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NARAC: An Emergency Response Resource for Predicting the Atmospheric Dispersion and Assessing the Consequences of Airborne Radionuclides

Michael M. Bradley

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NARAC: An Emergency Response Resource for Predicting the Atmospheric Dispersion and Assessing the Consequences of Airborne Radionuclides

Michael M. Bradley[1]

[1] *National Atmospheric Release Advisory Center, Lawrence Livermore National Laboratory, L-103, P.O. Box 808, Livermore, California, USA (mbradley@llnl.gov)*

INTRODUCTION

Hazardous radioactive materials can be released into the atmosphere by accidents at nuclear power plants, fuel processing facilities, and other facilities, and by transportation accidents involving nuclear materials. In addition, the post-cold-war proliferation of nuclear material has increased the potential for terrorism scenarios involving radiological dispersal devices, improvised nuclear devices, and inadequately secured military nuclear weapons.

To mitigate these risks, the National Atmospheric Release Advisory Center (NARAC) serves as a national resource for the United States, providing tools and services to quickly predict the environmental contamination and health effects caused by airborne radionuclides, and to provide scientifically based guidance to emergency managers for the protection of human life. Located at the United States Department of Energy's (DOE) Lawrence Livermore National Laboratory, NARAC supports DOE facilities, DOE emergency response teams, and the Department of Homeland Security's (DHS) Interagency Modeling and Atmospheric Assessment Center (IMAAC). NARAC's original mission was limited to radiological releases, but during the 26 years since its inception NARAC also has developed capabilities to predict the atmospheric dispersion and health effects of hazardous chemicals and biological materials.

SERVICES PROVIDED BY NARAC

NARAC provides its customers with easy-to-use, real-time access to plume predictions and consequence analysis, enabling them to rapidly determine hazard areas, affected population, meteorological conditions, and relevant geographical information. There are three modes though which NARAC supports its customers.

The *NARAC Web* provides basic NARAC service to the user without requiring any special expertise, training, equipment, or software. NARAC web plume predictions use the same computer models that are used by NARAC staff. In addition to initiating and receiving plume predictions, the NARAC Web allows the NARAC staff and all NARAC users to instantly share plume prediction results with other specific users or groups of users.

The next level up in the hierarchy of access modes is the *NARAC iClient*. The iClient provides the user with more advanced capabilities, such as the ability to specify more complex atmospheric release scenarios and additional options for analyzing NARAC's predictions. iClient users can instantly share their results with NARAC Web users. The iClient software also allows users to do plume predictions using streamlined stand-alone models that run locally on their own laptop or desktop computers, without reaching back to NARAC.

The most powerful NARAC capabilities are provided by the NARAC Operations Team, that is available 24x7x365 for emergencies responses. Much more than just models and computers, NARAC is a full-service organization, and its most valuable resource is its professional staff. Working from the NARAC Operations Center, experienced scientists interact directly with emergency managers throughout the duration of an event, providing real-time plume predictions and emergency response guidance for a wide variety of hazardous atmospheric releases. The NARAC staff has access to additional modeling options, and can develop detailed and customized model predictions for special purposes. They also can refine model predictions, using field measurements of radioactivity in the air and on the ground.

In a typical emergency response, the remote stand-alone capability provides initial plume estimates within less than one minute. Within 5 to 15 minutes, the reach-back capability delivers a higher-fidelity, automated initial plume prediction from NARAC. Then, throughout the course of an ongoing emergency response, NARAC continues to provide technical and scientific support, including quality assuring model input data and predictions, refining calculations by iteratively combining field measurements with model predictions, and assessing the long-term consequences of the atmospheric release.

NARAC'S TOOLS AND CAPABILITIES

Atmospheric Transport and Diffusion Models

NARAC's scientists have developed a diverse tool kit of numerical modeling capabilities to respond to different types of release events, distance scales (local, regional, continental, and global), and response times. For regional-to-global-scale atmospheric dispersion, NARAC's primary tool is the LODI (Lagrangian Operational Dispersion Integrator) three-dimensional dispersion model, which was developed by NARAC to simulate the processes of advection, turbulent diffusion, radioactive decay, first-order chemical reactions, wet deposition, gravitational settling, dry deposition, and buoyant/momentum plume rise. NARAC uses a Lagrangian, rather than Eulerian, model because the Lagrangian approach avoids numerical dispersion, can resolve point sources, and can simulate turbulent diffusion in greater detail.

The iClient software's stand-alone, fast-running Gaussian plume and puff dispersion models provide almost instantaneous initial response calculations for emergencies (usually followed by higher-fidelity reach-back calculations), simple screening calculations, and a back-up capability for remote users if communications failures preclude reach-back to NARAC.

For detailed simulations of the airflow and dispersion of airborne material around buildings, NARAC uses the FEM3MP Computational Fluid Dynamics (CFD) model (Chan and Stevens, 2000). Although more computationally intensive than LODI, FEM3MP can simulate the dynamics of turbulent flows and represent fine-scale features, such as flow jetting between obstacles, impingement and separation regions, wake vortices, recirculation zones caused by obstacles or terrain features, and the lingering of contaminant material in recirculation zones behind buildings after the main body of a plume has moved farther downwind.

Validation studies using analytic mathematical solutions, field experiments, and data from actual accidents has shown that NARAC's models can accurately simulate atmospheric dispersion on local, regional, and continental scales. The most recent field experiment was conducted cooperatively with the Chinese Institute of Radiation Protection at the Qinshan Nuclear Power Plant, Zhejiang Province, China, in July of this year.

Numerical Diagnostic Weather Model

The LODI model uses two types of three-dimensional, time-varying weather data to characterize the atmosphere in the vicinity of an event: *observations* of actual weather conditions (from surface stations, rawinsondes, and profilers), and *predictions* of weather conditions from numerical weather prediction models. The weather data for LODI simulations is pre-processed by the ADAPT model (Sugiyama and Chan, 1998), which assimilates the appropriate atmospheric data and land-surface characterization data, and constructs three-dimensional, gridded, fields of dynamically balanced winds, pressure, precipitation, temperature, and turbulence quantities. ADAPT typically processes real-time observational data for input to LODI in less than one minute.

Numerical Weather Prediction Models

For ongoing atmospheric releases that are expected to continue for hours or days, and for threatened future atmospheric releases (such as for a terrorist scenario), LODI uses prognostic data from numerical weather prediction (NWP) models. NWP models predict future three-dimensional atmosphere states by solving the conservation equations for mass, momentum, and thermodynamic energy. These models represent the relevant physical processes for moisture, cumulus convection, and radiation, and subgrid-scale turbulence. NARAC also uses NWP models to provide current or past atmospheric conditions for LODI simulations over geographical areas devoid of weather observations.

NARAC routinely runs its own version of the Naval Research Laboratory's (NRL) Coupled Oceanographic and Atmospheric Mesoscale Prediction System (COAMPS) model (Hodur, 1997), which can produce forecasts for any region on Earth. NARAC has developed an urban canopy parameterization for COAMPS (Chin et al., 2005), that improves the representation of urban flow fields. Several external agencies provide NARAC with continuous flows of forecast data from NWP models, including the National Weather Service (NWS) GFS model, the U.S. Navy NOGAPS model, the NWS ETA model, and the NWS RUC model. NARAC also can obtain data from external organizations that run the COAMPS and MM5 models.

Models of Hazardous Material Sources

Atmospheric dispersion models require information about the mass or activity released into the atmosphere, and the emission rate, height, spatial distribution, and particle size distribution. For nuclear power plant accidents, NARAC uses the Nuclear Regulatory Commission's (NRC) RASCAL model (Sjoreen, et al., 2001) for source term estimates based on plant conditions. NARAC and NRC have developed an interface to quickly import nuclear power plant source terms into the RASCAL model. For radiological dispersal devices (such as explosives and sprayers), NARAC uses source characteristics from Sandia National Laboratories. The gross activity, spatial distribution, and particle size distribution of stabilized nuclear debris clouds for nuclear detonations are calculated according to Harvey and Serduke (1979). Buoyancy-driven and/or momentum-driven plume rise from continuous sources such as fires or stack emissions is computed by LODI. The CAMEO/ALOHA software and associated databases (EPA, 1999a and 1999b) are used for chemical material properties and toxic industrial chemical releases mechanisms (such as leaking tanks).

Prediction Refinement using On-Scene Radiological Measurements

When responding to radiological events, NARAC works closely with other DOE teams who rapidly deploy to the location of the event to take surface and airborne measurements of radioactivity. In an iterative process, NARAC's plume predictions guide the measurement teams, and their measurements, in turn, are used to refine NARAC's predictions.

Supporting Databases

In addition to continuously collecting and archiving immense quantities of "perishable" weather observations and NWP model forecasts from around the world, NARAC also maintains extensive databases of terrain elevation, land-surface characteristics, and population. NARAC uses its global terrain elevation and land-use classifications databases to specify the lower boundary conditions for its atmospheric models. These data are provided by several US government organizations, and have horizontal resolutions ranging from 10km to as fine as 30m. NARAC uses population density data to estimate the number of persons potentially affected by a model-predicted contamination or dose level. NARAC's population databases include global coverage at 30-minute (approximately 1 km) resolution. For the US, NARAC can account for diurnal population variations due to commuting (250m resolution), and also for local population density increases during special events.

Dose and Health Effects Analyses, and Decision-Support Products

NARAC products include maps showing areas where dose limits are exceeded, areas where protective action (sheltering, evacuation, relocation) thresholds are attained, estimated affected population, and geographic reference data (e.g., roads, political boundaries, terrain, water bodies, aerial photography, critical facilities such as schools and hospitals). Radiation doses are calculated from model-computed air- and ground contamination values, using several dose conversion factor databases. The factors are functions of radionuclide, chemical form, and particle size. Radiological dose limits from the U.S. Environmental Protection Agency for guiding protective actions (sheltering, evacuation, relocation) and for emergency workers engaged in property protection and life saving activities are automatically displayed as plume model contour areas on NARAC map products. Population data, dose-response models, and risk factors are used to estimate the number of casualties from acute dose exposures and the number of latent cancer incidents from chronic doses.

SUMMARY

NARAC's expert staff uses computer models, supporting databases, software systems, and communications systems to predict the plume paths and consequences of radiological, chemical, and biological atmospheric releases. The reader is referred to Nasstrom, et al. (2005) for a more complete description NARAC and a comprehensive list of references.

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