ORIGINAL RESEARCH

Recovery and Resilience After a Nuclear Power Plant Disaster: A Medical Decision Model for Managing an Effective, Timely, and Balanced Response

C. Norman Coleman, MD, Daniel J. Blumenthal, PhD, CHP, Charles A. Casto, MPH, Michael Alfant, Steven L. Simon, PhD, Alan L. Remick, Heather J. Gepford, PhD, Thomas Bowman, MS, REHS, Jana L. Telfer, MA, Pamela M. Blumenthal, MPP, and Michael A. Noska, MS

ABSTRACT

Resilience after a nuclear power plant or other radiation emergency requires response and recovery activities that are appropriately safe, timely, effective, and well organized. Timely informed decisions must be made, and the logic behind them communicated during the evolution of the incident before the final outcome is known. Based on our experiences in Tokyo responding to the Fukushima Daiichi nuclear power plant crisis, we propose a real-time, medical decision model by which to make key health-related decisions that are central drivers to the overall incident management. Using this approach, on-site decision makers empowered to make interim decisions can act without undue delay using readily available and high-level scientific, medical, communication, and policy expertise. Ongoing assessment, consultation, and adaption to the changing conditions and additional information are additional key features. Given the central role of health and medical issues in all disasters, we propose that this medical decision model, which is compatible with the existing US National Response Framework structure, be considered for effective management of complex, large-scale, and large-consequence incidents. (*Disaster Med Public Health Preparedness*. 2013;7:136-145)
Key Words: nuclear power plant, disaster resilience, disaster recovery, medical decision model

The earthquake, tsunami, and nuclear power plant (NPP) disaster in Japan in March 2011 was a unique situation. It resulted in massive regional infrastructure damage and required a level of real-time incident management not previously seen in other nuclear or radiological disasters. Based on our experiences and observations during the response,[1,2] we propose integrating a medical decision model for planning, exercising, and supporting the management of a NPP or other large-scale radiation emergency should one occur in the United States. This functional approach could be applicable to other types of disasters, and is compatible with the Incident Command System framework.[3]

The basis of response to a disaster is to take immediate action as necessary to save lives, protect property and the environment, and meet basic human needs.[4] Recovery begins simultaneously but can continue for months or years, as is seen in Chernobyl where recovery efforts continue after more than 25 years. The National Disaster Recovery Framework identifies several core principles for recovery, including leadership and local primacy, public information, timeliness and flexibility, resilience and sustainability, and psychological and emotional recovery.[5] All of these elements support the integration of a medical decision model, which involves providing data and recommendations to decision makers so that they can make, implement, and communicate timely decisions that have direct impact on the well-being of residents and their ability to recover from the disaster.

The approach we recommend is based on the following premises:

1. The overriding concern is for the well-being of the potentially affected population, which requires a valid ongoing assessment of all actual and potential health and medical consequences.
2. Radioactive releases and some expectation regarding the radionuclide content released can be predicted from ongoing assessment of the physical damage to and radiation emissions from the NPP.
3. Risk for long-term health consequences from radiation exposure and the environmental impact

of any radioactive releases can be roughly projected from radiation measurement data, mindful of uncertainties related to the general health status of the population and the exposure conditions.
4. The paradigm of medical decision making used in emergency medicine can support incident management by providing timely decisions using on-site subject matter experts based on the best available information as it emerges and by modifying the course as new information is acquired. It is in contrast to a deliberative multistep and time-consuming decision-making process that depends on the greater degree of certainty when more of the outcome is known. While using experts and committees for consultation and advice, the medical decision model differs by having on-site decision makers empowered to make interim decisions and on-site experts making time-critical decisions and refining the course based on the data available.
5. Timely and understandable presentation of ongoing decisions, risk assessment, and the incident management strategy enhances public comprehension of the incident and accompanying risks as well as confidence in authorities.
6. Community resilience is a key goal: "A resilient community is not only prepared to help prevent or minimize the loss or damage to life, property and the environment, but also it has the ability to quickly return citizens to work, reopen businesses, and restore other essential services needed for a full and swift economic recovery."[6]

These decisions are not hasty but informed, and they are made without excess debate and are revised as situational awareness evolves and new data are acquired. As in managing medical illnesses, not to make a decision and to continue an existing course is to make a decision.

BACKGROUND

The Fukushima Disaster

The March 2011 disaster in Japan involved an earthquake and tsunami that massively disrupted local infrastructure including extensive damage to a NPP facility, a situation originally thought to be extremely unlikely.[7] More than 15 000 lives were lost, thousands were missing,[8,9] and hundreds of thousands more were disrupted locally and throughout the country by the combined sequential phenomena. Deaths at and outside of the Fukushima Daiichi NPP were due to the earthquake and tsunami and not to radiation exposure.

Japan's emergency responders were overburdened with response to the 3 crises; a large number of the population had lost their homes and been dislocated; and fear and uncertainty were prevalent throughout Japan and elsewhere. Experts in various technical fields from Japan, the United States, and around the world worked to understand and mitigate the consequences of actual and potential releases of radioactive material. The United States activated emergency response assets to ensure the safety of American citizens both in Japan and elsewhere.

Numerous important and time-sensitive decisions to protect the health of the public had to be made based on the best available information, with the recognition that it was far from complete. The public health response to the NPP involved sheltering, evacuation, interdiction of food and water, radiation measurement, medical countermeasure use, risk assessment, and managing exclusion zones. The health and safety of the Japanese residents were guided by the Japanese; however, citizens of the United States were guided by US recommendations. The use of different recommendations[10-13] caused confusion among the public.

Decisions about the health-related consequences resulting from the NPP encompassed more than just the potential risk from the radiation, which dominated the media and public discourse. Also considered were risks associated with evacuation and public relocation, the impact on physical and mental health from disruptions to normal life, economic losses, and the ongoing anxiety of living through a widespread physical and economic disaster.[14,15]

Rationale for the Proposed Medical Decision Model

The authors' experiences from the US response to the Fukushima NPP closely paralleled the decision-making steps conducted in medical management, particularly in making decisions promptly, as is often necessary in emergency medicine and oncology. In a catastrophic medical occurrence such as a sudden collapse of a person, interventions are required expeditiously. A "cardiac arrest working group" is not convened to discuss treatment options for the injured. Rather, treatment is administered immediately, based on the best information available at that time, experience, and knowledge-based algorithms,[16] and follow-up care is based on the examination of more data when available. As the situation stabilizes, further consultation can occur.

Oncology management is also an excellent analogy for disaster management, particularly one that involves a release of radiation. The risks and benefits of radiation and other potentially carcinogenic treatments are a consideration, and management of the bone marrow component of the acute radiation syndrome is similar to that for oncology. The competing risks of efficacy and toxicity are evaluated on the patient's overall medical condition, the properties of the tumor (not all of which will be immediately known), and current scientific data; and a course of action is selected to avoid tumor growth and dissemination.[17] Working closely with patients and their families, physicians develop a treatment plan, initiate it in a timely manner; monitor its effectiveness, and modify its course as appropriate.

The concerns of the individuals and families, the reliance on expertise, the need to communicate complex scientific and

https://doi.org/10.1017/dmp.2013.5 Published online by Cambridge University Press

medical concepts, and the need to make decisions immediately based on the data available at the time and to modify those decisions as the situation evolves are the same elements used in the response to a NPP accident. The model that is effective in the medical situation can be equally applicable to support management of the disaster.

US FEDERAL RESPONSE

The US response to disaster uses a chronological framework of early, intermediate, and late phases to describe its evolution, with some intermediate and late phase activities identified as beginning in the early phase.[18] A broad range of expertise is available for a US federal response, as described in the National Response Framework.[18-34] The Table describes the federal response by sector and the actions, managements, and assessments required to manage the incident.

Data and Decisions

Initial assessment of physical damage will be available promptly and refined as detailed inspections occur. The Nuclear Regulatory Commission (NRC) requires that NPPs have 2 preplanned emergency planning zones (EPZs), a plume EPZ of 10 miles and an ingestion pathway EPZ of 50 miles. Their configuration and plans are specific to the location and circumstance of the incident.[35] The NPP licensee is responsible for assessing the physical state of the reactor(s) and spent-fuel pools and mitigating the consequences of the incident in accordance with its NRC-mandated emergency plans.[40]

Analogous to the "golden hour" for medical care, radiation professionals can help minimize the dose to a population during a NPP crisis if they know where and when radioactive material is likely to spread from an environmental release. Because deploying field teams and making measurements take time, the Department of Energy bridges the gap during these golden hours by providing high-fidelity atmospheric dispersion modeling based on the best available radiological and meteorological data.[21]

The meteorological projections and the radionuclide dispersion models are followed by aerial measurements to gather environmental data quickly over large areas. These aerial measurements are supplemented, as conditions permit, by ground-based monitoring to confirm aerial measurements and identify the specific mix of radionuclides, which is critical to estimating the long-term dose to people. The Environmental Protection Agency's (EPA) protective action guidelines (PAGs) suggest precautions that state and local authorities can take during a radiation emergency based on the projected amount of radiation that might be received.[25,36,37] The projected doses derived from measurements can be used to help determine the time people can spend in an area. Sufficiently high projected doses may require the relocation of a population.

Because a radiological release may contaminate food and water supplies, decision makers will also need to determine when to instruct the population to limit consumption. Although a single measurement of radioactivity in food or water could be used to provide a risk estimate, it would be highly uncertain and not necessarily representative; hence, serial measurements would more accurately validate the initial estimate and provide a more precise assessment of the likely dose and the potential risk.[i] The US Food and Drug Administration's derived intervention levels guide decisions about food;[31] discussions regarding water protective action guidelines are ongoing.[36,37]

In the early phase of an NPP release, a major radiation health issue is the potential inhalation of radioactive iodine from the plume or ingestion of radioactive iodine in contaminated food and water. Sheltering, evacuation, and interdiction of possibly contaminated food and water are the primary responses to prevent internal exposure. Individuals at sufficiently high risk from internal contamination with radioactive iodine may be advised to take stable (nonradioactive) potassium iodide (KI) to reduce thyroid gland uptake of radioactive iodine.[38,39]

Radiation-Induced Cancer Concerns

The issue of greatest concern expressed both worldwide and in Japan was the risk of cancer induction caused by radiation exposure. The concept of radiation risk[41-43] is often poorly understood because of confusion between short-term and long-term health effects and the magnitude of exposure required to produce each. While symptoms such as nausea and vomiting may occur at a dose of 0.75 Gy, the more serious acute health effects occur after relatively high exposures (>2 Gy),[24] and the type and severity depend on the dose received. While NPP workers may be exposed to levels high enough to produce acute effects, the exposure from a NPP incident to members of the public at levels sufficient to produce such effects is unlikely and did not occur in Japan. Long-term effects are uncertain but may increase the chance for the development of cancer (or other health conditions) in later years.[44,45] Although extensively debated, most current radiation risk models conservatively assume that any radiation exposure increases the lifetime risk of developing cancer.[43,46] For the vast majority of people potentially affected by an NPP, increase in their life-time risk will be extremely small and undetectable above their background life-time cancer risk. Simon et al[47,48] and Gilbert and colleagues[49] discuss in detail the health risks from radioactive fallout.

Stress and Resilience

Based on experience from the Chernobyl incident, stress-related illness is another anticipated outcome for the affected

[i]A measurement of the Tokyo drinking water indicated a low level of iodine, prompting the logical response to use bottled water until further information was available from new measurements within 12-24 hours. This measurement actually was a one-time occurrence related to rainfall, which eliminated the need to stockpile water or panic about contamination. Fear in the population would have been averted and anxiety reduced if it were possible to explain promptly that only ingesting many tens or hundreds of liters would constitute a health concern and that washing with the water was not a problem.

TABLE

Sectors Requiring Management by Decision Makers for a Nuclear Power Plant (NPP) Incident

Sector	Actions, Measurements, and Assessments
Physical infrastructure: Roads, power, communications	Assess conditions and roads, power, communications ● Establish access for resources and evacuation ● Assess medical occupancy and infrastructure and the need for evacuation and/or to free-up beds for incoming casualties from the incident
NPP potential release, NRC Emergency Planning Zones (EPZs)[35]	Establish initial EPZs: plume (10 miles), ingestion pathway (50 miles) ● Manage EPZs as data become available
Radionuclides of concern	Xenon-133, noble gas: short lived; ● Risk mitigation: shelter-in-place Iodine-131: plume or ingested, 8-d half-life ● Exposure from plume or ingestion (primarily grass-cow-milk pathway) ● Risk mitigation: evacuation and food/water interdiction Cesium-137, Strontium-90: half-lives of approximately 30 years ● Exposure from particulate material: less dispersion distance but can enter food and water supply ● Risk mitigation: monitoring and interdiction
Environmental effects assessment, DOE, and EPA[a]	Modeling: National Atmospheric Release Advisory Center (NARAC)[21] ● Atmospheric dispersion models based on available radioactive release rate data, meteorological data, and monitoring data ● Bridge gap during "golden hours" to guide shelter and evacuation
Ambient environmental dose	Monitoring: aerial measuring system (AMS) ● Quickly map large areas for large-scale shelter and evacuation decisions ● Ongoing measurements during sustained release ● Assess radioactive decay and weathering effects Monitoring: ground-based ● Specific mix of radionuclides has strong effect on long-term dose in people ● Laboratory analysis (eg, air, water, soil, grass) ● Gamma spectrometry in situ ● Ground measurements validate and refine aerial measurements
	Protective active guidelines (PAGs)[25] ● Projection of cumulative dose over time ● Provide guidance for ○ Immediate evacuation ○ Relocation and re-occupancy ○ Long-term remediation
Water and food: FDA	Internal contamination ● Dose depends on specific radionuclide and its decay and metabolism by the body ● Projected dose based on a calculation of continued ingestion over 1 y ● Contamination at certain levels leads to protective action recommendations ● Derived intervention levels[31] determine restrictions on food; discussions are ongoing regarding applicable PAGs for water[36,37]
Medical countermeasures	Nonradioactive potassium iodide (KI) blocks thyroid uptake of radioactive iodine[38,39] ● Sheltering from plume and interdiction of food/water are primary modes of mitigation ● Infants, children, and young adults are at risk since thyroid is active; risk is very low for adults ● KI recommended for projected dose of 5 rem (50 mSv) ● KI effective given before or up to a few hours after exposure ● KI has toxic effects; it can damage developing thyroid
Population risk; long-term cancer risk	Serious acute effects (acute radiation syndrome)[30] unlikely Risk of radiation-induced cancer depends on dose ● Epidemiology studies may be conducted for those deemed at risk ● Certain health screening measures may be indicated for some people, eg, thyroid monitoring for those with significant dose from radioactive iodine
Anxiety/stress related to fear of radiation and disruption of lives	Risk must be anticipated and have psychological support to mitigate impact on individuals and overall recovery
Personal issues: degree of acceptance of risk for evacuation (based on US embassy experience)	In absence of identifiable and direct threat to life and health people appeared to accept more risk because of: ● Nonspecific resistance to change ● A rational analysis of the danger, with a conclusion that evacuation is not indicated by present circumstances ● An interruption of school and work ● A separation of family units and lack of a clear end point when they can return ● Economic factors of associated costs and potential lost income

https://doi.org/10.1017/dmp.2013.5 Published online by Cambridge University Press

Table. Continued

Sector	Actions, Measurements, and Assessments
For return from evacuation	Other individuals deemed returning to the evacuated area as too risky because of: ● Media sensationalism ● Absence of clear progress in halting radiological releases ● Difficulty in assuring safety of food and water supply ● Poor understanding of the risk of exposure to small amounts of radiation ● Confusion over radiation exposure standards
Economic production	Employees concern for safety ● Extent of employer responsibility uncertain
	Cessation of business activity within affected area ● Duration of cessation can have major impact on recovery
	Disruption of supply line ● Production from industry within EPZ can impact other dependent industries
	Cost of lost productivity ● Assess/model ongoing loses ● Risk of permanent business loss from sustained closure ● Cost of early resumption with possible secondary evacuation vs sustaining initial evacuation
	Modifying initial size of EPZ's aggressive measurement through use of data
Community resilience[6,15]	Community resilience in the context of national health security identified factors: ● Well-being of the population (both physical and psychological) ● Ability to address the underlying social and economic resources of that community ● Ability of the community to use risk communication tools and strategies to enhance pre-event preparedness and postevent recovery ● Involvement of government and nongovernmental entities in planning, response, and recovery ● Ability of communities to engage social networks for moving information and resources
Information management and communication Broad spectrum of communication methods needed	Confusion exists because varying radiation units (Sievert, rem, and various prefixes) are unfamiliar ● Standardization may be difficult but at least show relationship between systems and units Background radiation and radiation biology concepts important ● Radiation is ubiquitous ● Cells and animals have defenses against radiation damage
	Radiation risk based on projected cumulative doses challenging to explain ● Sufficient complexity required beyond "8th grade level" ● Simple assurances not sufficient or even detrimental or insulting to some ● Comparison with more routine sources of radiation variably received (eg, airplane flight)
	Information and data need to be tailored to audience ● Military and civilian missions differ ● Early, intermediate, and recovery phases use data differently ● Foreign citizens may receive different guidance than host country's citizens; explanation important
	Timeliness ● Dynamic situation early on and may persist for weeks, months, or years. ● Information gap will be filled by speculation or misinformation ● Lack of information is emotionally damaging ● Delay in information sharing fosters mistrust ● Prolonged vetting process can lead to presenting outdated information
	Credible spokesperson ● Subject matter experts ● Crisis management experience ● Senior credible leadership ● Patience is critical and repetition necessary
	Cultural and regional context ● For both international incidents and differing US regions
Guiding the decision process	Diverse opinions and assessments from experts ● In internal discussions: opportunity for "risk-free" expression of ideas and assessments among experts important to reaching consensus ● Decision makers depend on advice of experts who should understand what decision makers need to do ● Rapidly evolving situation will require rapid decision-making

Abbreviations: DOE, Department of Energy; EPA, Environmental Protection Agency; NRC, Nuclear Regulatory Commission.

[a] Note: For large-scale US incidents, Federal Radiological Monitoring and Assessment Center (FRMAC)[23] coordinates federal monitoring efforts. Interagency Modeling and Atmospheric Assessment Center (IMAAC)[22] coordinates federal modeling efforts.

https://doi.org/10.1017/dmp.2013.5 Published online by Cambridge University Press

population.[14] For US citizens who are in Japan or planning to travel there for business and education, travel *warnings*[50] can limit their ability to be there, creating stress for individuals and families. (Travel *alerts* provide a warning but more flexibility.) Based on observations in Japan, risk acceptance may vary markedly among individuals, with a very high level of concern shown particularly by women with young children.

Community resilience depends on preparation and the ability to minimize the effects of the disaster and respond to and move on afterward.[15] Minimizing disruption to everyday life and returning individuals to their daily lives are key features of resilience.[6,51] Returning to work, reopening businesses, and restoring essential services are needed. However, economic recovery in the postdisaster period will be determined by the degree to which local radioactive contamination impedes public acceptance of the living and working conditions and products produced there. As radiation levels decline and industries within an EPZ consider resuming activity, complex issues emerge regarding personal risk to employees and responsibility of employers to protect their workers (M.A., oral communication, September 2011).

During the crisis, a good deal of information was available from various forms of media (eg, the media and Internet sources). Much of it was inaccurate; some provided opinion or overly simplistic explanations or exaggerated the situation, all of which can add to stress and reduce resilience. Given the complexity of the incident and the limited information available, this was not unexpected. To minimize misinformation and unnecessary concern or anxiety, messages need to be as factual and timely as possible. The means of communication and use of language can differ substantially by culture, and it is important to understand such differences. While the government may issue recommendations or mandates, families need to be able to evaluate that information and interpret it according to their beliefs and risk tolerance.

Communicating information about radiation and risk is challenging, as it requires complex, yet timely, nuanced discussions to convey concepts simply and adequately. Issues of radiation-related health effects and risk, public fear of radiation, polarization of opinion regarding nuclear power, sensationalism by the media, and a rapidly changing situation based on an array of data make a nuclear incident among the most complex for leadership and decision making. In Japan, the US embassy used multiple forms of communication that reinforced consistent messages. In-person sessions and discussions for US citizens were supplemented by extensive use of social media and embassy website resources. Having expert spokespersons who could present information, listen to concerns, and clarify issues—as physicians do in patient management—was reassuring during the rapidly evolving situation. The complexity of both the evolving situation and the decisions to be made makes clear and timely communication with the public critical to improve resilience for individuals and the community.

APPLICATION OF THE MEDICAL DECISION MODEL WITHIN US RESPONSE

Guiding an emergency response requires the simultaneous consideration of a range of issues, some based on objective measurements (eg, contamination levels) and others on subjective evaluation of consequences (eg, need for voluntary evacuation). Crises that are extended in time tend to be dynamic; thus, we propose using a medical decision approach to support effective incident management. This approach empowers decision makers to manage health consequences promptly through informed choices based on on-site, readily available expert input, with additional experts accessible when needed, to assist in the analysis of the data available at the time and in longer term planning.[ii]

Progress toward a "new normal" can be achieved by basing the decision to implement 1 of 3 possible choices at each decision-making juncture on real-time data: (1) stop; (2) proceed with caution; or (3) return to normal operating procedures. An important element of this process reflects the dynamic nature of the crisis; a decision made at one point in time will be reviewed and can be modified as more data become available.

Decision Model

The Figure is a conceptual chart of how a NPP incident might unfold over time. Decision makers will need to simultaneously assess the range of issues and guide overall response supported by continual expert input.

For some sectors, guidance on the appropriate level of precaution will be derived by the inflow of data on infrastructure functionality, radioactivity release, and contamination of the environment. In general, data available in each sector will improve over the phases of response; however, the changing status of *environmental contamination* shows how an initial change in status (red to yellow) might temporarily stop (back to red) based on newly received data and then resume again with caution (yellow).

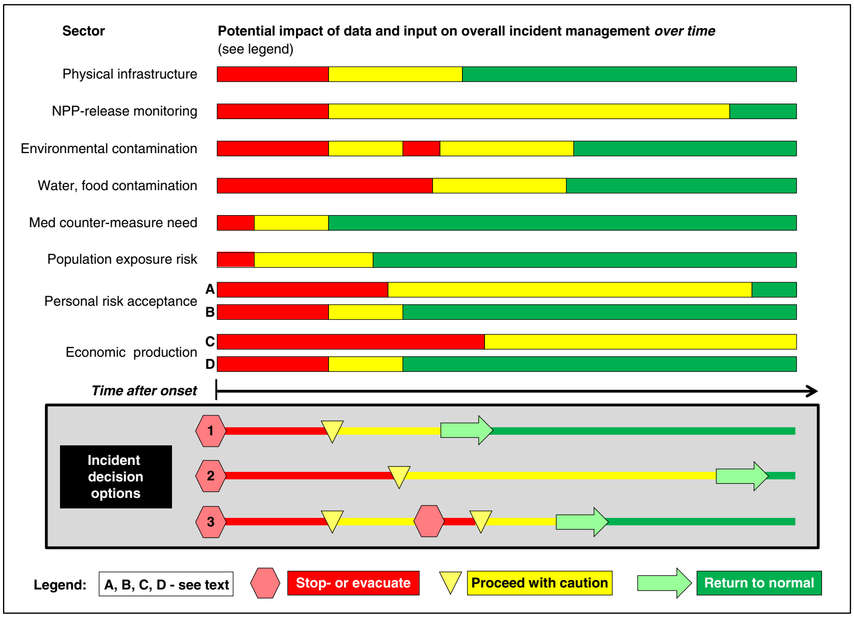
There will be situations in which recommendations from experts or guidelines from agencies may differ, as occurred between International Commission on Radiological Protection (ICRP) and EPA radiation exposure guidelines. The medical decision-making model proposed is particularly useful, as the decision maker would discuss the different opinions and options available and then select a series of next steps. Analogous to the primary care physician and patient coming to a decision after collecting and reviewing various expert opinions is the community and its leadership deciding on the risks, benefits, and timing for returning and rebuilding. The EPA protective action guidelines provide guidance to the local decision makers, as this is a local decision.[25,26]

[ii] For example, the discussion to evacuate the Tokyo embassy was ended when it was realized that staff could rotate between Tokyo and other embassies if exposure to low-dose radiation was sustained.

https://doi.org/10.1017/dmp.2013.5 Published online by Cambridge University Press

FIGURE

Using a Medical Decision-Making Model to Support Incident Management of a Nuclear Power Plant Disaster. During the response, conditions in the different sectors over time can cause the overall progression to normal (or to new normal) to stop (red stop sign and bar), based on data that indicate a serious risk of harm. As the situation improves, indications for stopping will no longer be present for various sectors, so some may begin normal activity, which may require a period of caution (yellow caution triangle and bar) if manageable risk remains. The box illustrates 3 incident decision options.



The two bars for *personal risk acceptance* illustrate how different individuals might interpret the same situation. Bar A is a very conservative, risk-averse approach, while bar B indicates that more risk would be acceptable. For *economic production*, bar C indicates an area that remains shut or limits activity due to a very conservative approach to resuming operations or to more widespread concern of a "funtional quarantine" of products from the impacted area. Bar D is a more aggressive approach to returning toward normal, with resumption of activities as soon as possible. Bar D assumes very small risk, with the idea that prolonged shut down could have serious and possibly permanent economic consequences for the people, region, and country. For all 4 bars, ongoing monitoring would be needed to provide continuing assessment.

In the Figure, the box of *Incident Decision Options* shows 3 ways in which the same overall incident decisions could be managed. Option 1 would be a more aggressive return toward normal; the overall activity would go from *stop* (red) to *cautionary return* (yellow) when all of the absolute indications for stopping had passed. While *stop* (bars A and C) may apply to some people or businesses, and some aspects of the economy would maintain a red condition (interdiction of food supply in a limited region), the *overall restrictions* would be reduced. This process would lead to a more rapid return to familiar life and the new normal.

Option 2 takes a very conservative approach and sustains the red condition much longer, until uncertainty is less. This approach would have a greater negative effect on business, family life, routine activities, and a sense of the new normal. Option 2 might possibly produce severe long-lasting impact to a region, such as permanent loss or relocation of businesses and other activities and long-term anxiety or stress from prolonged periods of caution.

Option 3 employs a more rapid return toward normal and, as in option 1, accepts the possibility of a return to a more restricted state if the situation deteriorates. The option of a return from evacuation with the possible need for a subsequent repeated evacuation might seem costly. However, this approach might aid the resumption of routine function and progress to the new normal. Option 3 might be much less expensive to public and regional well-being than a sustained state of emergency and might prevent a permanent loss of some industries.

DISCUSSION

Experience during the Fukushima NPP crisis demonstrated the challenge of decision-making before knowing the final outcome of the incident. Waiting until the consequences are fully defined prolongs the emergency period and delays the development of a new normal set of living conditions.

https://doi.org/10.1017/dmp.2013.5 Published online by Cambridge University Press

Postdisaster incident management has important similarities to emergency medical management or medical management of a potentially rapidly fatal disease such as cancer, in which decisions must be made on the best available information, the consequences are carefully evaluated, and the treatment course is continued or modified as appropriate. The process of reevaluation and adjustment may be repeated numerous times. While some extended consultation may be possible, waiting to make a decision until an outcome is certain, reviewed, and approved may result in a decision that is not effective, timely, or useful. The medical management approach is consistent with Department of Defense crisis action planning, a component of adaptive planning in which decisions must be made within hours.[52] The US Incident Command System[3] and the present model both emphasize the importance of decision-making at levels as close to the incident as possible.

Clinicians, particularly those operating in emergency conditions, have to make the best possible decisions for their patients using incomplete information. This process contrasts with scientific and political decision-making, which requires debate, review, revision, and generally committee discussion and consensus. Yet even in these spheres, the importance of using data to inform policy is recognized. Sunstein argues that decision makers need to recognize the cognitive limitations to which they are subject—particularly reliance on the availability heuristic (which leads to overestimating risk) and neglect of probability (which causes data to be ignored when strong emotions are triggered). To counter these limitations, he recommends relying on quantitative assessments to determine the magnitude of the problem, recognizing trade-offs, and exploring alternatives that may meet the same goal with lower costs and fewer risks.[53]

Effective leadership requires an understanding that criticism of early decisions may be inevitable, but that inaction may equally result in criticism and in inadequate protection of those in need. Moreover, inaction may also be perceived as a decision. The medical decision model requires that decision makers be fully empowered to make timely choices. In a rapidly evolving situation, science and communication advisors and decision makers must be able to think like clinicians and, through timely discussion and exchange of ideas, formulate decisions on the best data available at the time.[1,2] Having expertise available at the "command center" facilitates the exchange of information and the formulation of a plan of action.

This medical decision-making approach fits within the National Disaster Recovery Framework[4,5,18] by bringing together decision makers, subject matter experts, and communication experts at the incident scene. Enhanced communication and confidence building occurs when people physically work together in challenging situations. This situation allows for dialogue and understanding the subtleties and nonverbal communication that are not conveyed in formal reports. As with medical care, camaraderie among physicians, patients, and families allows for deeper appreciation of the issues and confidence that the best is being done at the time, while reserving the willingness to change as the situation warrants. There is often no single right course, and the reach-back expertise from working groups and agencies can inform local decision makers about more global issues. Having this expertise on-site would more likely be viewed as an integral part of a team approach rather than as recommendations from people distant from the action.

CONCLUSIONS

The combined tragedy in Japan was a unique experience in terms of its severity and complexity, yet sophisticated technology was available to monitor the ongoing situation. Based on our observations in assisting with the US response, we propose a medical decision-making model for use in managing incidents involving radiation. This model would also be applicable to large-scale and large-consequence disasters, in which risk is assessed, managed, and mitigated in a timely manner based on the available information as it emerges, so that inaction does not cause harm. Months or years may pass before the full impact of an incident is known, yet real-time decisions need to be made based on the best available data. The incident management process is best done by on-site decision makers empowered to make interim decisions along with on-site experts, so that the decision-making team has a sense of local community needs, the uncertainties of the information, the rate of evolution of the incident, and the ability to communicate their recommendations and the rationale for them directly with each other. We do not recommend hasty decisions; rather we recommend that informed decisions be made without excess debate, allowing for revisions as situational awareness evolves and new data are acquired. As in clinical medicine, not to make a decision and continue a course is to make a decision. To assist and enable decision makers, science, communication, and policy advisors will have to think and act like clinicians. Such an approach may allow resumption of functions and a new-normal life sooner and enhance the sense of resilience[6,18] to a community whose functionality may be severely compromised in many ways by the crisis.

About the Authors

Office of the Assistant Secretary for Preparedness and Response (Dr Coleman); Radiation Research Program, Division of Cancer Treatment and Diagnosis (Dr Coleman); Division of Cancer Epidemiology and Genetics (Dr Simon); National Cancer Institute, National Institutes of Health, Bethesda, Maryland; National Nuclear Security Administration, Department of Energy, Washington, DC (Dr Blumenthal and Mr Remnick); Nuclear Regulatory Commission, Rockville, Maryland (Dr Gepford and Mr Casto); American Chamber of Commerce in Japan, Tokyo (Mr Alfant); Division of the Strategic National Stockpile (Mr Bowman); Agency for Toxic Substances and Disease Registry (Ms Telfer); Centers for Disease Control and Prevention, Atlanta, GA; Department of Housing and Urban Development, Washington, DC (Ms Blumenthal); Food and Drug Administration, Silver Spring, Maryland (Mr Noska)

https://doi.org/10.1017/dmp.2013.5 Published online by Cambridge University Press

Address correspondence and reprint requests to C. Norman Coleman, MD, 9609 Medical Center Drive, Room 3W102, Rockville, MD 20850 (e-mail: ccoleman@mail.nih.gov).

DISCLAIMER

The opinions and conclusions in this paper are those of the authors and subject matter experts. This is not the opinion, policy or conclusions of the US Government or any of its agencies.

Acknowledgments

Nicole Lurie, MD, MSPH, Assistant Secretary for Preparedness and Response (ASPR), provided leadership and support of the health and medical team in Japan and contributed key insights and suggestions for this new conceptual model. Many members of the US embassy staff in Tokyo who underwent a very challenging set of circumstances provided outstanding service, dedication, creative thinking, and effective leadership. Members of ASPR and the Secretary's Operations Center, Health and Human Services (HHS), especially Kevin Yeskey, MD, Thomas Sizemore, MD, Michael Vineyard for 24/7 mission support, and Lee Larson and Derek Estes, ASPR, created linkage with the Department of Defense Joint Operation Planning. Members of the Centers for Disease Control and Prevention (CDC) provided outstanding 24/7 support for the HHS team in Japan while managing complex issues within the United States. Rae T. Benedict, PhD, and Jeffrey Nemhauser, MD, CDC, provided editorial assistance. Alicia A. Livinski, National Institutes of Health library, provided editorial review and prepared the manuscript for publication.

Published online: April 4, 2013.

REFERENCES

1. Coleman CN, Simon SL, Noska MA, Telfer JL, Bowman T. Disaster preparation: lessons from Japan. *Science*. 2011;332: 1379.
2. Simon SL, Coleman CN, Noska MA, Bowman T. Response of the US Department of Health and Human Services in protecting civilian Americans in Japan during the Fukushima nuclear crisis. *Health Physics*. 2012;102:570-579.
3. Incident Command System website. *http://www.fema.gov/incident-command-system*. Accessed March 4, 2012.
4. Federal Emergency Management Agency. *National Response Framework*. Washington, DC: Federal Emergency Management Agency; January 2008. *http://www.fema.gov/pdf/emergency/nrf/nrf-core.pdf*.
5. Federal Emergency Management Agency. *National Disaster Recovery Framework: Strengthening Disaster Recovery for the Nation*. Washington, DC: Federal Emergency Management Agency September 2011. *http://www.fema.gov/pdf/recoveryframework/ndrf.pdf*.
6. Community and Regional Resilience Institute website. *http://www.resilientus.org/about-us/definition-of-community-resilience.html*. Accessed March 4, 2012.
7. Piore A. Planning for the black swan. *Sci American*. 2011;304:49-53.
8. World Health Organization. *The Great East Japan Earthquake*. Geneva, Switzerland: World Health Organization March 11, 2011. *http://www.wpro.who.int/publications/docs/japan_earthquake.pdf*.
9. Ohnishi T. The disaster at Japan's Fukushima-Daiichi nuclear power plant after the March 11, 2011 earthquake and tsunami, and the resulting spread of radioisotope contamination. *Radiat Res*. 2012;177:1-14.
10. International Commission on Radiological Protection (ICRP). Application of the commission's recommendations for the protection of people in emergency exposure situations (No. 109); 2009. *http://www.icrp.org/publications.asp*. Accessed March 4, 2012.
11. International Commission on Radiological Protection (ICRP). 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 (No. 111); 2009. *http://www.icrp.org/publications.asp*. Accessed March 4, 2012.
12. Butler KM, Cool D. Answer to question 8900 submitted to "Ask the Experts." McLean, VA: International Commission on Radiological Protection; March 25, 2010. *http://www.hps.org/publicinformation/ate/q8900.html*. Accessed March 4, 2012.
13. International Atomic Energy Agency. *Manual for First Responders to a Radiological Emergency*. Vienna, Austria: International Atomic Energy Agency; October 2006: *http://www-pub.iaea.org/MTCD/publications/PDF/EPR_FirstResponder_web.pdf*. Accessed March 4, 2012.
14. Bromet EJ, Havenaar JM, Guey LT. A 25 year retrospective review of the psychological consequences of the Chernobyl Accident. *Clinical Oncol*. 2011;23:297-305.
15. Chandra A, Costa J, Meredith LS, et al. *Understanding Community Resilience in the Context of National Health Security: A Literature Review*. Santa Monica, CA: RAND Corp; 2010. *http://www.rand.org/pubs/working_papers/WR737.html*. Accessed March 4, 2012.
16. American Heart Association. Advanced cardiovascular life support—classroom. American Heart Association website. *http://www.heart.org/HEARTORG/CPRAndECC/HealthcareTraining/AdvancedCardiovascular-LifeSupportACLS/Advanced-Cardiovascular-Life-Support—Classroom_UCM_306643_Article.jsp*. Accessed March 4, 2012.
17. Coleman CN. *Understanding Cancer: A Patient's Guide to Diagnosis, Prognosis, and Treatment*. Baltimore, MD: Johns Hopkins University Press; 2006.
18. Department of Energy website. *http://www.energy.gov/*. Accessed March 4, 2012.
19. National Nuclear Security Administration website. *http://nnsa.energy.gov/aboutus/ourprograms/emergencyoperationscounterterrorism/respondingtoemergencies*. Accessed March 4, 2012.
20. National Atmospheric Release Advisory Center (NARAC) website. *https://narac.llnl.gov/*. Accessed March 4, 2012.
21. Interagency Modeling and Atmospheric Assessment Center (IMAAC) website. *https://imaacweb.llnl.gov/web/signIn.html*. Accessed March 4, 2012.
22. Federal Radiological Monitoring and Assessment Center (FRMAC) website. *http://www.nnsa.energy.gov/aboutus/ourprograms/emergencyoperationscounterterrorism/respondingtoemergencies/consequencemanagem-1*. Accessed March 4, 2012.
23. Radiation Emergency Assistance Center/Training Site (REAC/TS). Oak Ridge Institute for Science and Education website. *http://orise.orau.gov/reacts/*. Accessed March 4, 2012.
24. US Environmental Protection Agency. Protective Action Guides (PAGs). *http://www.epa.gov/radiation/rert/pags.html*. Accessed March 4, 2012.
25. US Environmental Protection Agency. Radiation Protection. Washington, DC: US Environmental Protection Agency. *http://www.epa.gov/radiation/*. Accessed March 4, 2012.
26. Nuclear Regulatory Commission (NRC) website. *http://www.nrc.gov/*. Accessed March 4, 2012.
27. Office of the Assistant Secretary for Preparedness and Response (ASPR) website. *http://www.hhs.gov/open/contacts/aspr.html*. Accessed March 4, 2012.
28. Centers for Disease Control and Prevention website. *http://www.cdc.gov/*. Accessed March 4, 2012.
29. US Department of Health and Human Services. Public Health Emergency (PHE) website. *http://www.phe.gov/preparedness/Pages/default.aspx*. Accessed March 4, 2012.
30. Radiation Emergency Medical Management (REMM) website. *http://www.remm.nlm.gov/*. Accessed March 4, 2012.
31. US Food and Drug Administration. Radiation Safety. Silver Spring, MD: US Food and Drug Administration. *http://www.fda.gov/newsevents/publichealthfocus/ucm247403.htm*. Accessed March 4, 2012.
32. US Food and Drug Administration. Food Facility Registration and U.S. Agent Requirements**.** Silver Spring, MD: US Food and Drug Administration; July 2004. *http://www.fda.gov/Food/FoodSafety/FoodContaminantsAdulteration/ChemicalContaminants/Radionuclides/ucm078341.htm*#guides.
33. US Department of Agriculture. Radiation Safety. US Department of Agriculture website. *http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=radiation_safety.html*. Accessed March 4, 2012.
34. National Security Council website. *http://www.whitehouse.gov/administration/eop/nsc/*. Accessed March 4, 2012.
35. Nuclear Regulatory Commission. *Emergency Planning Zones (EPZs)*. Washington, DC: Nuclear Regulatory Commission. *http://www.nrc.gov/about-nrc/emerg-preparedness/about-emerg-preparedness/planning-zones.html*. Accessed March 4, 2012.

36. Preparedness directorate; protective action guides for radiological dispersal device (rdd) and improvised nuclear device (IND) incidents. *Fed Register*. 2006;71(1):174-180. *http://ogcms.energy.gov/71fr174.pdf*.
37. Borchardt RW. U. S. Environmental Protection Agency revisions to the protective action guidance manual. Washington, DC: US Environmental Protection Agency; June 9, 2011. *http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2011/2011-0078scy.pdf*. Accessed March 17, 2012.
38. Centers for Disease Control and Prevention. *Radioisotope Brief: Iodine-131*. Atlanta, GA: Centers for Disease Control and Prevention; August 18, 2004. *thttp://emergency.cdc.gov/radiation/isotopes/pdf/iodine.pdf*. Accessed March 4, 2012.
39. American Thyroid Association. Toxicity of KI. American Thyroid Association website. *http://www.thyroid.org/?s=toxicity*. Accessed March 4, 2012.
40. US Nuclear Regulatory Commission. *Incident Response Plan*. NUREG-0728. Washington, DC: US Nuclear Regulatory Commission; April 2005. *http://www.nrc.gov/about-nrc/emerg-preparedness/respond-to-emerg/ml050970236.pdf*. Accessed March 4, 2012.
41. Land CE. Estimating cancer risks from low doses of ionizing radiation. *Science*. 1980; 209(4462):1197-1203.
42. Brenner DJ, Doll R, Goodhead DT, et al. Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. *PNAS*. 2003;100(24):13761-13766.
43. National Research Council (NRC). *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: National Academy Press; 2006. *http://www.nap.edu/catalog.php?record_id=11340#toc*.
44. Hall EJ, Giaccia AJ. *Radiobiology for the Radiologist*, 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006.
45. Christodouleas JP, Forrest RD, Ainsley CG, Tochner Z, Hahn SM, Glatstein E. Short-term and long-term health risks of nuclear-power-plant accidents 2011. *N Engl J Med*. 2011;364:2334-2341.
46. The National Academies. *Report in Brief: BEIR VII: Health Risks from Exposure to Low Levels of Ionizing Radiation*. Washington, DC: National Academy Press; 2006. *http://dels-old.nas.edu/dels/rpt_briefs/beir_vii_final.pdf*.
47. Simon SL, Bouville A, Land CE. Fallout from nuclear weapons tests and fallout risks. *Am Scientist*. 2006;94:48-57.
48. Coleman CN, Adams S, Adrianopoli C, et al. Medical planning and response for a nuclear detonation: a practical guide. *Biosecur Bioterror*. 2012;10:346-371.
49. Gilbert E, Land C, Simon SL. Health effects from fallout. *Health Physics*. 2002;82(5):726-735.
50. US Department of State. International travel information. US Department of State website. *http://travel.state.gov/travel/cis_pa_tw/cis_pa_tw_1168.html*.
51. Deyle R, Eadie C, Schwab J, Smith R, Topping K. Policies for guiding planning for post disaster recovery and reconstruction. In: *Planning for Post-Disaster Recovery and Reconstruction*. Washington, DC: American Planning Association; 1998. *http://www.fema.gov/pdf/rebuild/ltrc/fema_apa_ch3.pdf*.
52. Department of Defense. *Joint Publication (JP-5): Joint Operation Planning*. Fort Belvoir, VA: Defense Technical Information Center; August 11, 2011. *http://www.dtic.mil/doctrine/new_pubs/jp5_0.pdf*. Accessed March 4, 2012.
53. Sunstein CR. *Risk and Reason: Safety, Law, and the Environment*. Cambridge, UK: Cambridge University Press; 2002.

https://doi.org/10.1017/dmp.2013.5 Published online by Cambridge University Press