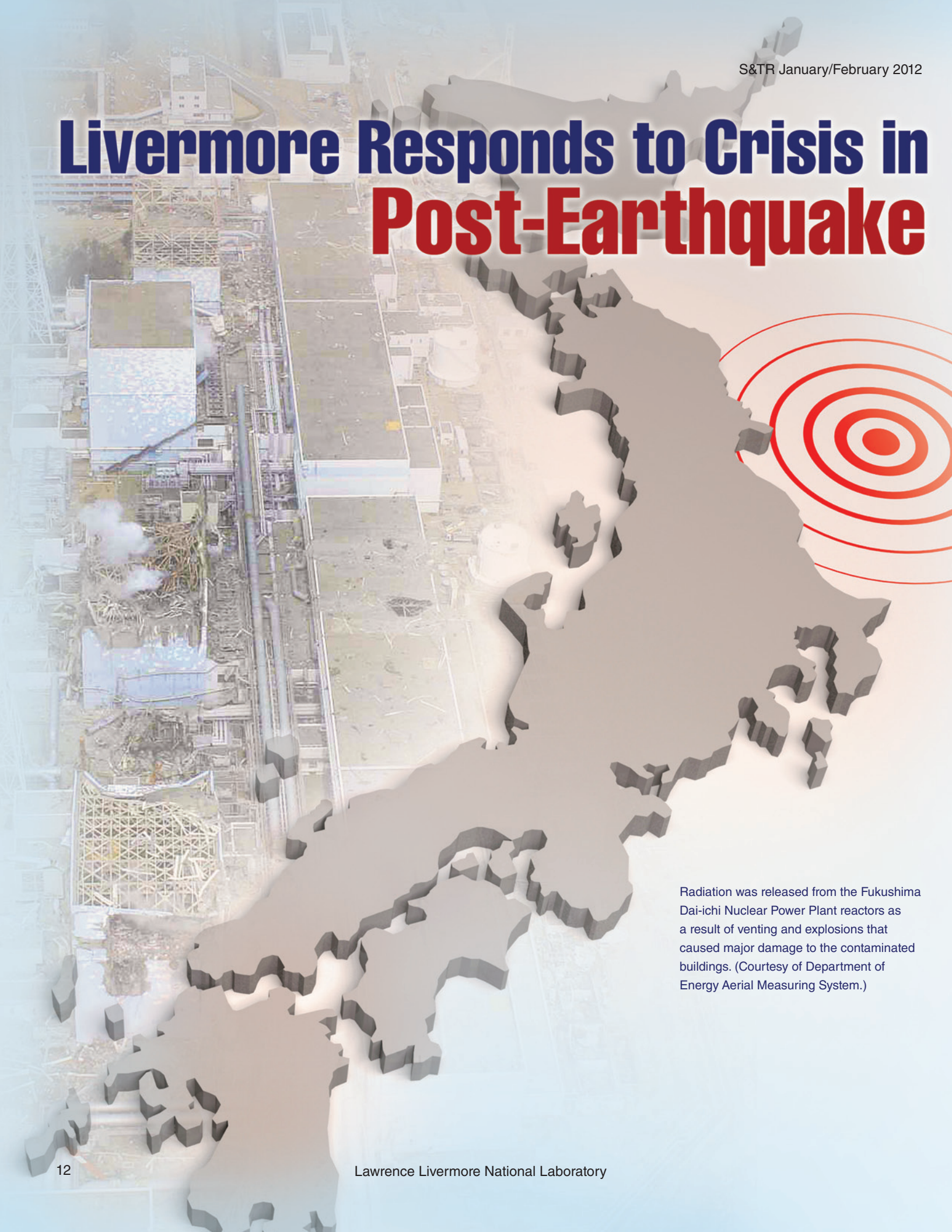


Livermore Responds to Crisis in Post-Earthquake

The image features a background aerial photograph of a large industrial complex, likely a nuclear power plant, showing significant structural damage and debris. Overlaid on the right side of the image is a 3D map of the United States, with a red bullseye target symbol positioned over the East Coast region. The overall composition is set against a light blue gradient background.

Radiation was released from the Fukushima Dai-ichi Nuclear Power Plant reactors as a result of venting and explosions that caused major damage to the contaminated buildings. (Courtesy of Department of Energy Aerial Measuring System.)

Japan

For several months in 2011, Livermore scientists contributed to the nation's response to the nuclear accident at the Fukushima Dai-ichi Nuclear Power Plant complex in Japan.

ON March 11, 2011, an earthquake of historic proportions unleashed its 9.0-magnitude destructive power on the northeast coast of Japan, triggering a devastating tsunami that turned cities to rubble and claimed thousands of lives. Soon the news got even worse: Japan found itself on the brink of a major nuclear crisis after a 14-meter (45-foot) wave struck the Fukushima Dai-ichi Nuclear Power Plant complex. The plant itself survived, but electrical power to cool the reactors was lost and backup generators were damaged. The resulting heat buildup in reactor cores and in spent fuel pools then led to the release of radioactive materials.

As the world held its collective breath, the scientific community swung into action to assess the extent of the crisis

and help guide protective actions. Among the responders was a team of Livermore experts who have developed sophisticated computer systems that model the spread of nuclear materials in the atmosphere. Their goal was to provide government officials in the U.S. and Japan with answers to some of the most urgent questions on everyone's mind: how much radiation was being released, where it would travel, and what protective actions might be warranted.

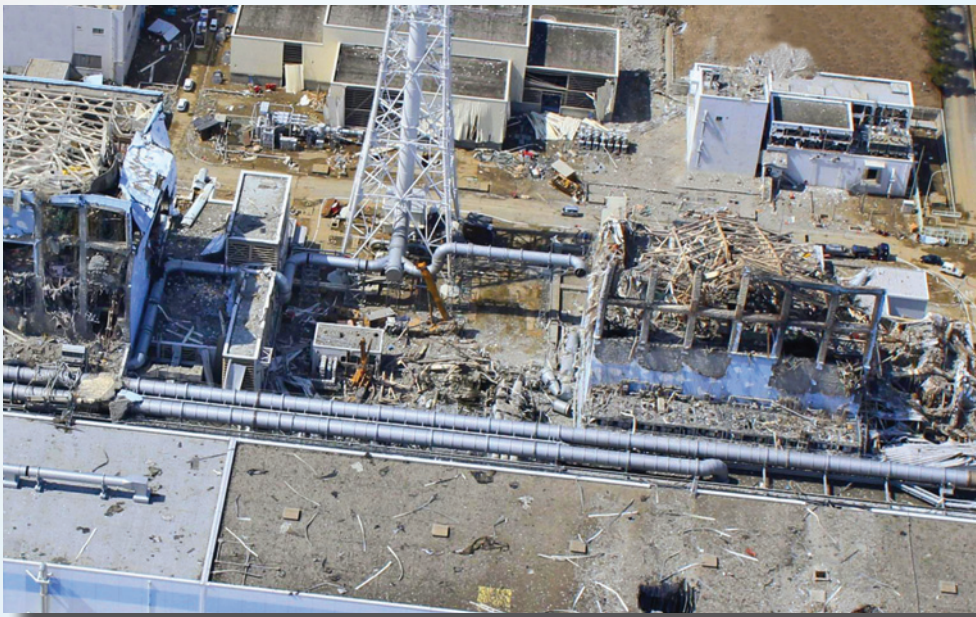
Livermore's National Atmospheric Release Advisory Center (NARAC) was activated on March 11 to provide top governmental authorities and emergency response teams both in the U.S. and Japan with daily meteorological forecasts and atmospheric dispersion predictions. The center's analyses provided scientifically based guidance that was used in making

decisions affecting U.S. citizens in Japan, including the potential need for evacuation, sheltering, or iodine administration.

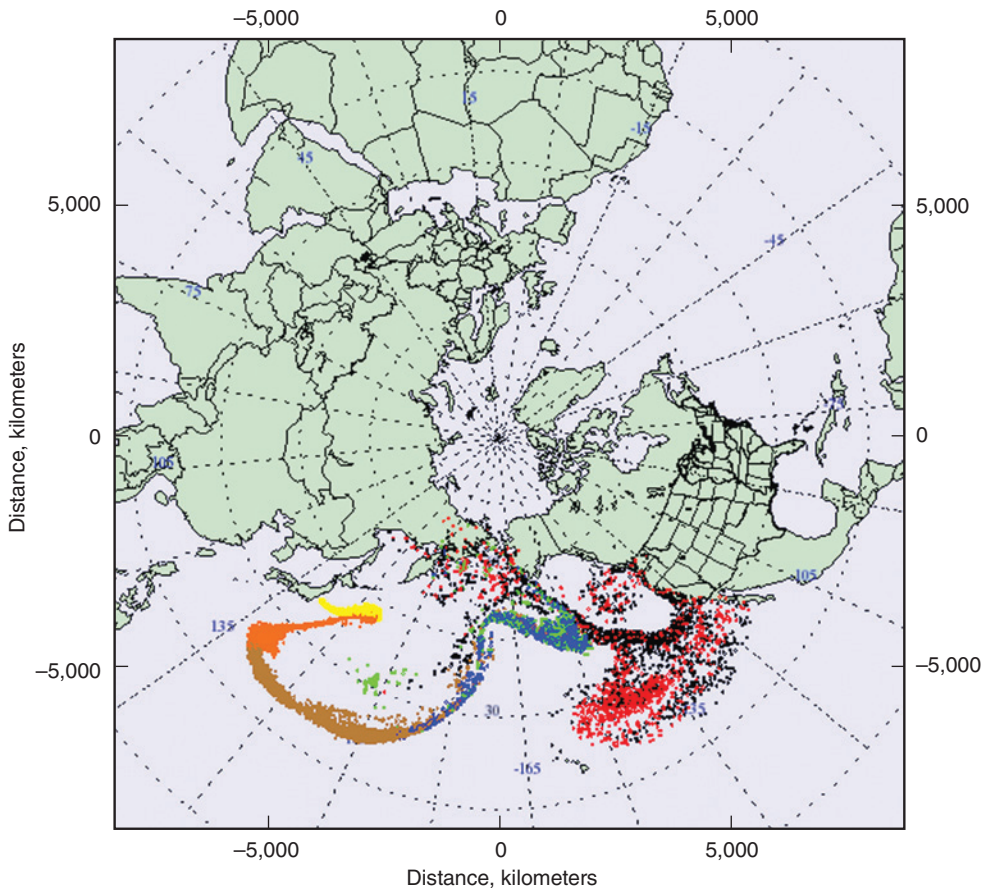
Based in part on NARAC projections and Nuclear Regulatory Commission (NRC) guidance, on March 16, the U.S. Department of State advised American citizens living within 80 kilometers of the damaged nuclear power plant to evacuate or take shelter indoors. Factors such as weather and wind direction were cited by the embassy as key reasons for this recommendation. "None of the recommendations were based solely on model results," says Gayle Sugiyama, program leader for NARAC. "But modeling analyses were certainly important in providing guidance, especially in the early phases of the crisis."

NARAC was tasked with making projections of plume arrival times in U.S. territories with corresponding radiation doses. NARAC models correctly estimated an initial four- to five-day transit time before radioactivity would reach the West Coast and predicted that the radioactivity was unlikely to reach the U.S. at hazardous levels after the trans-Pacific journey. Measurements subsequently confirmed these projections.

NARAC operated as part of the Department of Energy's (DOE's) Consequence Management Home Team (CMHT), a network of national laboratory scientists who complement each other in their respective areas of expertise. The CMHT was drawn from scientists working at the Remote Sensing Laboratory in Las Vegas, Nevada, and in



The National Atmospheric Release Advisory Center's (NARAC's) team of multidisciplinary scientists, engineers, technicians, and administrators worked around the clock for weeks during the height of the 2011 Japan nuclear reactor crisis. Principal Deputy Administrator Neile Miller (center in yellow) of the Department of Energy's (DOE's) National Nuclear Security Administration visited Livermore on March 29, 2011, to thank the team members for their efforts.



This NARAC model of plume transport from Japan to U.S. territories shows the complexity of the trans-Pacific dispersion. Colored particles represent airborne radioactivity, with different colors indicating different days of potential releases from Japan.

Washington, DC, as well as personnel from Lawrence Livermore, Sandia, Los Alamos, and Savannah River national laboratories.

Areas of staff expertise included radiological monitoring, sample collection and analysis, atmospheric dispersion, and dose assessment. CMHT scientists provided DOE with information to support the U.S. government in advising its citizens on protective actions, the Department of Defense in conducting humanitarian assistance and disaster relief operations, and the Japan government in developing its own guidelines for population relocation. NARAC served as the CMHT plume modeling center, analyzing data supplied by other members to use in its models and predictions.

Decades of Atmospheric Modeling

Founded in 1979 as part of the response to the Three Mile Island nuclear power plant accident, NARAC has been on the cutting edge of the science of atmospheric dispersion modeling ever since. Its multidisciplinary staff of physicists, atmospheric scientists, computer scientists and technicians, engineers, and health physicists has access to high-performance computers

and sophisticated modeling software. The center's stored databases of geographical and meteorological information are combined during real-life events with disaster-zone data to create three-dimensional maps of hazardous plumes.

The center serves the nation by responding to U.S. and global disasters, from fires and toxic spills to nuclear accidents. Its thousands of users include federal, state, and local agencies and emergency operations centers both in the U.S. and around the world. As the modeling center for radiological and nuclear events for DOE's National Nuclear Security Administration (NNSA), NARAC has responded to dozens of nuclear emergencies over the years, including the 1986 Chernobyl nuclear reactor disaster and the 1999 nuclear fuel accident in Tokaimura, Japan. As such, it was especially well positioned to lend its expertise to this latest crisis in Japan.

"What's unique about our center is how we integrate all the pieces: knowledge of nuclear material and atmospheric transport, understanding of radiological monitoring data and radiological dose, access to the multidisciplinary talent at the Laboratory, and collaborations with other DOE organizations," says John Nasstrom, NARAC's deputy leader. "We can put all these pieces together and then translate science into information that decision makers can act on."

One of NARAC's major tasks during the Japan response was to work with NRC, DOE, and the White House to construct a wide range of hypothetical scenarios, or "what-if" predictions, for the atmospheric dispersion and deposition of radioactive releases. NARAC scientists used scenarios provided by NRC to develop products such as maps of potential evacuation and sheltering areas. Says Brenda Pobanz, an atmospheric scientist with NARAC for the past 20 years, "Based on a given source term (the amount of radioactive material released) and the location of people in the

area, we projected whether dose levels warranting sheltering or evacuation would or would not be reached."

A Challenge Second to None

For all of NARAC's experience, nothing approached the complexity and urgency of responding to the nuclear accident in Japan—by far the most challenging event in the center's history. In the response to Chernobyl, NARAC experts provided longer range and fewer assessments. This time, they were part of the daily action throughout the crisis, constantly revising their models in response to data streaming in at all hours of the day and night.

The center needed to deal with ever-changing meteorological conditions, Japan's complex topography, and the overwhelming amount of data. Winds were shifting continually, alternating

between blowing offshore and onshore. To compound a bad situation, rain washed radioactivity out of the air in some areas, resulting in complex patterns of ground contamination.

NARAC computational resources and personnel were frequently strained to respond to the stream of requests. "So many reactors were experiencing problems over so many days that the requests for simulations were immense," says Nasstrom. "And each simulation had complicated atmospheric release characteristics, requiring simulation of weather and radioactive material transport over multiple days."

The scientific challenge, however, was only part of the equation. Throughout the crisis, NARAC supplied information to DOE, which in turn passed the information on to other U.S. agencies, the Department of State, and the White



DOE activated NARAC on March 11, 2011, to provide daily meteorological forecasts and atmospheric dispersion predictions to government officials in the U.S. and Japan. The center provided over 300 plume analyses, such as this one, in collaboration with DOE's Consequence Management Home Team, the Nuclear Regulatory Commission, and other agencies. (Background map courtesy of Google.)

House. A Web site hosted by NARAC also shared model projections and monitoring data with DOE and other government organizations.

“We dealt with a constant stream of requests from Washington,” says Sugiyama, who was in regular contact with government authorities. “Understandably, everyone wanted more information, more quickly. But NARAC staff supplemented by other scientists from the rest of the Laboratory rose to the challenge in an extraordinary way. We have practiced being able to do something like this for years, and that practice paid off.”

Making Sense of a Tsunami of Data

During the early days of the crisis, data were scarce. The tsunami brought down power lines, and many stations were off-line. But within days, the floodgates of 21st century communications opened up. NARAC carried out calculations based on

information from a multitude of sources—weather and monitoring stations in Japan, the DOE teams deployed to Japan, other national laboratories, NRC, and a plethora of Web sites and e-mail streams, many of which had to be translated and checked for accuracy.

Once in Japan, DOE’s Aerial Measuring System and ground-monitoring teams began to send large volumes of valuable data to CMHT, as did Japanese organizations. Soon, NARAC was flooded with an abundance of riches. “Having to process, quality assure, and analyze all the data so they could be used in support of modeling efforts was a major challenge,” says Sugiyama.

Counting on Nuclear Experience

While NARAC used real-time weather data to develop computerized forecasts and models, another team at Livermore supported DOE with radiological analysis

of air and soil samples sent directly from Japan by the DOE team deployed there. The Livermore Japan Response Lab Analysis Support Project and the DOE Triage Program leveraged the Laboratory’s expertise with radionuclide analysis and gamma spectrometry to answer two key questions: Had actual nuclear fuel been released into the environment, and is the amount of radiation released posing a real danger to U.S. and Japanese citizens? To determine the physical state of the reactor fuel, scientists looked for the presence of actinide signatures in the samples. High-resolution gamma-ray spectroscopy was used for dose assessment. The sample analysis also provided NARAC scientists with measurement data they could use to refine their predictions.

The Lab Analysis Support Project collaborated with other institutions as part of DOE’s CMHT. Livermore’s Carolyn Wong coordinated the distribution of Japanese samples to multiple laboratories for analysis. As the primary analysis laboratory, Livermore performed the bulk of these tasks, including sample screening, gamma spectrometry, depth profiling, and actinide analysis. Savannah River conducted strontium analysis, gamma spectrometry on soils, and actinide analysis. Los Alamos also performed a few strontium and actinide analyses. In addition, Livermore team members who normally serve as part of the DOE Triage Program supported analysis of hundreds of gamma spectral measurements taken in Japan and provided technical peer review of analytical products, such as correlating and corroborating results from CMHT members.

From the end of March through the end of June, hundreds of field samples from Japan arrived at Livermore, testing to the extreme the capabilities of personnel and facilities that had never responded to a crisis of this magnitude. “The system had



Gamma spectroscopists P. Todd Woody (foreground), Bob Haslett (center), and Cindy Conrado (standing) of the Laboratory’s Nuclear Counting Facility analyzed Japan air and soil samples for radionuclides measured with high-purity germanium gamma detectors.



Livermore chemists Rachel Lindvall (left) and Amy Gaffney (right) analyzed Japan air particulate samples for uranium and plutonium isotopic composition with Nu Plasma HR™, a multicollector, inductively coupled plasma mass spectrometer.

not been exercised for such a sustained period of time in many years,” says project lead Steve Kreek, who heads the Nuclear Detection and Countermeasures Research Program in Global Security. “We had not experienced anything even remotely similar since the end of nuclear weapons testing in 1992.”

Samples collected by DOE personnel in Japan, many from the Remote Sensing Laboratory in Las Vegas and other laboratories, included paper and charcoal air filters that trap airborne particulates, surface soils and swipes used to assess ground deposition of radionuclides, and soil cores collected for depth profiling to assess how quickly radioactive isotopes migrate into the ground.

On arrival at Livermore, the samples were delivered to the Radiological Measurements Laboratory, where they were barcoded for sample tracking and screened for gross alpha and beta activity

to assess radioactivity levels and to monitor for contamination. Next, all of the air filters and charcoal cartridges and some of the soil samples were sent to Livermore’s Nuclear Counting Facility for gamma spectroscopy. A few were also analyzed at the mass spectrometry laboratories in Livermore’s Chemical Sciences Division to determine if actinides (uranium, plutonium, americium, and curium) were present.

“Five to seven days later, we had peer-reviewed analytical products we could confidently present to DOE for dose assessment,” Kreek says. “We could not have done this work had we not been a weapons laboratory with a long history of performing such analyses. We needed a large nuclear counting facility and large analytical laboratories.”

At the Nuclear Counting Facility, the samples were placed in gamma counters for measuring and then analyzed

with GAMANAL, a software program developed by the Laboratory during the nuclear testing program for gamma spectra analysis. “We extended the program’s use to environmental and emergency response samples,” says Bryan Bandong, head of the Nuclear Counting Facility.

Gamma spectroscopy was used to identify the presence of various radionuclides, including cesium and iodine isotopes, and for dose assessment. Chemical separation and purification followed by mass spectrometry and alpha spectroscopy determined whether actinides such as uranium and plutonium were present. For gamma spectrometry, Bandong says, “Most radioisotopes have signature gamma rays by which we can identify them. Depending on the intensity of the peak, we can tell how much of the radioisotope is present in the sample.”

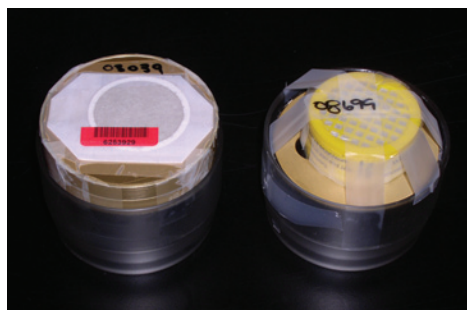
The rate at which samples came in combined with the tight turnaround requirements imposed by the ongoing crisis forced the facility to put all its ongoing research and development operations on hold. According to Bandong, DOE needed analytical results in as few as two days, and more than 90 percent of the time, his team delivered on time. Meeting the requirements was both the greatest challenge and the greatest accomplishment for the Nuclear Counting Facility staff. “Working long days and weekends for several weeks definitely got us tired, but we felt good knowing we could support the government at a time of crisis,” he says.

Measuring Success

By the time NARAC ended its active operations in late May and the lab analysis team at Livermore sent its last data set to DOE on August 19, Livermore had invested more than 7,600 person-hours of time in support of the Japan response effort. NARAC produced more than 300 analyses and predictions, the lab analysis team



Soil samples collected by the DOE field team from locations throughout Japan were sent to DOE national laboratories, including Livermore, for radionuclide analysis.



Particulate filter (left) and carbon cartridge (right) samples were barcoded for analysis tracking and mounted on holders for gamma counting.



Air samples were collected by a 5-centimeter-diameter particulate glass fiber filter (right) and passed through a 5-centimeter-diameter carbon cartridge (left) filled with triethylenediamine.

performed more than 1,500 analyses, and the DOE triage team processed hundreds of field gamma spectra. NARAC's Web site had received 3 million hits.

"Our computer systems, containing millions of lines of codes, functioned 24 hours a day, seven days a week for three months, well beyond any anticipated requirement," Sugiyama

says. "As we look back, we realize it was a remarkable accomplishment."

People seemed to be as indestructible as the machines, with the NARAC core team working for 22 days straight during the height of the crisis, manning the center 24 hours a day in rotating shifts, nights and weekends. The lab analysis and triage teams did much the same during the height of samples arriving at Livermore. "It was difficult to keep up the pace in the early phase," says Kreek, "and changing requirements complicated our ability to respond and optimize our throughput."

A total of 78 people contributed to the combined efforts. For their outstanding contributions in support of the Japan emergency, the Laboratory honored the teams with Gold Awards, Livermore's highest honor, on July 8, 2011.

The true measure of NARAC's efforts came down to the quality of the modeling products it put out, as judged against actual measurements. "Given the many complexities involved in modeling this release, we were surprised that all of our calculations, using different sets of data, produced similar estimates of release quantities," Sugiyama says. "But much work still remains to be done to accurately reconstruct the Fukushima releases."

Ultimately, what Livermore scientists accomplished during the Japan response effort lies at the heart of the Laboratory's fundamental mission: to harness the power of high-level science, Laboratory expertise, and computing and apply them to real problems affecting the nation and the world. Livermore can bring together specialists from many fields, integrate their efforts, and sustain their expertise over the decades.

Says Nasstrom, "Science has advanced so much over the years. We can do many things now that we could not have done 10 or 20 years ago. Seeing the payoff from that investment in science is especially rewarding."

—Monica Friedlander

Key Words: actinide analysis, alpha spectroscopy, atmospheric dispersion model, Consequence Management Home Team (CMHT), gamma spectroscopy, National Atmospheric Release Advisory Center (NARAC), nuclear accident, Nuclear Counting Facility, Radiological Measurements Laboratory.

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