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National Atmospheric Release Advisory Center (NARAC) Capabilities for Homeland Security

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National Atmospheric Release Advisory Center (NARAC) Capabilities for Homeland Security

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ABSTRACT: The Department of Energy's National Atmospheric Release Advisory Center (NARAC) provides critical information during hazardous airborne releases as part of an integrated national preparedness and response strategy. Located at Lawrence Livermore National Laboratory, NARAC provides 24/7 tools and expert services to map the spread of hazardous material accidentally or intentionally released into the atmosphere. NARAC graphical products show affected areas and populations, potential casualties, and health effect or protective action guideline levels. LLNL experts produce quality-assured analyses based on field data to assist decision makers and responders. NARAC staff and collaborators conduct research and development into new science, tools, capabilities, and technologies in strategically important areas related to airborne transport and fate modeling and emergency response. This paper provides a brief overview of some of NARAC's activities, capabilities, and research and development.

1 INTRODUCTION

The National Atmospheric Release Advisory Center (NARAC), one of Lawrence Livermore National Laboratory's (LLNL) signature facilities, offers unique expertise and tools to map the spread and potential impacts of airborne hazardous materials.

1.1 *NARAC Mission*

NARAC's primary mission is to protect public health and safety by providing timely and accurate plume predictions that assist emergency responders and decision makers. LLNL subject matter experts are available within minutes during emergencies. The 24/7 center supports preparedness planning, exercises, special events, and real-world incidents and is able to respond to multiple simultaneous events. Upon request, NARAC may deploy staff to major events to ensure communications, coordinate with field teams, and supply interpretational guidance on plume modeling products.

NARAC serves thousands of users from over 300 federal, state, and local agencies, emergency response teams and operations centers, and international organizations. In a typical year, the center delivers 10,000 plume simulations to users, participates in 100 major exercises, and responds to 25 real-world incidents. The types of events supported include nuclear power plant accidents (e.g., Chernobyl reactor accident in the Ukraine, USSR, 1986); nuclear fuel and processing plant accidents; nuclear weapons accidents; nuclear-powered satellite re-entries; railroad tank car accidents; toxic industrial chemical facility fires and spills; and environmental hazards resulting from warfare (e.g., the Kuwaiti oil fires in the Persian Gulf, 1991) or natural causes (e.g., Mount Pinatubo volcanic eruption, 1991; sulfur-dioxide venting from Kilauea volcano, HI, 2008). In addition, the center is regularly on stand-by for potential incidents at National Security and other Special Events.

1.2 *NARAC Roles, Sponsors, and Users*

NARAC became operational in 1979 during the response to the Three Mile Island nuclear power plant accident. The center provides the Department of Energy (DOE) / National Nuclear Security Agency (NNSA) Office of Emergency Response with a centralized modeling capability for nuclear incident response. NARAC personnel serve as part of the Consequence Management Home Team (CMHT) that supports the DOE-led Federal Radiological and Monitoring center (FRMAC), the DOE Nuclear Incident Team, national and regional radiological response teams, as well as DOE sites across the country.

NARAC is the primary operations center for the Department of Homeland Security (DHS)-led Interagency Modeling and Atmospheric Assessment Center (IMAAC), which was created in 2004. The IMAAC responds to hazardous chemical, biological, radiological, and natural releases. Under the National Response Framework (NRF), the IMAAC's mission is to provide a "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. IMAAC functions under an agreement between eight federal agencies: DHS, DOE, the Department of Defense (DoD), the Environmental Protection Agency (EPA), the Department of Health and Human Services (HHS), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Nuclear Regulatory Commission (NRC). IMAAC services are provided to state and local agencies upon request for major real-world events.

In addition, NARAC supplies plume modeling services to other organizations. Under the DOE International eXchange Program (IXP), the center provides approved member states of the International Atomic Energy Agency (IAEA) with access to selected atmospheric dispersion modeling capabilities. The DOE/DoD Naval Nuclear Propulsion Program (NNPP) utilizes NARAC for emergency planning and response for its sites. The center also is required to be on alert for potential accidents during NASA spacecraft launches involving radiological sources, such as the successful Cassini (1997) and Pluto New Horizons (2006) launches, and the Mars Science Laboratory launch scheduled 2011.

2 NARAC PRODUCTS, EXPERT SERVICES, AND TOOLS

Automated standard plume product sets are delivered within minutes to federal, state, and local agencies. NARAC experts provide quality-assured refined products based on updated information and field data. Such products including information on:

- Airborne and ground contamination areas
- Potentially affected population counts
- Health effect levels based on public exposure guidance
- Protective action guideline levels (for sheltering/evacuation, emergency worker protection, and public relocation, if available)
- Geographical information, including maps and aerial or satellite photos
- Multi-page consequence reports with expanded descriptions of plume products, input data, assumptions, approvals, and interpretational information (pdf format)

First responders and decision makers use NARAC products and reports to help determine safe approach routes, incident command post locations, recommendations for evacuation or sheltering-in-place, worker protection, and sampling plans. NARAC products also include potential impacts to emergency response and health service facilities, possible numbers of casualties or fatalities, likely areas that may require public relocation, locations where buildings or facilities might need decontamination, or regions where agricultural crops could be affected by radiological contamination.

2.1 *NARAC Expert Services*

NARAC is staffed by nationally recognized experts who work closely with emergency responders, emergency operations centers, technical experts, field teams conducting monitoring and sampling, and members of federal, state, and local agencies. Center personnel provide quality-assured model predictions based on their expertise in atmospheric dispersion, meteorology, numerical modeling, computer science, software engineering, geographical information systems (GISs) and visualization, hazardous material properties, atmospheric chemistry, and health physics. Staff expertise and interagency relationships are critical to the center's ability to respond to new or unexpected threats and events. Scientific staff source-to-effects analyses include:

- Modeling of atmospheric transport and dispersion from instantaneous and continuous emissions for a range of distances and times at any location
- Analysis and forecasting of meteorological flows
- Determination of physical and chemical characteristics for a broad array of chemical, biological, radiological/nuclear (CBRN) sources and release mechanisms (e.g., spills, explosions, fires, reactors, sprayers)
- Modeling of deposition, resuspension, degradation processes, and radiological decay
- Estimation of human dose and exposure limits for radiological, chemical and biological material, and corresponding protective action guideline levels
- Geospatial analysis of impacted areas and population
- Chemical, biological and radiological measurement data analysis and integration into model predictions (data-driven modeling for source or event reconstruction)

2.2 *NARAC Modeling Tools and Data*

The NARAC system includes an advanced suite of meteorological and dispersion models, GIS capabilities, and supporting databases. The center utilizes models developed by both LLNL and external agencies (integrated to varying degrees into the NARAC system) to assess the consequences of hazardous airborne releases. NARAC computer systems acquire real-time global meteorological data and weather-forecast model output from NOAA, DoD, regional networks, and supported facility meteorological towers. NARAC maintains and regularly updates worldwide databases of maps, terrain, land-use, and population as well as CBRN material and dose-response relationships.

The key physics models used in the NARAC real-time automated system are:

- LLNL coupled ADAPT-LODI 3-D meteorological data assimilation and Lagrangian particle dispersion models
- LLNL HotSpot radiological plume model for planning and initial emergency response, available as both a stand-alone and Web-based tool
- LLNL KDFOC nuclear fallout model
- Community-developed Weather Research and Forecasting (WRF) numerical weather prediction model for high-resolution applications
- Sandia National Laboratories (SNL) BLAST empirical model for prediction of prompt blast effects from explosions

- SNL NUKE empirical model of prompt nuclear detonation effects from overpressure, thermal and prompt radiation

Basic descriptions of most of the above models can be found at https://narac.llnl.gov.

A wide range of source term models include:

- Buoyant & momentum plume rise model for fires or stack emissions in LODI
- SNL Source Term Calculator models of explosive dispersal devices, including airborne fractions and particle-size distribution
- SNL Source Term and Dose Response Assessment Tool models of chemical and biological weapons sources, such as sprayers
- EPA/NOAA toxic industrial chemical source models for leaks, spills, and tank storage

In addition, NARAC maintains stand-alone versions of key models, including FEM3MP (a LLNL building-resolving computational fluid dynamics model for urban applications and planning), the Joint Effects Model (DoD), CAMEO (EPA/NOAA system used to plan for and respond to chemical emergencies), and RASCAL (NRC model for nuclear power plant release characteristics). For nuclear power plant accidents with the potential for off-site consequences, the NRC directly provides NARAC with source terms based on its knowledge of reactor status.

Models undergo intensive testing. LLNL scientists conduct regular benchmarking, verification with analytic solutions, evaluation and validation against real-world tracer experiments, and operational testing, including after-action reviews of usability, efficiency, consistency and robustness of models and data under real-world and real-time constraints. An example of a model validation case for the ADAPT/LODI model is shown in Figure 1.

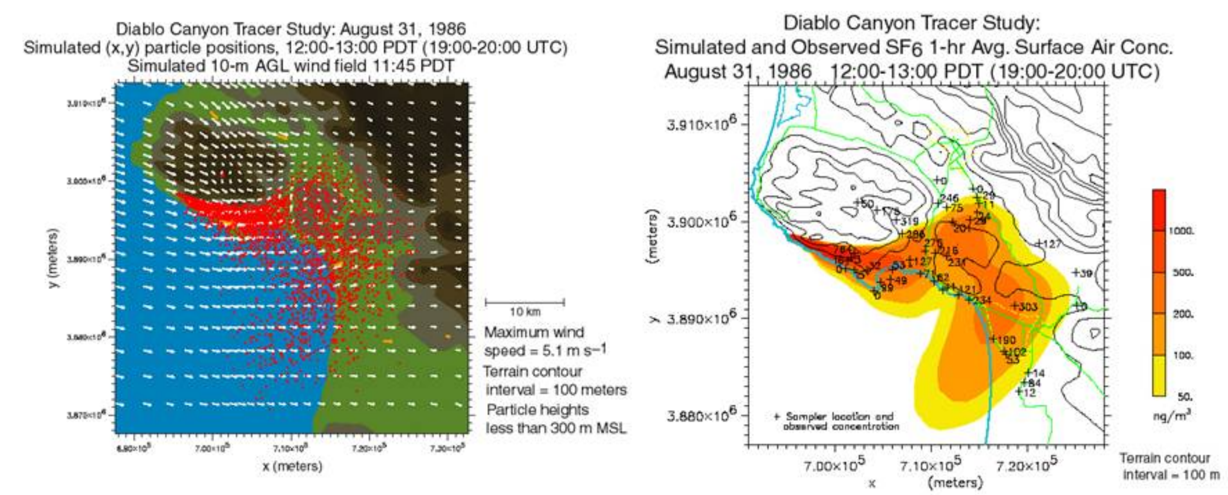


Figure 1. The figure shows a NARAC model evaluation case using data from the Diablo Canyon Tracer Experiment. The left panel shows the ADAPT-generated wind field and a snapshot of the Lagrangian particles used in the simulation. The panel on the right compares LODI surface air concentrations (color contours) with experimental values (numbers next to "+" symbol) showing good agreement in complex terrain and meteorological conditions.

2.3 *NARAC Software and Hardware*

The NARAC system provides both fully automated model simulation tools and expert analysis capabilities. The system is able to support multiple simultaneous events and is designed to be robust and scalable in order to support thousands of users. A schematic diagram of the system is shown in Figure 2. The software connects data (weather, geospatial, material property, dose response, health effect information) and physics models with built-in visualization capabilities that are used to generate graphics, maps, plots, and reports. Software provides input data preprocessing, run management and control, and status monitoring. LLNL experts use advanced features of the system to conduct model analyses to provide quality-assured, refined analyses.

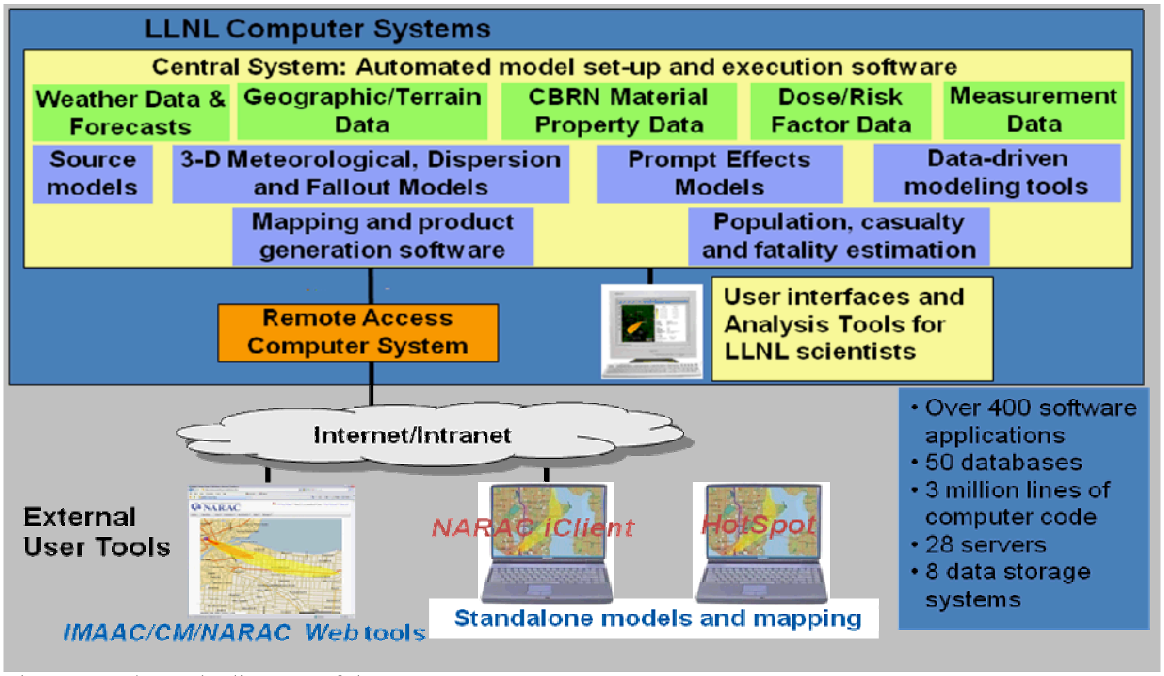


Figure 2. Schematic diagram of the NARAC system.

A Web-based interface provides authorized users with remote access to NARAC. The NARAC iClient desktop application provides deployed mapping and modeling tools. The secure password-controlled Web site permits remote users to request NARAC predictions, view and manage the results of model runs, and share predictions, including maps of plume-model-predicted hazard areas, full consequence reports describing the predictions, and incident information, with multiple agencies. LLNL maintains four Web access points, by which authorized users may access the system: the NARAC Web, IMAAC Web, CMweb, and IXP. The CMweb is the DOE Office of Emergency Management unified Web site for the distribution of consequence management model and products from NARAC and FRMAC. The IXP is a separate Web system with approved capabilities for international users.

Web users may run preparedness calculations or initial hazard estimation by entering basic information about a release (type, location, time, and quantity of material released) or selecting a pre-defined scenario (e.g., reactor release, chemical sprayer, radiation dispersal device). Model results are returned within minutes. Users may select from a variety of geographical layers (e.g., maps, satellite or aerial photography) on which to overlay plume model results. ESRI shapefile and Google KMZ file output are automatically generated to allow users to import NARAC plume analyses into their own GIS software or Google Earth.

The dedicated facility at LLNL houses the NARAC emergency operations center, computer rooms, staff offices, classified and unclassified space, and operational infrastructure, including:

- Computer systems with redundant fault-tolerant systems
- Connectivity to LLNL supercomputing resources for surge capacity
- Redundant communications systems (internet, satellite, dial-up, phone/fax, DOE Emergency Communication Network)
- Video teleconferencing capabilities

- Uninterruptible Power Supply system, power distribution units, battery systems and diesel power generations for maintaining 24/7 electrical power

3 NARAC RESEARCH AND DEVELOPMENT

NARAC capabilities are continuously advanced via research and development and improvements in computer hardware and software. Research topics include boundary-layer meteorology and turbulence, urban flow and dispersion, indoor exposures, shielding and sheltering effects, CBRN source term modeling, nuclear fallout, and data-driven simulation. A few examples are summarized below.

3.1 *Urban Modeling*

NARAC has conducted research into the development of building-resolving Computational Fluid Dynamics (CFD) models for many years. LLNL researchers developed and advanced the FEM3MP CFD model for urban applications, as described, for example, by Chan and Leach (2007) and references cited therein. Lundquist and Chan (2007) and Hanna et al. (2007) compared CFD models applied to New York City. Recently, LLNL added a new dense gas treatment to FEM3MP (see Figure 3), including non-isothermal physics. Two sub-grid large eddy simulations models were incorporated, and the model was tested against data from the Burro Series field study conducted at the Nevada Test Site (Kosovic and Mirocha, 2008).

LLNL researchers and collaborators at the University of California, Berkeley, are exploring an alternate path to urban modeling based on modifying the WRF model. They added an immersed boundary method to treat urban structures (Lundquist, et al., 2009) and large-eddy simulation sub-filter-scale (SFS) turbulence models for urban areas. In principle, such an approach could provide seamless coupling of urban and larger-scale weather and terrain effects with urban effects.

Urban canopy parameterizations (UCPs) model the area-averaged effects of urban areas. Delle Monache, et al. (2009) recently developed an UCP for the ADAPT/LODI operational models and tested it against field study data.

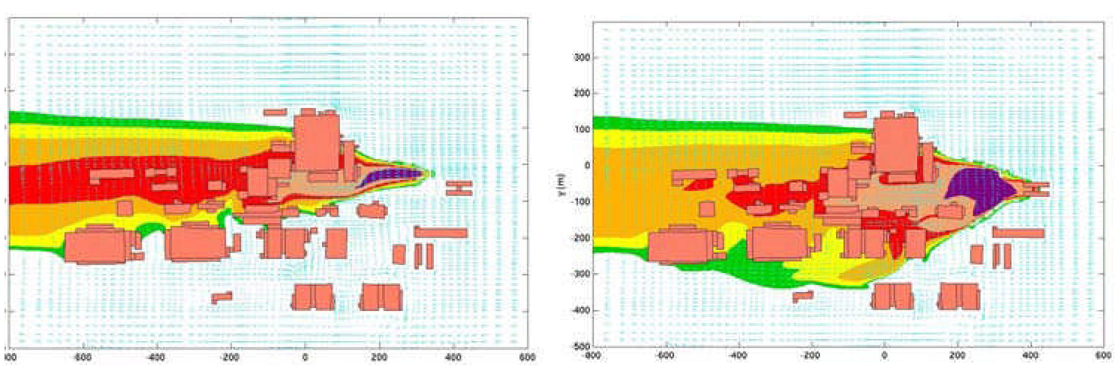


Figure 3. FEM3MP model results are shown for a neutrally-buoyant gas (left) and a dense gas (right) for an area of moderate terrain (roughly sloping from top to bottom of the grid) and two dozen buildings. The source is 200 m upwind of a 15 m tall building. The neutrally-buoyant gas exhibits significantly less lateral and upwind spread, and a lower residence time near the source location than the dense gas.

3.2 *Data-Driven Modeling and Event Reconstruction*

In modeling real-world hazardous atmospheric releases, the source term is often the greatest unknown. A key part of NARAC's mission is to conduct data-model analyses in order to perform source reconstruction and reduce uncertainty in its plume model predictions. Current emergency response methods rely on analysts to refine estimates of source characteristics. NARAC has developed a variety of operational tools for quality assuring and filtering data, identifying measurement outliers, and statistically and graphically comparing data with models.

LLNL is developing statistically rigorous methods for event reconstruction which are applicable to a wide range of release mechanisms and scales. One such approach combines Bayesian inference with stochastic sampling to determine unknown source parameters (e.g., the source location, time, and quantity released) and to produce probabilistic plumes. The method has been successfully implemented and tested with multiple models and spatial scales (see Figure 4).

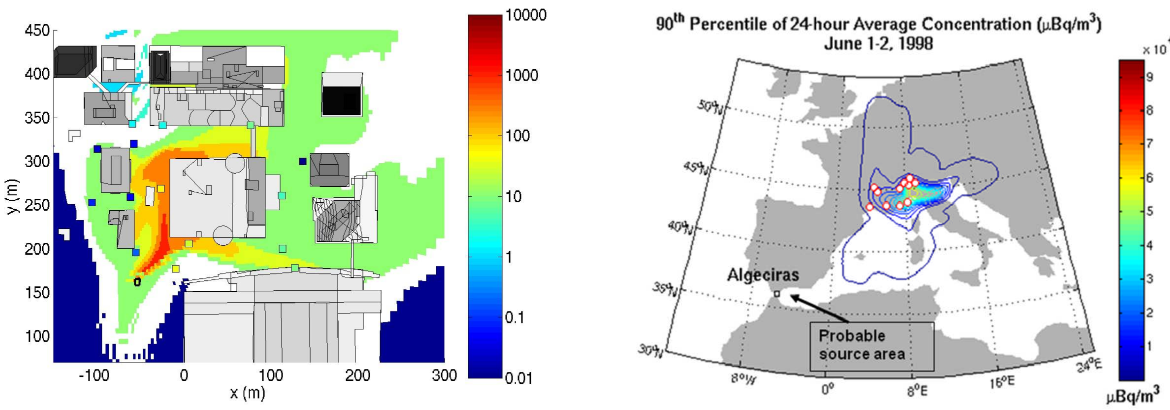


Figure 4. The left panel shows the 90% confidence level composite air concentration contours for an event reconstruction test based on the Joint Urban 2003 Oklahoma City field study using the FEM3MP CFD model (Chow et al, 2008). Colored squares show measured air concentration data. The methodology accurately estimated both the release rate and source location to within a half city block. The same methodology was used with the ADAPT/LODI models (right panel) to estimate the source location on a continental scale for a release from Algeciras, Spain (Delle Monache, et al., 2008). Red circles show the location of the subset of measured air concentration data used.

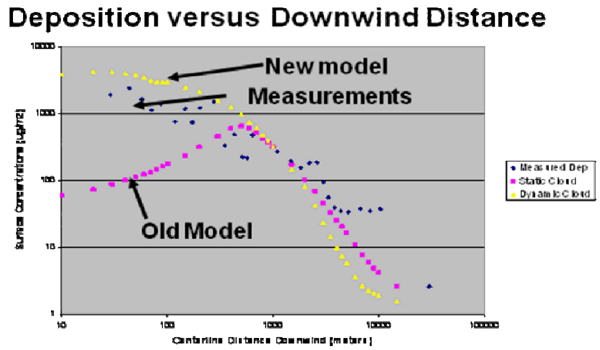
3.3 *Nuclear / Radiological Modeling*

Improving nuclear and radiological effects modeling is a high NARAC priority. LLNL has developed a unified nuclear detonation and explosive dispersal model by combining the following (Foster, 2008):

- SNL's dynamic buoyant explosive cloud rise model
- Oak Ridge National Laboratory's ORIGEN fission product inventory,
- LLNL's Livermore Weapons Activation Code treatment of neutron activation (based on device information and surface chemical composition),
- LLNL's LODI Lagrangian particle transport and dispersion model which incorporates spatially and temporally varying winds, terrain, precipitation and weathering effects.

The new code (see Figure 5) tracks "global" fallout (particles less than 10 microns) as well as larger particles and key individual isotopes (for crop and food contamination). LLNL is currently incorporating fractionation processes into the nuclear detonation model.

LLNL and SNL are currently improving the NARAC's ability to model ballistic-size particles from radiological dispersal devices. NARAC also recently completed an enhancement to its deposition and dose projection modeling for nuclear reactors by adding algorithms that account for gas-to-particle transformation in the atmosphere due to noble gas decay (Larsen, 2009).



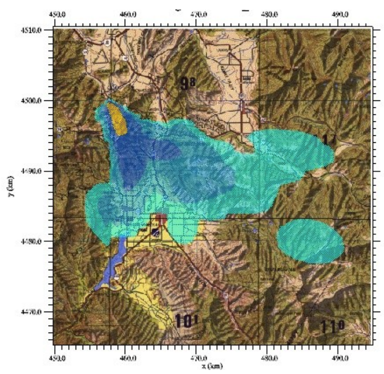


Figure 5. The new LODI model shows dramatic improvements in comparisons of predicted air concentration and deposition against explosive test data, especially near to the detonation location (left). The coupling of the new nuclear detonation source with the LODI model results in more realistic complex plumes and deposition patterns (right).

4 CONCLUSION

This paper provides an overview of the scope, capabilities, and ongoing development interests of NARAC. Additional information may be found at https://narac.llnl.gov.

5 ACKNOWLEDGMENTS

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