LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-CONF-217377

National Multi-agency Support for Airborne Hazard Prediction

J. Nasstrom, G. A. Sugiyama, R. L. Baskett,
S. C. Larsen, M.M. Bradley, R. D. Aines

November 28, 2005

Sharing Solutions for Emergencies and Hazardous
Environments
Salt Lake City, UT, United States
February 12, 2006 through February 15, 2006

Submitted to American Nuclear Society 2006 International Joint Topical Meeting:
"Sharing Solutions For Emergencies and Hazardous Environments",
Feb. 12-15, 2006, Salt Lake City, Utah

National Multi-agency Support for Airborne Hazard Prediction

John S. Nasstrom, Gayle Sugiyama, Ronald L. Baskett, Shawn Larsen,
Michael M. Bradley, and Roger D. Aines

Lawrence Livermore National Laboratory, PO Box 808, L-103, Livermore, CA 94550
(925) 423-6738, jnasstrom@llnl.gov

Abstract – *Lawrence Livermore National Laboratory (LLNL) provides hazardous material plume modeling tools and services for a large number of emergency managers and responders. This paper describes ongoing advancement of LLNL's support for multiple agencies through the National Atmospheric Release Advisory Center (NARAC) and the Interagency Atmospheric Modeling and Atmospheric Assessment Center (IMAAC). A suite of software tools developed by LLNL and collaborating organizations includes simple stand-alone, local-scale plume modeling tools for end user's computers, and Web- and Internet-based software to access advanced 3-D flow and atmospheric dispersion modeling tools and expert analyses from the national center at LLNL.*

I. INTRODUCTION

Lawrence Livermore National Laboratory (LLNL) provides hazardous material plume modeling tools and services for a large number of federal, state and local emergency managers and responders [1]. The primary sponsors of this work are the Office of Emergency Response in the U.S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA), the Department of Homeland Security (DHS) and the U.S. Naval Reactors program.

The National Atmospheric Release Advisory Center, located at LLNL, is an integral part of the DOE's contribution to the Federal Radiological Monitoring and Assessment Center (FRMAC), and also provides support to over 40 individual DOE and U.S. Department of Defense (DOD) facilities. NARAC also supports DOE's International Emergency Management and Cooperation (IEMC) Program which cooperates with other governments on nuclear emergency preparedness technology.

According to the new U.S. National Response Plan [2], the DHS-led IMAAC generates the single Federal prediction of atmospheric dispersions and their consequences utilizing the best available resources from the Federal Government and "provides a single point for the coordination and dissemination of Federal dispersion modeling and hazard prediction products that represent the Federal position during an Incident of National Significance". Current collaborating agencies include the Department of Commerce's (DOC) National Oceanic and Atmospheric Administration (NOAA), the Department of Defense (DoD), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), and the Nuclear Regulatory Commission (NRC). The IMAAC was created under the auspices of the Homeland Security Council on April 15, 2004 and NARAC is the designated primary initial provider of IMAAC capabilities. Under the auspices of both DOE and DHS, NARAC works with over 100 collaborating state and federal organizations involved in emergency preparedness activities.

A LLNL-developed suite of software tools include simple stand-alone, local-scale plume modeling tools for end-user's computers, and Web- and Internet-based software to access advanced 3-D flow and atmospheric dispersion modeling tools as well as expert analyses from the national center at LLNL. In numerous actual emergencies and national-to-local exercises, including the Top Officials (TOPOFF) series, utilization of a national center for hazard prediction and the simultaneous distribution to federal, state and local agencies has proven extremely valuable for situation awareness and emergency management.

A recent paper [1] reviews the current NARAC simulation models and systems, including their testing and evaluation. Described below are recent advances of LLNL-based modeling tools and products in collaboration with other organizations in support of the NARAC and IMAAC.

II. SIMULATION MODELS

The mission to provide near-real-time model predictions of atmospheric dispersion anywhere in the world requires access to large volumes of current and forecast weather data, and to extensive databases of population density, hazardous material source characteristics, radiological, chemical, and biological material properties, dose factors, dose limits, and protective action guides. NARAC uses population density data to estimate the number of people potentially affected by a particular contamination or dose level.

Recent advances in population density databases have included a database from Los Alamos National Laboratory [3], which uses U.S. Census Bureau residential data augmented with business population (from the State Business Directory) and estimates of day-night worker migration, providing a population density database that accounts for time-of-day population variation for the entire U.S. on a 250-m resolution grid. The LandScan global population database from Oak Ridge National Laboratory is also used. 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 using methodologies published by the EPA [4] and NCRP [5].

A specialized residential building leakiness database for calculating the infiltration of exterior air into residential buildings has been developed in collaboration with Lawrence Berkeley National Laboratory [6] in order to predict indoor air concentration from outdoor releases. This database is derived from U.S. Census data and studies of U.S. building leakiness. A commercial building air infiltration modeling capability is currently in development.

Atmospheric dispersion models require a source term that describes characteristics such the mass or activity released to the atmosphere, the emission rate, height, spatial distribution, and particle size distribution. LLNL collaborates with several organizations to incorporate improved characterization airborne material characteristics, including released quantities and particle size distributions. For RDDs, radiological dispersal devices such as explosives and sprayers, source characteristics from research at Sandia National Laboratories [7] are used. Previous work on nuclear explosion cloud characteristics [8] is being updated to simulate more detailed particle size distributions and longer-range dispersion using the LODI 3-D regional dispersion and deposition model [9]. In order to improve and streamline LLNL plume model predictions of nuclear power plant accident, an interface between the U.S. Nuclear Regulatory Commission RASCAL [10] source term code and LLNL's NARAC modeling system has been developed.

In addition to the COAMPS, ADAPT and LODI regional- and continental-scale atmospheric flow and diffusion models for complex terrain [1], LLNL is developing and evaluating building- and urban-scale models. One fast-running model capable of near-real-time applications is the Urban Dispersion Model (UDM) Gaussian puff model [11]. This model is being integrated within the NARAC operational software system. The UDM is an empirical urban model, which includes the time- and space-averaged effects of building complexes on transport and diffusion. For detailed studies of flow and dispersion of airborne material around buildings and in the urban environment, LLNL uses the FEM3MP computational fluid dynamics model [12], which is based on solving the three-dimensional, time-dependent, incompressible Navier-Stokes equations on massively parallel computer platforms.

Conventional or nuclear explosions produce potentially harmful, prompt effects from blast overpressure, thermal radiation or ionizing radiation. LLNL software predicts conventional high explosive blast overpressure effects using the Sandia National Laboratories BLAST model, which utilizes overpressure relationships published by Caltagirone [13]. Prompt effects from nuclear detonation associated with direct blast injury, tumbling/impact, thermal injury, and prompt radiation are predicted using the Sandia NUKE model, which utilizes relationships published by Glasstone and Dolan [14]. A Nuclear Explosion program in Hotspot software provides a simple, PC-based deployable tool for predicting the effects of a surface-burst nuclear weapon, including prompt effects (from neutron and gamma radiation, blast, and thermal radiation), and fallout effects [15].

III. INTEGRATION OF MEASUREMENT DATA WITH MODEL PREDICTIONS

Because of limitations and uncertainties in input data (e.g., source term estimates) and other modeling assumptions, it is important to incorporate field measurements into predictions and assessments of dose as soon as possible during an incident or accident. For terrorist scenarios (e.g., an RDD) little may be known about the characteristics of the dispersed and airborne material. In this case, an idealized gas or aerosol source with a unit amount of material can be used to initially predict the downwind area in which to focus air- or ground monitoring activities. For nuclear power plant accidents, estimates of the source term may be available from plant conditions or data from a monitored stack. However, refinement of source term estimates requires additional data.

Integration of measurements of air or ground contamination or exposure rate is especially valuable in the early and intermediate phases of an event. Even if only sparse measurement data are available, they can be used to calibrate initial model predictions to more accurately predict areas potentially needing protective actions (such as sheltering, evacuation or relocation). NARAC predictions, in turn, can help guide field teams to potentially contaminated areas that need monitoring. Models can then be used to interpolate between measurements and extrapolate beyond areas that have been monitored by measurement teams. By using this approach to the problem, low levels of contamination that are difficult to measure can be simulated more accurately. This methodology also can aid in helping guide crop and food field sampling teams to areas in which contamination might result in a long-term ingestion-pathway dose that exceeds regulatory limits.

Since its inception, NARAC has included the use of measurement data to update model predictions. Today, NARAC routinely participates in emergency response drills with organizations that collect air concentration, ground deposition, and radiation exposure measurements. NARAC provides modeling support and works closely with regional and national measurement and dose assessment teams, including those at supported DOE and DOD sites and the Department of Energy (DOE) National Nuclear Security Administration (NNSA) Office of Emergency Operations' regional Radiological Assessment Program (RAP), Accident Response Group (ARG), and Aerial Measurement System (AMS), as well as the Federal Radiological Monitoring and Assessment Center (FRMAC).

NARAC works as part of the FRMAC to utilize measurement data for updating model predictions. Data are collected, assessed, and stored in FRMAC databases, and then electronically transmitted to NARAC. An Extensible Markup Language, or XML, file has been developed in a collaboration with the Remote Sensing Laboratory and Sandia National Laboratories to electronically transfer measurement data from FRMAC databases to the NARAC modeling system [16]. XML has proven to be a simple, flexible, self-describing text format for this use. Data are stored with necessary metadata, such as units of measure, time of measurement, type of instrument, type of radiation or isotope.

NARAC scientists visually and statistically compare measured and computed values for each monitoring location point. A useful statistic is the average ratio of measured and computed values. These ratios provide good statistical measures for values that can vary over many orders of magnitude, and can be used to scale the airborne source amount assumed in the model. A range of values for uncertain model input data (in particular wind data from several possible sources, particle size distributions and release heights for buoyant releases) are analyzed to determine the input data that result in the best-fit model predictions, as measured by the measured-computed ratios.

Examples of NARAC's use of field measurements to update model predictions and estimate source terms include the Uranium Criticality accident at Tokaimura, Japan, in 1999, and the accidental melting of a Cesium source at a steel-processing facility in Algeciras, Spain in 1998 [17].

In order to automate the use of measurement data to infer unknown source characteristics produce improved plume model predictions, LLNL is developing a flexible and robust data-driven modeling capability that will be suitable for future operational integration. The LLNL approach couples data and predictive models with Bayesian inference and stochastic sampling to provide backward analyses to determine unknown source characteristics, optimal forward predictions for consequence assessment, and dynamic reduction in uncertainty as additional data become available [18, 19, 20]. The new capability uses stochastic sampling methods to solve source inversion problems and compute source term parameters taking into consideration measurement errors and forward model errors. Stochastic sampling methods are suitable even for the problems characterized by non-Gaussian distribution of source term parameters and when the underlying dynamical system is non-linear. Using the MCMC capability, LLNL scientists have demonstrated source inversion with a three-dimensional, building-resolving, computational fluid dynamics code [21, 22].

IV. COMPUTER SYSTEMS

NARAC's software system utilizes a multi-tiered distributed software architecture that provides real-time access to the global meteorological and geographical databases and atmospheric modeling tools. The software infrastructure is composed of two primary components: (1) the NARAC Central System (NCS) and (2) the NARAC Enterprise System (NES). The Central System integrates a sophisticated modeling environment with data warehousing capabilities, and contains tools to generate end-user products. In-house NARAC staff has direct access to the Central System. The NES provides user-friendly web and other internet-based tools that allow registered users to remotely access advanced NARAC services and to share products with other users. In addition, the NES has a stand-alone capability that allows remote users to run simple plume models when internet and other communication channels to the Central System are not available. The NES consists of three components: the Enterprise or Middle Tier, the *NARAC Web*, and the *NARAC iClient*. Information exchange between the Central System, Enterprise Tier, and the iClient and NARAC Web end-user tools is handled via Extensible Markup Language (XML) and Hyper Text Markup Language (HTML).

The NARAC Web and iClient are end-user tools that allow remote access to the NARAC Central System via the Enterprise Tier. The NARAC Web is a secure web site that permits remote users to input simple release scenarios, automatically run NARAC models, and view and manage the results of model runs. The iClient is a more sophisticated desktop application that provides NARAC reach-back capability and stand-alone operation using local models on a user's remote system. It was designed using Java and web-based technology to provide a platform independent tool for deployed emergency response analysts. The iClient is designed for subject matter experts, whereas the NARAC Web is targeted at a wider audience. Currently, there are approximately 100 iClient and over 1200 NARAC Web external users. The NARAC Web has been used very successfully in major exercises, such as the Top Officials exercise series, to quickly share model and measurement-based products describing hazard areas with multiple local, state and federal agencies.

V. CONSEQUENCE ASSESSMENT PRODUCTS

Atmospheric dispersion and deposition models predict quantities such as time-integrated or time-averaged air concentration, peak air concentration experienced at any interval during the total exposure time, and accumulated surface deposition. These quantities are converted into products, such as dose limits and corresponding protective action guides, that are useful to a wide range of users, including emergency responders, support scientists, emergency managers, and decision makers.

Radioactive dose is calculated from model-computed air and ground contamination values, using dose conversion factor databases provided by Oak Ridge National Laboratory. For internal 50-year committed dose from inhalation, these factors were published by the EPA [23] and are a function of radionuclide, chemical form, and particle size. The factors are derived from the International Commission on Radiological Protections (ICRP) Publication 30 lung model and methodologies for internal dose. Optionally, inhalation dose conversion factors, based on the ICRP-66 lung model and ICRP 60/70 series methodologies published by the EPA [24], can be used. For external dose from ground or air immersion exposure, dose conversion factors published by EPA [25] are used. In addition, acute (24-hour) dose factors published by Eckerman [26] are used for estimating non-stochastic effects, from high acute radiation doses for applicable target organs (the lung, small intestine wall, and red bone marrow).

Radiological dose limits from the U.S. Environmental Protection Agency [4] for guiding protective actions (sheltering, evacuation, and 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 as described above.

NARAC report generator software, being developed in collaboration with Sandia National Laboratories, is used to reliably and accurately assemble a detailed effects and consequences report, which combines effects contour maps, tables of plume centerline values, and the assumptions, background, and explanatory text relevant to the calculations. Methods of importing plume model predictions in to Geographical Information System (GIS) software tools are continuing to be developed to facilitate geospatial analysis of impacted areas, population, key facilities, and other emergency management information.

VI. SUMMARY

This paper has described some current capabilities and ongoing advancement of hazardous airborne material dispersion prediction capabilities by Lawrence Livermore National Laboratory and collaborating organizations. In order to accomplish a mission of providing near-real-time atmospheric hazard predictions, a wide range of supporting databases, computer models, software systems, and services have been integrated. Ongoing advances include (1) affected population estimates that vary with time of day, (2) building air infiltration models, (3) more detailed radiological and nuclear source characteristics models, (4) algorithms for predicting prompt effects from blast overpressure, thermal radiation or ionizing radiation, (5) methods of integrating measurement data into model predictions, and (6) Internet- and Web-base technologies for quickly obtaining and sharing hazard prediction products. Utilization of capabilities such as these from a national center for airborne hazard prediction, and the rapid distribution of products to federal, state and local agencies, has proven extremely valuable for situation awareness and emergency management in actual emergencies and national-to-local exercises, including the Top Officials (TOPOFF) series.

Additional information on NARAC can be found at http://narac.llnl.gov.

ACKNOWLEDGEMENTS

Portions of this work were sponsored by the DOE Office of Emergency Response, DHS Science and Technology Directorate, and the LLNL Laboratory Directed Research and Development program. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

REFERENCES

1. Nasstrom, J.S., G. Sugiyama, R.L. Baskett, S.C. Larsen and M.M. Bradley, 2005: The National Atmospheric Release Advisory Center (NARAC) Modeling and Decision Support System for Radiological and Nuclear Emergency Preparedness and Response, *International Journal of Risk Assessment and Management,* accepted.
2. DHS, 2004: *National Response Plan*, December 2004, Department of Homeland Security, Washington, DC.
3. McPherson, T.N. and Brown M.J. 2003: *U.S. Day and Night Population Database*

(Revision 2.0) - Description of Methodology, Report LA-UR-03-8389, Los Alamos National Laboratory, Los Alamos, NM.

4. EPA, 1992: *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC 20460

5. NCRP, 1993, *Limitation of Exposure to Ionizing Radiation*, Report No, 116, National Council on Radiation Protection, March 31, 1993

6. Chan, W., P. Price, A. Gadgil, W. Nazaroff, G. Loosmore, and G. Sugiyama, 2004: Evaluate Shelter-in-Place as Part of an Emergency Operation Plan, *AMS Symposium on Planning, Nowcasting, and Forecasting in the Urban Zone*, AMS 84th Annual Meeting, 2004 January 11-14, American Meteorological Society, Boston, MA.

7. Harper, F.T., S. Musolino and W.B. Wente, 2005: Realistic Radiological Dispersal Device Hazard Boundaries and Ramifications for Early Consequence Management Decisions, *International Journal of Risk Assessment and Management,* accepted.

8. Harvey, T.F., and F.J.D. Serduke, 1979: *Fallout Model for System Studies*, Report, UCRL-52858, Lawrence Livermore National Laboratory, Livermore, CA.

9. Nasstrom, J.S., G. Sugiyama, J.M. Leone, Jr., and D.L. Ermak, 2000: A real-time atmospheric dispersion modeling system, *Eleventh Joint Conference on the Applications of Air Pollution Meteorology*, Long Beach, CA, Jan. 9-14, 2000. American Meteorological Society, Boston, MA, 84-89

10. Sjoreen, A. L.. J. V. Ramsdell, Jr., T. J. McKenna, S. A. McGuire, C. Fosmire, and G. F. Athey, 2001: *RASCAL 3.0: Description of Model and Methods*, NUREG-1741, US NRC.

11. Griffiths, I.H., D.R. Brook, D.J. Hall, A. Berry, R.D. Kingdon, K. Clawson, C. Biltoft, J.M. Hargrave, D. C. Strickland, and A. M. Spanton, 2002: Urban Dispersion Model (UDM) Validation, *AMS 4th Symposium on the Urban Environment*, Norfolk VA, 20-24 May 2002, American Meteorol. Soc., Boston MA.

12. Chan, S.T. and D. Stevens, 2000: An Evaluation of Two Advanced Turbulence Models for Simulating the Flow and Dispersion Around Buildings, *The Millennium NATO/CCMS Int. Tech. Meeting on Air Pollution Modeling and its Application*, Boulder, CO, May 2000, 355-362.

13. Caltagirone, J., 1986: *Contents of Structures to Resist the Effects of Accidental Explosions* (TM 5-1300, NAVFAC P-397, AFM 22), Army Belvoir Research Development and Engineering Center, Fort Belvoir, VA.

14. Glasstone, S. J., and P. J. Dolan, 1977: *The Effects of Nuclear Weapons*, U. S. Department of Defense and U. S. Department of Energy, (3rd edition).

15. Homann, S.G.,1994: *HOTSPOT Health Physics Codes for the PC*. Report UCRL-MA-106315, Lawrence Livermore National Laboratory, Livermore, CA.

16. Foster, K., C. Logan, E. Arnold, D. Bonner, B. Eme, K. Fischer, H. Walker, J. Gash, J. Nasstrom, A. Guber, P. Wasiolek, J. Fulton, 2005: *Integration of AMS and ERDS Measurement Data into NARAC Dispersion Models*, Report UCRL-TR-215614, Lawrence Livermore National Laboratory, Livermore, CA.

17. Vogt, P.J., B. M. Pobanz, F. J. Aluzzi, R. L. Baskett, T. J. Sullivan, 1999: ARAC Modeling of the Algeciras, Spain Steel Mill Cs-137 Release, *Proceedings American Nuclear Society 7th Topical Meeting on Emergency Preparedness and Response*, Santa Fe, NM, September 14-17, 1999, American Nuclear Society, Inc., La Grange Park, IL. Also: Report UCRL-JC-131330, Lawrence Livermore National Laboratory, Livermore, CA.

18. Johannesson, G., Hanley, W., and Nitao, J., Dynamic Bayesian Models via Monte Carlo – An Introduction with Examples, 2005. Report UCRL-207173, Lawrence Livermore National Laboratory, Livermore, CA.

19. B. Kosovic, G. Sugiyama, K. Dyer, W. Hanley, G. Johannesson, S. Larsen, G. Loosmore, J.K. Lundquist, A. Mirin, J. Nitao, R. Serban, 2004: Dynamic Data-

Driven Event Reconstruction for Atmospheric Releases, 8th Annual George Mason University Transport and Dispersion Modeling Conference, Fairfax, VA, July.

20. B. Kosovic, G. Sugiyama, S. Chan, F. Chow, K. Dyer, R. Glaser, W. Hanley, G. Johannesson, S. Larsen, G. Loosmore, J. Lundquist, A. Mirin, J. Nitao, R. Serban, and C. Tong, 2005: Stochastic Source Inversion Methodology and Optimal Sensor Network Design, 9th Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling, July 2005.
21. Chow, T., B. Kosovic, and S. Chan 2005: Source inversion for contaminant plume dispersion in urban environments using building-resolving simulations, 6th Symposium on Urban Environment, Annual American Meteorological Society Meeting, Atlanta, GA, January 2006. Also LLNL Report UCRL-CONF-216903, Lawrence Livermore National Laboratory, Livermore, CA.
22. Chow, T., B. Kosovic, and S. Chan, 2005: Source inversion for contaminant plume dispersion in urban environments using building-resolving simulations, 9th Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling, July 2005.
23. EPA, 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. Federal Guidance Report No. 11, Document No. EPA 520/1-88-020, U.S. Environmental Protection Agency, 1988.
24. EPA, 1999: *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*. Federal Guidance Report No. 13, Document No. EPA-402-R-99-001, U.S. Environmental Protection Agency, 1999.
25. EPA, 1993: *External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance* Report No. 12, Document No. EPA-402-R-93-081, U.S. Environmental Protection Agency, 1993.
26. Eckerman, K., 2001: Dose Coefficients for Acute Health Effects, Oak Ridge National Laboratory, Oak Ridge, TN.