LLNL-JRNL-406691

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Overview of Hazard Assessment and Emergency Planning Software of Use to RN First Responders

E. Waller, K. Millage, W. F. Blakely, J. A. Ross, J. R. Mercier, D. J. Sandgren, I. H. Levine, W. E. Dickerson, J. B. Nemhauser, J. S. Nasstrom, G. Sugiyama, S. Homann, B. R. Buddemeier, C. A. Curling, D. S. Disraelly

September 2, 2008

Health Physics, The Radiation Safety Journal

Disclaimer

LLNL-JRNL-406691

Overview of Hazard Assessment and Emergency Planning Software of Use to RN First Responders

Ed Waller[1]
Author to whom correspondence should be addressed

Kyle Millage[2]

William F. Blakely[3], James A. Ross[3], John R. Mercier[3], David J. Sandgren[3], Ira H. Levine[3], William E. Dickerson[3]

Jeffrey B. Nemhauser[4]

John S. Nasstrom[5], Gayle Sugiyama[5], Steve Homann[5], Brooke R. Buddemeier[5]

Carl A. Curling[6], Deena S. Disraelly[6]

Abstract – *There are numerous software tools available for field deployment, reach-back, training and planning use in the event of a radiological or nuclear (RN) terrorist event. Specialized software tools used by CBRNe responders can increase information available and the speed and accuracy of the response, thereby ensuring that radiation doses to responders, receivers, and the general public are kept as low as reasonably achievable. Software designed to provide health care providers with assistance in selecting appropriate countermeasures or therapeutic interventions in a timely fashion can improve the potential for positive patient outcome. This paper reviews various software applications of relevance to radiological and nuclear (RN) events that are currently in use by first responders, emergency planners, medical receivers, and criminal investigators.*

[1] University of Ontario Institute of Technology, Faculty of Energy Systems and Nuclear Science, 2000 Simcoe St. N., Oshawa, ON, Canada, Email: ed.waller@uoit.ca, Phone: 905-721-8668 x2609, Fax: 905-721-3046
[2] Applied Research Associates, Inc., 801 N. Quincy St., Suite 600, Arlington, VA 22203
Email: kyle.millage@ara.com
[3] Armed Forces Radiobiology Research Institute, 8901 Wisconsin Avenue, Bethesda, MD 20889-5603
Email: blakely@afrri.usuhs.mil
[4] Centers for Disease Control and Prevention, 4770 Buford Highway, NE Atlanta, GA 30341-3717
Email: jnemhauser@cdc.gov
[5] Lawrence Livermore National Laboratory, 7000 East Ave. Livermore, Ca 94550
Email: jnasstrom@llnl.gov
[6] Institute for Defense Analyses, 4850 Mark Center Drive, Alexandria, VA 2231-1882
Email: ccurling@ida.org

INTRODUCTION

A CBRNe device has the potential of harming humans, disrupting the food chain, and/or creating havoc and terror within a populace by use of chemical (C), biological (B), radiological (R), nuclear (N), or explosive (e) means. An explosive or non-explosive radiological dispersal device (RDD) is an example of just such a weapon. In preparing to respond to possible terrorist use of an RDD, rapid and appropriate first response asset allocation, training, and planning are essential.

Airborne release of radionuclides via detonation of an explosive laced with a radioactive source is considered by many to be highly plausible. This is the so-called (R) or radiological scenario. In addition to RDDs, some rogue governments may be both capable and willing to develop low yield nuclear weapons outside of the Non-Proliferation Treaty; non-state sponsored groups may also be capable of producing crude nuclear weapons. As a result, the nuclear (N) threat is also a current reality. Together, planning for the RN threat makes up a significant portion of today's CBRNe preparedness efforts.

Although the detonation of both RDDs and nuclear weapons can generate radioactive particulate matter, unique physical characteristics associated with the explosion of these devices help distinguish one from the other. RDDs generate near-field blast effects, localized distribution of radioactive material, and aerosolized concentrations of radionuclides. This suggests that a primary hazard to the public from such a device (excluding near-field direct radiation and blast effects) is inhalation of radioactive particulate matter, and possibly external radiation from air or ground contamination. By contrast, a large fraction of the energy released from a nuclear weapon is released as a blast wave and thermal pulse that impact a large geographic area. In addition to the prompt release of photon and neutron radiation, significant levels of radioactive material are aerosolized and transported by lower and upper atmosphere winds. The physical nature and magnitude of the particulate release is such that the ground shine dose will present a much greater hazard to the population than will the potential committed dose due to inhalation of radioactive particulates.

Regardless of the type of event, its pertinent physical characteristics, or the resultant health effects on the population, RN events will severely test the ability of government services, first responders, and hospitals to respond in an organized and coordinated fashion. Moreover, it is of vital importance that there be a rapid response at all levels to an RN event.

During the various phases of a response to an incident, software tools can help with a range of critical actions and decisions, which include the following (NCRP, 2001):

- Early phase (minutes to hours)
    - Safe approaches to incident scene
    - Incident command site selection
    - Use of personal protective equipment
    - Evacuation and sheltering to avoid acute and chronic exposure effects
    - Impacted facilities and infrastructure
    - Controlling access to hazard areas by responders and public
    - Medical treatment and decontamination of population
    - Air and ground contamination sampling planning
- Intermediate phase (hours to days) and Late phase (months to years)
    - Restriction of access and relocation of population to avoid chronic exposure effects
    - Decontamination and restoration on contaminated areas

- Control of contaminated agriculture crops and water
- Medical care

The advent of small and powerful computing platforms in the last decade have made it possible for responders and receivers to take the necessary steps to appropriately and quickly respond following an RN event. Newly developed electronic tools now allow incident first responders to make use of robust health physics, predictive models and medical data that formerly only existed in reach-back facilities. National reach-back centers have developed even more detailed and comprehensive, services, software tools and databases using the larger computing and scientific staff capacities that can be housed in such centers.

This paper discusses the various categories of both end users and software applications, and also presents some current software useful to RN first response personnel. Although the list of software presented here is not exhaustive, it does provide a reasonable overview of the types of materials available.

END USER CATEGORIES

A coordinated and integrated RN terrorist event response will necessarily involve a number of diverse groups. As part of this effort, these various groups will be called upon to make assessments (such as patient triage, medical dose assessment, and hazard prediction) that will determine the overall effectiveness of the response. The advent of mobile computing technology, such as personal digital assistants (PDAs) as well as laptop and hand-held personal computers (PCs) has made it possible for software tools to be deployed into the field to facilitate rapid decision making. In addition, the increasing computational power of workstations and the promulgation of internet connectivity have each made it possible for extremely powerful radiological prediction software to be available for use in incident response command posts and reach-back facilities.

For any user, proper response begins with proper training. Regular training, whether overseen by local, State, or federal agencies, is among the most important criteria by which RN response effectiveness can be predicted. Familiarization with and practice using software tools that will be used in the field during a response is critical to team preparation. Training of responders and incident commanders on the proper use of software tools can increase the efficiency of the response and maximize their ability to allocate available assets.

There are, by the nature of first response incident command structure, a number of categories of end-users to consider when identifying software applicability and requirements. These categories are discussed below.

First-on-the-Scene

This category of end user is generally, *ab initio*, the first responder. An RN event will usually (but not necessarily) be indicated by some sort of energetic dispersal of radionuclide (or in the case of a nuclear weapon event, a nuclear detonation). The nature of the dispersal will initiate a response from police, fire, emergency medical services and possibly local military units. It is common for these services to put themselves in harm’s way for the sake of the public’s protection. These responders are first-on-the-scene and their primary functions include hazard mitigation, implementation of security and establishment of safe boundaries, and initial medical management of casualties. It is common that these first-on-the-scene responders have limited knowledge of RN event consequences, and therefore the proper software tools can assist these personnel in primary decision making and patient triage.

CBRNe Responders

Dedicated CBRNe response teams will be deployed to the incident following an assessment of the threat by first-on-the-scene responders. CBRNe response teams will assume responsibility for performing hazard assessment, determining and establishing personal protective equipment (PPE) requirements, conducting contamination surveys and implementing control efforts, making dose estimates, and communicating these efforts to the incident commander. Specialized software tools used by CBRNe responders can increase the speed and accuracy of the response, thereby ensuring that radiation doses to responders, receivers, and the general public are kept as low as reasonably achievable.

Incident Commanders

The incident commander provides overall response oversight. From the onset of the response effort, the incident commander is tasked with guiding the command staff who, in turn, will have teams of responders under their respective control. It is common for the incident commander to establish a command post out of which the command staff will coordinate the response. The incident commander may change as dictated by operational requirements and jurisdictions of agencies involved. There are a number of software tools available to aid incident commanders in identifying required assets, predicting hazard promulgation and conducting dose assessments.

Health Physics Reach-Back

As part of a comprehensive response to an RN event, it is critical to have “reach-back” health physics support, over and above what may be available in the command post. Health physicists called upon to fulfill this reach-back role generally have the resources available to perform more detailed calculations than do the health physics staff serving within the command post. In addition, health physicist(s) serving in this capacity may have the additional advantage of working as part of a larger staff, thereby enabling individual team members to concentrate on specific problems as directed by the incident commander. There are numerous advanced and specialized software tools available to health physicists tasked with the reach-back role.

Hospital Emergency Services

After completion of the field assessment and initial triage of personnel (civilian and non-civilian), exposed, contaminated, and/or injured patients will be transferred to a medical facility. The ability of emergency departments to properly assess and treat persons with ionizing radiation exposure and/or contamination varies widely from location to location. Medical response will be highly dependent on individual emergency health care provider training and departmental commitment to CBRNe response. Typically, the nursing staff will triage patients as they arrive, and physicians and nurses will treat patients based upon presenting signs and symptoms or some other diagnostic technique. Emergency physicians and nurses have experience in managing critically ill and injured patients using pre-scripted algorithms; software tools that collate and simplify presentation of medical triage rules and treatment data can both greatly improve the throughput of patients in the emergency department and assist in diverting uninjured persons concerned about potential exposure to radiation (i.e., the “concerned public”) from overloading the hospital system.

Radiation Biodosimetry

Use of biological dosimetry to individualize treatment will form an important part of the early medical response after an RN event (Blakely, et al., 2005; Alexander et al., 2007). Whether by tracking prodromal clinical signs/symptoms, following lymphocyte counts, or ordering cytogenetics, and/or chromosome aberration analysis studies (the "gold standard"), health care providers will rely upon biodosimetry to guide their decisions concerning management of radiation casualties.

Software designed to collect biodosimetry data and record and track results will help first in the triage process and next in the appropriate implementation of treatment strategies. Although the work of cytogeneticists is typically conducted within a longer time frame than might be considered first response, these efforts nonetheless form an important part of dose assessment follow up. Chromosome aberration analysis represents a key piece of data collected and tracked by biodosimetry software.

Forensic Criminal Investigation

Historically, the criminal investigation into intentional mass casualty events typically begins after an initial response phase during which efforts are directed toward saving lives and critical property. However, evidence collected during this first phase can prove crucial to law enforcement efforts. Evidence in many forms, both radioactive and non-radioactive, may need to be gathered. Detecting radioactive materials used in an RDD or left behind as nuclear weapon residue often requires the use of special analysis techniques. In the aftermath of a nuclear weapon detonation, the debris collection point may be established within a very high radiation field, necessitating the use of robotics or other remote types of retrieval. In this respect, appropriate software can help law enforcement officials determine appropriate collection points, as well as provide analysis and archiving tools for forensic RN data.

SOFTWARE APPLICATION CATEGORIES

Software categorization can help provide potential users with a framework for selecting programs of the greatest possible utility. Several reasonable approaches to software classification systems have been proposed – independent of hazard assessment or emergency response – and each has its relative merits. Examples of software categorization schemes include (a) by operating system, (b) by hardware platform, (c) by computational technique (such as database, deterministic, stochastic), (d) by end user, or (e) by application.

Whereas the aforementioned categories of operating system, hardware platform, and computational technique may dictate the type of software that can be used in the field, none of these parameters has a direct impact on the usefulness of the software application itself. For this reason, these classification systems will not be considered further in this paper. Alternatively, categorization of software by end user may be highly useful. End users (as described in the previous section) will be matched to software tools (described in the next section). In this section, the important application categories, as related to RN event first response, are discussed.

Medical Triage

In the early stages of an RN event, there will be a pressing need for the potentially exposed and/or contaminated population to be triaged into one of several groups: (a) those believed to have been exposed only; (b) those believed to have been contaminated only; (c) those believed to be both contaminated and exposed; and (d) those who have been neither contaminated nor exposed. Radiation exposure at levels characteristic of an RDD are not expected to cause acute symptoms (prodromal effects); hence, these patients will typically not present with the characteristic signs and symptoms of acute radiation poisoning. Nevertheless, these individuals will require some degree of medical attention, diagnostics and appropriate follow-up care.

Once it has been established that a person has been exposed or contaminated, they can then be triaged depending upon the implicated radioisotope, their estimated internal activity (e.g., activity in the lungs), and/or the time since their exposure or contamination occurred. This triage approach can also be useful in the screening of the "concerned public," who may exhibit prodromal symptoms in the absence of true exposure. Medical and first response facilities that lack a comprehensive triage system, can quickly be overwhelmed by the "concerned public," a situation that has been observed in past mass casualty events. Software designed to enable responders to discern those who have been exposed or contaminated from the "concerned public" will facilitate more appropriate resource allocation.

Medical Treatment

By itself, the medical management of radiation injury is complex. In the case of mass casualties, further confounders exist. [See recent review article and the references cited for an update on the current status of medical treatment of radiation injuries in the U.S. (Jarrett et al., 2007).] Health care providers must be able to determine the severity of exposure or the degree of contamination (or both) and then decide upon potential therapies.

For internal contamination, decorporation strategies may be deemed useful. Since the effectiveness of decorporation decreases with time since exposure, timely identification of the internalized isotope(s) is vital. For individuals who have been both exposed and internally contaminated, different treatment strategies based on the hematologic profile of the patient or other prodromal adverse health effects may be appropriate (AFRRI, 2003). Software designed to provide health care providers with assistance in selecting appropriate countermeasures or therapeutic interventions in a timely fashion can improve the potential for positive patient outcome.

Hazard Prediction

Upon detonation of an explosive RDD or low yield nuclear weapon, it is critical for responders to understand the direction of the generated plume, as well as airborne and ground concentration of radionuclides. This information will be used by the incident commander to guide sampling and monitoring efforts, to issue protective action guidance for workers and the public, to recommend specific interventions, and to allocate first response assets. Although measurements are always required to validate and update predictions about the nature of the plume, computer software is routinely used to develop plume evolution models and to estimate radionuclide hazards from inhalation, cloudshine and groundshine, before and, then, after measurements become available. Software to predict physical parameters related to RN dispersal events greatly increases the information available to incident commanders.

Dosimetry

Early response also involves determining the doses of radiation to which responders and the public have been exposed. Exposure dose determination methods include: (a) calculation based upon physical measurements; (b) calculation based upon predicted values; and (c) use of biological markers. The sooner incident commanders and government agencies can assess the scope of the radiation hazard, the sooner it is that response assets may be allocated. Radiation dosimetry software can aid in the determination of individual and collective doses.

Training

Inadequate training of first response personnel will manifest itself as confusion and inappropriate decision making during an RN event. For this reason, the need for proper training is germane to any discussion of CBRNe first response. Two types of software applications should be considered within this category. First, software packages exist that can assist planners in developing and conducting emergency response exercises. Second, exercises should serve as an opportunity to both become familiar with and identify problems associated with any software intended to be deployed during an actual event. For this reason, software designed for use by field responders should be integrated into any and all training exercises.

Some of the software packages described below have specific exercise modes. For example, the HotSpot program can be run on a laptop or palmtop computer equipped with a GPS to provide virtual instrument readings as the user moves in the simulated affected area. This is an important tool in helping responders understand the impact of their decisions on turn back levels, site boundaries, and worker safety.

SOFTWARE TOOLS DESCRIPTION

A number of software tools and applications have been developed over the years that may be of use to RN first response. These tools can be placed into two broad categories:

1. Software of generic applicability, and
2. Software of specific use to CBRNe response

The first category of software includes applications developed, historically, for nuclear power operations, medical radiation techniques, radiation transport and shielding, aerosol transport, radiation dosimetry and general health physics. The second category includes software specifically designed for applicability to nuclear weapons or RDD events.

In the sections below, various software applications of use to the RN first response community are discussed in terms of their use, target end-users, software application category and potential availability. It should be noted that since these software tools are, in general, developed for a particular target user, it is very important that they be used within their intended scope and that users be appropriately trained.

HPAC

The Hazard Prediction and Assessment Capability (HPAC) is a software application that models the transport and dispersion of chemical, biological, radiological and nuclear (CBRN) releases into the atmosphere and predicts the effects of those hazards on civilian and military populations. HPAC was first released in 1992 and continues to be improved through development funding by the Defense Threat Reduction Agency (DTRA). HPAC includes several integrated source terms for chemical and biological hazards, as well as for radiological dispersal devices (RDDs), nuclear facility accidents, and nuclear weapon detonations. The transport engine for the HPAC software, a second-order closure, integrated puff (SCIPUFF) model is based on a 3-dimensional puff methodology. The transport and dispersion calculation utilizes local terrain effects, including urban terrain, and can utilize real-time weather input. The airborne concentration and downwind deposition of the hazard plumes are calculated and the results can be used to predict human effects. As a result, the model can plot not only airborne and deposited activity concentrations, but also internal and external dose estimates. In addition, casualty predictions are estimated based on both prompt nuclear weapon effects and protracted radiation exposure.

HPAC is used by both military and civilian users for planning, training and exercises, as well as for real-time assessments of on-going incidents. Requests for HPAC software can be made at the following website: https://acecenter.cnttr.dtra.mil/registration/mainpage.cfm.

HotSpot

The HotSpot codes provide emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating radioactive airborne hazards using a Gaussian plume model. The software is also used for safety-analysis of facilities handling nuclear material. Hotspot provides a fast and usually conservative means for estimation the radiation effects associated with the short-term (less than 24 hours) atmospheric release of radioactive materials over short distances (less than 10 kilometers). HotSpot can be used for quick, initial estimates of the near-term, near-field dose and effects.

The HotSpot plume model, as well as the more advanced NARAC plume modeling system described below, have options for a general point source, fire dispersal and explosive dispersal of radioactive material. Dose can be calculated due to plume passage, inhalation, submersion, ground shine and resuspension, as well as ground deposition. A nuclear explosion model calculates fallout dose and dose rate, and prompt nuclear effects, blast overpressure, thermal radiation, and ionizing radiation. HotSpot and NARAC incorporate Federal Guidance Reports 11, 12, and 13 (FGR-11, FGR-12, FGR-13) Dose Conversion Factors (DCFs) for inhalation, submersion, and ground shine. In addition to the inhalation 50-year Committed Effective Dose Equivalent DCFs, acute (1, 4, 30 days) DCFs are available for estimating deterministic effects. This acute mode can be used for estimating the immediate radiological impact associated with high acute radiation doses (applicable target organs are the lung, small intestine wall, red bone marrow, and thyroid).

The Hotspot program has an exercise mode that can help illustrate what the responder's instrument would actually be reading at the scene of an incident. Maps can be imported into HotSpot, and the contamination contours can be overlaid on them. Virtual instrument readings are provided by attaching a GPS unit to the computer, or by simply hovering the cursor over point of interest on the map. Many common instruments are programmed into HotSpot, and the user has the ability to add instruments used by their response team. Special purpose programs are also included in HotSpot, including FIDLER Calibration and Lung Screening, and Radionuclides in the Workplace.

HotSpot is maintained by NARAC at Lawrence Livermore National Laboratory (LLNL) for the U.S. Department of Energy National Nuclear Security Administration's Office of Emergency Response. The HotSpot software is available via Web download: https://www-gs.llnl.gov/hotspot.

NARAC/IMAAC

The National Atmospheric Release Advisory Center (NARAC) and the Interagency Modeling and Atmospheric Assessment Center (IMAAC) maintain a distributed modeling system, which provides airborne plume modeling and geographical information tools for deployment to an end user's computer system as well as real-time access to an advanced suite of three-dimensional meteorology and plume/fallout models from a reach-back center at Lawrence Livermore National Laboratory (LLNL). This system includes extensive global geographical and real-time meteorological databases to support model calculations. The 3-D NARAC modeling system complements the simple, fast-running HotSpot software, by providing more detailed, longer range plume simulations that account for complex meteorology and terrain effects. NARAC models can simulate chemical, biological, radiological, and nuclear material dispersal from fires, industrial and transportation accidents, radiation dispersal devices, hazardous material spills, sprayers, nuclear power plant accidents, and nuclear detonations.

The *NARAC-IMAAC Web* and the *NARAC iClient* software tools provide authorized government users with the ability to run HotSpot, as well as run fully-automated three-dimensional plume model predictions using the ADAPT/LODI modeling system in 5 to 15 minutes on LLNL servers. NARAC software tools provide an easy-to-use map viewer to display plume predictions, and reports that include affected population counts, casualty/fatality count estimates, air/ground contamination and dose levels, and EPA Protective Action Guide information. The suite of models and databases used by NARAC for atmospheric dispersion, fallout, and effects calculations were described by Nasstrom, et al. (2006).

The *NARAC-IMAAC Web* also allows users to obtain reach-back analyses from scientists at LLNL and collaborating organizations, and share model predictions with other users via a password-controlled Web site. Reach-back staff provide 24/7 technical/scientific subject matter expertise and detailed weather, plume and fallout model analyses. They can use field measurement data to refine plume model simulations and estimate unknown source amounts.

The primary sponsors of the center at LLNL are the Office of Emergency Operations in the U.S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA), the Interagency Modeling and Atmospheric Assessment Center (IMAAC) of the U.S. Department of Homeland Security (DHS); and the U.S. Naval Reactor program. Under the National Response Plan (NRP) Notice of Change May 2006, the IMAAC's mission is to serve as the "single point for the coordination and dissemination of Federal dispersion modeling and hazard prediction products that represent the Federal position during actual or potential incidents requiring federal coordination", including Incidents of National Significance. LLNL manages IMAAC Operations and coordinates use of the best available capabilities of participating agencies. The current IMAAC Federal partners are the Department of Homeland Security, the Department of Defense, the Department of Energy, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration (Department of Commerce), the Nuclear Regulatory Commission, the National Aeronautics and Space Administration, and the Department of Health and Human Services. More information can be found at http://narac.llnl.gov.

CHRNEM

The Combined Human Response Nuclear Effects Model (CHRNEM) is a DOS software application that models combined injury from nuclear weapon effects, estimating human response to simultaneous ionizing radiation (R) blast overpressure (B), and thermal flash burn (T) insults. The effects of these injuries are expressed in terms of performance over time – a soldier's continued ability to perform physically undemanding and demanding tasks following a nuclear event. After applying a series of insult and performance-based rules, the user can estimate the total number of people who are injured and become casualties, the number of casualties caused by types of insult (i.e. R-B-T or R-T casualties), and the number of fatalities over time. (Levin 1993, Levin and Fulton 1993)

The program uses a three-dimensional logarithmic interpolation routine for performance estimation at various insult levels. The program includes related algorithms for evaluating symptoms vs. dose and time, crew performance, equivalent prompt dose from a detonation plus fallout event sequence, mortality probability, and early transient incapacitation probability. Psychological or "battle fatigue" casualties are estimated with an independent technique based on expert evaluation and data analysis for highest correlation to actual battle experience.

CHRNEM includes estimates of nuclear environments as a function of range from a low air burst generic fission weapon of yields ranging from 0.1 to 500 kT, or the user can put in their own environment estimates. Any values of radiation, thermal, and blast (within the permitted ranges) can be entered instead of using the weapon model. Multiple values of one of these can be accommodated to produce families of performance vs. time curves when plotted. Both plotted and tabular results can be produced. CHRNEM will also estimate psychological casualties (battle fatigue cases) based on an algorithm which considers the population density and cohesiveness, whether or not there is a warning of the nuclear event, and the yield of the weapon. CHRNEM has not been accredited by the DoD, although it has been in use for several years both within the United States and other countries. Although questions on the validity and quality of the tool have arisen, CHRNEM and related models may be the best available representations for conducting combined injury estimates following a nuclear detonation.

RIPD/RIPDLIPI

The Radiation Induced Performance Decrement (RIPD) software is an application that models the probability of injury and mortality from protracted exposure to a radiation field. The RIPD Lethality and Injury Probability Interpolation (RIPDLIPI) is a fast-running tool based on RIPD calculations for the radiation dose rate profile associated with exposure to fallout from a nuclear detonation. RIPDLIPI is the casualty estimation tool for protracted radiation exposure implemented into the Hazard Prediction and Assessment Capability (HPAC) software package. The RIPD code uses a quantitative description of the sign/symptom severities of acute radiation sickness (ARS) developed in the early ‘80s. The six categories of the major signs and symptoms of ARS are: 1) Upper Gastrointestinal Distress (UG), 2) Lower Gastrointestinal Distress (LG), 3) Fatigability and Weakness (FW), 4) Fluid Loss and Electrolyte Imbalance (FL), 5) Infection and Bleeding (IB), and 6) Hypotension (HY). The RIPD code estimates a probability of injury based on the incidence of UG and FW symptoms. It calculates a severity level for each of the six sign/symptom categories, which are in turn used to estimate decrements in human performance capability. The RIPD code also estimates the incidence of mortality and the typical time of mortality using a bone marrow cell kinetic model.

The target users of RIPD are both military and civilian and RIPD is most useful for planning, training and exercises, although it may be used for real-time assessments of on-going incidents.

NBC CREST

The medical Nuclear, Biological, and Chemical Casualty Resource Estimation Support Tool (NBC CREST) performs two key functions: casualty estimation for an NBC scenario and analysis of resource allocation necessary to effectively treat those casualties. The casualty estimation capability will not only predict the number of injuries and fatalities, but also the level of the injury, and the time-dependent nature of the injury progression. The casualty calculations include the individual and combined effects from the blast overpressure, thermal pulse and prompt radiation from a nuclear weapon event. The resource estimation module uses information from the Defense Medical Standardization Board (DMSB) Task, Time and Treater (TTT) files and Deployable Medical Systems (DEPMEDS) databases to compute the time-phased resource requirements for the casualty stream. These data are presented as a series of Excel spreadsheets that can be manipulated by a logistician. The types of resources estimated include bed usage, equipment, blood and other materiel, personnel by occupational specialty, transports, and evacuation resources. The tool can assign the resource consumption to specific medical treatment facilities, allowing the medical planner to optimize the medical footprint and the evacuation network by performing an iterative analysis to eliminate resource shortfalls. NBC CREST was developed in conjunction with the Army Office of the Surgeon General and the Defense Threat Reduction Agency (DTRA).

Currently, NBC CREST is primarily targeted for military users for planning, training and exercises, as well as for real-time assessments of on-going incidents.

BAT

The Biodosimetry Assessment Tool (BAT) is a comprehensive software application developed by the Armed Forces Radiobiology Research Institute (AFRRI) for recording patient-specific diagnostic medical information in suspected radiological exposures (Sine et al., 2001; Salter et al., 2004). An updated application (Version 1.03) was released in September 2007. BAT operates under the Microsoft Windows operating system (XP) and provides data-collection templates for dynamically recording data in seven folders including: physical dosimetry, contamination/wound, prodromal symptoms, hematology, lymphocyte cytogenetics, erythema, and infection. The software application includes the additional features of dose assessment algorithms for: i) onset of vomiting, ii) lymphocyte cell count, and iii) lymphocyte cell depletion kinetics. A body-mapping tool permits recording the body locations for: a) physical dosimeters, b) erythema/wounds, and c) radioactivity contamination. Five additional screens permit recording: 1) overview information, 2) patient's report, 3) exposure information, 4) radioisotope information, and 5) physician's notes. BAT also includes a summary report feature with the ability to output a report file compatible with the NATO Standardization Agreement (STANAG 2474 NBC/MED) entitled "Determination and Recording of Ionizing Radiation Exposure for Medical Purposes". The application is extensively documented internally and can also serve as a training tool for use in a variety of radiological scenario exercises. BAT is distributed on-line upon review of a download request application accessible at website www.afrri.usuhs.mil.

FRAT

The First-responder Radiological Assessment Triage (FRAT) is a software application being developed by the AFRRI to enable first responders to triage suspected radiation casualties based on the prodromal features listed in the Emergency Radiation Medicine Response—AFRRI Pocket Guide [AFRRI, 2008]. FRAT is being developed initially for the Palm operating system for personal digital assistant (PDA) devices, and may eventually be available for other PDA devices. With minimum text entry, FRAT provides screens to record and analyze: (1) signs and symptoms, (2) blood lymphocyte counts, and (3) dosimetry data. An expert panel provided input to permit weighing these multiple individual biodosimetric indices. The program will assess the multiparameter triage dose or the exposure without an assigned dose, or it will indicate there is no evidence of overexposure. Additional

FRAT output features include triage dose-specific messages addressing (1) hematology guidance, (2) reliability and diagnostic information, (3) hospitalization estimations, and (4) mortality projections. The application can also serve as a training tool for use in a variety of radiological scenario exercises (Blakely et al., 2007).

MEDECOR

After a radiological dispersal device (RDD) event, it is possible for radionuclides to enter the human body through inhalation, ingestion, skin and wound absorption. From a health physics perspective, it is important to know the magnitude of the intake to perform dosimetric assessments. From a medical perspective, removal of radionuclides leading to dose aversion is of high importance. The efficacy of medical decorporation strategies is extremely dependant upon the time of treatment delivery after intake. The "golden hour", or more realistically 3-4 hours, is imperative when attempting to increase removal of radionuclides from extracellular fluids prior to cellular incorporation. To assist medical first response personnel in making timely decisions regarding appropriate treatment delivery modes, it is desirable to have a software tool which compiles existing radionuclide decorporation therapy data and allows a user to perform simple diagnosis leading to potential appropriate decorporation treatment strategies. Sponsored by the Canadian Department of National Defence (DND), the software application entitled MEDECOR (MEDical DECORporation) was developed. The MEDECOR tool was designed initially for use in either a PDA or laptop PC environment using HTML/Jscript to allow for ease of portability amongst different computing platforms.

The target end users are trained EMS first responders, triage nurses and physicians. The software falls under the categories of both medical triage and medical treatment. The availability is through the Department of National Defence (CANADA).

REMM

The Radiation Event Medical Management (REMM) web portal (http://www.remm.nlm.gov), produced by the Department of Health and Human Services (DHHS), Office of the Assistant Secretary for Preparedness and Response, was formally launched by DHHS in March, 2007. REMM was (and is) produced in cooperation with the National Library of Medicine, Division of Specialized Information Services, in collaboration with subject matter experts from the National Cancer Institute and the Centers for Disease Control and Prevention. Many US and international consultants provide ongoing support and oversight of the information included on REMM.

The REMM web portal was conceived as a comprehensive resource for health care providers (primarily, although not exclusively physicians) who may be called upon to respond to victims of a mass casualty RN event. REMM includes information and guidance about clinical diagnosis and treatment; it also provides users with just-in-time, evidence-based, usable information supplemented with sufficient background and context to make complex issues understandable to those without a formal background or expertise in radiation medicine. Examples of guidance found on REMM include: easy-to-follow procedures for diagnosis and management of radiation contamination and exposure, recommendations for the use of radiation medical countermeasures, and a variety of other features to facilitate medical response.

In addition to online access, the information on REMM is available (and intended) to be downloaded to laptop and desktop computers in the event of a loss of internet connectivity (e.g., during training or for deployment in an actual event). Users can also register for automatic e-mail updates to alert them whenever information is changed, added to, or otherwise updated on the REMM web portal. Future plans for REMM include formatting the information for use on Personal Digital Assistant (PDA) devices, additional multimedia graphics, and expanding the current list of topic areas to include subjects such as the Cutaneous Radiation Syndrome and management and follow-up patient care for the chronic effects of radiation exposure and/or contamination.

AFRRI-CD

The Radiation Training and Assessment Tool CDROM contains a suite of resources developed by the AFRRI Military Medical Operations (MMO) Directorate to facilitate training and medical management responses for radiation casualty incidents. The CDROM operates under the Microsoft Windows operating system (XP) and an updated version (Fourth Edition) was released in December 2007. The CDROM application is organized as: a) guidance documents, b) medical record forms, c) extensive additional resources, and d) the Biodosimetry Assessment Tool software application. The casualty management guidance section contains: 1) AFRRI's Pocket Guide—Emergency Radiation Medicine Response (2007; PDF and HTML format), 2) AFRRI's Medical Management of Radiological Casualties Handbook, Second Edition (2003; PDF and HTML format), 3) National Council of Radiation Protection and Measurements (NCRP) – Quick Reference Information, adapted from NCRP Report 65 (Management of Persons Accidentally Contaminated with Radionuclides) (PDF format), and 4) internal contamination guidance documents (PDF format) related to use of potassium iodide, Prussian Blue (Radiogardase), and U.S. Army's policy for management of Army personnel exposed to depleted uranium. The medical record forms section contains: i) Adult/Pediatric Field Medical Record, ii) Biodosimetry Worksheet, and iii) Radiocesium Worksheet; all in annotatable PDF format. The resource sections consist of descriptions of the AFRRI's Medical Radiobiology Advisory Team (MRAT) and Medical Effects of Ionizing Radiation Course (MEIR), emergency contact information, website links for additional information, and numerous relevant publications on the medical management of radiation casualties. The CDROM also contains the AFRRI Biodosimetry Assessment Tool (BAT) software application. The MMO CDROM is distributed to registered attendees of the MEIR course.

In addition to the specialty codes listed above, there are a number of other codes extremely useful to the health physicist that may be responsible for responding to an RN event. Some of these codes are considered below.

Shielding Codes

There are a number of codes available to perform radiation shielding calculations, ranging from point kernel approximations, to deterministic techniques to Monte Carlo simulation. For the first responder, shielding analysis can be very important for determining required protective measures. The primary drawback of performing numerical shielding analysis is that it generally requires special expertise to generate accurate results. The greatest need for shielding analysis comes from the RDD scenario which uses a gamma emitting radionuclide. One of the most simple to use shielding codes commercially available is the Microshield code, discussed below.

Microshield (Grove, 2008) is a extremely simple analytical (point kernel) photon shielding code that is useful for determining doses from a number of fixed geometries, source configurations and shielding materials. The user simply needs to select a pre-defined geometry similar to their situation, select shielding materials, select a source, and run the calculation. Although it is limited to photon shielding problems, this source category encompasses the principle RDD scenarios that require shielding calculations to be performed. Fluence rate and a number of dose rate evaluations are provided in the output. Microshield is available from Grove Software Inc. at http://www.radiationsoftware.com/mshield.html

More sophisticated shielding calculations generally require a more sophisticated technique. The advent of the modern computer platform makes it possible for full three-dimensional Monte Carlo analysis to be performed in the field on a laptop. The caveat is that, although a point kernel code may be mastered by someone with rudimentary shielding skills, a Monte Carlo simulation requires an expert user. Candidate codes for the first response community are the Monte Carlo Neutral Particle codes: **MCNP** (MCNP, 2008) or the eXtended capabilities version **MCNPX** (MCNPX, 2004). An expert user can quickly generate the required geometry, source and detector input parameters for even a moderately complicated scenario and generate accurate results relatively quickly. The flexibility of these codes are balanced by the user expertise required. Both MCNP and MCNPX are available through the Radiation Safety Information Computational Center (http://www-rsicc.ornl.gov/). As an alternative to MCNP(X), the European code GEANT (2006) is available, also requiring expert users. **GEANT** is available at http://geant4.web.cern.ch/geant4/.

Internal Dosimetry

One of the greatest radiological threats from an RDD is the threat of inhaled radionuclides from device aerosolization. The determination of internal dose is critical to determining triage and understanding treatment requirements. Simple committed effective dose calculations can be performed by assessing intake and using appropriate dose conversion factors. For example, **ICRP68/72 CD-ROM** of dose conversion factors is available (ICRP, 2001). For more complicated bioassay assessments, compartment codes to solve the differential equations governing the movement of radionuclides in the body are required.

The Integrated Modules for Bioassay Analysis (**IMBA**, 2005) is a software application that allows a user to perform detailed internal dosimetry assessments, both dose calculations and bioassay. The bioassay module allows a user to define an intake regime (inhalation, ingestion, injection, wound, or vapour), timeframe (acute or chronic) and radionuclide/intake (activity), and is capable of generating bioassay data (for example, excretion in urine, feces, etc) and effective dose. An alternate calculation mode allows the user to specify bioassay data (as may be available forensically after an RDD event) and estimate intake (hence dose). IMBA is a simple to use GUI oriented application, although departure from default model parameters requires the user to have expertise with internal dosimetry. IMBA Professional Plus is available at http://www.imbaprofessional.com.

Multi-Purpose Radiological Codes

There are a number of codes that provide extremely useful data for radiological assessments that are of use to the RN first responder. The following codes represent a useful sub-set of many general purpose applications.

RadProCalculator provides the user with a toolset to perform (i) simple half-life related calculations, (ii) dose-rate to activity type calculations (beta and gamma emitters) for point sources, including shielding, (iii) calculation of bremsstrahlung dose, with shielding, (iv) simple x-ray device dose, with shielding, (v) ALARA type calculations, (vi) Uranium and Plutonium activity to mass calculations, (vii) simple units conversion, (viii) uranium enrichment calculations, and (ix) detection limit statistics calculations. Data is presented directly and can be exported to a spreadsheet. RadProCalculator can be obtained here: http://www.radprocalculator.com/Index.aspx

The radiological toolbox (**Rad ToolBox**) is an electronic handbook with an abundance of data important to calculating exposure to radionuclides and assessment of hazard. The toolbox contains radioactive decay data, biokinetic data, internal and external dose coefficients (with simple internal dose calculations), elemental composition of a large number of materials, radiation interaction coefficients, kerma coefficients, and other tabular data of interest to the health physicist, radiological engineer, and others working in fields involving internalization of radionuclides. The toolbox includes a means to export the tabular data to an Excel worksheet for use in further calculations. The RadProCalculator and Rad Toolbox together provide a suite that enables the user to perform simple calculations related to external and internal dosimetry. Rad Toolbox can be obtained here: http://ordose.ornl.gov/

Radiation Decay and **NUCHART** are useful programs for obtaining radiological and physicochemical properties of radionuclides. The programs allow the user to select the element and isotope of interest using a simple graphical user interface (either list based or period table based lookups), and presents information such as half-life, decay series, and particle types and energies emitted during decay.

Radiation Decay can be obtained at http://www.radprocalculator.com/RadDecay.aspx and NUCHART can be obtained at http://www.iaea.or.at/programmes/ripc/physics/faznic/nuchart.htm .

CONCLUSIONS

The potential impacts of a radiological or nuclear (RN) event can place on government services, first responders and hospitals can be overwhelming. It is therefore of vital importance to ensure rapid response at all levels. The advent of small and powerful computing platforms in the last decade have made it possible to take rich health physics and medical data that only existed in reach-back facilities and bring it forward to the incident responders. Furthermore, reach-back centers and client-server software tools are making it easier to access even more advance software tools and databases (e.g., such as from the NARAC/IMAAC center for weather data, plume modeling and scientific reach-back support) when more detailed analysis and expertise is needed for major planning or response activities.

This paper provided an overview of some of the various categories of both end users and software applications, and also presents some current software of use to RN first response personnel. The list presented here is not exhaustive, but does provide a representation of the depth and breadth of software tools available.

ACKNOWLEDGEMENTS

Dr. Blakely acknowledges the contributions by AFRRI colleagues (W. E. Jackson, C. A. Salter), collaborator (Dr. Ronald Goans, MJW Corporation), and the AFRRI for supporting his research under work unit BD-02.

Dr. Waller acknowledges Ray McGinnis (developer of RadProCalculator) for his input, and his collaborator on MEDECOR, Dr. Diana Wilkinson (Defence R&D Canada – Ottawa).

Portions of this work were performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Finally, the authors wish to acknowledge the efforts of the numerous developers and contributors, past and present, to the codes described in this paper.

REFERENCES

AFRRI, Medical Management of Radiological Casualties – Handbook, Second Edition, 2003.

AFRRI, AFRRI Pocket Guide: Emergency Radiation Medicine Response, accessed on July 30, 2008 at website http://www.afrri.usuhs.mil/.

Alexander GA, Swartz HM., Amundson SA, Blakely WF, Buddemeier B, Gallez B, Dainiak N, Goans RE, Hayes RB, Lowry PC, Noska MA, Okunieff P, Salner Al, Schauer DA, Trompier F, Turteltaub KW, Voisin P, Wiley AL Jr., and Wilkins R. BiodosEPR-2006 Meeting: Acute dosimetry consensus committee recommendations on biodosimetry applications in events involving uses of radiation by terrorists and radiation accidents. Radiation Measurements 42(6-7):972-996; 2007.

Blakely WF, Salter CA, and Prasanna PG. "Early-response biological dosimetry--recommended countermeasure enhancements for mass-casualty radiological incidents and terrorism", Health Phys. 89(5):494-504; 2005.

Blakely WF, Ossetrova NI, Manglapus GL, Salter CA, Levine IH, Jackson WE, Grace MB, Prasanna PGS, Sandgren DJ, and Ledney GD. "Amylase and blood cell-count hematological radiation-injury biomarkers in a rhesus monkey radiation model—use of multiparameter and integrated biological dosimetry", Radiation Measurements 42(6-7), 1164-1170; 2007.

Bunker A. "The ICRP Database of Dose Coefficients Workers and Members of the Public", Journal of Radiation Protection, Vol. 19: 290; 1999.

DTRA. Defense Threat Reduction Agency (DTRA) Assessment of Catastrophic Events Center (ACECenter) Public Page: http://www.dtra.mil/rd/programs/acec/hpac.cfm; accessed February 2007.

Allison J. GEANT4 Developments and Applications, IEEE Trans Nuc. Sci., Vol. 53 : 270-278; 2006.

GROVE. Microshield Version 7.02, Grove Software Inc., Lynchburg, VA; 2008.

ICRP. ICRP Database of Dose Coefficients: Workers and Members of the General Public, Version 2.0.1, ICRP 68/72; 2001.

IMBA. User Manual for IMBA Professional Plus Version 4, Health Protection Agency, Chilton, UK; 2005.

Jarrett DG, Sedlak RG, Dickerson WE, and Reeves GI. "Medical treatment of radiation injuries—current U.S. status", Radiation Measurements 42(6-7):1063-1074; 2007.

Levin SG. The effect of combined injuries from a nuclear detonation on soldier performance. Defense Nuclear Agency; Alexandria: AD-B175 117; 1993.

Levin SG, and Fulton JW. Consolidated human response nuclear effects model (CHRNEM). Defense Nuclear Agency; Alexandria: AD-B176 745; 1993.

MCNP. MCNP – A General Monte Carlo N-Particle Transport Code – Version 5, Los Alamos National Laboratory, LA-UR-03-1987; 2003.

MCNPX. MCNPX Extensions Version 2.5.0, Los Alamos National Laboratory, LA-UR-04-0570; 2004.

Nasstrom, J.S., G. Sugiyama, R. L. Baskett, S.C. Larsen, and M.M. Bradley, "The NARAC Modeling and Decision Support System for Radiological and Nuclear Emergency Preparedness and Response", *Int. J. Emergency Management*, **4**, 3, 2006

NCRP. Management of Terrorist Events Involving Radioactive Material, National Council on Radiation Protection and Measurements (NCRP) Report No. 138, Bethesda, MD; 2001.

Sine RC, Levine, IH, Jackson WE, Hawley AL, Prasanna, PG, Grace MB, Goans RE, Greenhill RG, and Blakely WF. "Biodosimety Assessment Tool: a post-exposure software application for management of radiation accidents", Mil. Med. 166(12 Suppl):85-7; 2001.

Salter CA, Levine IH, Jackson WE, Prasanna PGS, Salomon K, and Blakely WF. Biodosimetry tools supporting the recording of medical information during radiation casualty incidents. In: *Public Protection from Nuclear, Chemical, and Biological Terrorism.* Health Physics Society 2004 Summer School, Gaithersberg, MD: Health Physics Society, 481-488; 2004.