ARAC: A Unique Command and Control Resource

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ARAC: A Unique Command and Control Resource

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Abstract

The Atmospheric Release Advisory Capability (ARAC) at Lawrence Livermore National Laboratory (LLNL) is a centralized federal facility designed to provide real-time, worldwide support to military and civilian command and control centers by predicting the impacts of inadvertent or intentional releases of nuclear, biological, or chemical materials into the atmosphere. ARAC is a complete response system consisting of highly trained and experienced personnel, continually updated computer models, redundant data collection systems, and centralized and remote computer systems. With over 20 years of experience responding to domestic and international incidents, strong linkages with the Department of Defense, and the ability to conduct classified operations, ARAC is a unique command and control resource.

1 Overview of ARAC

Whether assigned to a global- or national-level command post, the office of emergency services in a major city, or a tactical operations center in a remote combat zone, command and control specialists face difficult challenges in making timely life-and-death decisions regarding toxic materials released into the atmosphere. Intentional acts of war; terrorism; manufacturing, transportation, and storage accidents; and natural disasters such as earthquakes, fires, hurricanes, and floods are among the many potential scenarios in which health- or life-threatening nuclear, chemical, or biological agents may be released into the atmosphere. Military command and control specialists must be prepared to respond not only to military scenarios, but also to civilian emergencies in which all civilian resources have been exhausted and military assistance has been requested. The complexity of the challenge is greatly magnified by the wide range of possible toxic materials and the almost endless combinations of atmospheric conditions such as wind direction, wind speed, stability, and precipitation, all of which vary horizontally, vertically, and temporally. Simple look-up tables and PC-based models are rarely adequate to support successful responses to serious atmospheric emergencies.

The Atmospheric Release Advisory Capability (ARAC) at Lawrence Livermore National Laboratory (LLNL) is a centralized federal facility that stands ready to support emergency command and control centers by providing real-time assessments (analyses and predictions) of the impacts of inadvertent or intentional releases of hazardous materials into the atmosphere. Although originally tasked to respond to radiological emergencies, for the past two years ARAC has been developing new capabilities to respond to atmospheric releases of toxic chemicals and biological agents. Since 1974, ARAC has responded to over 70 domestic and international incidents, working closely with local and state officials, major departments of government (Department of Defense, Department of Energy, Department of State, etc.), and numerous foreign governments. In addition, ARAC has participated in over 700 exercises during this time period. The characteristics of some notable ARAC responses are summarized in Table 1.

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ARAC provides a means for quickly determining the probable scope of an atmospheric emergency by providing graphical plots of toxic contamination and exposure, overlaid on the local geography. Emergency managers can use these products to determine the best emergency response strategy for minimizing hazards to life and property in the affected regions. For radiological and many toxic chemical incidents at ARAC-supported facilities, the time to create and deliver plots to the remote site's computer can be as short as 10 to 15 minutes after the initial receipt of accident information. For incidents at non-supported sites (locations that do not maintain computer workstations on-line with ARAC), the response time depends on the complexity of the source term, the availability of meteorological data, and the preparation of unique model-input parameters. Our chemical response project already allows us to achieve relatively rapid responses for many additional toxic chemical incidents, generally under 30-45 minutes. As we gain further expertise with toxic chemicals and further refine our databases, we expect to shorten this response time.

ARAC uses a robust suite of three-dimensional atmospheric transport and diffusion models, extensive geophysical and source-description databases, and automated real-time meteorological data acquisition systems. Numerous model evaluation studies have confirmed the practicality of ARAC's modeling system, and many past real-time applications of the system have resulted in significant enhancements. ARAC's computational resources include a DEC ALPHA/VAX-based computer system at LLNL and over 40 remote-site computer systems.

ARAC's most valuable asset is its experienced staff, currently consisting of 44 members (about half operations staff and half computer scientists). Assessment meteorologists, known as assessors, coordinate and quality control ARAC's responses. A customer support center interfaces with supported sites, monitoring communications and equipment status and correcting problems. A technical staff maintains and upgrades ARAC's internal computers. Separate groups of computer scientists maintain and upgrade specific functions within ARAC: the core ARAC transport and diffusion models, the site workstation software, and the ARAC Emergency Response Operating System (AEROS). Finally, research scientists in the Regional Atmospheric Sciences Group of LLNL's Atmospheric Science Division contribute to the continual improvement of ARAC's numerical modeling capabilities.

2 Command and Control Support Capabilities

ARAC is uniquely suited for the support of real-time command and control operations. A critical aspect of emergency response support is the timely and effective interaction with command and control authorities; ARAC has extensive experience in this area. Over the years, ARAC has teamed effectively with military and civilian command and control elements at various federal, state, and international agencies, providing a wide variety of radiological and non-radiological predictions at locations across the United States and around the world. ARAC cooperates with specialized DOE emergency response and assessment organizations such as the Accident Response Group (ARG), the Federal Radiological Monitoring and Assessment Center (FRMAC), the Radiological Assistance Program (RAP), and the Nuclear Emergency Search Team (NEST). Federal agencies can request ARAC's services for radiological accidents through the DOE as specified in the U.S. Federal Radiological Emergency Response Plan. Because of its location at a major National Laboratory, ARAC has access to a wide range of scientific, engineering, and computational expertise. The facilities at LLNL also provide ARAC with the capability to support classified operations. ARAC personnel are trained and equipped to rapidly deploy to incident locations if required, and ARAC can use atmospheric and source term data from sensors deployed in the field.

ARAC also is well suited for the support of strategic and tactical planning. For example, using "what-if" scenario assessments, ARAC can provide valuable quantitative information to assist in planning the best defensive response to military or terrorist threats and attacks using nuclear, biological, or chemical weapons. ARAC calculations can also be used to optimize the effectiveness of preemptive or offensive military operations, and to minimize collateral damage and the risks to friendly forces during such actions.

ARAC is also capable of supporting both the planning and real-time execution portions of special (e.g., counter proliferation, etc.) missions. In another example of its potential benefits for military planning, ARAC is currently providing its dispersion modeling expertise to a state-of-the-art electronic war gaming project at LLNL.

3 ARAC Support for Military Operations

ARAC has substantial experience in supporting military operations. At various times, ARAC has
supported over 70 facilities within the Department of Defense (DOD) and the Department of Energy (DOE) with dedicated, on-site computer systems linked directly to ARAC's central computer system at LLNL. Although this support was primarily for nuclear weapon accident contingencies, ARAC's 1991 operations illustrate the increasing diversity of its military support capabilities. On 16 January 1991, just as Operation Desert Storm began in the Persian Gulf, DOE Headquarters requested that ARAC model the hypothetical dispersal of chemical or biological warfare agents that might be carried on SCUD missiles. This request was closely followed by two others asking ARAC to model the dispersal of radioactive material that might be released from bombed Iraqi nuclear reactors, and to prepare realistic evaluations of hypothetical and actual oil-fire scenarios that might affect aircraft and weapon system operations. This last effort paid off in the post-war period, when ARAC was able to use its newly developed oil-fire assessment tools to forecast the position of the smoke plume from the fires set by the Iraqis in Kuwait's oil fields. These forecasts continued through 6 November 1991, when the last fire was extinguished. On 14 June 1991, in the midst of work on the smoke plumes in Kuwait, Mt. Pinatubo in the Philippines erupted, and the U.S. Air Force asked ARAC to forecast the locations and concentrations of the volcanic ash plumes to assist in the selection of safe flight corridors through the ash-filled sky for the evacuation of American citizens.

In another military support role in 1994, ARAC provided real-time calculations to the Sixth U.S. Army Operations Center (SAOC) at the Presidio of San Francisco in support of a major earthquake exercise. The exercise scenario included damage to many chemical production facilities in the quake area. Using actual current weather conditions, ARAC provided calculations of the plume locations and associated chemical concentrations. This information was entered into the SAOC's Emergency Information System (EIS) which was used in briefings to the Sixth Army Commander and was available for display on the EIS workstations for each of the Crisis Action Team officers.

In 1995, ARAC provided support for the launches of one Peacekeeper and two Minuteman missiles at Vandenberg AFB, CA. In another recent exercise, ARAC provided calculations to a U.S. Navy facility for an exercise scenario in which nuclear warheads were damaged and put at risk by the crash of a small civilian aircraft.

4 ARAC Support for Civilian Emergencies

ARAC also has extensive experience in supporting civilian emergency responses, ranging from small accidental ventings of radionuclides, to the Three Mile Island nuclear accident (1979), to the major disaster at the Chernobyl reactor in the Ukraine (1986). One of ARAC's more unique challenges was to estimate the environmental consequences of the reentry and burn-up of the nuclear-powered Russian satellites COSMOS 954, that littered radioactive debris across northern Canada in 1978, and COSMOS 1402, that reentered the atmosphere in two pieces and sank into the Indian and South Atlantic Oceans in 1981. ARAC's long-term response to the Kuwaiti oil fires took on a new dimension in April 1991, when two working groups, one sponsored by the World Meteorological Organization (WMO) in conjunction with the World Health Organization (WHO), and the other consisting of members of the U.S. government's scientific community, proposed airborne sampling programs to evaluate the local and global atmospheric consequences of the fires. ARAC was tasked to produce daily forecasts of the location and density of the smoke plumes in support of these research aircraft missions. Shortly after the flights began, the agencies involved, including the National Science Foundation (NSF), DOD, DOE, the Environmental Protection Agency (EPA), the National Oceanographic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research (NCAR), and Battelle Pacific Northwest Laboratories (PNL), requested copies of ARAC's calculations and forecasts. In addition, ARAC plots were requested by WMO Headquarters in Geneva and by institutions and supporting contractors in the Middle East and in Washington, DC. Concurrently, the WMO encouraged local governments to acquire a variety of meteorological and air-pollutant measurements for use in future evaluations of the effect of the oil-fire plumes on the region. To focus these data collection efforts, the WMO requested that ARAC distribute the calculations to all affected countries. By early June 1991, ARAC was faxing its calculations to Iran, Kuwait, Pakistan, Oman, Bahrain, Qatar, Yemen, Turkey, and Saudi Arabia: a total of 20 agencies and countries were receiving daily ARAC calculations. Also in 1991, ARAC responded to a train accident in which a toxic herbicide (metam sodium) spilled from a tank car into the upper Sacramento River. The herbicide flowed 80 km down the river into Lake Shasta, killing nearly all the fish in the river. Because metam sodium is
water soluble and decomposes into toxic gases that are released into the atmosphere, there was concern for public safety in the vicinity of Lake Shasta, California's largest reservoir and a popular summer recreation area. The California Office of Emergency Services, through the DOE, asked ARAC to estimate the air concentrations of toxic gases. ARAC's response to this incident [Sullivan et al., 1993] demonstrated a framework for developing a toxic-chemical emergency-response modeling capability. This capability was reaffirmed on 26 July 1993, when a major rail car spill of oleum occurred in Richmond, California and ARAC once again rendered emergency assistance to state and local government agencies.

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Source</th>
<th>Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>North Carolina</td>
<td>Train accident</td>
<td>Uranium hexafluoride</td>
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<tr>
<td>1978</td>
<td>Northern Canada</td>
<td>COSMOS 954 reentry</td>
<td>Fission products</td>
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<tr>
<td>1979</td>
<td>Harrisburg, Pennsylvania</td>
<td>Three Mile Island Nuclear Power Plant</td>
<td>Mixed fission products</td>
</tr>
<tr>
<td>1980</td>
<td>Damascus, Arkansas</td>
<td>Titan II missile</td>
<td>Missile fuel</td>
</tr>
<tr>
<td>1981</td>
<td>Indian Ocean</td>
<td>COSMOS 1402 reentry</td>
<td>Fission products</td>
</tr>
<tr>
<td>1982</td>
<td>South Carolina</td>
<td>Savannah River Plant</td>
<td>Hydrogen sulfide leak</td>
</tr>
<tr>
<td>1986</td>
<td>Gore, Oklahoma</td>
<td>Sequoyah Fuels Plant</td>
<td>Uranium hexafluoride</td>
</tr>
<tr>
<td>1986</td>
<td>Chernobyl, USSR</td>
<td>Nuclear Power Plant</td>
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<tr>
<td>1988</td>
<td>Miamisburg, Ohio</td>
<td>Mound Plant</td>
<td>Tritium gas</td>
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<tr>
<td>1989</td>
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<td>Pantex Plant</td>
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<td>1991</td>
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<td>1991</td>
<td>Philippines</td>
<td>Mt. Pinatubo</td>
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<td>1991</td>
<td>Northern California</td>
<td>Railroad car spill</td>
<td>Toxic gas products</td>
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<tr>
<td>1992</td>
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<td>1993</td>
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<td>Sulfur trioxide</td>
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<td>1993</td>
<td>Tomsk-7</td>
<td>Explosion in fuel rod tank</td>
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<td>Tracer Experiment</td>
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<td>Fire</td>
<td>Cs-137</td>
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<tr>
<td>1994</td>
<td>Papua New Guinea</td>
<td>Volcano</td>
<td>Volcanic ash</td>
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<tr>
<td>1995</td>
<td>Vandenberg AFB</td>
<td>Missile launch support</td>
<td>Hydrochloric acid</td>
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Table 1. Some ARAC responses over the history of the project.
5 Four Diverse ARAC Responses

This following section describes four examples of ARAC responses, covering spatial scales from a local community to the globe, and includes examples of nuclear, chemical, and biological incidents.

5.1 Richmond, California Oleum Spill: A Local-Scale Toxic Chemical Accident

The Richmond, California oleum spill [Baskett et al. 1995] is a good example of ARAC's ability to respond to very local-scale problems. The spill was caused by the failure of a pressure relief valve while a railroad tank car was being heated during a transfer operation. Midway through the 3-3/4 hour release, state and local agencies requested real-time modeling from ARAC. With approval from the DOE, ARAC responded to the accident under an Agreement in Principle with the State of California. News reports indicated that the 10^4-kg (100-ton) tank car was loaded with 5 x 10^4 liters (13,000 gal) of 35 grade (35%) oleum (H_2S_2O_7). Sulfur trioxide (SO_3) gas was released to the atmosphere under high pressure and temperature, beginning at 7:15 a.m. PDT and ending when the tank was capped at about 11:00 a.m. After exiting the 7.5-cm (3-in.) diameter valve opening, the heated oleum rapidly expanded and cooled, quickly condensing into a sulfuric acid liquid aerosol in the moist marine atmosphere. Initially the ARAC team was given a worst-case estimate that the full tank contents could be released over 1.5 hr. Later the source rate was revised to half the tank car over 3.75 hr.

A major strength of the ARAC system is that experienced assessor-meteorologists are involved in each step of the emergency response process. Their expertise and keen judgment are essential components of ARAC's quality control of both input data and model output. In the case of the Richmond spill, there was a problem with the wind direction that would have been overlooked by a totally automated system. The proximity of meteorological stations to the release and cloud locations strongly affects the accuracy with which a diagnostic model can determine the plume position. Figure 1 shows that the accident was situated between three airports--Napa 32 km to the north, Concord 26 km to the east, and Alameda Naval Air Station 17 km to the south. Interpolating between these three stations produced a 7:00 a.m. wind direction from 280° when it was known the wind was actually from the southwest.

Due to the complex meteorological conditions, wind data from the airports alone were insufficient to reasonably determine the wind direction at the accident. Fortunately ARAC was able to acquire in real time 15-minute average wind data from a Bay Area Air Quality Management District (BAAQMD) tower at Pt. San Pablo, about 5 km west of the accident location. Figure 1 shows a 3 m/s wind from 221° at the start of the release at Pt. San Pablo. By 8:00 a.m., the wind shifted toward the south, and remained between 200 and 211° for the rest of the release period.

Beyond the source location, the plume position was determined by interpolating between hourly observations from Napa and Concord. Figure 2 shows the mass-adjusted wind field at a single level, using all available observations. Without the intervention of experienced meteorologists and the availability of the BAAQMD tower data, the diagnostic wind model would have been off by 60°. Had there been no tower data, ARAC meteorologists could have specified wind values to match the southwesterly flow expected due to channeling by the topography.

Figure 1. Surface wind barbs for the northern San Francisco Bay area at 7:15 PDT, July 26, 1993. Accident location is in the Center of the box [Baskett et al., 1995]
ARAC produced the first set of plots for the worst-case full-tank-car release just as the release was ending. These plots were used by the California Office of Emergency Services and the California Department of Health Services to initially scope the magnitude of the potential health effects. Later in the afternoon ARAC used the half-tank-car source rate to refine the calculation; Figure 3 shows the hour-average air concentration for the second hour after the release began for this lower source rate. Air concentration plots describing the location and progress of the toxic cloud were faxed to the agencies managing the response. The primary protective action for the public was to shelter in place. In addition, highways, rail lines, and public transportation systems were blocked. The incident was significant enough that over 24,000 people sought medical attention within the week following the release. The ARAC model results were within a factor of 2 of a single 3-hr average measurement of sulfuric acid taken by the BAAQMD on a high-volume sampler 2.3 km downwind on the east side of the plume.

5.2 Sabotage of Kuwaiti Oil Wells: A Regional-Scale Smoke Problem

As mentioned previously, ARAC calculated the dispersion of smoke from the burning Kuwaiti oil fires for a few events during the Persian Gulf War, and later provided daily calculations to numerous customers from mid-May to November 6, 1991, during the intense effort to extinguish the fires [Ellis et al., 1992]. One of the principal uses of the ARAC plots was to support an airborne sampling program. For the longer flights, ARAC's products were particularly helpful in locating the "edges" of the plume several hundred kilometers downwind from the oil fires, where the smoke was too diffuse to be seen.

Sadam Hussein's forces ignited an estimated 605 wells in Kuwait, resulting in 6.2 million barrels of oil flowing out each day. Fifty wells were extinguished by early May, and by early June 100 had been extinguished. For ARAC's calculations, eight oil fields were grouped into three source regions, the south field (Burgan, Ahmadi, and Magwa), the north field (Raudhatain, Sabriya, and Bahrah) and a third region (Minagish and Umm Gudair). A buoyant plume rise representation was used in conjunction with ARAC's ADPIC model to calculate the injection and dispersion of the smoke plume. Because meteorological observations in the Persian Gulf region were sparse, ARAC used three-dimensional forecast winds provided by the U.S. Air Force Global Weather Central's Relocatable Wind Model (RWM). The air concentration of smoke in the horizontal plane was calculated at nine levels in the vertical, and deposition of smoke on the ground...
was also calculated. The results for the vertical levels were combined to generate contours of optical depth (a number representing the total attenuation of light in a vertical column of air).

As an example of the ARAC calculations, Figure 4 shows the position of the modeled smoke plume at 1200 UTC, 3 June 1991 using the analyzed initial wind field from the RWM. The modeled plume covers most of the northern Persian Gulf and has spread inland to the south of Qatar. For comparison, Figure 5 shows the NOAA-11 satellite visible image of the plume at 1105 UTC.

5.3 Anthrax Attack: A Regional-Scale Biological Agent Scenario

We have run the ARAC models for a variety of biological agent release scenarios as part of a recent study of proposed sensors for the detection of biological agents in the battlefield. The model calculations were used to quantify the likely particulate air concentrations (as a function of time and location) available for detection through the use of various sensor technologies, and to estimate the battlefield casualties associated with several different sensor deployment strategies.

Figure 6 illustrates the results from one of these calculations. In this hypothetical winter-time scenario an aircraft flies at approximately 75 meters above the surface from east to west at the head of the Yesong river valley in North Korea. The aircraft releases 1 kilogram of respirable (less than 10 microns) anthrax particles per kilometer for an approximately 29-kilometer flight path. The isopleths shown in Figure 6 represent the integrated air concentration of the anthrax cloud as it is carried by the typically northerly (from the north) winter winds of the area. The magnitude of each of the five isopleths is shown in the legend in units of gram-seconds per cubic meter, along with the area covered by each isopleth value. Through the application of appropriate conversion factors and the model’s capability to move point “receptors” (i.e. troops, population groups, etc.) through the computational domain as a function of time, these values may be expressed as a dose to stationary or moving individuals within the cloud path to yield estimates of potential casualties from this hypothetical attack. Alternatively, the isopleth values can be easily converted to quantitatively express short-time-averaged concentrations of the agent-containing particles that form the cloud
Figure 6. Modeled anthrax plume over Korea, resulting from a hypothetical aircraft line release at the head of the Yesong River Valley in North Korea. Plot shows integrated air concentrations at 1.5 m above the ground for the 15-hour period immediately following the release.

These particles would be measured by many of the currently proposed sensor devices, the movement of which can also be simulated by ARAC's models (as the doubly dynamic interaction of a moving "receptor" within the modeled agent-containing cloud).

Note that, as in most areas of complex terrain, the isopleth patterns are quite intricate in detail. These patterns result from the interaction of the modeled terrain of the area with the three-dimensional wind field used in the calculations. Although the ARAC capability for real-time collection of worldwide meteorological data was used in many of these biological-sensor-related calculations, the climatologically-based winds shown in Figure 7 were used for the anthrax calculation shown in Figure 6. Here, the wind vector for every other grid point in the domain is shown for a horizontal slice near the modeled surface (vectors point in the direction the wind is blowing to, with the vector length proportional to the wind speed). This particular wind field was generated by specifying input wind velocities (at three point locations within the domain) with directions ranging from north to northwest, and very stable atmospheric stability conditions. The resulting complex flow shown in Figure 7 was created by producing a mass-consistent wind field, based upon the input wind velocities and using a stability-dependent adjustment of flow (either around or over significant terrain features). In this example, flow around mountainous terrain located just to the north-northeast of the domain's center leads to the reduced concentrations in the middle of the isopleth pattern shown in Figure 6.

5.4 Chernobyl Reactor Disaster: A Global-Scale Nuclear Accident

The 1986 Chernobyl nuclear accident in the former Soviet Union provides an example of ARAC's ability to respond to global-scale problems [Lange et al. 1988; Lange and Foster, 1992]. ARAC used long-range atmospheric dispersion modeling to estimate the amount of radioactivity released from the Chernobyl reactor and to calculate the radiation dose distribution due to exposure to the radioactive cloud over Europe and the Northern Hemisphere.
Later, after the Soviet Union released data on the accident, ARAC used a mesoscale model to study the radiation dose distribution within the Soviet Union and in the vicinity of the Chernobyl plant.

Radioactivity measurements over Europe, Japan, and the U.S. indicated that the release from the Chernobyl reactor contained a wide spectrum of fission and activation products; a few days after the initial explosion, these products were detected at heights up to 7 km. The presence of radioactivity at such high altitudes probably was caused not only by the thermal energy of the initial release, but also by atmospheric processes. The most important radionuclides of global concern were $^{137}$Cs, $^{134}$Cs, and $^{131}$I, because of their relative abundance and their radiological and chemical characteristics. The Soviets reported a discharge of 20% of the core inventory of $^{131}$I and 13% of the inventory of $^{137}$Cs, based on material deposited in the near-field inside the USSR. However, investigators in Western Europe estimated an additional 20% of the core inventory of these nuclides was transported into their area, and analysis of aircraft data indicated that yet another 20% of the core inventory of $^{131}$I and $^{137}$Cs was transported into the rest of the Northern Hemisphere, as far away as Japan and the United States. In the absence of accurate data from the USSR at the time, $^{131}$I and $^{137}$Cs measurements were used to estimate the source term. Using its atmospheric models, and measurements from Denmark, Finland, France, Germany, Japan, Kuwait, the Netherlands, Norway, Sweden, the United Kingdom, and the United States, as well as from the World Health Organization and the International Atomic Energy Agency, ARAC was able to estimate a source term that was likely to be within a factor of two or three of the actual amount released. ARAC's calculations indicated that a total of $1.7\times10^{18}$ Bq of $^{131}$I and $8.9\times10^{16}$ Bq of $^{137}$Cs were released. Some features of the release suggested that the source term consisted of two phases: an early explosion-like phase, with up to 50% of the total release injected to heights of several kilometers; and a later, longer burn that injected smaller amounts of material at lower heights.

As an example of ARAC's hemispheric Chernobyl calculations, Figure 8 shows a polar view of the modeled clouds of radioactive material at 2, 4, 6, and 10 days after the initial explosion (April 26, 1986). By the end of April 27 (day 2),

the activity near the surface had traveled northwesterly toward Scandanavia, passing over the northeastern corner of Poland. The activity continued its expansion into Scandanavia until April 29 (day 4), and also moved southwesterly through Poland toward eastern and central Europe. During this period, the emissions were also transported eastward. By May 1 (day 6), the surface activity had spread throughout central and southern Europe, as well as east and south of Chernobyl. By May 5 (day 10), the material had spread throughout most of the Northern Hemisphere and had reached the United States. Quantitative plots of the modeled daily average surface air concentrations for $^{131}$I over Europe at two-day intervals are shown in Figure 9.
6 Conclusion

ARAC is a unique federal resource for command and control operations, capable of responding in real time to local, regional, or global atmospheric releases of nuclear material, toxic chemicals, and biological agents. As a national resource located at a major National Laboratory, ARAC has access to an unsurpassed range of scientific, engineering, and computational expertise, and has the capability to support classified operations. With a professional staff of 44 personnel and over 20 years of experience in supporting atmospheric emergency responses, ARAC stands ready to support command and control centers throughout the world.

7 Inquiries

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