constitute significant effects of nuclear accidents.[12] These effects can be widespread and long-lasting and can spread to areas beyond the region directly impacted with significant radioactive contamination. Social, psychological, and behavioral impacts also pose challenges for every aspect of disaster preparedness and response, from planning and preparedness to response and recovery.

Several decades of risk perception research have demonstrated that incidents involving nuclear technology and radiation are among the most feared of all hazards. Such incidents have the capacity to produce a profound sense of vulnerability and a continuing sense of alarm and dread. Dr. Becker identified a host of perceived characteristics that are responsible for this:[13]

- Radiation is invisible.
- Radiation is unfamiliar to most people.
- The threat is perceived as unbounded or open-ended.

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[8] Worgul B.V., Kundiyev Y.I., Sergiyenko N.M., Chumak V.V., Vitte P.M., Medvedovsky C., Bakhanova E.V., Junk A.K., Kyrychenko O.Y., Musijachenko N.V., Shylo S.A., Vitte O.P., Xu S., Xue X., Shore R.E., 2007, Cataracts among Chernobyl clean-up workers: Implications regarding permissible eye exposures, Radiat Res,167(2):233-243.

[9] United Nations Scientific Committee on the Effects of Atomic Radiation. 2013. Sources, Effects and Risks of Ionizing Radiation: UNSCEAR 2013 Report, Volume I, Report to the General Assembly, (Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 Great East-Japan earthquake and tsunami, New York: United Nations, April, http://www.unscear.org/docs/reports/2013/13-85418_Report_2013_Annex_A.pdf.

[10] http://www.fmu.ac.jp/radiationhealth/results.

[11] The rate of thyroid cancer in the United States is about 4-5 cases per 100,000. See, for example, Enewold L., Zhu K., Ron E., Marrogi A.J., Stojadinovic A., Peoples G.E., Devesa S.S., 2009, Rising thyroid cancer incidence in the United States by demographic and tumor characteristics, 1980-2005. Cancer Epidemiol Biomarkers Prev18(3):784-791; Chen A.Y., Jemal A., Ward E.M., 2009, Increasing incidence of differentiated thyroid cancer in the United States, 1988-2005. Cancer,115(16):3801-3807.

[12] Becker S.M., 2007, Communicating risk to the public after radiological incidents, BMJ, 335(7630):1106-1107; Becker S.M., 2004, Emergency communication and information issues in terrorism events involving radioactive materials, Biosecur Bioterror, 2:195-207.

[13] Dodgen D., Norwood A.E., Becker S.M., Perez J.T., Hansen CK., 2011, Social, psychological and behavioral responses to a nuclear denotation in a U.S. city: Implications for healthcare planning and delivery (Special Issue on Medical and Public Health Response to a Nuclear Denotation), Disaster Med Public Health Prep 5(S1):54-65; Becker S.M., 2001, Psychological effects of radiation accidents. Chapter 41 in I. Gusev, A. Guskova, F.A. Mettler, Jr., eds., Medical Management of Radiation Accidents, 2nd ed., Boca Raton, FL: CRC Press.

- There is the potential for long-term contamination.
- Radiation has the potential to cause hidden damage.
- The health effects have long latency.
- Radiation is seen as representing special danger to children and pregnant women.
- Radiation is associated with forms of illness or death that in most cultures arouse dread, in particular cancer.

Dr. Becker covered seven broad classes of social, psychological, and behavioral impacts that can result from nuclear accidents:

1. Individual mental health impacts.[14] It is known that after nuclear accidents, there can be an increased incidence of anxiety, depression, post-traumatic stress symptoms, and medically unexplained physical symptoms. Typically, people in affected regions report or experience a sense of having *poor health*. Research has shown that the highest-risk groups are mothers of young children and cleanup workers. In the latter group, symptoms range from alcohol abuse to some indications of elevated suicide rates.
2. Spontaneous evacuation. Following the 1979 Three Mile Island accident, unclear, inadequate, and ambiguous information, coupled with a lack of trust in officials and a lack of credibility of authorities, led to a mass flight from the area. For every person who was advised to evacuate, about 45 people actually evacuated, resulting in about 150,000 evacuees.[15] According to Dr. Becker this is not an inevitable result of nuclear accidents but a possibility in situations where communication is poor.
3. Disruption from evacuation and relocation.[16] With evacuation and relocation, there is loss of community connections, loss of work, loss of activity, and continuing uncertainty about the future. Fifty percent of the families that had been intact prior to the Fukushima Daiichi accident are no longer intact 3 years later. These families have members living in different locations, principally because of housing issues, work requirements, and children's educational needs. The processes of moving and relocating people have serious costs by themselves: Elderly who were relocated as a consequence of the accident have died, either en route or afterward.
4. Social stigma. Social stigma is the phenomenon where people, products, and places perceived as being in any way connected to the disaster are seen as tainted, something to be feared, or something to be avoided. In some cases, those objects may become the targets of discrimination. This impact was described by Dr. Becker as a *secondary disaster*. Although it has been seen in previous accidents, no nation at the present time has a plan for addressing, preventing, or mitigating it. In the case of the Fukushima Daiichi accident, there has been avoidance of produce from the Fukushima prefecture (the region is known for its peaches, tomatoes, cucumbers, apples, and pears); fishing boats that had formerly stopped at ports in Fukushima prefecture discontinued docking there out of concern that the public would associate their catches with the accident; and tourism and educational field trips to the region have dropped.

   Evacuees became the object of social stigma. There were significant numbers of cases where hotels refused to accept evacuees from Fukushima. Some healthcare facilities refused to provide treatment to people unless they presented certificates proving they had not been exposed to radiation.[17] There were

[14] Bromet E.L., 2014, Emotional consequences of nuclear power plant disasters, Health Phys, 106 (2):206-210; Bromet E.J., 2012, Mental health consequences of the Chernobyl disaster, J Radiol Prot, 32(1):N71-N75; The Chernobyl Forum: 2003-2005, 2006, Chernobyls Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Government of Belarus, the Russia Federation and Ukraine,2nd Rev., Vienna, Austria: International Atomic Energy Agency; Havenaar J.M., Rumyantzeva G.M., van den Brink W., Poelijoe N.W., van den Bout J., van Engeland H., Koeter M.W., 1997, Long-term mental health effects of the Chernobyl disaster: An epidemiologic survey in two former Soviet regions, Am J Psychiatry, 154(11):1605-1607; Bromet E.J., 2014, Emotional consequences of nuclear power plant disasters, Health Phys 106(2):206-210; Bromet E.J., 2012, Mental health consequences of the Chernobyl disaster, J Radiol Prot, 32(1):N71-N75.

[15] Stallings, R.A., 1984, Evacuation behavior at Three Mile Island, Int J Mass Emerg Disasters, 2(1):11-26, https://www.training.fema.gov/EMIWeb/downloads/IJEMS/ARTICLES/Evacuation%20Behavior%20at%20Three%20Mile%20Island.%20Robert%20Stallings.pdf.

[16] Nomura S., Gilmour S., Tsubokura M., Yoneoka D., Sugimoto A., Oikawa T., Kami M., Shibuya K., 2013, Mortality risk amongst nursing residents evacuated after the Fukushima Daiichi accident: A retrospective cohort study, PLoS ONE 8(3):e60192, doi:10.1371/journal.pone.0060192.

[17] Atomic evacuees getting cold shoulder at shelters, Jpn Times, April 16, 2011, p. 2.

suggestions made that women from Fukushima are now tainted and should not marry or have children.[18] Children who found themselves evacuated to other areas sometimes were the targets of bullying because of concerns that they were tainted. (Similar kinds of impacts from social stigma were also seen after the Chernobyl accident.)

5. Culture of fatalism.[19] Research has shown the general public has fairly strong fatalistic attitudes about radiation and radioactive contamination. Particularly after Chernobyl, but not limited to Chernobyl, there was a strong sense of lack of control over peoples' lives extending to populations beyond the immediately affected areas.
6. Reactions of hospital, healthcare personnel, and families.[20] A large body of literature suggests that hospital and healthcare personnel have a lower willingness to be involved with or respond to events that involve radiation. Their families, particularly those with young children, also have concerns and fears that remain largely unaddressed. The net result of that is a flight of healthcare professionals, hospital professionals, and their families after incidents involving radiation, a phenomenon seen following the Fukushima Daiichi accident.

   A survey carried out in Fukushima Prefecture by the hospital association showed that by July 2011, 5 months after the accident, over 500 physicians and nurses had left the area. The Japan Nursing Association reported a 40 percent drop in the number of hospital nurses in the prefecture between March 2011 and September 2012. Dr. Becker noted that hospitals cannot attract trainee doctors to fill residencies in the prefecture. In the middle of 2012, the Japan Nursing Association reported that they had 768 open positions in the prefecture and only 174 applicants. Obviously, Dr. Becker said, this creates problems for recovery because there is curtailment of medical services in some areas at a time when the demand for medical services is rising because of the disaster.

   Dr. Becker identified a second problem resulting from the loss of hospital and healthcare personnel: Typically, healthcare professionals are trusted and close to the top of the list of people to whom members of the public would turn to address their concerns. The fact that these trusted sources are leaving the area because of their own and their families' concerns may send a message to the general public that the area is not safe to live in.
7. Broader demographic shifts with implications for the viability of communities.[21] People are especially concerned about their children. There has been a huge outflow of families with children from the affected region. As a result, the aged population (greater than 65 years old) has increased compared with the population before the accident.

Dr. Becker emphasized that there is a pressing need to systematically address these social, psychological, and behavioral impacts. In his view, to address these impacts, there needs to be a research-driven agenda based on understanding what the public is concerned about and what it wants to know. Using social stigma as an example, Dr. Becker noted that it is crucial to learn from the largely unpublished isolated efforts that have been made to address stigma issues. How we address social, psychological, and behavioral impacts will play a large role in determining whether future efforts to manage and recover from a nuclear reactor accident are a success or a failure.

In response to a question from a symposium participant about whether federal agencies such as the Nuclear Regulatory Commission (NRC) should consider social, psychological, and behavioral impacts, for example, in

[18] Haworth, A., 2013, After Fukushima: Families on the edge of meltdown, The Guardian, Feb. 23, http://www.theguardian.com/environment/2013/feb/24/divorce-after-fukushima-nuclear-disaster.

[19] Becker S.M. 2004. Emergency communication and information issues in terrorism events involving radioactive materials, Biosecur Bioterror 2(3):195-207; Wray R.J., Becker S.M., Henderson N., Glik D., Jupka K., Middleton S., Henderson C., Drury A., Mitchell E.W., 2008, Communicating with the public about emerging health threats: Lessons learned from the CDC-ASPH Pre-event Message Development Project, Am J Pub Health, 98(12):2214-2222.

[20] Smith E.C., Burkle F.M., Jr., Archer F.L., 2010, Fear, familiarity, and perception of risk: A quantitative analysis of disaster concerns of paramedics. Disaster Med Public Health Prep 5(1):46-53.

[21] Hori A., Tsumuraya K., Kanamori R., Maeda M., Yabe H., Niwa S., 2014, Report from Minamisoma City: Diversity and complexity of psychological distress in local residents after a nuclear power plant accident. Seishin Shinkeigaku Zasshi, 116 (3):212-218.

their environmental impact statement[22] on the licensing of nuclear power plants, Dr. Becker noted that anything we can do to recognize and assist people in dealing with these impacts and to make them less the object of stigma is a step in the right direction. He mentioned that, based on news reports, it appears that the Japanese government has identified some mental health impacts as compensable.[23]

EARLY-PHASE RESPONSE TO A NUCLEAR REACTOR ACCIDENT

During the early phase of a nuclear reactor accident, response activities need to happen fast, likely with limited information related to the accident conditions and prognosis, and with little time to analyze options. Presentations related to early-phase response to a nuclear reactor accident focused on the following five activities:

1. Atmospheric modeling and radiation monitoring and analysis,
2. Protective actions,
3. Population monitoring,
4. Medical planning and response, and
5. Biodosimetry.

Presenters identified the various challenges related to these activities and in some cases provided their views on how they can be addressed to better prepare the United States for responding to a future nuclear reactor accident.

Atmospheric Modeling and Radiation Monitoring and Analysis

Dr. Daniel Blumenthal, program manager, Consequence Management, Office of Emergency Response, National Nuclear Security Administration (NNSA), talked about his experience related to NNSA's radiation monitoring during the initial response to the Fukushima Daiichi accident in Japan. An NNSA team of radiation monitoring experts was dispatched to Japan the day following the accident. It had data collection, analysis, and assessment capabilities (see Chapter 1 for a description of Department of Energy (DOE) NNSA assets) which were coordinated with those from other federal agencies through the Federal Radiological Monitoring and Assessment Center (FRMAC).[24]

Initially, the NNSA team focused on atmospheric dispersion modeling. This modeling was used to predict the path of radioactive material released from the Fukushima Daiichi reactors, and from that, provide initial guidance on protective actions and locations for sampling of products to assess contamination levels.

The FRMAC received many requests for modeling support during the Fukushima accident from the United States and Japan. In particular, there were requests for modeling hypothetical scenarios: What if the reactors and spent fuel pools released 100 percent of their inventories? What if this happened when the wind was blowing toward Tokyo for 24 hours? Some of the scenarios that the FRMAC was asked to model were not realistic according to Dr. Blumenthal.

Atmospheric dispersion models can be refined once there is information from environmental measurements and used to project into the future, taking into account some model assumptions on weather conditions and other factors. Environmental monitoring can be both aerial and ground based. Aerial monitoring is conducted by aircraft and typically occurs first because it can cover wide areas quickly and cost-effectively. Also, it is considered to be a

[22] An environmental impact statement is a document required by the National Environmental Policy Act (NEPA) that describes the impacts of a proposed action on the environment.

[23] See Compensation for residents' mental damage to continue beyond Aug. TEPCO president-designate ready to treat all residents equally, Fukushima Minpo News, June 1, 2012; Court orders TEPCO to compensate family of Fukushima woman who committed suicide, The Asahi Shimbun, August 26, 2014; Fukushima stress deaths top 3/1 toll: Uncertainties amid nuclear crisis acutely felt by the elderly, The Japan Times News, February 20, 2014.

[24] In response to the Fukushima nuclear accident, RadResponder was designed to collect and manage environmental radiation monitoring data from field surveys; fixed-point sensor arrays; and soil, water, and other samples. In the event that FRMAC is activated, any data collected by RadResponder can be directly imported into FRMAC's database and made available to agencies with environmental monitoring responsibilities. In addition, modeling or data products such as maps developed by the FRMAC can be distributed through RadResponder and used by participating organizations. See https://www.radresponder.net/signupsignin/faq.aspx#101.

safer way to collect information because it does not require physical entry into potentially contaminated areas or, in the case of the Fukushima region, to areas that were affected by the earthquake and tsunami. Dr. Blumenthal said that some measurements from DOE's Aerial Measuring System were available within 1 day of the NNSA team's arrival at Fukushima. Products from the environmental monitoring could be framed in terms of EPA Protective Action Guides (PAGs) to inform protective actions or agricultural protective action guides.

Dr. Blumenthal provided the following lessons learned relevant to emergency planning for environmental monitoring within the United States:

1. During a nuclear emergency, there is a need for fast, accurate, and comprehensive information when data about the nuclear reactor status are incomplete and conditions (e.g., nuclear reactor status and prognosis, weather) change with time.
2. Confirming the lack of radioactive contamination in an area is as important as providing information on contamination levels in a different area. In both cases, the information on contamination needs to be updated with time.
3. Federal capabilities for radioactive contamination data collection are large. However, there is not enough subject-matter expertise to perform the needed quality controls and integrate and interpret the data.
4. Information on radioactive contamination acquired from nongovernmental organizations needs to be formally integrated in the national response to a nuclear reactor accident.

Dr. Blumenthal noted that the organization *SafeCast*[25] was created in Japan during the Fukushima Daiichi accident by volunteers with backgrounds in computers, nuclear engineering, and media. The organization performed radiation measurements using small detectors mounted on cars and bicycles. Individual members of the public may also have capabilities for measuring radiation in the environment during a nuclear reactor accident. Ms. Gerilee Bennett, deputy director, National Disaster Recovery Planning Division, Federal Emergency Management Agency (FEMA), discussed software that can turn a cell phone camera into a radiation detector. Although not as sensitive as professional equipment, such equipment would likely be used by the public if it is available.[26]

Protective Actions

Initial protective actions for members of the public during a nuclear reactor accident are based on plant conditions and projected doses. If projected doses exceed the PAGs, then protective action orders are considered by decision makers. The purpose of these protective actions is to minimize the health effects to members of the public. Protective actions issued at the early phase of a nuclear reactor accident include evacuations and sheltering in place and may include issuance of potassium iodide (KI).

Evacuations and Sheltering in Place

PAGs consider the risks to individuals from exposure to radiation and the risks and costs associated with a specific protective action such as evacuation and sheltering in place. Ms. Sara DeCair, health physicist, Office of Radiation and Indoor Air, Environmental Protection Agency (EPA), explained that the risk-benefit analysis to establish the evacuation PAG used several assumptions, for example, that 50 percent of the dose could be avoided by evacuating versus sheltering in place. When establishing the evacuation PAG, EPA also considered detriments such as high traffic volume while evacuating. However, the agency's analysis did not take into account other known effects, such as psychosocial and socioeconomic effects, which in her view are hard to quantify. Also, EPA did not consider sensitive populations, such as fetuses and children, separately because information on radiation

[25] http://blog.safecast.org/.

[26] The Health Physics Society states that applications to measure radiation using smart phones should not be a substitute for measurements made by qualified radiation protection professionals to evaluate the user's safety or to issue protective actions. (See http://hps.org/hpspublications/positions.html.)

sensitivity of these populations was not available at the time. "A lot of this analysis was based on 1970s' and 1980s' science," Ms. DeCair said, but she noted that EPA has committed to redoing the risk-benefit analyses with more current information.

Decisions on early-phase protective actions are made by the state and local governments where the nuclear reactor is sited. Frequently, as is the case with Vermont Yankee Nuclear Power Station located in Vernon, Vermont,[27] multiple states can be affected by a nuclear reactor accident, making collaboration among governments critical and confusion of citizens possible. Dr. William Irwin, chief, Radiological and Toxicological Sciences, Vermont Health Department, explained that some jurisdictions such as those in Vermont and neighboring New Hampshire plan to evacuate or give shelter-in-place orders for whole towns, whereas for the same reactor accident, another state may only plan to evacuate or issue orders for sheltering in place for parts of those towns or for particular neighborhoods that are in the 10-mile emergency planning zone (EPZ).

Dr. Irwin spoke of the difficulty of issuing an order to evacuate or shelter in place, especially when information about the status of the plant and accident prognosis is imperfect, which has been the case for previous reactor accidents. He emphasized that protective actions should produce more good than harm in the affected population, and, he discussed some general considerations for making a decision to evacuate or shelter in place.

Evacuation is preferable before evacuees receive significant radiation dose when there is time to do so safely. Dr. Irwin noted that nuclear reactor accidents may be slow in developing, and so, provide sufficient time to evacuate. He discussed the challenges of evacuating large populations: evacuations take a long time and a lot of resources to complete and may result in serious consequences including evacuee deaths.

Dr. Irwin commented that sheltering in place is preferred when conditions may result in greater dose or harm if people were evacuated, for example, because high radiation conditions already exist from deposition or a plume; extreme weather or another natural disaster restricts travel, or hostile actions in the area pose a threat to evacuees. However, sheltering in place may lead to high radiation doses from highly radioactive plumes, especially where buildings provide poor shielding. He noted that some people may choose to evacuate despite the issuance of a shelter-in-place order.

Dr. Irwin reminded symposium participants that decisions on early-phase protective actions also determine future actions that need to be taken. For example: Where do evacuees go? How can evacuees be monitored for protective care? How can evacuees register for dose reconstruction and medical follow-up? What guidance is being provided to persons who do not evacuate? What do we do for persons who self-evacuate? Dr. Irwin suggested that the nation needs to work to answer these questions.

Potassium Iodide

KI is recommended for use as an adjunct emergency measure to evacuation and sheltering in place to prevent or reduce the uptake of radioiodine by the thyroid gland. Dr. Jan Wolff, National Institutes of Health (retired), co-discovered the mechanism by which potassium iodide protects the thyroid from radioiodine uptake (Wolff-Chaikff effect) and presented it at the symposium. Briefly, iodide intake by the thyroid gland in substantial excess of what is required for hormone synthesis leads to inhibition of numerous metabolic processes within the thyroid including thyroid vascularity, adenylyl cyclase, and iodide transport into the gland by the Na/I symporter. Such inhibitions are probably caused by iodination of double bonds in arachidonic acid and other unsaturated lipids. These compounds then act as inhibitors without further need of iodide or oxidized iodine. Although the half-life of iodide ion is brief (5-6 hours), once oxidized and incorporated into thyroxine in thyroglobulin, the biological half-life becomes long (about 40 days), with the effective half-life (6.7 days) approaching the physical half-life of the isotope (8 days). For this reason, oral application of KI for protection against iodine-131 must be as fast as possible. (As discussed later in the symposium, this has implications for methods of KI distribution during an emergency.) Side effects of KI include skin rashes, swelling of the salivary glands, and iodism.[28] Persons with

[27] The Vermont Yankee Nuclear Power Station is scheduled to cease operations by the end of 2014.
[28] http://www.fda.gov/drugs/emergencypreparedness/bioterrorismanddrugpreparedness/ucm072265.htm#W.

known iodine sensitivity and individuals with dermatitis herpetiformis and hypocomplementemic vasculitis (which are rare diseases) should not take KI.

The Food and Drug Administration (FDA) first approved KI as an over-the-counter drug in 1978. Dr. Leissa, deputy director, Office of Counter-Terrorism and Emergency Coordination, Center for Drug Evaluation and Research, FDA, listed the three FDA-approved KI forms available today:

1. Iosat, manufactured by Anbex, a tablet containing 130 mg of KI.
2. ThyroSafe, manufactured by Recip, a tablet containing 65 mg of KI.
3. ThyroShield, manufactured by ARCO Pharmaceuticals (formerly by Fleming and Company), which is a liquid preparation.

FDA provides instructions on how to prepare liquid KI using the tablet form. FDA also issues operational considerations for KI in an emergency. Three of these considerations were discussed by Dr. Leissa at the symposium:

1. FDA understands that a KI administration program that sets different thyroid radiation exposure thresholds for treatment of different population groups may be logistically impractical to implement during a radiological emergency. If emergency planners reach this conclusion, FDA recommends that KI be administered to both children and adults at the lowest intervention threshold, for example, the greater than 5 cGy projected internal thyroid exposure threshold for children.
2. If local emergency planners conclude that graded dosing is logistically impractical, FDA believes that the overall benefits of taking up to 130 mg of KI far exceed the small risks of overdosing. However, where feasible, adherence to FDA guidance should be attempted when dosing infants.
3. Although special precautions should be taken when administering KI to pregnant women and to newborns within the first month of life, the benefits of short-term administration of KI as a thyroid blocking agent far exceed the risks of administration to any age group.

Although our scientific understanding of the protective mechanisms of KI has remained unchanged for over two decades, federal and state policies related to KI distribution have changed over the years. Table 1 provides a time line of the federal and state policies based on information provided by two symposium speakers: Ms. Patricia Milligan, senior advisor, Office of Nuclear Security and Incident Response, Division of Preparedness and Response, Nuclear Regulatory Commission (NRC); and Mr. Steven Adams, deputy director, U.S. Strategic National Stockpile Program, Centers for Disease Control and Prevention (CDC).

To support the 2001 rule change and to make it easier for states to consider including KI into their programs, the NRC agreed to supply KI tablets to states with populations within the 10-mile EPZ. That included 33 states and one tribal nation, the Prairie Island Tribe in Minnesota. Currently, 25 states are participating in the program and approximately 47 million KI tablets have been distributed by the NRC to requesting states. Ms. Milligan, NRC, noted that when the tablets reach their factory-specified expiration date (based on the 6-year shelf life recommended by the FDA), NRC purchases more tablets to distribute to the states, and the states dispose of the expired tablets.[29] To date, the NRC has spent approximately $12.5 million on KI for populations within the 10-mile EPZ.

The NRC has considered the expansion of KI beyond the 10-mile EPZ. However, according to Ms. Milligan, the agency believes that the interdiction of food and water—milk in particular—within the 50-mile ingestion exposure pathway EPZ is the most effective pathway to protect those at risk during a nuclear reactor accident.

Mr. Adams, CDC, described how decisions are made by the Public Health Emergency Medical Countermeasures Enterprise (PHEMCE) about what goes into the strategic national stockpile. PHEMCE examines the threats identified by federal partners,[30] the medical consequences that may develop as a result of those threats,

[29] Dr. Wolff, NIH (retired), noted that KI is very stable and that its shelf-life is longer than 6 years, if stored under appropriate conditions. Dr. Leissa, FDA, commented that his agency has issued shelf-life extension guidance specifically toward federal agencies and state and local governments. There was no discussion at the symposium of whether any states follow the guidance to extend the shelf life of the KI offered by NRC.

[30] These include CDC, FDA, Department of Homeland Security (DHS), Department of Defense (DoD), the Department of Veterans Affairs, and the Department of Agriculture.

TABLE 1 Time Line of Potassium Iodide Distribution Policies

Year	Event or Policy Implementation
1979	Recommendation to have KI available regionally as a stockpile for distribution to the general population and to workers affected by emergency.[a]
1980	NRC/FEMA guide states that there should be KI available for emergency workers and institutionalized persons.
1999	Strategic National Stockpile (SNS) program starts.
2000	SNS acquires KI tablets (130 mg).
2001	NRC amends emergency preparedness regulations to require that states consider the use of KI as a supplemental protective measure for the general population.
2002	Public Health Security and Bioterrorism Preparedness and Response Act establishes potential for HHS support of KI distribution for a zone 10-20 miles[b] from nuclear power plants.
2005	HHS acquires KI for the SNS to address 10- to 20-mile zone.
	NRC and CDC collaborate to offer Thyroshield to eligible states.
2008	John Marburger, White House Office of Science and Technology Policy Director, invoked a waiver to the 2002 law requiring states to consider the use of KI in the 10- to 20-mile KI distribution zone.
	Public Health Emergency Medical Countermeasures Enterprise (PHEMCE)[c] eliminates the SNS requirement for strategic storage of KI.
	NRC and CDC collaborate to offer the SNS's Thyroshield and KI tablets to eligible states.
	PHEMCE determines final disposition of stored KI; the remaining SNS-held KI tablets are transferred to NRC and the remaining Thyroshield to be held by SNS until their 2012 expiry.
2014	PHEMCE decides to reintroduce modest quantities of KI.[d]

[a] This policy was implemented after the Three Mile Island accident.
[b] This is a zone larger than the 10-mile EPZ that is currently used for KI distribution planning.
[c] PHEMCE has three functions:

1. Defines and prioritizes requirements for public health emergency medical countermeasures;
2. Integrates and coordinates research, early- and late-stage product development, and procurement activities addressing the requirements;
3. Sets deployment and use strategies for medical countermeasures held in the SNS.

PHEMCE is led by the HHS Assistant Secretary for Preparedness and Response.
[d] This policy was implemented after the Fukushima Daiichi accident.

and the potential to intervene in disease prevention. Based on this information, PHEMCE performs a relative prioritization across the threat spectrum and identifies opportunities to make investments to address the threats. If a decision is made to acquire the relevant countermeasure, it is maintained under strict commercial good manufacturing standards to ensure that it is viable at a time of need. The national stockpile is held by commercial partners under CDC's control and oversight in areas that are not considered to be at risk of being directly impacted by the threats they are designed to mitigate.

Once the appropriate material is acquired in the national stockpile, there need to be pathways to provide it to the area of need in a time frame that is clinically relevant. Providing a countermeasure at the time needed is often the challenge and certainly one with KI, Mr. Adams said. The time frame for administration (less than 4 hours post-exposure) precludes use of strategic storage and distribution models.

States are responsible for determining how KI is going to be used within their jurisdiction based on their unique situations and circumstances. States have generally different distribution plans. Dr. Adela Salame-Alfie, acting director, Division of Environmental Health Investigations, New York State Department of Health, and member of the symposium organizing committee, provided a state's perspective about the process of deciding whether to distribute KI to its population.

When the KI distribution policy changed in 2001 to make it available to the general public, New York State assembled a radiation advisory committee tasked with assessing whether information that was available from the

Chernobyl accident supported the distribution of KI to the general population. That committee concluded that the benefits of distributing KI to the public far outweighed the risk and recommended making KI available to the public. New York State then convened a multidisciplinary group to focus on implementation of KI distribution including instructions on when to take KI and how to administer it to children and outreach, education, and communication issues related to KI distribution. This group included representatives from state and local health agencies, emergency management organizations, state education department, the board of pharmacy, and the nuclear utilities.

Dr. Salame-Alfie described some of the implementation considerations of KI distribution that her state faced at the time, particularly relevant to distribution in daycare settings: KI was only available in 130 mg tablets which are not the FDA-recommended dose for children. Therefore, to enable the distribution of tablets to children, the Health Commissioner had to provide a letter to the State Education Department and the Office of Children and Family Services Commissioners stating that it was acceptable during emergencies to use one 130-mg dose for children. Since liquid KI was not available at the time, the state had to distribute instructions for pill crushing and mixing in their information sheets; they needed approval for nonnurses to dispense KI in school settings. Finally, they created an *opt out* form for those parents who did not want their children to receive KI in schools during an emergency.

New York State is a Home Rule State.[31] Consequently, approaches on how to make KI available may differ among jurisdictions within the state. For example, some counties within New York distribute KI through pharmacies or the grocery stores; other counties have designated *KI days* when members of the public can pick up KI from the county health department.

Dr. Salame-Alfie was asked to list the reasons why some states have opted out of the NRC's KI distribution program. These included:

- Cost of implementation, not just for the state but also for counties;
- Low population densities and short evacuation times for some EPZs;
- Concern that people may incur increased radiation dose from a radioactive plume if they assume that KI will protect them from all radiation; and
- Difficulty experienced by other states in maintaining and tracking previously distributed KI.

Medical Planning and Response

Dr. Albert Wiley, Jr., medical and technical director, REAC/TS and head, World Health Organization Collaborating Center at Oak Ridge, discussed medical planning and response to a nuclear reactor accident.

Except for the Chernobyl accident, the medical significance of radiation exposures to workers and the public from the other three major nuclear reactor accidents has been generally minimal. Nevertheless, the public and regulatory agencies insist on excellence in medical preparedness and response for these types of accidents. Medical preparedness and response for nuclear power plant incidents is needed for a spectrum of activities including using bioassays and other methods to reassure people that they are not at risk and providing medical care to acute radiation syndrome casualties.

Dr. Wiley discussed two lessons for medical planning and response from the Chernobyl accident:

1. Chernobyl responders died from poorly matched bone marrow and other stem cell transplants due to graft-versus-host disease. In response, a program was created, the C.W. Bill Young Cell Transplantation Program,[32] that among other things has resulted in national emergency plans to be implemented in case of a mass casualty incident that results in marrow-toxic injuries.
2. Measurements of genetic damage rate following exposure to radiation using methods such as chromosome painting using fluorescence in situ hybridization, in vivo somatic cell mutation assay which uses immunolabeling and flow cytometry, and electron paramagnetic resonance dosimetry with tooth enamel

[31] That means that cities, municipalities, and/or counties have the ability to pass laws to govern themselves as they see fit.
[32] See http://bloodcell.transplant.hrsa.gov/about/.

proved useful in assessing doses following the Chernobyl accident. Automated scoring of the results from the above-mentioned methods would be important for any event that results in a large number of casualties.

Dr. Wiley also discussed two lessons learned from the Fukushima Daiichi accident:

1. There is a need for training of medical and other responders on medical radiological preparedness and response. Medical centers both near and distant from the Fukushima Daiichi plant were unprepared to accept contaminated people.
2. There is a need for better guidance related to use of PAGs for evacuations of special populations such as the elderly and the hospitalized. Dr. Wiley reiterated the point made previously by Drs. Becker and Irwin that although there were no radiation-induced injuries or deaths during the Fukushima Daiichi accident, at least 60 elderly and hospitalized people died from lack of medical supportive care and basics such as food, water, and heat.

Population Monitoring

Dr. Armin Ansari, health physicist, Radiation Studies Branch, CDC, spoke about the early phase of the response to a nuclear reactor accident and population monitoring. He said that identifying people who are in need of immediate medical attention, irrespective of whether they have been exposed to radiation, takes precedence. Population monitoring of those who have been contaminated with radioactive materials or think that they have been exposed to radiation or radioactive materials starts as soon as possible.

Initial population monitoring activities are focused on preventing acute radiation health effects. Cross-contamination[33] is a secondary concern, especially when the contaminated area or affected population (i.e., a population that lives in an area or location that is contaminated) is large. The population to be screened includes the people in affected communities, service animals, and pets, with priority given to people and service animals. Populations need to be monitored for radioactive contamination, provided assistance with decontamination, and registered for subsequent follow-up and long-term health monitoring, if necessary. There is some importance in monitoring people who are unlikely to be contaminated because of their location at the time of the accident and provide them necessary reassurances. He emphasized that plans for population monitoring need to be *scalable* and *flexible*. For example, the criteria used for contamination screening and specific methods used for radiation detection may have to be adjusted to accommodate the magnitude of the incident and availability of resources.

Population monitoring is the responsibility of local government and engages multiple local government agencies including radiation control, public health, emergency management, and law enforcement. Population monitoring happens at community reception centers.[34] In Dr. Ansari's view, organizations within the United States with mass-care responsibilities such as FEMA, the American Red Cross, and state health departments are now beginning to realize the importance of planning for population monitoring. CDC, together with these organizations, is developing guidance on how to operate and organize public shelters for radiation emergencies, especially when resources such as staff and radiation detectors are limited.

Using as an example the displacement of people after Hurricane Katrina,[35] Dr. Ansari noted that people evacuated and displaced to other cities and communities following a nuclear reactor accident will likely be in need of monitoring for contamination, treatment of injuries and other immediate medical care, shelter and other health-

[33] CDC defines cross-contamination as "spreading of radioactive materials from one person, object, or place to another." See http://emergency.cdc.gov/radiation/pdf/population-monitoring-guide.pdf.

[34] Sites used for points of dispensing (PODs) may be used for community reception center operations. PODs are locations intended to distribute pharmaceuticals from the Strategic National Stockpile (SNS) during a public health emergency. Most public health jurisdictions in the country have a plan to set up PODs. Public health departments work with school districts and other organizations to identify facilities that can be used as PODs.

[35] Over 1 million people left New Orleans within 3 weeks after the city was flooded and were dispersed to all states of the United States. See http://www.nytimes.com/imagepages/2005/10/02/national/nationalspecial/20051002diaspora_graphic.html.

related services. "It does not matter where you live; you are going to be impacted by a major radiation incident regardless of where it happens in the country," Dr. Ansari said.

The burden of providing radiation screening and monitoring services is likely to fall on local organizations who host the displaced populations. As noted by Dr. Irwin, Vermont Department of Health, in his presentation, there is a concern that states without nuclear facilities may have little or no radiological emergency planning or training; he emphasized the need for such planning and training across the country.

Planning and training for a nuclear reactor accident is needed even for nuclear reactor accidents in other countries. Dr. Ansari noted that as population monitoring activities were occurring in Japan following the accident at the Fukushima Daiichi plant,[36] monitoring activities were also occurring in other countries, including the United States,[37] to deal with potentially contaminated passengers traveling from Japan. The CDC worked with state and local public health departments, the Conference of Radiation Control Program Directors (CRCPD), and U.S. Customs and Border Protection to develop protocols for dealing with contaminated travelers from Japan.[38]

The CDC recognizes the need to collect information on individuals for future contact. The agency has developed electronic tools for population monitoring that can be adapted by the state and local government agencies. However, the effectiveness of these tools has not been evaluated. Dr. Irwin, Vermont Department of Health, confirmed that different registration tools have been tested at community reception centers in Vermont. However, he does not expect that all members of the public will use those tools during an emergency, and so, subsequent outreach efforts may be needed.

Biodosimetry

Dr. William Blakely, senior scientist, Armed Forces Radiobiology Research Institute (AFRRI), focused his talk on early-phase biodosimetry methods for potential acute deterministic effects following radiation exposure. He said that biodosimetry information, together with medical diagnostic information for individuals suspected or known to have been exposed to ionizing radiation, can contribute to decisions related to medical treatment strategies and radiation protection management. In case of a nuclear reactor accident, the populations that would be most served by biodosimetry assessments are the power plant workers and accident responders because these groups are at risk of being exposed to the highest levels of radiation. On the other hand, the local population is likely to be exposed to doses that are typically below the limit of detection of most current biodosimetry assays.

Early-phase emergency response for a radiological accident involves a multiple-parameter biodosimetry diagnostic strategy,[39] since no single assay is sufficient to address all potential radiation scenarios including partial-body exposures. Dr. Blakely provided general guidance regarding biodosimetry actions needed in suspected radiation exposures:[40]

1. Measuring for radioactivity associated with the exposed individual;
2. Observing and recording early signs and symptoms;
3. Obtaining serial complete blood counts with white blood cell differential;

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[36] Kondo H., Shimada J., Tase C., Tominaga T., Tatsuzaki H., Akashi M., Tanigawa K., Iwasaki Y., Ono T., Ichihara M., Kohayagawa Y., Koido Y., 2013, Screening of residents following the Tokyo Electric Fukushima Daiichi nuclear power plant accident, Health Phys, 105 (1):11-20.

[37] Approximately 543,000 travelers arriving directly from Japan at 25 U.S. airports were screened between March 17 and April 30, 2011. See Wilson T., Chang A., Berro A., Still A., Brown C., Demma A., Nemhauser J., Martin C., Salame-Alfie A., Fisher-Tyler F., Smith L., Grady-Erickson O., Alvarado-Ramy F., Brunette G., Ansari A., McAdam D., Marano N., 2012, US screening of international travelers for radioactive contamination after the Japanese nuclear plant disaster in March 2011. Disaster Med Public Health Prep, 6(3):291-296.

[38] From the time of the accident on March 11, 2011, to end of April 2011, over half a million travelers arrived in the United States on a direct flight from Japan.

[39] Blakely W.F., 2002, Multiple parameter biodosimetry of exposed workers from the JCO criticality accident in Tokai-mura, J Radiol Prot 22(1):5-6.

[40] Blakely W.F., Salter C.A., Prasanna P.G., 2005, Health Phys 89(5):494-504; Waselenko J.K., MacVittie T.J., Blakely W.F., Pesik N., Wiley A.L., Dickerson W.E., Tsu H., Confer D.L., Coleman C.N., Seed T., Lowry P., Armitage J.O., Dainiak N., Strategic National Stockpile Radiation Working Group, 2004, Medical management of the acute radiation syndrome: Recommendations of the Strategic National Stockpile Radiation Working Group, Ann Intern Med, 140(12):1037-1051.

4. Sampling blood for the chromosome-aberration cytogenetic bioassay using dicentric assay or other suitable cytogenetic chromosome aberration assay for dose assessment;
5. Bioassay sampling from various sources (e.g., urine, blood, nasal samples), if appropriate, to determine radionuclide contamination;
6. Sampling blood for measurement of proteomic and gene-expression radiation-responsive biomarkers;
7. Sampling nail clippings for measurement of free radicals by electron paramagnetic resonance for dose assessment; and
8. Using other available dosimetry approaches.

To select the most appropriate biodosimetry method, one would need to consider factors such as time for analysis, costs, ability to assess severity of acute radiation syndrome, and dose or acute radiation syndrome response category level. When asked by a member of the audience how many biomarkers one needs to assess dose, Dr. Blakely responded that according to Ossetrova et al.,[41] one can use a minimum group of three biomarkers, but these change as a function of time after exposure. The reason they change, he added, is because different organs have different sensitivity to dose and time since exposure.

Dr. Blakely and his colleagues at AFRRI have been working on a diagnostic triage system for use in radiological mass-casualty incidents. This system needs to use rapid sentinel biodosimetry tests to prioritize casualties for subsequent confirmatory radiation injury, and also use dose diagnostic tests to develop guidance for medical management treatment decisions. He explained that readiness for a potential nuclear reactor accident relies on local capability which needs to be broadly based and include:

1. Access to radiation detection devices,
2. Stockpiling of supply materials and protocols for appropriate biosampling, and
3. Stockpiling of reagents and devices for sample analysis.

Recording dynamic medical and other radiologically relevant data to support dose reconstruction is an important component of an effective response to a suspected radiation exposure incident. Ideally, one would want to provide first responders a smart tool that can assist with assessment of dose by weighting the various parameters. Dr. Blakely described AFRRI's WinFRAT (First-Responders Radiological Assessment Triage for Windows),[42] which is intended for use by radiological and nuclear emergency response professionals to assess and record medical information from a suspected radiation event.

At present, Dr. Blakely said, FDA has not approved any biodosimetry devices. However, the nation's response to the September 11, 2001, terrorist attacks has prompted a renaissance of biodosimetry research activities to develop point-of-care and laboratory biodosimetry devices to enhance response capability. Research focusing on early and rapid assessment of partial-body exposures is needed to inform early-phase medical management treatment decisions. Dr. Blakely called for strategies and funding to establish and sustain functional national and global networks of expert reference laboratories to perform dose assessments.

INTERMEDIATE- AND LATE-PHASE RESPONSE TO A NUCLEAR REACTOR ACCIDENT

During the intermediate and late phases of an accident, there is typically more time to plan the response and analyze the options. Still, according to the symposium presenters, activities conducted during these phases that include planning for long-term follow-up and health risk studies and transition to recovery need to start as soon as possible. Discussants also noted that stakeholder participation is crucial for the conduct of these activities.

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[41] Ossetrova N.I., Sandgren D.J., Blakely W.F., 2014, Protein biomarkers for enhancement of radiation dose and injury assessment in nonhuman primate total-body irradiation model, Radiat Prot Dosimetry, 159(1-4):61-76.
[42] http://www.usuhs.edu/afrri/outreach/pdf/WinFRATbrochure.pdf.

Planning for Long-Term Follow-Up and Health Risk Studies

Dr. Martha Linet, chief, Radiation Epidemiology Branch, NCI, and symposium organizing committee chair, described planning for long-term follow-up and health risk studies. She noted that despite the extensive literature on late health effects associated with radiation disasters from over 60 years of studies of Japanese atomic bomb survivors and 20 years of studies of persons exposed to radiation from the Chernobyl nuclear accident, many important questions remain about health effects (cancer and other diseases) following a nuclear incident.

Dr. Linet identified three reasons for conducting long-term follow-up studies of persons exposed to radiation from a nuclear reactor accident:

1. Address concerns of exposed populations and general societal anxiety;
2. Provide important clinical and public health information; and
3. Contribute to understanding of effects of low-dose radiation exposures.

She discussed two major types of long-term follow-up studies that can provide some quantification of risk following a nuclear reactor accident: epidemiological studies and risk-projection studies.

Risk-projection studies have been carried out for some nuclear accidents and other radiation incidents to estimate the number of persons in a population who are expected to develop an adverse health effect such as cancer as a result of radiation exposure. Risk is estimated using information from previous epidemiological studies and is usually expressed in terms of adverse health effects above a baseline rate. Risk projection studies can be useful to estimate the types and numbers of adverse health effects.

High-quality, comprehensive, long-term follow-up studies after a nuclear reactor accident may be difficult to carry out because of concurrent events such as the earthquake and tsunami associated with the Fukushima Daiichi accident. Dr. Linet noted that it took investigators over 10 years to plan the first long-term study of health effects from the Chernobyl accident. Delays can affect the quality of the studies because memories of the event fade, and so, interviews become less reliable. Also, people are more likely to move, making it more difficult for investigators to track and interview the affected populations.

There are many reasons to prepare and plan for long-term follow-up of populations and workers exposed to radiation from severe nuclear reactor accidents. Dr. Linet listed the following key requirements for conducting such studies:

- Large exposed population;
- Wide range of radiation exposures within the population;
- Well-vetted study protocol with major scientific and stakeholder input;
- High level of identification of the exposed population, with special attention to subgroups that have been disproportionately affected by radiation exposure;[43]
- Very high follow-up rates or participation levels;
- Complete ascertainment of disease outcomes of interest;
- High-quality radiation exposure assessment undertaken soon after the accident; and
- Minimization of bias and confounding.

Dr. Linet argued that if the above-mentioned key requirements are not met, epidemiologic studies are unlikely to provide meaningful results. In particular, they would have inadequate statistical power to estimate risks for rare outcomes or detect small risks, and results may reflect bias or confounding. She recognized that even if the requirements are not met, such studies may be undertaken because of public pressure.

Some of the scientific and logistical considerations associated with conducting long-term follow-up studies are summarized in Table 2.

[43] For example, children and fetuses in utero, pregnant and lactating women, patients with medical disorders associated with greater sensitivity to radiation, seriously ill or immunosuppressed patients, and the elderly.

TABLE 2 Key Considerations in Launching a Long-Term Follow-up Study

Scientific	
	How to quickly and completely identify and recruit population
	Identify which outcomes to study
	Identify and validate outcomes
	Methods to be used for exposure assessment
	How to maximize participation and retain participation in long-term follow-up
	Strategies for evaluating potential confounders
Ethical, Funding, Logistical	
	Developing a protocol; obtaining scientific and stakeholder input
	Institutional review board (IRB) approvals; informed consent (explaining benefits and risks)
	Obtaining funding for a long-term follow-up and need for firewall between funders and study team
	Length of time to develop protocol, obtain approvals, identify population, and conduct study
	Communications with stakeholders

Post-Emergency Transition to Recovery

Dr. Irwin noted that reactor emergency exercises are heavily weighted to test decisions on early-phase protective actions such as evacuation and sheltering in place. On the other hand, exercises to test preparedness for long-term consequences and recovery of affected areas occur only every 8 years.[44] He noted that the Fukushima Daiichi accident demonstrated that the highest costs for emergencies are incurred for long-term recovery.

Ms. Gerilee Bennett, FEMA, noted that there are federal efforts to incorporate lessons from the Fukushima Daiichi accident into the ongoing update of the Nuclear Radiological Incident Annex to the Federal Interagency Operational Plan. The updated Annex, previously appended to the National Response Framework (NRF), will support both the NRF as well as the National Disaster Recovery Framework.

Ms. Bennett noted that although individuals have a right to self-determination, it is important to support government decisions that promote community cohesiveness. She also noted that the national plans are a general framework of support, and the actual plan for recovery has to happen at the local level.

Three long-term effects of a nuclear reactor accident were discussed by the panelists: relocation,[45] reentry, and reoccupancy. The term reentry is used for emergency workers and members of the public entering contaminated areas temporarily and under controlled conditions to perform critical infrastructure and lifesaving work to protect the community. Reoccupancy occurs when people are allowed to permanently reenter previously evacuated areas. Relocation and reentry may occur during the intermediate phase of a nuclear reactor accident. Reoccupancy (together with cleanup discussed by Dr. S.Y. Chen, director, Professional Health Physics Program, Illinois Institute of Technology) may occur during the late phase of an accident. Ms. Sara DeCair described EPA's 2013 Draft PAG manual guidance[46] for these three activities.

Ms. DeCair noted that considerations for selection of PAGs for relocation differ from those from early-phase protective actions such as evacuation and sheltering in place primarily with regard to implementation factors. Specifically, she said, they differ with regard to the costs of avoiding radiation exposure, the practicability of leaving infirm persons and prisoners in the affected area, and avoiding radiation exposure to fetuses. She noted that alternatives to relocation include decontamination and shielding.

[44] Liberty RadEx was mentioned by a number of symposium presenters as an informative national exercise to practice and test federal, state, and local assessment and cleanup capabilities in the aftermath of a dirty bomb. See http://www.epa.gov/sciencematters/june2010/scinews_liberty.htm.

[45] See Chapter 1 for definition.

[46] http://www.epa.gov/radiation/docs/er/pag-manual-interim-public-comment-4-2-2013.pdf.

Regarding reentry, EPA's 2013 Draft PAG manual provides guidance related to dose-based limits, time frames, and pathways of exposure related to reentry tasks as well as food and agriculture guides.[47]

Regarding reoccupancy during cleanup operations, Ms. DeCair noted that the experience in Japan following the Fukushima Daiichi accident has shown that it is difficult to determine when the time is right for a population to move back to a contaminated area. In a very large radiological incident, achieving final cleanup goals will undoubtedly take a long time and will depend on the community agreeing what the cleanup goal is. EPA's 2013 Draft PAG manual does not set community-specific cleanup levels beforehand. Instead, it states: "Although it may take years to achieve the final cleanup goals for all land uses, reoccupancy of the affected area will be possible when interim cleanup can reduce short-term exposures to acceptable levels."

Dr. S.Y. Chen,[48] Illinois Institute of Technology, echoed Ms. DeCair's comments, noting that to date there is no experience within the United States or elsewhere on how to clean up large contaminated areas. In Fukushima the size of the contaminated area is 13,000 km^2 if the long-term cleanup goal of additional individual dose is 1 mSv/year.[49] Such a cleanup goal has generated an enormous amount of radioactive waste, estimated to be 29×10^6 m^3, or about 1 billion ft^3.[50] This radioactive waste volume exceeds the commercial low-level waste disposal capacities within the United States, he said.

International radiation protection agencies such as the International Commission on Radiological Protection (ICRP)[51] advocate for the principle of *optimization* when it comes to setting cleanup criteria for wide-area contamination. Optimization is a departure from the conventional approach used for cleanup of contaminated sites or decommissioning of nuclear facilities that is based on risk or dose criteria related to long-term health effects. Using an optimization approach, after restoration of critical infrastructure, economic conditions can be considered in prioritizing the restoration of commercial interests. The recovery is community focused. For stakeholders to have meaningful participation, decisions cannot be made beforehand, although guidance for the decision making can be formulated. Dr. Chen called for timely development of guidance on the late-phase optimization process, preferably well before any future nuclear incident. He referred to NCRP Report 157[52] for a discussion of elements of an effective optimization process. He reiterated that engagement with stakeholders is fundamental to decision making during late-phase recovery.

COMMUNICATIONS

The symposium organizing committee invited nine experts representing the Office of the President, six federal agencies, the states, and news media to provide comments on communications during a nuclear reactor accident. The presenters offered their comments and shared experiences for different aspects of communications related to the U.S. response to the Fukushima Daiichi accident: Interagency communication and coordination in response to an international event; interagency communications in the United States; communications between states and the federal government; communications with the public, and communications with the media. For clarity of the presenters' messages, the following summary is organized by these different communication topics.

[47] The guidance was informed by the operational guidelines developed by federal agencies and published in draft form by DOE in February 2009 (DOE/HS-0001, ANL/EVS/TM/09-1), available online at http://ogcms.energy.gov/review.html; and the FRMAC Assessment Manual, Overview and Methods, available online at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

[48] Dr. Chen spoke at the symposium in his capacity as chair of the National Council on Radiation Protection and Measurements' (NCRP's) scientific committee that authored a report to be published as NCRP Report 175, titled Decision Making for Late-Phase Recovery from Nuclear or Radiological Incidents.

[49] Follow-up International Atomic Energy Agency (IAEA) International Mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Daiichi Nuclear Power Plant, held October 14-21, 2013.

[50] Follow-up International Atomic Energy Agency (IAEA) International Mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Daiichi Nuclear Power Plant, held on 14 to 21 October 2013.

[51] ICRP, 2009, Application of the Commission's Recommendations to the Protection of People Living in Long-Term Contaminated Areas After a Nuclear Accident or a Radiation Emergency, ICRP Publication 111, Ann. ICRP 39(3).

[52] NCRP, 2007, Radiation Protection in Educational Institutions, NCRP Report No. 157, Bethesda, MD: NCRP.

Interagency Communication and Coordination in Response to an International Event

The Fukushima Daiichi accident was the first experience for the U.S. government in responding to a large-scale nuclear reactor accident. The U.S. involvement in responding to this accident went beyond humanitarian assistance[53] that it typically provides to countries on request. It also included *technical assistance* involving specialized equipment and expertise. Major General Julie Bentz, director, Strategic Capabilities Policy on the National Security Staff, Office of the President, described the context for the U.S. government response to the Fukushima Daiichi accident, which was to:

1. Provide assistance to Japan as an ally nation;
2. Safeguard the well-being of U.S. citizens who were visiting or were relocated to Japan;
3. Safeguard the well-being of the homeland, for example, the safety of populations in Hawaii, Alaska, and the West Coast that are geographically nearest to Japan;
4. Protect U.S. critical infrastructure in Japan such as U.S. military bases and equipment; and
5. Protect economic assets in Japan and materials coming into the United States through trade.

Major General Bentz commented on the challenges that the U.S. government faced in providing *technical assistance*. These challenges highlighted some lessons learned for the United States to improve its response coordination for future chemical, biological, radiological, or nuclear (CBRN) emergencies that occur abroad.

First, there was no framework to guide the U.S. response to an international event and determine a federal agency to lead the response. Roles and authorities were adapted from the NRF which is used in domestic emergency management[54] or created ad hoc to meet the response needs. There were three federal agencies with statutory authority: the U.S. Department of State, which is concerned with foreign affairs and Americans abroad; DoD, because U.S. assets were stationed at a U.S. military base in Japan awaiting a formal request for assistance from the Japanese government; and DHS, which has the overall responsibility for coordinating the response to states in need. An immediate challenge was how to prioritize and share assets among these three federal agencies. Also, since these federal agencies had their own lines of communication and information-sharing mechanisms with Japanese counterparts, how to centralize the information received and achieve a joint response was another challenge.

Second, there was lack of a plan for coordination of *technical* expertise and resources to address radiological hazards within Japan. Interagency coordination efforts occurred within the U.S. Embassy in Tokyo and the White House National Security Staff in Washington, D.C. However, coordination was difficult because the agencies and their representatives were unclear about their roles and those of partner agencies. Dr. Steven Simon, NCI, who had been dispatched to the U.S. Embassy in Tokyo during the Fukushima Daiichi accident to serve as an HHS technical expert in radiation dose and risk, commented that he did not always have the information or equipment that he needed. He was told that the radiation monitoring information (collected by NNSA) needed to predict dose to the populations belonged to the Japanese and he could not access it. He was told that his expert opinions would need to be vetted through quality control systems. Moreover, his own understanding of his authority was vague and undefined. "Who was supposed to be telling who what? Did I really have the authority to say you are *safe*, you are not safe, or I don't know?" Dr. Simon hoped that the roles and authorities would be better defined in the future. Dr. Blumenthal, speaking from the perspective of an expert who was deployed to Japan to provide environmental monitoring information during the accident, noted that it was a challenge to prioritize who to answer first: the U.S. Ambassador to Japan, the United States Forces Japan Commander, or the White House.

There appeared to be similar confusion in the United States about the roles of the agencies and agency staff in providing advice. Dr. Linet, NCI, shared her experience in responding to requests for information about the

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[53] Major Jama VanHorne-Sealy, director, Radiation Safety, Uniformed Services University of the Health Sciences, described in some detail the U.S. military's' support of Japan's disaster response through Operation Tomodachi. The U.S. military provides in-country support to the government of Japan, in accordance with the 1945 World War II agreement.

[54] Mr. James McIntyre, director, Disaster Operations, Cadre Management and Training, FEMA, outlined the NRF. He did not, however, talk about any considerations for changes to the framework to describe roles and authorities of the federal agencies in response to an international event.

accident from the media and members of the public. She was not informed at the time of the accident about who within the federal government was responsible for providing this type of information.

Third, there were no funding mechanisms in place for providing *technical assistance* to Japan. Major General Bentz reiterated that the U.S. response to the Fukushima Daiichi accident was beyond the traditional humanitarian assistance for which funding mechanisms exist.

Ms. Patricia Milligan, NRC, provided a perspective on the lack of a framework for guiding the U.S. response to the Fukushima nuclear accident. During the accident, the NRC was trying to determine its role and authority for providing assistance. Federal and state colleagues and other stakeholders were depending on the NRC for information. If a nuclear reactor accident occurred within the United States, NRC staff would report to preassigned duty stations at the headquarters operations center and NRC regional emergency response centers as appropriate. The NRC would use its staff and resources to provide expert consultation, support, and assistance to the state and local authorities. NRC's response actions would include:

- Assessment of plant conditions,[55]
- Evaluation of protective action recommendations,
- Support for offsite officials related to plume dispersion and dose assessment calculations,
- Coordination with federal partners for producing and disseminating predictions of the effects from radiological releases, and
- Communication with the news media about NRC actions.

The NRC's response to the accident was 24/7 for 9 weeks. During this period, the NRC provided ongoing assessments of radiological conditions, dose predictions, and protective action recommendations for U.S. citizens located in the United States and Japan. The agency also provided technical assistance to the U.S. Ambassador to Japan and to the Japanese government, when requested. Ms. Milligan noted that her agency did not have access to information related to conditions at the Fukushima Daiichi plant, which made it difficult to carry out some actions.

Ms. Milligan also spoke about the NRC's March 16, 2011 recommendation to the State Department that U.S. citizens located within 80 kilometers of the Fukushima Daiichi plant should evacuate because of concerns that the accident could worsen. She noted that the State Department routinely issues warnings and advice to U.S. nationals traveling abroad and this recommendation was issued under the same framework.[56]

Ms. Milligan named a few actions that the NRC has taken since the accident to improve its communication. These included:

1. Establishment of dedicated technical staff to provide periodic updates to state and local officials,
2. Establishment of a public incident call center to handle high call volumes and ensure that the public received information as quickly as possible, and
3. Revised procedures to enhance NRC's ability to share sensitive information with state and local authorities.

Ms. Milligan mentioned that several federal interagency initiatives are under way to develop the necessary protocols for responding to international events. She did not provide details.

Interagency Communications Within the United States

Ms. Lee Veal, director, Center for Radiological Emergency Management, Radiation Protection Division, EPA, spoke about the difficulties and importance of good communications among government agencies. She also discussed her experience at EPA during the accident. She noted that EPA's role in responding to a domestic or an international accident is to collect data on radiation levels in air, drinking water, and milk in the United States.

[55] A major source of information for the NRC's assessment during a domestic incident is the Emergency Response Data System which automatically transmits information on certain plant parameters to the NRC and state governments.

[56] Several countries, including France, Italy, Germany, Canada, and Australia, recommended to their citizens that they evacuate from Japan.

She noted that it is almost certain that any significant release of radioactive material will be detectable throughout the hemisphere by national monitoring programs. The challenge of conveying the meaning of these technical monitoring data deserves special attention.

Ms. Veal noted that during the accident, there were extensive internal and external communications at EPA. These included leadership briefings, updates for congressional staff and members, and communications among scientific experts who advise federal, state, tribal, and local officials representing health, environmental, and emergency response communities. Information provided to these officials needed to be consistent, and the relative timing, scope, and level of details needed to be tailored to individual needs. These types of communications demand significant resources. To facilitate communications it is important to know the federal, state, tribal, and local partners' capabilities and organizational structure.

Communicating information such as technical radiation data across agencies with staff having varying expertise is a particular challenge. A further complication is the demand for transparency and the expectation of quick and broad access to information. It is important, as early in a response as possible, to explain that data collection, analysis, and interpretation take time—otherwise, Ms. Veal said, lag time in providing information can be seen as a tactic to delay or cover up. It is also important to explain how soon data will become available, how it will be vetted, and how it will be shared with various stakeholders. Ms. Veal encouraged members of the audience with emergency response responsibilities to work closely with the communication professionals in their agencies to develop appropriate communication materials.

Communication Between States and the Federal Government

During the Fukushima Daiichi accident, members of the public in the United States turned to public health and other state departments for information and advice. However, some have claimed[57] that the NRF was not followed during the accident. As a result, states did not have timely access to information and were therefore unable to communicate public health messages to their residents effectively. Ms. Veal, EPA, noted that when the Fukushima accident was unfolding, she would call a state official and say "in 5 minutes we are putting on the Web that we are seeing radiation in milk in your state." She agreed that this procedure was not ideal but that was all EPA could do under the circumstances. She recognized that EPA's communications with the states need to be improved.

The response to the accident provided insights on the gaps that currently exist in the United States on integrating data from a variety of sources into a single comprehensive repository for analysis and decision making. Dr. Salame-Alfie, New York State Department of Health, talked about a partnership among nine states,[58] which is being coordinated by the CRCPD with support from the EPA and in collaboration with FEMA, DOE, and NRC, to overcome data integration issues in the future. The partnership resulted in a task force for Interagency Environmental Data Sharing and Communication. The partnership has five main charges:

- Evaluate current data collection efforts of state and federal programs to
  - Identify availability of data currently collected,
  - Identify data gaps, and
  - Identify quality assurance procedures used to ensure data quality;
- Develop automated channels for access to environmental data;
- Formalize manageable policies to guide data collection and communication activities in coordination with CRCPD and EPA leadership;
- Ensure that monitoring methods and quality assurance procedures are packaged with the data in easily accessible form; and
- Assess training gaps and the need for tools to launch this initiative.

[57] Salame-Alfie A., Mulligan P., Fisher-Tyler F., McBurney R., Fordham E., 2012, Fukushima disaster response—the states' perspective, Health Phys 102(5):580-583.

[58] California, Delaware, Hawaii, Illinois, New Jersey, New York, Oregon, Vermont, and Washington.

The task force is focusing on expanding a pilot project initiated by the New Jersey Department of Environmental Protection involving an improved method to share New Jersey's nuclear power plant data among state agencies for the purposes of decision making and protection of public health and the environment. The task force is also working on a pilot project to upload and share environmental data among several states.[59] Dr. Salame-Alfie mentioned a national drill that was planned to be held in summer 2014 (a few months after this symposium took place) to test whether data integration occurs smoothly.[60]

Communication with the Public

Several speakers and participants noted that if an accident occurs at a nuclear reactor, whether in the United States or in another country, there will be public concern no matter how far away or how limited the expected health consequences might be. The general public's fear of radiation magnifies that interest. The fact that units and concepts associated with radiation are unfamiliar to almost everyone but specialists makes communicating radiation-related messages challenging. The fact that information, at least in the first critical hours and days of an accident, is uncertain or incomplete is another challenge for communication. During the Fukushima Daiichi accident federal agencies and scientific societies received an enormous volume of calls and Web inquiries from members of the public who wanted information. Successfully responding to these requests requires resources, for example, staff for answering these inquiries and language resources for non-English speakers.

A crucial task for the communicators is to provide clear and consistent messages to the public. Inconsistencies in the messages from the different authoritative sources may lead to public distrust and actions other than those recommended by authorities. Ms. Leeanna Allen, health communications fellow, Radiation Studies Branch, CDC, spoke about her agency's efforts to communicate information about radiation health effects and emergency instructions under different situations. These efforts were informed by research with public and professional audiences as well as past radiation emergencies. When asked by a member of the audience about the methods that CDC uses for its research, Ms. Allen noted that CDC assembles focus groups to develop and test different messages (e.g., protective action messages and health messages). The messages are tested for appropriateness and relevance in different cities, cultures, and languages.

Ms. Allen said that in a nuclear reactor accident, people want to know what to do to protect themselves and their families. They may have questions about KI. Special populations such as pregnant women and nursing mothers will have unique health concerns. Many medical and public health professionals will have the same questions and concerns as the public. Travelers may have concerns about their health following an international incident. CDC will work with state and local partners to communicate information about population monitoring efforts and health registries. CDC will also communicate information to the public health and medical communities about risks, screenings, and treatments using a variety of tools and channels, including traditional and social media.

A key communication channel for CDC is the radiation emergencies website (http://emergency.cdc.gov/radiation) which provides information about radiation emergencies and information on protective actions that people can take. This website uses icons and graphics to explain technical concepts. The content has been tested with the public to ensure that it is comprehensible, credible, and can motivate the desired actions.

Two symposium presenters discussed the sensitivities of communicating *risk* and *safety* issues related to radiation with members of the public. Ms. Allen's experience is that people want to define their own *acceptable* risk based on information they receive; they do not want their acceptable risk to be defined by someone else. Ms. Veal noted that her agency stays away from describing something as *safe*. Yet, a number of symposium participants who were involved in the U.S. response to the Fukushima Daiichi accident, including Drs. Steven Simon and Norman Coleman, NCI, commented that the public wants to know whether it is *safe* to drink the water, whether it is *safe* to drink the milk, and whether it is *safe* to live in the area.

[59] When asked by a member of the audience about the format for data sharing, Dr. Salame-Alfie responded that the data format has not yet been decided.

[60] The following document provides some information on the drill: Salame-Alfie A., 2014, Nationwide background radiation drill is no longer a dream, CRCPD NewsBrief, pp. 7-10, http://www.crcpd.org/Pubs/Nsbf/August%202014%20NB%208-28-14.pdf.

Communication with the News Media

Mr. Miles O'Brien, science correspondent, PBS NewsHour, delivered an annotated presentation that contained various video clips of news broadcasters and on-the-scene reporters covering the Fukushima Daiichi accident. They provided messages to the public that were in some cases uninformed and inaccurate, likely the result of their own lack of understanding of nuclear accidents and radiation health effects. But it was not only media persons who delivered such messages. Mr. O'Brien showed a video clip of the U.S. Surgeon General's office issuing a statement indicating that it was appropriate for West Coast residents to take KI despite the fact that radioactive material releases from the Fukushima Daiichi plant did not result in doses to the populations in the United States that would require consumption of KI.

Mr. O'Brien's bottom-line message was that newsrooms are filled with individuals who do not have scientific backgrounds. So when it comes to stories about highly complex subjects such as nuclear accidents and radiation health effects, it should be no surprise that the facts are seldom allowed to get in the way of a good story. Mr. O'Brien suggested to those with emergency management responsibilities that they engage with the media in advance rather than waiting to introduce complicated radiation concepts at the time of an emergency. This is the only way, in his view, to make sure that when an emergency does happen, news media representatives will contact the experts with whom they have already established relationships to get information. He also encouraged those scientists with the ability to communicate effectively to develop a public presence and communicate their knowledge to the public using YouTube or other means. This will help these scientists to become credible *faces and voices* so that they will be contacted in crisis.

CLOSING REMARKS

Symposium organizing committee chair, Dr. Martha Linet, NCI, thanked the speakers and symposium participants for sharing their experiences. She stated that sharing of the lessons learned related to communications was a great first step for improving capabilities and effectiveness of communications. She expressed her hope that the discussion started at the symposium will continue so that agencies build familiarity with each other's roles, capabilities, and procedures and are able to perform better in the next emergency.

SUMMARY OF CURRENT CHALLENGES IN RESPONDING TO A NUCLEAR REACTOR ACCIDENT

During the symposium speakers and participants identified several challenges of responding to a nuclear reactor accident that, according to some, if addressed effectively, may better prepare the United States for responding to a future nuclear reactor accident. These challenges are outlined here in four themes.

Theme 1: Lack of evidence-based science related to nuclear reactor accident response measures and risk reduction. Several symposium speakers noted that a key principle for an improved emergency response to a nuclear reactor accident is incorporating evidence-based science in the accident's impact assessments. According to these symposium speakers, incorporating evidence-based science in emergency response could better prepare the nation in responding to the immediate and long-term physical, mental, and broader societal effects of an accident; inform protective action guides and training of the responders; and improve communications.

Two approaches for incorporating evidence-based science in emergency response were discussed:

1. Performing a systematic analysis of radiation-related accidents and associated research conducted in the past and
2. Developing mechanisms to conduct research during an emergency.

Both approaches could help facilitate an effective response during the next emergency.

Theme 2: Nuclear reactor accident response plans are also needed in regions that are not immediately impacted by the accident. A number of symposium speakers noted that for any significant nuclear reactor accident, no matter how far away or how limited the expected health consequences, there will be widespread public concern and political and media interest nationally and internationally. The need for response plans in regions likely to be impacted directly by a nuclear reactor accident is obvious. Symposium speakers discussed two main reasons why regions not immediately impacted by a nuclear reactor accident also need to have response plans:

1. Populations will likely request information from emergency response organizations to be reassured that their region is *safe*.
2. Communities might host populations that evacuated from the affected areas and need to provide shelter, medical assistance, decontamination, and other support. In addition, these communities may receive or be asked to receive products exported from the affected areas.

A symposium participant emphasized that response plans need to be *scalable* and *flexible* according to the nature of the accident and the number of people affected and be adaptable to changes.

Theme 3: Need for formal integration of the different information capabilities into a nuclear reactor accident response. Using emergency environmental monitoring as an example, a few symposium speakers noted that there are various sources for real-time information. This information comes from the nuclear industry, federal and state governments, nongovernmental organizations, and residents of communities affected by a nuclear reactor accident. Some symposium participants noted that there is no centralized system for formal integration of information from these multiple sources into a single comprehensive repository for analysis and decision making. According to some participants, such an integrated system with appropriate quality checks on the reliability of the information is needed to provide confidence in the information and allow for effective information exchange during an emergency.

Theme 4: Need to improve communication and coordination. Regarding communication, a number of the symposium speakers commented that the Fukushima Daiichi accident revealed vulnerabilities in communication in response to an international event; interagency communication; communications between federal agencies and the state, with the public, and with the news media. Several symposium participants noted that demand for information and transparency has grown significantly and that people expect quick and broad access to data and information.

Regarding coordination, various participants discussed the lack of clear roles and responsibilities of the different U.S. agencies in providing *technical assistance* to an international nuclear reactor accident. Also, some participants discussed difficulties in coordinating a response to an international event when there was no framework to guide that response in terms of integrating assets, assessing information on radioactive releases, drawing conclusions about *safety*, and systematically providing the information within agencies and to the general public.

Individual speakers and discussants noted that nuclear reactor accidents share some common characteristics with other radiological emergencies and more broadly with other types of disasters. Therefore, in their view, the themes outlined above are relevant for responses to other types and scales of emergencies and are not restricted to responses to nuclear reactor accidents.

Appendix A

Symposium Agenda

8:00 AM **Call to Order and Welcome**
Kevin D. Crowley, National Academy of Sciences

8:05 AM **Past Nuclear Reactor Accidents: Where? When? Why?**
Steven L. Simon, National Cancer Institute

8:20 AM **Emergency Response Research Needs**
Nicole Lurie, Department of Health and Human Services

SESSION 1 HEALTH AND OTHER EFFECTS
Moderated by Martha S. Linet, committee chair

8:40 AM **Physical Health Effects**
Alina V. Brenner, National Cancer Institute

9:05 AM **Social, Psychological and Behavioral Impacts**
Steven M. Becker, Old Dominion University College of Health Sciences

9:30 AM **Session 1 Discussion**

9:50 AM **BREAK**

SESSION 2 EMERGENCY RESPONSE: Part 1 Management of Health Effects
Moderated by Steven L. Simon, committee member

10:05 AM Emergency Biodosimetry
William F. Blakely, Armed Forces Radiobiology Research Institute/Uniformed Services University of the Health Sciences

10:25 AM Some Lessons Learned Regarding Medical Preparedness and Response from Several Types of Nuclear Power Plant Accidents
Albert L. Wiley, Jr., REAC/TS and WHO Collaborating Center at Oak Ridge

10:45 AM Potassium Iodide – Mechanism of Action
Jan Wolff, National Institutes of Health (retired)

11:05 AM Issues in Planning for Potassium Iodide Distribution
Patricia A. Milligan, Nuclear Regulatory Commission
Steven A. Adams, Centers for Disease Control and Prevention
Brad Leissa, Food and Drug Administration
Adela Salame-Alfie, New York State Department of Health

11:40 AM Session 2 Part 1 Discussion

12:10 PM LUNCH (Available for purchase at the refectory—3rd floor)

SESSION 2 EMERGENCY RESPONSE: Part 2 Protective Measures
Moderated by Adela Salame-Alfie, committee member

1:00 PM Environmental Radiation Measurements
Daniel J. Blumenthal, Department of Energy

1:20 PM Population Monitoring after a Radiation Emergency: The Early Response
Armin Ansari, Centers for Disease Control and Prevention

1:40 PM Planning for Long-Term Follow-Up and Health Risk Studies
Martha S. Linet, National Cancer Institute

2:00 PM Post Emergency Transition to Recovery
William E. Irwin, Vermont Department of Health
Gerilee W. Bennett, Federal Emergency Management Agency
Sara D. DeCair, Environmental Protection Agency
S.Y. Chen, Illinois Institute of Technology

2:40 PM Session 2 Part 2 Discussion

3:00 PM BREAK

SESSION 3: COMMUNICATIONS
Moderated by Jerome S. Puskin, committee member

3:15 PM **The Federal Response; Lessons Learned from Fukushima**
Major General Julie A. Bentz, National Security Staff, Office of the President

3:30 PM **Environmental Data Sharing During Radiological Emergencies: A Collaboration Effort between Local, State and Federal Radiation Programs**
Adela Salame-Alfie, New York State Department of Health

3:45 PM **Media Meltdown**
Miles O'Brien, PBS NewsHour

4:00 PM **Communication in Nuclear Emergency**
James McIntyre, Federal Emergency Management Agency
Patricia A. Milligan, Nuclear Regulatory Commission
Lee Ann B. Veal, Environmental Protection Agency
Daniel J. Blumenthal, Department of Energy
Leeanna Allen, Centers for Disease Control and Prevention
Major Jama VanHorne-Sealy, Uniformed Services University of the Health Sciences

5:00 PM **Session 3 Discussion**

5:40 PM **Final Remarks**
Organizing committee

5:45 PM **Adjourn Symposium**

Appendix B

Biographical Information on Symposium Speakers and Session Moderators

Steven A. Adams has served as the deputy director of the U.S. Strategic National Stockpile Program located within Department of Health and Human Service's Centers for Disease Control and Prevention (CDC) from the time of its inception in 1999. As such, he has been intimately involved with the development and evolution of the national doctrine for response to a public health crisis and directly engaged with state and local authorities in the planning and implementation of the civilian medical response to large-scale public health emergencies. His extensive interagency planning and coordination efforts include membership on the U.S. Department of Agriculture National Veterinary Stockpile's formal advisory committee. In addition to programmatic leadership, Mr. Adams has managed large-scale emergency responses and led rapid field deployment teams.

Mr. Adams has served CDC in a variety of leadership roles for 25 years in contingency response programs as well as public health efforts as varied as HIV field epidemiology and radiological dose reconstruction related to cold war–era nuclear weapons production. He holds a master's degree in public health from the University of North Carolina at Chapel Hill.

Leeanna Allen, M.P.H., M.C.H.E.S., is a health communications fellow with the Radiation Studies Branch (RSB) at the Centers for Disease Control and Prevention. Since 2008, she has worked on radiological and nuclear terrorism preparedness communication initiatives, research, and products for RSB. During the 2011 Japan Earthquake and Tsunami Response, she served as the subject-matter expert in the CDC Joint Information Center. Ms. Allen received her B.S. from the Georgia Institute of Technology, and her M.P.H. from Emory University. She has previously served as training and exercise coordinator in the hospital preparedness program for the Georgia Division of Public Health, and also as an emergency risk communicator and health educator for the Arizona Department of Health Services.

Armin Ansari is a health physicist at the Centers for Disease Control and Prevention, the lead author of the CDC guide for state and local public health planners on population monitoring, and a contributing author to the federal planning guidance for response to a nuclear detonation. He is also an adjunct associate professor of nuclear and radiological engineering at Georgia Institute of Technology, and author of the textbook *Radiation Threats and Your Safety: A Guide to Preparation and Response for Professionals and Community.* Dr. Ansari earned his B.S. and Ph.D. degrees in radiation biophysics from the University of Kansas, starting his career as a radiation biologist, and did his postdoctoral research at Oak Ridge and Los Alamos National Laboratories. He is certified in comprehensive practice by the American Board of Health Physics and is the past president of the Health Physics Society.

John S. Applegate, J.D., is executive vice president for university academic affairs of Indiana University and Walter W. Foskett Professor of Law in the Indiana University (IU) Maurer School of Law. He teaches and has written extensively in the fields of environmental law, regulation of chemicals and hazardous wastes, international environmental law, risk assessment, and the management of radioactive waste. From 1993 to 1998, he chaired the Fernald Citizens Advisory Board at the Department of Energy's Fernald facility in Ohio, and he served on the Department of Energy environmental management advisory board from 1994 to 2001. He has participated in several National Research Council studies as committee member or reviewer. In addition to academic affairs, Professor Applegate is responsible for public safety, emergency management, and environmental safety and health across IU's campuses. A member of the American Law Institute, Professor Applegate has taught at the University of Paris 2 (Panthéon-Assas) and University of Erlangen-Nürnberg and been a research fellow at Cardiff University. Before moving to Indiana, he was the James B. Helmer, Jr., Professor of Law at the University of Cincinnati College of Law, and was a visiting professor at Vanderbilt University Law School. He was a judicial law clerk for the U.S. Court of Appeals for the Federal Circuit and an attorney in private practice in Washington, D.C. Professor Applegate received his B.A. in English from Haverford College in 1978 and his J.D. from Harvard Law School in 1981.

Steven M. Becker, Ph.D., is professor of community and environmental health at Old Dominion University. He is an internationally recognized expert on community impacts, reactions, and responses to radiation emergencies. Dr. Becker has had extensive field experience at the sites of radiation incidents around the world, including the 1999 nuclear criticality accident in Tokaimura, Japan. He has done Chernobyl disaster follow-up work in Ukraine and Belarus, and was a member of a three-person radiological emergency assistance team invited to Japan in 2011 in response to the earthquake-tsunami disaster and the Fukushima Daiichi accident. Dr. Becker serves on the National Council on Radiation Protection and Measurements (NCRP), and on the recently formed National Academy of Sciences/National Research Council scientific panel examining cancer risks in populations living near nuclear facilities. In September 2012, Dr. Becker was appointed by President Barack Obama to the U.S. Nuclear Waste Technical Review Board.

Julie A. Bentz is the director, strategic capabilities policy on the national security staff within the Executive Office of the President. She is responsible for writing presidential policy, coordinating interagency dialogue, informing presidential budgetary decisions, and building consensus on interagency initiatives in programs that develop U.S. strategic capabilities to meet 21st-century requirements.

Gerilee W. Bennett is the deputy director of FEMA's National Disaster Recovery Planning Division. Ms. Bennett's team is responsible for leading implementation of the National Disaster Recovery Framework, published in September 2011. She has been responsible for leading national disaster recovery planning and exercise initiatives since 2003. Ms. Bennett has supported an array of disaster assistance operations at headquarters and field offices, including Hurricanes Isaac and Sandy in 2012, the 2010 Gulf Coast oil spill, the 2004 and 2005 hurricanes, the 2001 World Trade Center attacks, Hurricanes Opal and Fran in the 1990s, and the 1993 and 2008 Midwest floods. Ms. Bennett has a bachelor of arts degree in political science and German language and literature from the University of Idaho. She is currently completing a master of arts degree in security studies at the Naval Postgraduate School Center for Homeland Defense and Security.

William F. Blakely received his Ph.D. in 1980 at the University of Illinois, Urbana-Champaign in radiation biology; his doctoral advisor was Dr. Howard S. Ducoff. He completed his postdoctoral study on DNA radiation chemistry in Dr. John F. Ward's laboratory at the University of California, San Diego. In 1983, he joined the Armed Forces Radiobiology Research Institute (AFRRI)–Uniformed Services University of the Health Sciences, his present affiliation.

Dr. Blakely's research activities have focused on molecular mechanisms of radiation sensitivity, cell-cycle effects, DNA damage and repair, and biological dosimetry. He served as a guest editor for several issues of journals associated with international meetings, an associate editor for the *Radiation Research* journal, and chairman of the North Atlantic Treaty Organization (NATO) Research Study Group–Radiation Bioeffects and Countermeasures (RTG-033). He presently is the director of the radiation biology graduate course at his university. He also serves as a U.S. representative on the International Organization for Standardization (ISO) Technical Committee (TC)85/SC2 (Radiation Protection) Working Group 18 (Performance Criteria for Service Laboratories Performing Biological Dosimetry by Cytogenetics), council member for the National Council on Radiation Protection and Measurements (NCRP), assistant professor in the Uniformed Services University of the Health Sciences Preventive Medicine and Biometrics Department, and as senior associate faculty at the Radiation Emergency Assistance Center/Training Site (REAC/TS).

Daniel J. Blumenthal manages the Consequence Management programs in the Office of Emergency Response at the National Nuclear Security Administration (NNSA) within the Department of Energy (DOE). In 2009, he transferred from the Department of Homeland Security's Domestic Nuclear Detection Office where he was the chief test scientist. Prior to joining the federal government, he was a senior scientist at DOE's Remote Sensing Laboratory from 1996 to 2006, where he managed or provided scientific support to several DOE emergency response teams. Most recently, Dr. Blumenthal led the initial DOE response team to Japan where he spent a total of 7 weeks following the Fukushima Daiichi nuclear power plant accident in March 2011. Dr. Blumenthal's background is in nuclear physics and he is also a certified health physicist.

Alina V. Brenner received her M.D. and Ph.D. (in immunology) degrees in 1995 from the Russian State Medical University, Moscow. She completed an M.P.H. program in epidemiology at the George Washington University and joined the Radiation Epidemiology Branch, NCI, as a postdoctoral fellow in 1999. In 2004, she became a staff scientist. Dr. Brenner has a long-standing involvement in studies of health consequences from the Chernobyl nuclear power plant accident and more recently in studies of atomic bomb survivors. Her scientific interests include epidemiology of thyroid and brain cancers with a special focus on radiation exposure. More generally, she is interested in how radiation risk depends on age, genetics, immunologic, and other factors. Dr. Brenner has served on the Public Health Committee of the American Thyroid Association (2012-2014) and International Atomic Energy Agency Working Group on Radiological Consequences of Fukushima nuclear power plant accidents (2014). In 2013, as part of the Chernobyl studies team, she received an NIH Merit Award.

S.Y. Chen is currently director of the Professional Health Physics Program at the Illinois Institute of Technology (IIT), Chicago. Prior to joining IIT, he was senior environmental systems engineer and manager at Argonne National Laboratory. Dr. Chen is a member of the National Council on Radiation Protection and Measurements (NCRP); he also serves on the U.S. Environmental Protection Agency's Science Advisory Board/Radiation Advisory Committee. Dr. Chen chairs the NCRP Program Area Committee on Environmental Radiation and Radioactive Waste Issues. He also chairs NCRP Scientific Committee SC5-1, which work is to be published as NCRP Report 175, *Decision Making for Late-Phase Recovery from Nuclear or Radiological Incidents*.

Sara D. DeCair has been a health physicist with the Environmental Protection Agency's Office of Radiation and Indoor Air since 2003. She works on policy, planning, training, and outreach for EPA's radiological emergency preparedness and response program. Ms. DeCair is the project and technical lead for revising the Protective Action Guides and is especially interested in emergency worker dose limits and turnback levels.

William "Bill" E. Irwin leads a group of scientists who provide guidance on the health consequences of chronic and acute exposures to ionizing and non-ionizing radiation, toxic chemicals, and other physical phenomena. He and his team place great emphasis on emergency preparedness. The team works closely with state and federal agencies for health, public safety, emergency management, homeland security, environmental protection, and agriculture on radiological emergency preparedness. Dr. Irwin and his team exercise and train regularly and collaborate with numerous national working groups to improve their readiness. He has a master of science in radiological physics, a doctor of science in work environment engineering, and is a certified health physicist. Before coming to Vermont, Dr. Irwin worked as a technician in the U.S. Navy reactor program, as a trainer at numerous commercial nuclear facilities, and as a health physicist at Massachusetts Institute of Technology (MIT) and Harvard.

Brad Leissa received his medical degree from The Ohio State University. He received postgraduate training in internal medicine and pediatrics at the Ohio State University Hospitals. He went on to receive subspecialty training in pediatric infectious diseases from George Washington University and the Children's National Medical Center in Washington, D.C. He began his career at the Food and Drug Administration (FDA) back in 1989 as a medical officer with a focus on anti-infective drug development in the Center for Drug Evaluation and Research (CDER). During the October 2001 anthrax attacks, Dr. Leissa was assigned as the FDA liaison to the Secretary's Bioterrorism Command Center at the Department of Health and Human Services. Since then, he has continued to work on medical countermeasure development at FDA. He currently holds the position of deputy director in CDER's Office of Counter-Terrorism and Emergency Coordination (OCTEC).

Martha S. Linet has served as chief of the Radiation Epidemiology Branch of the National Cancer Institute (NCI) since 2002. She has been a senior investigator at NCI since 1987, and was previously an associate professor in the Department of Epidemiology at the Johns Hopkins School of Public Health. Dr. Linet is principal investigator of studies assessing the role of protracted low-dose radiation exposure and cancer risks in medical radiation workers, including radiologic technologists and physicians performing fluoroscopically guided interventional procedures. She has also studied the role of magnetic field exposures from power lines and electrical appliances in relation to childhood leukemia; cellular telephone use and risk of adult brain tumors; and ultraviolet solar radiation exposure and risk of skin and other cancers. Dr. Linet has a long-standing interest in assessment of a broad range of postulated risk factors for childhood and adult hematopoietic malignancies, including occupational benzene and other occupational and environmental exposures, medical conditions, medications, measures of early-life infections, and potential protective factors such as breastfeeding, vitamin D, and preconceptional folic acid supplements. She served on the board of directors (1999-2004) and as president of the American College of Epidemiology (2004-2005) and is currently a member of the National Council on Radiation Protection and Measurements and the National Academy of Sciences Nuclear and Radiation Studies Board. Dr. Linet has also served on other advisory groups to the International Agency for Research on Cancer and the Leukemia and Lymphoma Research Society, and on editorial boards (*American Journal of Epidemiology* and *Journal of the National Cancer Institute*) Among her honors are election to the American Epidemiological Society, the NIH Director's and Merit Awards, the NCI Mentor of Merit Award, the Henry L. Moses Award for outstanding clinical paper, the American College of Epidemiology Distinguished Service Award, and election to the Johns Hopkins Society of Scholars.

Nicole Lurie is the Assistant Secretary for Preparedness and Response (ASPR) at the U.S. Department of Health and Human Services (HHS). The ASPR serves as the Secretary's principal advisor on matters related to bioterrorism and other public health emergencies. The mission of her office is to lead the nation in preventing, responding to, and recovering from the adverse health effects of public health emergencies and disasters. Previously, Dr. Lurie was senior natural scientist and the Paul O'Neill Alcoa Professor of Health Policy at the RAND Corporation. Dr. Lurie attended college and medical school at the University of Pennsylvania and completed her residency and M.S.P.H. at University of California, Los Angeles, where she was also a Robert Wood Johnson Foundation Clinical Scholar. Dr. Lurie continues to practice clinical medicine in the health care safety net in Washington, D.C.

James McIntyre serves as the director of Disaster Operations, Cadre Management and Training. As the Director, he serves as the senior external affairs official on incident response, and reports directly to the director of external affairs (ESF 15 Operations Director, when activated). He coordinates the External Affairs Emergency Support Function 15 activation activities to include the appointment and deployment of ESF 15 lead, deputy lead, and EA situational awareness teams. Mr. McIntyre also provides incident actions plans and deployment support through national and regional cadres and coordinates EA messaging and support with all EA functions as well as federal and nongovernmental partners. He oversees the recruiting, hiring, administrative support, and training qualification of the FEMA External Affairs Incident Management Workforce. Mr. McIntyre has a bachelor of arts degree in organizational management and is a former U.S. Air Force public affairs officer who retired in 1996 after 24 years of military service.

Patricia A. Milligan is a certified health physicist as well as a nuclear pharmacist. She works for the Nuclear Regulatory Commission in their headquarters office in the Rockville, Maryland office. She is a senior advisor in the Office of Nuclear Security and Incident Response Division of Preparedness and Response. Ms. Milligan has worked for the NRC since 1998. Prior to joining the NRC, she worked for 13 years in the nuclear power field as a health physicist and for 5 years as a nuclear pharmacist.

Miles O'Brien is a veteran, independent journalist who focuses on science, technology, and aerospace. He is the science correspondent for the *PBS NewsHour*, a producer and director for the PBS science documentary series *NOVA*, and a correspondent for the PBS documentary series *FRONTLINE* and the National Science Foundation *Science Nation* series. For nearly 17 of his 32 years in the news business, he worked for CNN as the science, environment, and aerospace space correspondent and the anchor of various programs, including *American Morning*. While at CNN, he secured a deal with NASA to become the first journalist to fly on the Space Shuttle. The project ended with the loss of *Columbia* and her crew in 2003–a story he told to the world in a critically acclaimed 16-hour marathon of live coverage. Prior to joining CNN, he worked as a reporter at television stations in Boston, Tampa, Albany, New York, and St. Joseph, Missouri. He began his television career as a desk assistant at WRC-TV in Washington, D.C. Mr. O'Brien is an accomplished pilot and is frequently called upon to explain the world of aviation to a mass audience. He has won numerous awards over the years, including a half-dozen Emmys, a Peabody, and a DuPont for his coverage of Hurricane Katrina and its aftermath.

In February 2014, a heavy equipment case fell on his forearm while he was on assignment. He developed Acute Compartment Syndrome, which necessitated the emergency amputation of his left arm above the elbow. Born in Detroit and raised in Grosse Pointe Farms, Michigan, he is based in Washington, D.C. He has a son at the U.S. Naval Academy and a daughter at Davidson College in North Carolina. He was a history major at Georgetown University.

Jerome S. Puskin has been director of the Center for Science and Technology within the Office of Radiation and Indoor Air of the Environmental Protection Agency since 1985. Prior to his work at the Center for Science and Technology, he was a biophysicist at the Nuclear Regulatory Commission. He is Distinguished Emeritus Member of the National Council of Radiation Protection and Measurements (NCRP) and member of the Committee to Assess the Risks from Low Energy Photons and Electrons. He received a B.A. from Johns Hopkins University and a Ph.D. from Harvard University.

Adela Salame-Alfie is the acting director of the Division of Environmental Health Investigations of the New York State Department of Health. Prior to this appointment, she was the director of the Bureau of Environmental Radiation Protection. Since joining the Bureau in 1993, Dr. Salame-Alfie has been actively involved in radiological emergency response, evaluation of remedial actions for contaminated sites, radon, and the radioactive materials and x-ray regulatory programs. She is the chair of the Conference of Radiation Control Program Directors' Homeland Security Emergency Response Task Force charged with the development of the radiological dispersal device first responder's pocket guide and the handbook for responding to radiological dispersal devices companion. Dr. Salame-Alfie is a member of the NCRP SC4-2 Committee charged with the development of a publication on population monitoring and decontamination following a nuclear or radiological incident and a workgroup charged with the development of a competency standard for first responders. Dr. Salame-Alfie received her B.S. in energy engineering in Mexico City and her M.S. and Ph.D. in nuclear engineering from Rensselaer Polytechnic Institute in Troy, New York.

Steven L. Simon, Ph.D., joined National Cancer Institute's (NCI) Radiation Epidemiology Branch in 2000 as an expert in dose reconstruction and presently heads the dosimetry unit in that group. Previously he was on the research faculty at the University of Utah, the academic faculty at the University of North Carolina, Chapel Hill, was a medical physicist for the University of New Mexico at Los Alamos National Laboratory, a senior staff officer at the National Research Council, and director of the Marshall Islands Nationwide Radiological Study. Dr. Simon has worldwide experience in monitoring nuclear test sites for residual radioactivity and assessing historical radiation doses from nuclear weapons fallout. He has provided advice over many years to national and international organizations on issues related to environmental contamination from nuclear testing and related radiation exposures. More recently, he has directed his efforts to estimating historical doses to patients and medical staff from medical diagnostic procedures. Dr. Simon has been a member of the NCRP for 10 years and is presently the NCRP vice president for radiation measurement and dosimetry. He has been an associate editor of *Health Physics* for 21 continuous years. In 2011, during the Fukushima crisis, he was part of the five-person team deployed by the U.S. Department of Health and Human Services to the U.S. Embassy in Japan to assist with the protection of American citizens. He received a B.S. in physics from the University of Texas, an M.S. in radiological physics from the University of Texas Health Sciences Center in Dallas, and a Ph.D. in radiological health sciences from Colorado State University.

Jama VanHorne-Sealy is an assistant professor of preventive medicine and biometrics and director of radiation safety for the Uniformed Services University of the Health Sciences. Concurrently, she is the primary advisor on nuclear and radiation issues for the Office of Health Affairs and the Chief Medical Officer of the Department of Homeland Security (DHS). She began serving in this position in May 2013. Major VanHorne-Sealy has served as the lead for the Department of Defense's Medical Radiobiology Advisor Team and Instructor for the Armed Forces Radiobiology Research Institute's Medical Effects of Ionization course. During the Fukushima reactor release in Japan, she established an in-country presumptive radiation detection laboratory for the Pacific U.S. Forces and served as a technical advisor to U.S. Forces Japan and U.S. Embassy staff. Major VanHorne-Sealy developed and implemented the first Radiation Safety Program for U.S. Forces in Afghanistan.

Lee Ann B. Veal joined EPA's Radiation Protection Division in 2010 as the director of the Center for Radiological Emergency Management. Her role during the Fukushima incident was to manage EPA's Emergency Operations Center. EPA's primary function was to collect and analyze environmental samples taken from locations across the United States and its territories and publicly report on all findings. EPA was significantly involved in the scientific team supporting the U.S. response in Japan and to concerns for American citizens living there. Prior to her current responsibilities, Ms. Veal held positions with the Department of Homeland Security, Los Alamos National Laboratory, EPA's Office of Homeland Security, and EPA's air pollution monitoring program. Ms. Veal began her career as an electrical engineer working for Dominion Energy.

Albert Lee Wiley, Jr., B.N.E., M.D., Ph.D., F.A.C.R., is the medical and technical director of radiation emergency medicine programs at REAC/TS, a DOE National Nuclear Security Administration (NNSA) asset managed by Oak Ridge Associated Universities. He is also head of the World Health Organization Radiation Emergency Medical Preparedness and Assistance Network Collaborating Center and of the Radiation Emergency Assistance Center/Training Site (REAC/TS)—International Atomic Energy Agency Response and Assistance Network (IAEA RANET) medical radiation emergency response team at Oak Ridge. He began his work as a nuclear engineer (B.N.E. from North Carolina State University) and later received an M.D. degree (University of Rochester Medical School). He also holds a Ph.D. in radiological sciences (minor in nuclear engineering) from the University of Wisconsin–Madison, where he also spent most of his career as professor of radiation oncology and is now an emeritus professor. He also has served as professor and interim director of the East Carolina University Cancer Center. He was medical director of U.S. Naval Radiological Defense Laboratory and at REAC/TS has been medical team leader for NNSA-sponsored courses in over 20 countries and has been deployed as a medical consultant to radiological accident sites in Venezuela, Trinidad, and Chernobyl. He has also worked with the National Aeronautics and Space Administration on the Pluto and Mars Science Lab radioisotope thermoelectric generator (RTG) launches and is in the U.S. Navy Reserves (retired).

Jan Wolff was born in 1925 and schooled in Germany, Holland, and California. Dr. Wolff worked on iodine metabolism at University of California, Berkeley (Ph.D., 1949). This was followed by an M.D. degree (Harvard,

1953) and internship at Massachusetts General Hospital and transfer to the new Clinical Endocrinology Branch at the National Institutes of Health (NIH) where he resumed studies on iodine metabolism, including two trips to the Marshall Islands and one to Kiev for the Chernobyl accident and consultations regarding KI prophylaxis with the U.S. Food and Drug Administration, National Center for Radiation Protection, and the Nuclear Regulatory Commission. He later switched to studies on adenosine receptors, toxic adenylyl cyclase in pertussis, and the protein tubulin. Dr. Wolff retired in 2006.