UCRL-52959

Utilization of the Atmospheric Release Advisory Capability (ARAC) services during and after the Three Mile Island accident

Joseph B. Knox
Marvin H. Dickerson
George D. Greenly
Paul H. Gudiksen
Thomas J. Sullivan

July 1, 1980

Lawrence Livermore Laboratory

UCRL-52959
Distribution Category UC-11

Utilization of the Atmospheric Release Advisory Capability (ARAC) services during and after the Three Mile Island accident

Joseph B. Knox
Marvin H. Dickerson
George D. Greenly
Paul H. Gudiksen
Thomas J. Sullivan

Manuscript date: July 1, 1980

LAWRENCE LIVERMORE LABORATORY
University of California • Livermore, California • 94550

Available from: National Technical Information Service • U.S. Department of Commerce
5285 Port Royal Road • Springfield, VA 22161 • $6.00 per copy • (Microfiche $3.50)

CONTENTS

Utilization of the Atmospheric Release Advisory Capability (ARAC) services during and after the Three Mile Island accident

ABSTRACT

At 0820 PST on 28 March 1979, the Department of Energy's Emergency Operations Center advised the Atmospheric Release Advisory Capability (ARAC) that the Three Mile Island nuclear power plant in Harrisburg, Pennsylvania, had experienced an accident some four hours earlier, resulting in the atmospheric release of Xenon-133 and Krypton-88. This report describes ARAC's response to the Three Mile Island accident, including the role ARAC played throughout the 20 days that real-time assessments were made available to the Department of Energy on-scene commander. It also describes the follow-up population-dose calculations performed for the President's Commission on Three Mile Island. At the request of the Nuclear Regulatory Commission, a questionnaire addressing the usefulness of ARAC products during the accident was sent to ARAC-product users. A summary of the findings from this questionnaire, along with recommendations for improving ARAC service, is also presented. The accident at Mississauga, Ontario, Canada, is discussed in the context of a well-planned emergency response by local and Federal officials.

INTRODUCTION

BACKGROUND

The Department of Energy is charged with responsibility for operating its nuclear research and production facilities and for developing new energy technologies in a manner consistent with the protection of public health and safety. This includes the development of strict safety standards and of emergency-response plans should a toxic substance be released accidentally from one of its operating facilities. In 1972, DOE's predecessor, the Atomic Energy Commission (AEC), realized that its response to nuclear accidents could be improved substantially by developing a capability for real-time estimation of pollutant transport and the dispersion of radioactivity released into the atmosphere. It was envisioned that this capability, when integrated with various radiation-measurement systems, could help emergency-response personnel improve their real-time assessments of the potential consequences of a release. That vision led to Lawrence Livermore Laboratory's (LLL's) development of the Atmospheric Release Advisory Capability (ARAC).[1] This capability uses advanced, three-dimensional transport modeling of pollutants entrained in regional-scale flow systems and improved communications for disseminating predictions to local accident-response officials.

The objective of the ARAC system, as designed in 1973, was to provide real-time predictions of dose levels resulting from accidental releases of radionuclides from AEC nuclear facilities. This objective has since been expanded to include support to the DOE Emergency-Response Team in the event of potential or actual releases of significant quantities of radioactivity from any nuclear accident. Thus, ARAC was asked by the DOE Emergency Operations Center (EOC) to respond to the Three Mile Island (TMI) reactor accident. This request was for real-time estimates of airborne radioactivity distributions in the Harrisburg, Pennsylvania, area resulting from the release of gaseous radioactivity from the damaged reactor core. By using meteorological and U.S. Geological Survey (USGS) topographic data as input to the regional-scale transport models, estimates of activity distributions (out to 80 km from the reactor site) were made in real time over a 20-day period following the accident.

ARAC representatives were sent to the Harrisburg area to interpret the results and to advise the on-scene DOE Emergency-Response Team commander. These results provided valuable guidance for the design and effective deployment of surface and airborne environmental measurement systems that became available for assessing the consequences of the emissions. In addition, the ARAC calculations served to advise the Federal Aviation Administration (FAA) about the safety of operating aircraft near the Harrisburg area from the standpoint of potential radiation exposures to passengers and crews. Several months after the accident, ARAC performed a detailed analysis of the total dose to the population in the Harrisburg area for the President's Commission on the accident at TMI.

THE ARAC SYSTEM

The ARAC system consists of the components shown in Fig. 1. Currently, four DOE sites are receiving ARAC service. They are the Savannah River Plant, the Rocky Flats Plant, the Mound Facility, and the Lawrence and Sandia Livermore Laboratories. The ARAC center at Livermore is the focal point for data acquisition, assessment, and communication with the other DOE sites. The center is linked by two-way communication with the LLL Computer Center, the four DOE sites, the Air Force Global Weather Central (AFGWC), the DOE Emergency Response Team, and the FAA. In addition, the center receives weather data from the National Weather Service (NWS).

ARAC has operational models that estimate the consequences of atmospheric releases of hazardous materials on local, regional, and global bases. Gaussian diffusion calculations, based on the site meteorology, are used for close-in local estimates (out to distances of 5 to 10 km) during the first 10 min after ARAC is notified of a release. Regional calculations (out to roughly 100 km) are performed with three-dimensional numerical transport and diffusion codes (MATHEW[1] and ADPIC[2]) for estimating air concentrations and ground deposition from continuous or instantaneous point sources. MATHEW is a meteorological data-adjustment model developed to provide ADPIC with input wind fields that are mass-consistent, three-dimensional, and representative of the available meteorological measurements (surface, tower, and upper-air soundings). The bottom

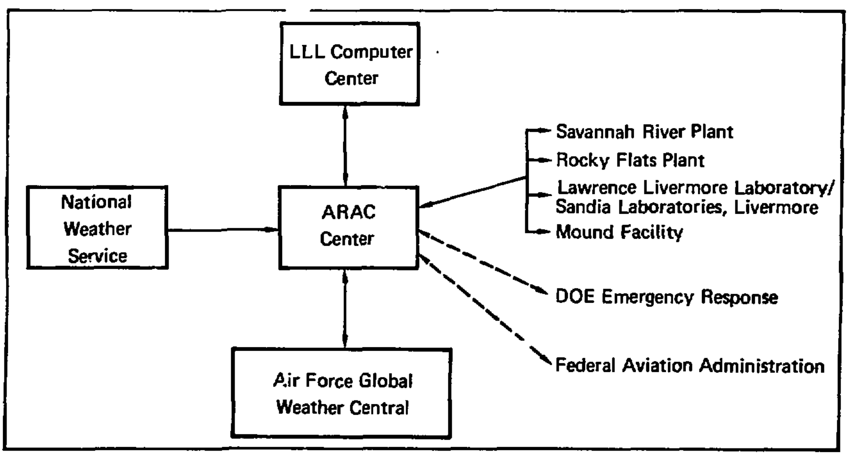

FIG. 1. Components of the Atmospheric Release Advisory Capability (ARAC) service. The solid lines represent voice and computer-to-computer links; the broken lines represent facsimile, teletype, voice, or telecopier links.

boundary in this model is determined by the actual topographic features of a given site (and its environs), which can play a very important role in defining or modeling the regional-scale patterns. ADPIC is a three-dimensional, particle-in-cell transport and diffusion code capable of calculating the time-dependent dispersion of inert or radioactive air pollutants. The code can include the effects of stratified shear flows, calm conditions, variable topography, and wet and dry deposition. This computer code has also been adapted to simulate fallout patterns of particulates with given particle-size distributions and plume depletion of particulates over various terrains. Assuming that an operating staff is available 24 h per day, these regional assessments can be available at any of the four ARAC-serviced sites within approximately 45 min.

During 1974–1978, the ARAC research staff designed and conducted, jointly with other groups, eight regional tracer experiments to obtain information on system performance, communication problems, and overall model verification. These experiments, which were conducted in Idaho and South Carolina, included fixed-location and mobile surface samplers, as well as helicopter-mounted tracer detection systems deployed out to 80 km from the release points. Data on the three-dimensional tracer distributions were obtained and compared to those of the model calculations. The results indicated that roughly 65% of the comparisons agreed within a factor of two and that 80% agreed within a factor of three even when topographic effects played a significant role in the transport processes.

For global-scale transport and diffusion problems associated with nuclear weapons, the current verified models used for fallout and long-range transport and diffusion are KDFOC2[3] and 2BPUFF,[4] respectively. These models were tested extensively from 1964 to 1970 at the Nevada Test Site. Isotopic airborne concentrations, surface air concentrations, and surface deposition patterns were, when compared to experimental data, within a factor of three at ranges up to thousands of kilometres.

METHODS OF OPERATION

ARAC's response to an accident is dependent on the nature and location of the accident. The quickest response is, of course, to an accident occurring at one of the four DOE sites currently receiving ARAC service. For these sites, data bases have been developed that include geography, topography, and the locations of meteorological measurement systems. These permanent data bases are stored in model input format. In addition, data describing the nature of potential accidental releases at each site are available at the center. Each of the four sites also has a minicomputer that:

- Collects, processes, and performs quality control of data from the site meteorological sensors.
- Transmits these data to the ARAC center in Livermore.
- Calculates and displays Gaussian diffusion estimates for close-in distances.
- Receives and displays the results of regional calculations.

Interactions between personnel at the ARAC center and the site are highly dependent on local site capabilities. Thus, some sites are almost totally dependent on the ARAC results for impact assessments of an accidental release, while other sites use regional model calculations to extend and provide more detail to their close-in (within the site boundaries) assessments.

ARAC support to the DOE Emergency-Response Team at sites not regularly serviced by ARAC requires a slightly different approach. Meteorological data throughout the region of interest are obtained through the AFGWC computer link, which provides access to surface and/or upper-air measurements at approximately 12,000 locations on a global basis. Measurements near the accident location are obtained by telephone from local authorities (i.e., air-pollution-control agencies, emergency-response teams, etc.). USGS tapes of terrain data, stored in the ARAC center, are used to extract topographical information for the continental U.S., while USGS maps provide both geographic and terrain data should the accident site be outside the U.S. These data are then processed in a manner analogous to that of an ARAC-serviced site to ensure compatibility with close-in Gaussian and three-dimensional regional transport models.

ARAC supports the FAA by evaluating radiation doses to passengers and crews aboard aircraft that may intercept radioactive debris clouds from Chinese atmospheric nuclear tests. Evaluation is done by means of the 2BPUFF long-range transport code, using input data from the AFGWC.

The results of calculations based on analyzed and forecasted winds at the appropriate levels in the troposphere and/or stratosphere are sent to FAA headquarters by telecopier. These results allow the FAA to determine whether deviations from normal flight operations are needed to minimize the doses.

This report describes ARAC's response to the Three Mile Island accident, including the role ARAC played throughout the 20 days that real-time assessments were made available to the DOE on-scene commander. It also describes the follow-up population-dose calculations performed for the President's Commission on TMI. At the request of the Nuclear Regulatory Commission (NRC), a questionaire addressing the usefulness of ARAC products was sent to ARAC-product users; it pertained to the TMI accident. A summary of the findings from this questionaire, along with recommendations for improving ARAC service, is also presented.

ARAC RESPONSE TO THE THREE MILE ISLAND ACCIDENT

At 0820 PST on 28 March 1979, the DOE Emergency Operations Center notified ARAC that Three Mile Island Unit No. 2 (TMI-2) in Harrisburg, Pennsylvania, had experienced a release some four hours earlier of steam and an unknown level of radioactivity and total heat content. DOE asked the ARAC center to respond with regional calculations of the radioactivity's temporal distribution since the start of the accident and to come up to real-time simulation as quickly as possible.

Within minutes after being notified by DOE of the TMI-2 accident, the ARAC assessment team was assembled and had begun to define the problem. Because TMI-2 and Harrisburg are not normally serviced by ARAC, meteorological and terrain information were not immediately available, and work to build the topography data base was begun. Most of the meteorological data were available within the ARAC data base; however, the data had to be formatted for the ARAC diffusion codes. (Since TMI-2, the ARAC center has developed the capability to define an ARAC accident site anywhere in the world and to automatically format all meteorological data for the ARAC codes.)

Gaussian calculations were available to the field within the first hour. After three hours, the past and currently projected temporal distributions of the released radioactivity had been produced out to a range of 60 km, using the MATHEW/ADPIC codes. The calculations contained the real meteorological data from AFGWC, but topography was not included.

Some 12 to 18 hours into this event, the ARAC staff had processed a detailed topographic data file for the ARAC diffusion codes and recalculated temporal distributions of the radioactive materials to incorporate the effects of topography on transport and diffusion. These data were then input as boundary conditions to both the regional-flow and transport diffusion models for all calculations of temporal radionuclide distribution for the next 20 days. Once these calculations were transmitted to the DOE and NRC (Nuclear Regulatory Commission) representatives, the ARAC center ceased operation for the day, intending to be back on line at 1200 GMT (0700 EST/0400 PST) the next day, 29 March 1979.

Members of the ARAC assessment team then turned their efforts toward the problem of sustained operations (i.e., forecasting local meteorological conditions, procuring additional meteorological data in the form of observations, and establishing a meteorological watch on the Harrisburg area). Contact was made with the National Weather Service (NWS) meteorologist in charge (MIC) at Harrisburg. The ARAC assessment meteorologist informed the MIC of ARAC's involvement in the problem and of the need to discuss the synoptic situation from time to time.

ON-SCENE ARAC SUPPORT

By the evening of 29 March, an LLL ARAC field representative was at Harrisburg to interpret the ARAC results and to act as liaison to the DOE emergency-response site commander. By 31 March, it was apparent that the TMI-2 accident could be long-lived, and a second LLL ARAC representative was sent to Harrisburg. These representatives played a role in designing suitable and effective deployment for the environmental monitoring systems that became available during the course of the accident.

Because it also became apparent that the regular ARAC team would require additional manpower, many members of the LLL Atmospheric and Geophysical Sciences Division (G Division) were pressed into service and many G-Division projects were put on hold. After one week, representatives from the National Oceanic and Atmospheric Administration (NOAA), Idaho Falls, Idaho, and the Savannah River Laboratory were called on to relieve the LLL representatives and to support the DOE emergency-response site commander.

In addition to providing liaison to the DOE emergency-response site commander, the ARAC field representatives were investigating new sources of meteorological information. They were successful, and by 1 April were querying meteorological instrumentation at the TMI-2 plant hourly and obtaining additional meteorological data from the Commonwealth of Pennsylvania Air Quality Management Station at Steelton, Pennsylvania, which is close to Harrisburg.

During the first few days following the accident, the ARAC team relied on upper-air meteorological data taken either at Pittsburgh, Pennsylvania, or at Washington, D.C., to define the Harrisburg upper-air profile for input to the MATHEW/ADPIC computer codes. On 31 March, the team learned that the USAF Air Weather Service Rawinsonde team was enroute to Harrisburg on a C5A; however, it was not known who had dispatched them or if they were aware of ARAC and the need for upper-air data.

Contact was made with the Military Airlift Command (MAC) command post at Scott Air Force Base, Illinois, and a message was relayed to the upper-air team chief aboard the C5A to call the ARAC center as soon as the plane arrived at Harrisburg. Communication was established with the Upper-Air Observing Team late on 31 March, and it was learned that the AWS team would be supplemented with National Weather Service (NWS) personnel from Pittsburgh.

During the next 17 days, the upper-air observing teams led by AWS and NWS provided upper-air meteorological data in the Harrisburg area. Later it was learned that NOAA's office of Special Projects had arranged for the upper-air support. This office was also instrumental in arranging for tailored forecast support via the Philadelphia NWS forecast office as a supplement to data already at the ARAC team's disposal. It should be noted, however, that the forecasts the team received were, in reality, the standard aviation forecasts for southeastern Pennsylvania. Now, having solved the problems of obtaining enough meteorological data and enough people to man the ARAC operations center, the team was left with the task of utilizing the personnel most efficiently.

By the third or fourth day following the accident, it was evident that the ARAC liaisons to the DOE and NRC representatives in Harrisburg would be on a 0700–1900 (EST) schedule. With that in mind, ARAC center operations were modified to accommodate three eight-hour shifts per day (24-h coverage): two main (calculational) shifts from 0400 to 1200 PST and from 1100 to 1900 PST and a third minimal-effort shift from 1900 to 0400 PST. During the main-shift period, calculations (via the MATHEW/ADPIC codes) were initially made each hour and then aperiodically as DOE/NRC requirements dictated and/or as the ARAC field representatives requested. During the remaining 12 h of the day, meteorological data were collected and stored in model input format so that calculations could, if required, be provided in a timely manner. These calculations were available to the ARAC field representatives 50 min to 1 h after the meteorological-data observation time. In addition, trajectories were constructed to depict the transport of the plume during the hours the models were not used.

In addition to the ARAC model calculations, NWS facsimile forecast charts and tailored forecasts for DOE/NRC operations in the Harrisburg area were sent via telecopier to the ARAC field representatives for their daily briefings to the DOE/NRC operations staff. By the end of the first week, ARAC center operations were so steamlined that even the major television network news personnel, who seemed to be ever-present, made only small perturbations.

Figures 2 through 7 illustrate typical calculations provided to the ARAC representatives at Harrisburg via telecopier from the ARAC center. The source term used in these calculations was a continuous, normalized unit rate per second. Figure 2 is an x–y view looking down on the ADPIC marker particle distribution produced by the ADPIC transport and diffusion model, using transport wind fields provided by the MATHEW mass-consistent wind-field model. This view shows

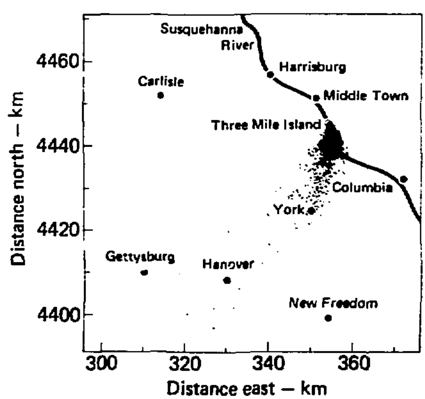

FIG. 2. ADPIC marker particle locations for a continuous unit rate release viewed in the x–y plane for 1 April, 1400 EST, based on meteorological data observed through 1200 EST.

the particle locations at 1400 EST on 1 April, based on meteorological data observed through 1200 EST. Figure 3 shows the instantaneous air concentration 65 m above the terrain, calculated from the marker particle distribution shown in Fig. 2 and based on a normalized, continuous unit rate release. Other calculations (not shown) available to the field representatives were integrated concentrations 2 m above terrain and instantaneous concentrations 150 m above terrain. Figures 4 through 7, which are similar to Figs. 2 and 3, are valid for 1500 and 1600 EST, respectively.

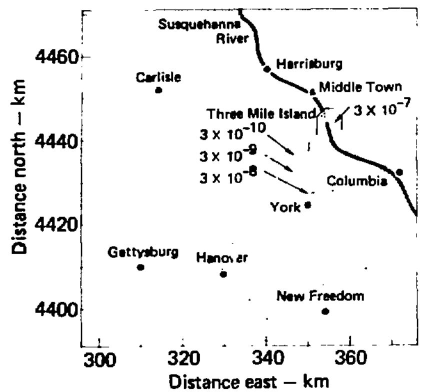

FIG. 3. Instantaneous air concentration (s/m^3) contours 65 m above terrain, calculated from the marker particle locations for the continuous unit rate release shown in Fig. 2.

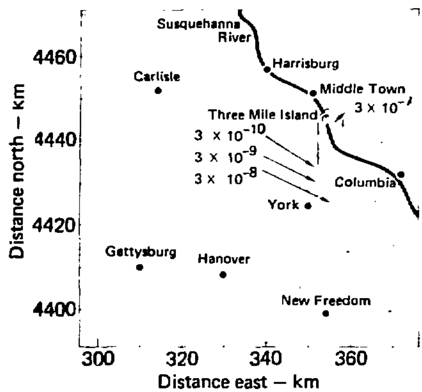

FIG. 5. Instantaneous air concentration (s/m^3) contours 65 m above terrain, calculated from the marker particle locations for the continuous unit rate release shown in Fig. 4.

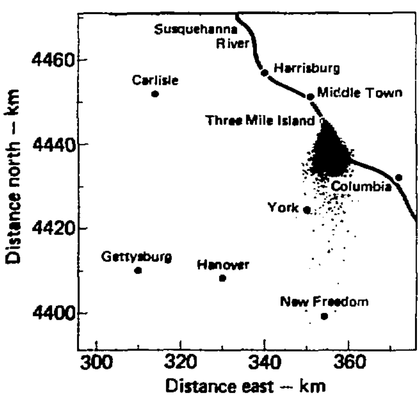

FIG. 4. ADPIC marker particle locations for a continuous unit rate release viewed in the x–y plane for 1 April, 1500 EST, based on meteorological data observed through 1200 EST.

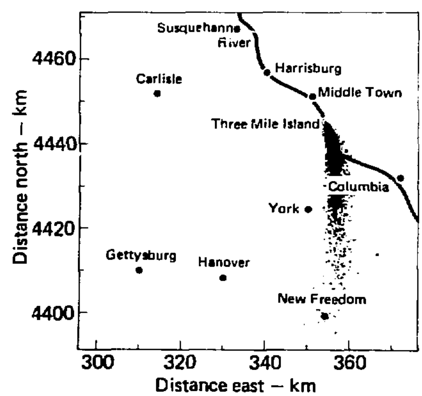

FIG. 6. ADPIC marker particle locations for a continuous unit rate release viewed in the x–y plane for 1 April, 1600 EST, based on meteorological data observed through 1200 EST.

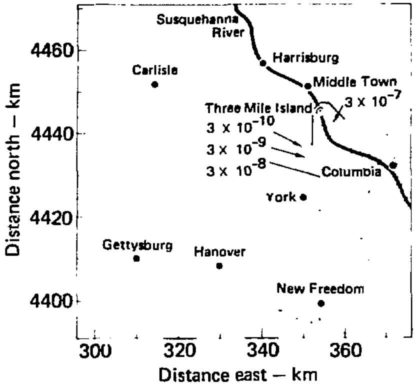

FIG. 7. Instantaneous air concentration (s/m^3) contours 65 m above terrain, calculated from the marker particle locations for the continuous unit rate release shown in Fig. 6.

The services provided by ARAC during and after the TMI-2 accident fell into five categories:

- Providing guidance on the deployment of ground and, to some extent, air-monitoring resources.
- Estimating the source term.
- Advising the FAA about air-corridor safety.
- Screening data for consistency.
- Performing detailed person-rem calculations several months after the accident.

Each morning the ARAC calculations, coupled with the NWS forecasts, were used to deploy monitoring teams to areas covered by the plume during the previous night and to deploy teams scheduled to make measurements during the day. As the day progressed, forecasted and observed changes in meteorological conditions were relayed to the field.

Although no direct comparisons can be made between the MATHEW/ADPIC calculations at TMI and measurements (the source term was relatively small and not well known), it is useful to compare the calculations shown in Figs. 2–7 with the logs of the helicopter flights. The flight logs for this time show the following:

- From 1300 to 1346 EST, 1.85 km from the reactor site and 152 m above terrain, the plume was in a sector between 175 and 192 deg.
- From 1408 to 1435 EST, 1.85 km from the reactor site and 152 m above terrain, the plume was in a sector between 140 and 180 deg.
- From 1515 to 1550 EST, 1.85 km from the reactor site and 152 m above terrain, the plume was in a sector between 140 and 170 deg.

These qualitative descriptions, which are typical of those made at the DOE command post during the accident, compare well with the plume locations shown in Figs. 3, 5, and 7.

The model calculations shown in Figs. 3, 5, and 7 were used with airborne measurements to estimate the average source term. On 30 March, prior aircraft measurements over approximately 1-1/2 days and equivalent calculations for the same period gave an estimated source term for ^{133}Xe in the range of 10–100 Ci/s, with a likely value of 20 Ci/s. This estimate is consistent with the values given by the President's Commission on TMI. These estimates were factored into the integrated air-concentration calculations to estimate the dose for 12-h periods.

The FAA used ARAC regional calculations during this time to determine if low-level flight plans of aircraft in the vicinity of Harrisburg should be modified to minimize exposure to passengers and crews. For this purpose, the FAA was in direct contact with the ARAC center for the required information and guidance.

Each afternoon, the DOE and several other agencies making radiological measurements in the area would meet to discuss the day's activities. At this time, data taken in the field and model calculations were discussed and carefully checked for consistency. Any inconsistency or discrepancy between the various measurements and/or measurements and calculations was checked and resolved during and immediately after the meeting. Daily spot checks were also made between measurements and calculations, particularly if either deviated significantly from expected values based on results from previous hours. These comparisons between measurements and calculations helped improve the credibility of both assessment tools to a degree that would not have been enjoyed by either operating alone.

The MATHEW/ADPIC models were used to carefully estimate the population dose resulting from the TMI accident. The results of these calculations are described later in this report.

RECOMMENDATIONS FOR IMPROVEMENT

Since 1975, when ARAC became involved in DOE emergency-response activities for off-site accidents (as opposed to accidents at regularly serviced on-line facilities), members of the ARAC team have been prepared to go to the scene of the accident and to provide an interface between ARAC services and the requirements of the on-scene commander and between data availability and model input requirements at the ARAC center. The planning and testing of this concept originally led ARAC representatives to Harrisburg for advice on laying out survey procedures, but quickly changed to emergency response on Friday morning, 30 March. Our experience at TMI has shown that ARAC field personnel provide a valuable service to the ARAC center by their knowledge of the ARAC capability and by their perception of the requirements of the on-scene commander and the implementation of assessments at the center.

We also learned that, for problems of considerable intensity and of long duration, other DOE facilities having knowledge of ARAC (e.g., SRL) can send personnel to the scene of the accident, which would allow a response team to rotate duties and provide relief for personnel during an extended accident.

Important to ARAC response in an emergency-response request is prompt notification. For the TMI accident, approximately seven hours elapsed between the time the release began and ARAC was notified. This caused considerable delay in bringing the ARAC center up to full response for the accident. Since TMI this time lapse has been shortened considerably, as shown by ARAC notification during the Red Wing, Minnesota, and Crystal River, Florida, nuclear power plant incidents. ARAC was notified by the DOE EOC within an hour of each incident. Fortunately, neither incident proved serious, but this early notification allowed ARAC to perform such preliminary work as developing meteorological data bases, locating supplemental meteorological data, locating the reactor site on USGS maps, and analyzing existing general weather conditions and forecasts for the area. This preparation, which does not require a large effort, is most valuable and allows a gradual rather than instant startup should ARAC services be required.

Recommendations for improving the efficiency of the on-scene advisory service fall into several categories. First is the method of holding briefings. During the TMI response, the ground-sampling teams—both those interested in where the radioactive concentrations had been during the night and those interested in sampling during the coming day—were briefed on a first-come, first-served basis. In the future, for an accident similar to TMI, where there is continued uncertainty, briefings should be regularly scheduled each morning. A joint briefing would take less time, and questions could be shared by all the teams involved in sampling during the day.

Second, updates to the briefing should be provided on a regularly scheduled basis so those in the field know when to expect new information. These updates should be held even though no change in meteorological conditions is expected. A more systematic approach to guidance for the sampling teams would improve efficiency and convey more information to the field.

Although the aircraft measurements were transmitted back to the center and analyzed by ARAC center personnel, comparisons were never consistently and continually displayed both at the center and on site. The analysis and interpretation of the assessments could be improved significantly if the measurements (particularly aircraft) were plotted with the appropriate assessment calculations and displayed on the same figure. This could be accomplished through a combination of ARAC efforts and NEST (Nuclear Emergency Search Team) capabilities, which would make these comparisons available to the field in an approximate real-time mode. A time history of these plots and a summary of field data would provide useful information on comparisons as a function of meteorological conditions which, in turn, could be folded into future calculations and assessments.

In the future, when a significant accident has occurred or is occurring, ARAC should contact and provide guidance to the FAA in a more timely fashion. During TMI, this part of the service evolved over several hours rather than as part of the initial response to the accident. The mechanism for this service is already established so that it can be implemented at the beginning of an accident.

In summary, the experience and assistance the ARAC representatives provided to the DOE on-scene commander was an important and necessary service during this accident. These representatives helped ensure that the ARAC capability was focused on the problem, and their specific requests to the ARAC center for assessments helped center personnel decide what was required in the way of calculations. In addition, by sending relevant information and data to the ARAC center, the center personnel were kept current on local events, which gave them more opportunities to contribute to the assessment of the accident.

THE ACCIDENT IN RETROSPECT

In retrospect, it is obvious that the first 24 to 48 h of any TMI-like emergency will be chaotic in an emergency-response facility like the ARAC center. Since March 1979, we have taken steps to smooth the transition from a normal 40-h-per-week operation to a national-disaster-response, 24-h-per-day operation. One important step in this transition is to automate the definition of an emergency-response ARAC site. When an emergency location is first identified (latitude/longitude), available data are identified and periodic retrieval sequences are started automatically. At the same time, input files for the ARAC codes are generated automatically. Work has also begun to streamline the construction of site-specific topographic files, the final goal being complete automation.

Two of the more difficult things to prearrange for this type of national disaster are (1) meteorological data that are not normally obtainable at the site and (2) tailored forecasts for the site environs from one voice, i.e., from one NWS office or field representative group whose primary function is to provide meteorological support for that specific disaster response. We were fortunate at TMI to have an upper-air observing team available to provide information on the vertical structure of the atmosphere, which was needed for the ADPIC models. We can only hope that at least that level of support will be available next time, that planning for future emergency responses will include the tailored meteorological support discussed previously, and that the antiquated telecopier will be replaced by a portable ARAC site system for use by the on-scene commander and ARAC representatives.

The TMI accident was a traumatic experience for most of the ARAC team and for those who supplemented the team. More importantly though, it was an extremely rewarding learning experience for all involved. From what we learned about ourselves and how we respond to stress to what we learned about emergency response on a nationwide scale, we have benefited.

POST-INCIDENT ANALYSIS

In late July 1979, ARAC received a request from the President's Commission on Three Mile Island to provide a calculation of the radiation dose experienced by the general population within a 93-km radius of the TMI-2 accident/plant site. The dose was to be based on an ^{133}Xe source term derived by the Commission staff from instrument records analyzed well after the critical time frame of the accident. The request called for a calculation spanning 21 days and a 93-km radius. After ARAC provided the Commission with an estimate of the computer and people costs to provide such a calculation, it was agreed to reduce the area of calculation to a 56-km radius and to reduce the time period to 10.5 days (252 h). The period of calculation extended from 1200Z 28 March through 0000Z 7 April 1979. To resolve the topographic features within the model domain, it was decided that the assessment would be run at two model grid intervals, namely 1 and 2.5 km, and that the final dose calculations would be merged. The merge complication arose because of computer memory limitations, which constrain the ARAC computational grid volume to a 41 × 41 × 15 (x·y·z) mesh.

DATA

During the accident at TMI-2, ARAC had collected the local meteorological data and archived them after use in the emergency calculations. Even data collected during the night, when emergency calculations were not provided, were archived. They included data, beginning 30 March, from the TMI meteorological tower and from the Commonwealth of Pennsylvania Air Monitoring System (COPAMS) in Steelton. Local upper-air meteorological data, also archived by ARAC, were provided by a joint USAF/NOAA effort at Middletown, commencing the evening of 31 March. Before calculations for the Commission were begun, the data were reviewed and checked for consistency. All the TMI-2 and COPAMS data for 28–30 March were acquired, and the input files were constructed.

The Commission provided source-term data, which were transformed into hourly average source rate (see Fig. 8), as required by the computer programs. An additional set of source terms provided by the utilities' environmental measurements contractor were also transformed. Four source terms were run simultaneously, namely the Commission's ^{133}Xe and the contractor's ^{133}Xe, ^{88}Kr, and ^{131}I.

PERSON-REM CALCULATIONS

In addition to the standard ARAC calculations of integrated immersion dose and deposition (by radionuclide), the Commission requested population dose. To generate a population-dose calculation, it was necessary to rapidly develop several new codes to process various forms of population data bases into a structure that could be used both with the model-calculated integrated doses and at various grid resolutions. Three different population data bases were incorporated in the calculations and evaluated: (1) gridded 1970 census enumeration district data from Oak Ridge National Laboratory, (2) gridded uniform projected 1980 county data from Brookhaven National Laboratory, and (3) an adjusted/projected 1980 radial population distribution from the TMI-2 *Final Safety Analysis Report* (FSAR). Ultimately, the adjusted/projected distribution from the FSAR was taken as the standard. Person-rem results were tabulated in 16 radial sectors for 9 intervals, as shown in Tables 1 and 2. For this assessment, based on the Commission's source-term information, a total population dose of 275 person-rem was calculated. This represented the combined effects of the estimated ^{133}Xe and ^{88}Kr releases and the assumed population distribution. For the population exposed to radioactivity during this accident, the calculated dose appears to be insignificant.

RESULTS

The evolution of the final population dose, as expressed in Tables 1 and 2, is a complex process that involves the calculation of meteorologically responsive, time-varying transport and diffusion fields over complex terrain and the time-varying release of a multispecies source term. Figures 9 through 14 depict the evolution of the integrated areal exposure pattern in millirems at 6, 24, 48, 72,

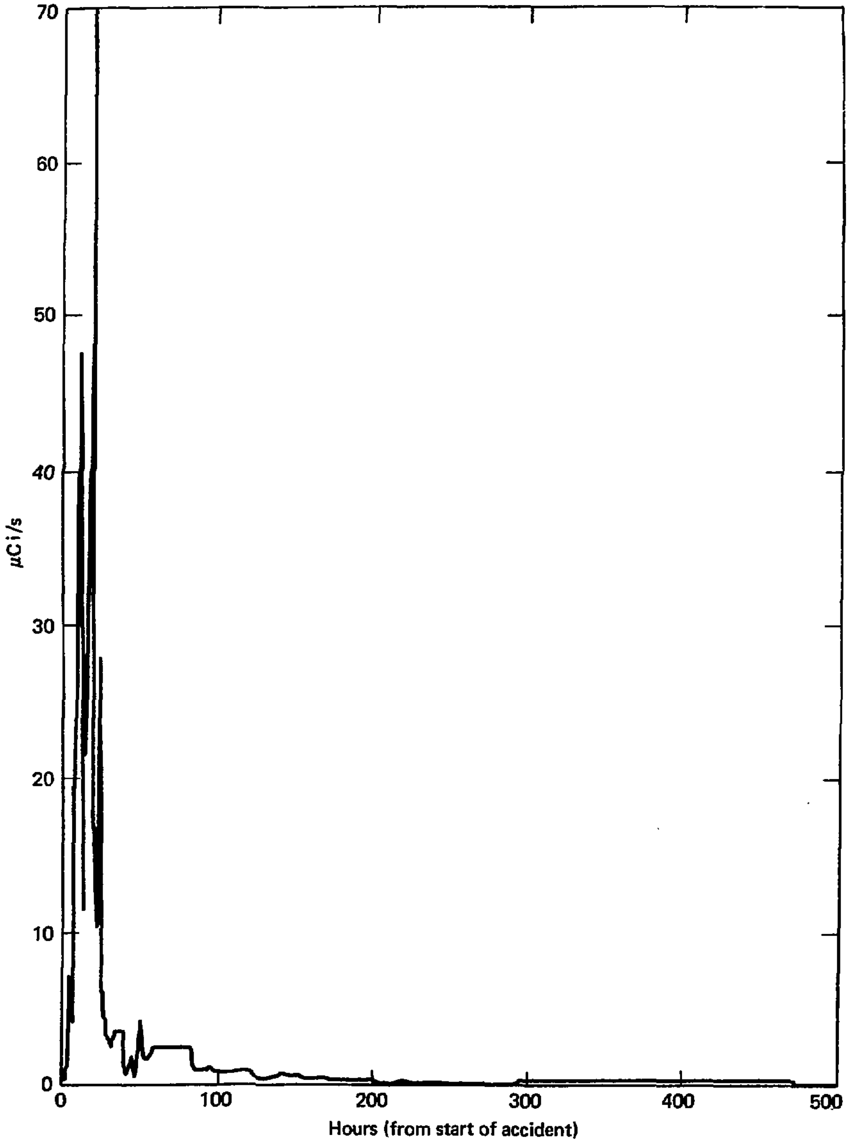

FIG. 8. Depiction of the Commission-supplied Xenon-133 source term as it evolved over the first 10.5 days.

TABLE 1. Integrated person-rem calculated for the Krypton-88 source term by 22.5-deg sectors for discrete intervals (miles) and the total person-rem for the first 10.5 days (based on the radial population distribution in the TMI-2 FSAR, projected to 1980).

Sector	0-1	1-2	2-3	3-4	4-5	5-10	0-10	10-20	20-30
N	9.374E-02	1.122E+00	1.708E+01	1.395E+01	1.368E+00	1.384E+01	4.745E+01	2.019E+00	1.564E-01
NNE	2.465E-01	3.575E-01	5.565E-01	9.942E-01	4.028E-01	1.586E+00	4.143E+00	1.360E-01	1.938E-02
NE	1.704E-01	6.332E-01	2.992E-01	5.147E-02	8.792E-03	4.269E-03	1.167E+00	4.925E-03	1.523E-02
ENE	1.450E-01	1.562E-01	2.824E-02	2.647E-02	1.309E-03	4.450E-04	3.577E-01	4.146E-04	4.037E-06
E	5.596E-02	4.122E-02	2.168E-03	1.210E-03	7.765E-04	6.895E-05	1.014E-01	1.582E-05	1.049E-05
ESE	8.660E-03	3.245E-02	4.252E-03	1.060E-03	2.859E-05	1.942E-05	4.647E-02	1.332E-05	1.272E-06
SE	8.494E-03	9.414E-02	2.501E-04	3.855E-04	7.180E-05	2.434E-05	1.034E-01	1.701E-05	1.546E-06
SSE	1.270E-01	7.913E-02	5.836E-04	4.730E-05	1.353E-05	2.062E-04	2.070E-01	1.162E-04	5.992E-08
S	1.237E-03	2.447E-04	5.714E-04	3.744E-04	5.878E-04	1.798E-03	4.813E-03	3.798E-04	3.694E-08
SSW	1.236E-03	3.378E-02	2.956E-03	1.795E-04	3.768E-04	8.783E-04	3.940E-02	2.696E-04	7.460E-07
SW	1.213E-03	8.939E-02	1.009E-03	1.360E-03	1.691E-04	3.382E-04	9.348E-02	8.898E-05	4.470E-04
WSW	1.236E-03	2.189E-01	1.027E-02	1.707E-02	1.374E-03	8.329E-04	2.497E-01	1.531E-04	3.732E-04
W	1.141E-03	2.368E-01	7.826E-03	2.311E-02	2.271E-02	4.651E-02	3.381E-01	1.041E-02	4.344E-04
WNW	2.868E-03	4.195E-01	1.818E-01	6.918E-02	3.151E-02	4.021E-01	1.107E+00	1.233E-01	1.166E-03
NW	5.292E-03	6.344E-03	1.419E-01	5.906E-02	8.785E-01	5.764E+00	6.855E+00	6.719E-01	6.931E-03
NNW	5.927E-03	6.423E-03	6.714E+00	3.580E+00	4.568E+00	1.257E+01	2.744E+01	2.120E+00	7.373E-02

Total integrated = 9.508E+01

TABLE 2. Integrated person-rem calculated for the Xenon-133 Commission source term by 22.5-deg sectors for discrete intervals (miles) and the total person-rem for the first 10.5 days (based on the radial population distribution in the TMI-2 FSAR, projected to 1980.

Sector	0-1	1-2	2-3	3-4	4-5	5-10	0-10	10-20	20-30
N	1.565E-01	1.817E+00	2.529E+01	2.096E+01	2.083E+00	1.373E+01	6.405E+01	2.843E+00	2.997E-01
NNE	3.410E-01	4.775E-01	6.758E-01	1.263E+00	5.360E-01	2.538E+00	5.831E+00	3.427E-01	1.137E-01
NE	2.435E-01	8.495E-01	5.189E-01	2.469E-01	6.181E-02	2.208E-01	2.141E+00	5.327E-01	1.311E-01
ENE	2.636E-01	2.305E-01	1.736E-01	2.538E-01	8.148E-02	2.231E-01	1.226E+00	3.402E-01	6.148E-02
E	1.420E-01	1.257E-01	3.139E-02	5.469E-02	1.724E-01	1.602E+00	2.128E+00	6.948E-01	2.711E-01
ESE	2.197E-02	9.187E-02	1.104E-01	8.359E-02	4.674E-02	1.976E-01	5.522E-01	6.161E-01	4.629E-02
SE	2.155E-02	2.700E-01	4.712E-02	1.084E-01	1.427E-01	2.496E-01	8.394E-01	1.799E-01	1.384E-02
SSE	3.222E-01	3.623E-01	1.290E-01	3.878E-02	1.916E-02	4.127E-01	1.284E+00	3.419E-01	6.491E-03
S	3.810E-03	1.545E-03	1.169E-01	2.906E-01	4.720E-01	1.756E+00	2.641E+00	6.241E-01	1.311E-02
SSW	4.594E-03	1.862E-01	4.909E-01	6.776E-02	2.070E-01	4.678E-01	1.424E+00	2.871E-01	4.972E-02
SW	4.506E-03	3.598E-01	1.194E-01	2.777E-01	5.043E-02	2.309E-01	1.043E+00	5.961E-02	1.538E-02
WSW	4.594E-03	9.462E-01	1.716E-01	4.414E-01	6.042E-02	1.898E-01	1.814E+00	2.983E-02	4.263E-03
W	4.241E-03	1.133E+00	8.248E-02	3.073E-01	3.573E-01	9.094E-01	2.794E+00	2.255E-01	6.543E-02
WNW	6.930E-03	9.505E-01	1.300E+00	5.404E-01	3.323E-01	4.567E+00	7.697E+00	1.377E+00	3.666E-02
NW	1.035E-02	1.190E-02	4.071E-01	1.827E-01	2.887E+00	1.628E+01	1.978E+01	2.444E+00	2.579E-02
NNW	1.131E-02	1.193E-02	1.117E+01	6.511E+00	8.213E+00	2.298E+01	4.890E+01	4.200E+00	1.744E-01

Total integrated = 1.808E+02

96, and 240 h, respectively. These integration patterns, which are for the 2-m immersion level, incorporate a Commission-supplied "dose conversion factor of 6.03×10^{-6} $(mR \cdot m^3)/(\mu Ci \cdot s)$." The results show how the dose pattern was quickly and predominantly established by the generally south-to-north flow during the major release period of the first 48 h. Thereafter, although the meteorological situation changed significantly, the low levels of release resulted in only relatively minor but discernible changes in the early dose pattern. Note particularly the southward extension of the pattern from 24 to 48 h (Figs. 10 and 11), then the east and southeast spread from 48 to 72 to 96 h (Figs. 11-13), and finally the "diffusion-like" effect of nine days of synoptic and diurnal meteorological variations with a small source term, as noted by the differences between Figs. 10 and 14.

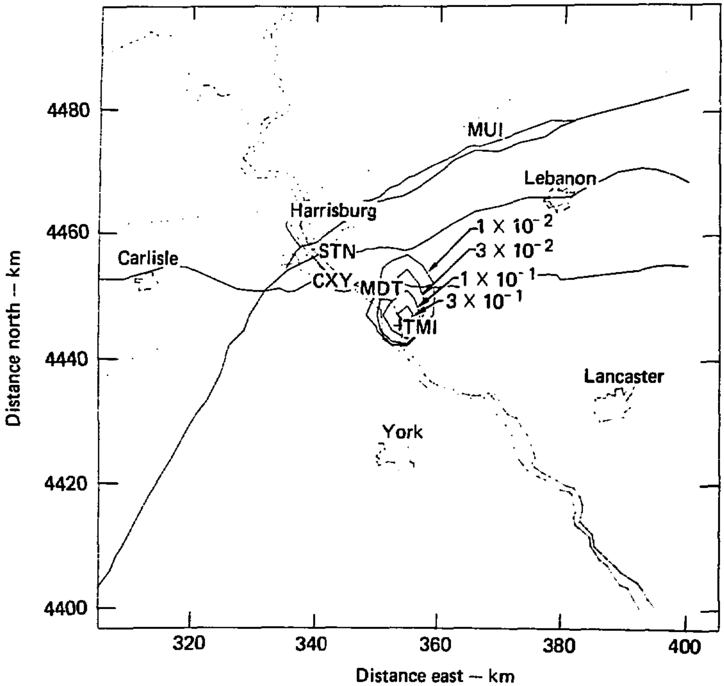

FIG. 9. Isopleths of integrated air concentration (millirem) for inhalation–immersion dose at 2-m elevation due to Xenon-133, as calculated in a 2.5-km resolution grid (this plot represents 6-h integration valid at 1800Z, 28 March 1979; the maximum calculated value is 0.484 mrem).

EFFORT

An assessment of this magnitude involves significant computer resources, extensive data recovery and preparation, and a tedious examination of computer input and output. A total of five weeks—from late July through August 1979—were spent on this assessment. Three and one-half weeks were spent in an intensive computer calculation mode, which involved a large number of hours of off-shift work. LLL/ARAC expended 5.5 person-months, using a total of 15 people and 1441 min (about 24 h) of CDC 7600 CPU (central processing unit) time. The dose results were hand-carried to the Commission staff at Oak Ridge National Laboratory on 24 August, and the final person-rem calculations were telecopied and mailed on 31 August.

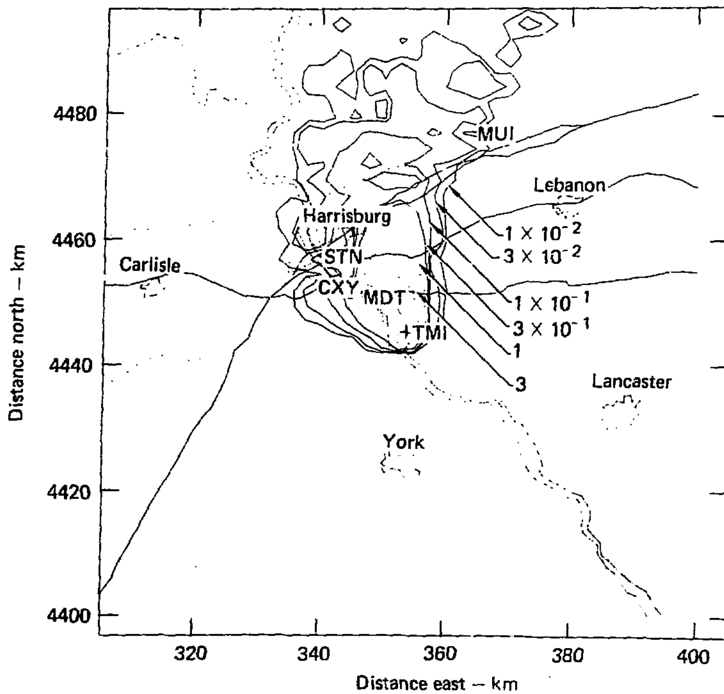

FIG. 10. Isopleths of integrated air concentration (millirem) for inhalation-immersion dose at 2-m elevation due to Xenon-133, as calculated in a 2.5-km resolution grid (this plot represents 24-h integration valid at 1200Z, 29 March 1979; the maximum calculated value is 8.63 mrem).

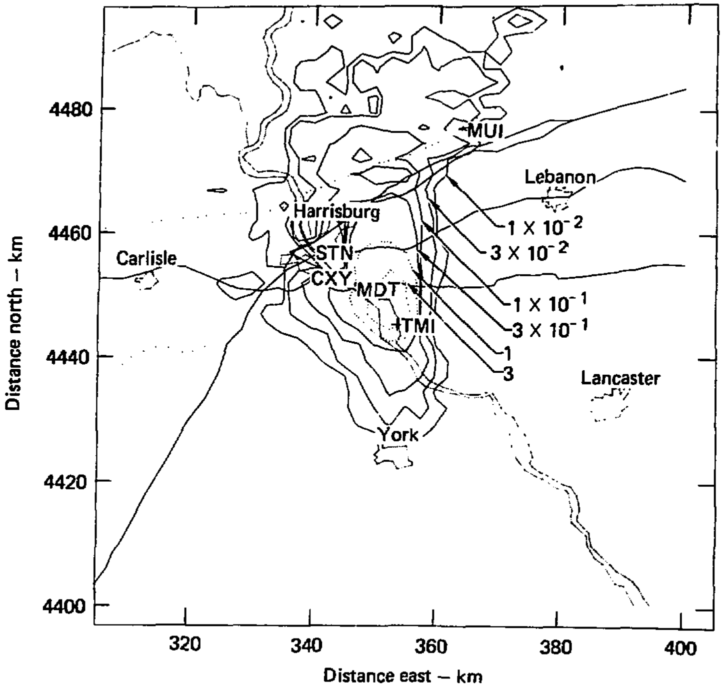

FIG. 11. Isopleths of integrated air concentration (millirem) for inhalation-immersion dose at 2-m elevation due to Xenon-133, as calculated in a 2.5-km resolution grid (this plot represents 48-h integration valid at 1200Z, *30 March 1979; the maximum calculated value is 10.3 mrem*).

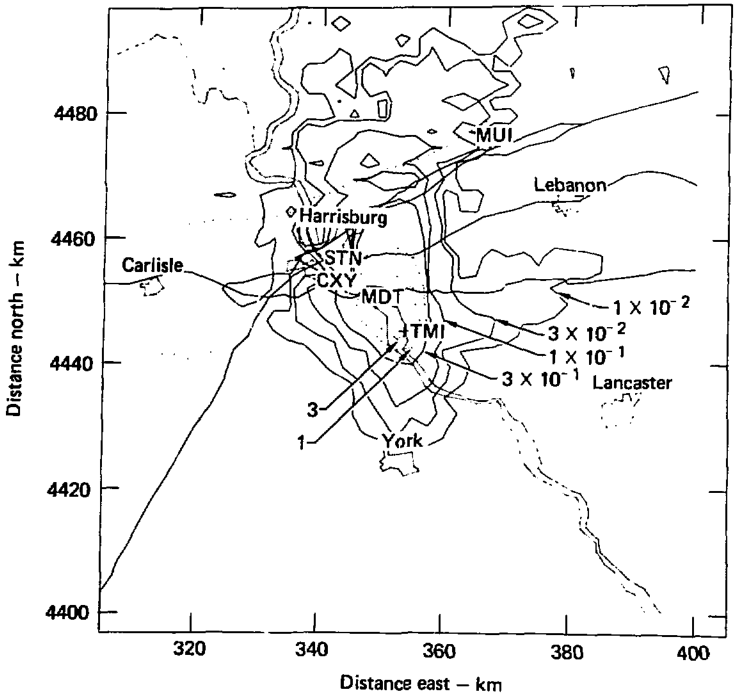

FIG. 12. Isopleths of integrated air concentration (millirem) for inhalation-immersion dose at 2-m elevation due to Xenon-133, as calculated in a 2.5-km resolution grid (this plot represents 72-h integration valid at 1200Z, 31 March 1979; the maximum calculated value is 11.1 mrem).

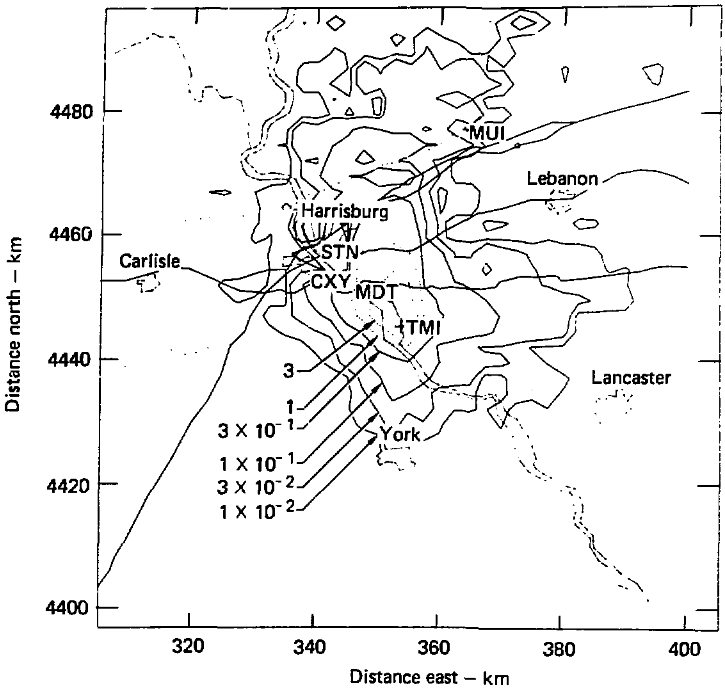

FIG. 13. Isopleths of integrated air concentration (millirem) for inhalation-immersion dose at 2-m elevation due to Xenon-133, as calculated in a 2.5-km resolution grid (this plot represents 96-h integration valid at 1200Z, 31 March 1979; the maximum calculated value is 11.4 mrem).

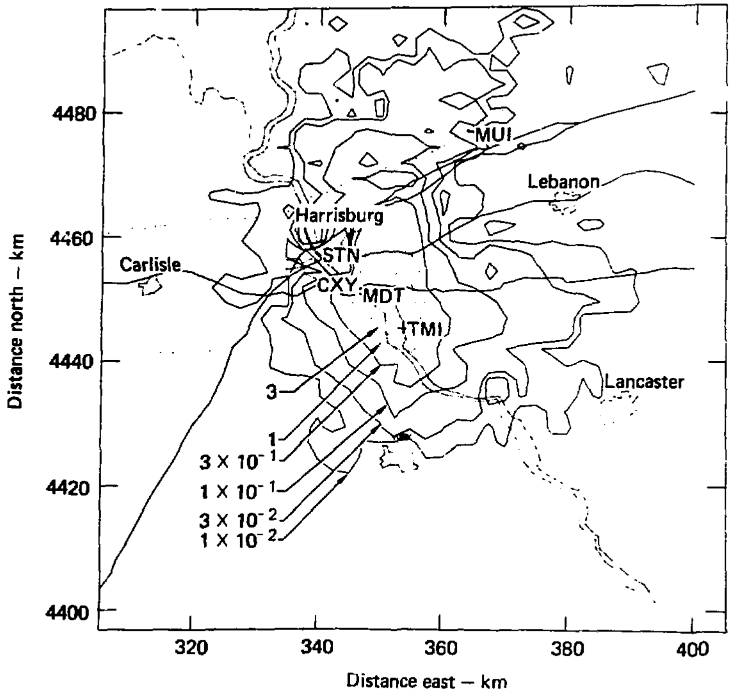

FIG. 14. Isopleths of integrated air concentration (millirem) for inhalation-immersion dose at 2-m elevation due to Xenon-133, as calculated in a 2.5-km resolution grid (this plot represents 240-h integration valid at 1200Z, 7 April 1979; the maximum calculated value is 11.9 mrem).

QUESTIONNAIRE FINDINGS

One of the principal objectives of this NRC-sponsored study is to report the findings developed from a questionnaire regarding the actual uses of ARAC products and services during the TMI-2 accident and the perceived potential of ARAC contributions to the management of any future emergency. Responses were solicited from many individuals in several agencies; Table 3 is a list of the respondents. The respondents are grouped by agency and include the DOE Headquarters staff, who participated in the DOE Command Post activities; DOE subcontractors, who participated in ground and aerial sampling and in the ARAC services; the EPA staff, who participated in dose assessments with the DOE; the FAA staff, who determined air-corridor safety during the accident; and several other users. These other users included the staff from BNL for ground monitoring, the Department of Health of the State of Pennsylvania, and a reviewer from the President's Commission on TMI. Only one of the seven NRC respondents reported any direct use of ARAC products and services during the TMI accident. In general, lack of familiarity with ARAC products and/or services was the reason given. It is clear that the NRC and other groups were involved in the same functions, using more familiar methods.

The questionnaire used in this study was designed by the ARAC project team. It was reviewed and approved by the NRC project monitor prior to its distribution. The questionnaire was circulated in December 1979, and most of the responses had been received by the end of January 1980. Preliminary findings of the survey were reviewed with the NRC project monitor in February 1980 during the drafting of this study paper.

QUESTIONNAIRE FOR THE LLL/NRC STUDY OF ARAC USERS IN THE TMI-2 ACCIDENT

(If space assigned for answering the questions is inadequate, feel free to use supplementary pages.)

1. a. Name ____________________

   b. Organization ____________________

   c. Position ____________________

   d. Phone ____________________

2. Familiarity with the DOE's Atmospheric Release Advisory Capability:

   a. Prior to TMI accident did you have access to or read any reports pertaining to the ARAC status, capabilities, or past uses? ____________________

   ____

   b. Prior to TMI had you ever participated in a briefing pertaining to the ARAC capabilities, its advisory informational products, or past uses? ____________________

   ____

   c. Prior to TMI had you ever seen the regional-scale ARAC dot plots defining the plume location or pollutant concentration distributions on the regional scale? ____________________

   ____

3. Did you first learn about ARAC or its advisory informational products during or after the TMI event?

4. Did you examine or use the ARAC products or advisory information during the TMI incident?

5. Did you examine or use the ARAC assessment products prepared after the TMI incident, namely the population-dose estimates prepared for the Staff of the President's Commission on TMI?

6. In what role(s) did you perceive the ARAC product to be useful:

   a. In the deployment of measurement systems to affected areas?

   b. In the early determination of the isotopic source term?

   c. In assisting in low-altitude aircraft safety determinations?

   d. As a possible or actual filter of questionable data?

   e. As an assessment methodology after the fact?

   f. Other (please explain)

7. What was your impression of the value of the ARAC contributions or products?

8. What improvements would you like to see in the ARAC products, guidance, or use in the future should another significant emergency occur?

9. What specific uses of the ARAC product did you personally observe or participate in during the TMI incident? (Please discuss function, dates, and result.)

10. Did you experience a lack of familiarity with the ARAC products or guidance which caused a problem in their use by you or your agency?

11. If education and training were available in regard to utility and application of the ARAC products in the improvement of emergency response, would you be interested in participating?

TABLE 3. Agency response to the TMI questionnaire.

Agency and respondees	No. of responses
Department of Energy	3
Paul Neeson, Health Physicist, Chicago Operations	
Wayne Adams, DOE-Nevada, Chief Measurements & Detection Branch	
Herbert F. Hahn, Program Manager, NEST/EAST	
Department of Energy Contractors and Subcontractors	6
Zolin G. Burson, Scientific Specialist, EG&G	
James F. Schubert, Staff Meteorologist, SRI	
John F. Doyle, Assistant Program Manager, NEST/AMS	
M. M. Pendergast, Research Meteorologist, SRI	
Walter Frankhauser/T. C. McGuire, EG&G	
Environmental Protection Agency	4
Erich W. Bretthauer, Director Nuclear Radiation Assessment	
Allen E. Smith, Assistant On-Site Coordinator, TMI	
Charles F. Costa, Deputy Director, Nuclear Radiation Assessment	
Joe E. Logsdom, Office of Radiation Programs	
Food and Drug Administration	1
John C. Villforth, Director FDA/Bureau Radiological Health	
Nuclear Regulatory Commision	7
Lewis G. Hulman, Chief Hydrology-Meteorology Branch	
Joseph R. Levine, Meteorologist	
Dr. Robert J. Bores, Chief Environ. & Special Projects Section	
James A. Martin, Emergency Planning Team Leader	
Harold E. Collins, Office State Programs	
Victor Stello, Jr., Director, OIE	
Frank J. Congel, Leader Radiological Impact Section	
Other TMI Participants	5
Andrew P. Hull, Supervisor Environmental Monitoring, BNL	
Keith Woodward, Utility Consultant	
Carol D. Berger, Health Physicist, ORNL, Staff Pres. Committee	
Margaret Reilly, Chief Div. Environ. Rad., State of Pennsylvania	
Bill Smith, Program Manager, FAA	
Total	26

In reviewing responses to the questionnaire, seven areas of information were evaluated:

1. *Familiarity with the ARAC concept, its models, and service or advisory information.* If the respondents for a particular agency indicated that they had examined most of the ARAC reports, attended ARAC briefings, and/or used ARAC products previously in an actual environmental evaluation in addition to or prior to TMI, they were evaluated as high in regard to familiarity. On the other hand, if the respondents indicated that they had never seen ARAC services or advisory information prior to TMI or that their lack of familiarity prevented them from making significant use of ARAC products during the TMI accident, they were evaluated as low in regard to familiarity.

2. *Perception of ARAC roles at TMI or in the future.* The questionnaire suggested five roles that ARAC products served at TMI, in actual practice in the DOE Command Post and in response to expressed inquiries by the DOE site commander. Respondents familiar with ARAC or involved in the DOE response had the greatest opportunity to perceive these roles during TMI and to project their relevance to future emergencies. Hence the DOE or DOE subcontractor respondents all perceived a majority of the roles. Those with low familiarity did not, by and large, perceive the functional roles being fulfilled at the time.

3. *User of ARAC products at TMI.* The questionnaire requested information on the use found for the ARAC products at the TMI accident. The DOE Command Post staff and subcontractors supporting that agency engaged in or observed multiple uses of the service and the ARAC products. Seventy-five percent of the EPA respondents indicated some use of the product in making assessments of the impacted areas in regard to dose during the accident. The FAA reported that ARAC regional information was the only timely and reliable information available for the execution of their agency charter, namely to control and certify the safe conduct of commercial and civil aviation in the Harrisburg area during the TMI accident. Seventy-five percent of the responses from the agency with the least familiarity with the ARAC system and products reported observation of some of the products, but little or no use was indicated.

4. *Value of the ARAC contribution.* Respondents familiar with ARAC and/or its involvement in DOE activities reported that the ARAC contribution was extremely valuable. The FAA, as indicated above, reported the contribution to be of very high value, stating that "it was the only useful information available." The concensus of the NRC respondents is that ARAC can be potentially useful in the future and could be valuable if adequate planning occurred.

5. *Improvements needed.* The respondents were asked to suggest improvements in ARAC products or service that occurred to them either in the course of their involvement in TMI or as observations made during the operations. A spectrum of suggestions resulted, some of which can or will be implemented in the future or in any potential planning of computer-assisted management schemes. However, several thought that the ARAC service and products were completely satisfactory and that no improvements were required. Respondents with less or little familiarity stated the need for an ARAC briefing as a first step.

6. *Lack of familiarity with the ARAC system as a barrier.* This question brought a spectrum of responses, as reflected in Table 4. Some respondents reported that lack of familiarity with ARAC was not a problem; others found it a real barrier to using the ARAC service or advisory information.

7. *Interest in ARAC education and training.* Almost all agencies reported a strong to unanimous interest in ARAC education and training. The one exception was the FAA, which reported a sufficient knowledge of the ARAC system and products and no need for further education. Table 4 summarizes the findings of the questionnaire.

Table 5 summarizes, by responding agency, another interesting aspect of the questionnaire, namely the actual uses of the ARAC product or service reported. The authors have paraphrased the respondents' statements about the product or service's practical utility and actual uses. Note that the actual number and kinds of uses reported exceed those specifically requested in the questionnaire: they were volunteered by the respondents.

TABLE 4. Questionnaire findings, by agency, for the LLL/NRC study of ARAC users in the TMI-2 accident.

Areas of information	Responding agencies						
	DOE	DOE contractors/subcontractors	EPA	FAA	FDA	NRC	TMI ARAC users
Familiarity with ARAC	Above average	Excellent	None. No respondees had seen ARAC products	High	Average	Low. Forty percent first learned of ARAC during or after TMI	Above average
Perception of ARAC roles at TMI or in future	Majority identified 4 of 5 roles	Five of 5 roles identified. Well supported	Low	Five of 5 roles identified. Most strongly supported	Two of 5 roles identified. Supported	Fifty percent saw one role for ARAC assessment	Three of 5 roles identified. Supported
User of ARAC products	100%	100%	Seventy-five percent had used some products	Yes. Active user for commercial aircraft radiation safety, Harrisburg	None	Seventy-five percent looked at products	100%
Value of ARAC contribution	Rated great by 66%	Extremely valuable was typical	Mixed. Rated great value to being unqualified	Rated high and as only useful information available	Claimed unknown	Rated potentially useful and valuable with planning	Rated high by most
Improvements suggested	None needed said 33%	All made useful, relevant suggestions	Need for education	None. Performance met FAA expectations	Useful ideas	Training and thorough ARAC briefing needed	Some useful suggestions
Lack of familiarity with ARAC a barrier	No	Only one person claimed lack of knowledge	Seventy-five percent had problems	No	No	Strong statement about lack of familiarity	Fifty percent said familiarity was a problem
Interested in ARAC education/training	100%	100%	75%	No	Positive	100%	100%

TABLE 5. Agency uses of ARAC products during the TMI response (x = one respondee, and xx = more than one respondee).

Product uses	Product users						
	DOE	DOE contractors/ subcontractors	EPA	FAA	FDA	NRC	Others
Assessing regional impact and aircraft safety near Harrisburg				x			
Deploying monitoring system (ground)	xx	xx	x			–[a]	
Deploying aerial monitors	xx	x					
Defining impacted areas for protective actions	x	x				x[b]	x[d]
Making comparisons with helicopter data during or after TMI		xx					
Weather information	x	x					
Briefings for DOE Command Post	xx	x	x				
Daily assessments with EPA source-term estimates		x	x				–[e]
Post-event assessment		x					
No direct use at TMI					x	–[c]	

[a]Observed DOE team.

[b]Used some ARAC products.

[c]Six of seven NRC staff were non-users.

[d]State of Pennsylvania.

[e]President's Commission.

SUMMARY OF SIGNIFICANT RECOMMENDATIONS

The NRC respondents suggested almost unanimously that more education was needed about the ARAC system, information, and products (see Table 6). Some indicated that ARAC training and briefings were definite requirements before there was a possibility of the potential of ARAC being tapped. Since December 1979, the Hydrology and Meteorology Section of NRC has funded LLL to install an ARAC site facility in the Incident Response Center in Bethesda, Maryland, for the express purpose of training and education. In addition to installing the site facility, proofing, and a few test runs, the LLL staff, jointly with members of the NRC, is to design scenarios of nuclear emergencies. The overall goal of this endeavor is to create a small body of ARAC operating experience and information, which would help the NRC staff evaluate the contribution of the present ARAC system to nuclear emergency-response management.

TABLE 6. Summary and discussion of suggestions to improve ARAC.

Suggestions	Current activity or comments
DOE Headquarters	
DOE Headquarters suggested that ARAC:	
• Place a site terminal in the DOE Command Center, rather than the telecopier. • Replace the telecopier with some faster link.	For some three to four years we have recommended that a NEST pod contain an ARAC site terminal. To date, the suggestion has not been acted on.
DOE contractors/subcontractors	
DOE contractors suggested that ARAC:	
• Provide cumulative dose assessments in real time.	ARAC was enhanced recently to provide this product.
• Provide a simple method to use simple models at site to help interpret data and, perhaps, to get early estimates of the source term.	
• Improve briefing aids (e.g., color) for conferences with aircraft crews and sampling teams.	
• Replace the telecopier with faster data-transmission links.	
• Improve 24-h meteorological predictions on the regional scale.	
EPA	
The EPA suggested that ARAC:	
• Educate potential ARAC users.	
• Refine the trajectory predictions.	
• Adapt the capability to local utility or state computer systems.	
FAA	
The FAA had no specific recommendations for improvement.	
FDA	
The FDA suggested that:	
• ARAC pursue ways to improve the quantity of local meteorological data.	
• ARAC service be expanded to give cumulative dose to data estimates on the regional scale.	See comment under DOE contractors.
• ARAC service be tailored to state and local needs.	This suggestion will be addressed in the FEMA pilot projects (see Various TMI-2 participants).
NRC	
The NRC suggested that:	
• Education be followed by exercises and ARAC simulations.	
• ARAC "define what is being plotted."	An explanation of the ARAC-code contour package has been developed.
• ARAC be available early for use by the utility, NRC, and state utility teams.	
• Cumulative dose estimates be updated frequently.	
• Real-time radiological information from sensors be added.	

TABLE 6. (Continued.)

Suggestions	Current activity or comments
NRC (Continued)	
• ARAC use be planned before the emergency.	
• Education and training be provided.	
Various TMI-2 participants	
1. The State of Pennsylvania suggested that pilot programs for civilian nuclear and nonnuclear facilities be expanded with all deliberate speed.	The NRC is funding LLL to install and proof-test an ARAC site facility in the Bethesda Incident Response Center and to educate and train the NRC meteorological and assessment staff. In addition, FEMA, in conjunction with DOE, is planning pilot projects in two states.
2. A President's Commission staff member suggests that the ARAC system be improved so that data in more than one format can be accepted. This suggestion refers to the population data for input to assessment work for calculating person-rem.	Steps have been taken to incorporate radial population distribution.
3. One TMI user of ARAC products, who had no suggestions for improvements stated that it "... seems good as (it) is."	
4. Some improvement in the definition of source term was deemed desirable. It was also recommended that ARAC be on line before the accident.	

MISSISSAUGA—IMPORTANT LESSONS FROM A NONNUCLEAR ACCIDENT

In Spring 1980, as our Federal government implements organizational structures, legislative rules about improved emergency-response planning, and systems of enhanced capability, it is well to recall and stress the important lessons of the Mississauga accident (Province of Ontario, 11 November 1979).

Because of a unique combination of historical events, the Province of Ontario, together with appropriate Canadian federal agencies, had a well-devised, tested, and proven emergency-response plan in place the night of 11 November 1979. A scalable and ingenious evacuation plan was used for the preventative evacuation of about 250,000 persons threatened by toxic materials when a train carrying these materials derailed in Mississauga, a suburban portion of Toronto. The "plan" contained clearly defined roles, a local commander with resources and plan experience, a public information plan (one clear voice), and a responsive federal interface for resources, information, advice, and capabilities not available at the provincial level. Command control of all phases of both the emergency and the remedial actions remained with the Province of Ontario and the county. It appears that such unilateral control is extremely crucial in the management of emergency responses in real time, where changing emergency conditions must be interfaced with rapid, effective decisions involving locally distributed resources and personnel. Local (provincial or county) site commanders with on-scene information, conditions, and resources are essential to such emergency-response planning. The following account of Mississauga is presented to support this important conclusion (Joseph B. Knox, "Mississauga: A Milestone in Emergency-Response Planning," Lawrence Livermore Laboratory, to be published in *Nuclear Safety*).

PROLOGUE

"In 1979, North America experienced two great energy-related accidents, Three Mile Island, Pennsylvania, and Mississauga, Ontario, Canada. The accident at Three Mile Island has left a legacy that will result in required changes and improvements in procedures and their implementation by the nuclear community and by all levels of government in the months and years ahead. Mississauga, in which many more persons were evacuated than at Three Mile Island, is in fact now a fading memory. Why? Success, even though based on thorough planning, is easily forgotten!

"The derailment of the freight train, which carried both liquid fuels and toxic materials such as chlorine, and the subsequent explosion occurred on November 11, 1979, in the town of Mississauga. While in the United Kingdom, I observed the reports carried in the British media. The reactions of the emergency-response community in Britain to the news indicated to me that a salient event in emergency-response history had occurred. This emergency prompted one of the largest peace-time evacuations of a populace in North American history. The reaction of the press to the management of this emergency was most favorable, the press noting the low incidence of looting and other crimes during the evacuation of 250,000 people.

"The significance of Mississauga was confirmed several days later in Canada during discussions with my Canadian host, Dr. Alistair Christie. Mississauga was indeed an outstanding event with respect to the successful management of an emergency. The brief text that follows is based on a dialogue with Mr. Tom Cross, Director, Air Resources Branch, Ministry of the Environment of the Province of Ontario, and his colleague and medical science advisor, Dr. M. Fitch, from the Ministry of Labour, and with Dr. A. Christie, who served as facilitating host. This account is obviously neither a complete description of this accident nor of the subsequent emergency but, as an accurate reflection of my impressions, points up the significance of this event.

THE TIME AND PLACE—MISSISSAUGA

"Mississauga is a lake front, suburban, bedroom community for the city of Toronto and is home to several small industries. The town is located on a major railway route that connects the major cities of Toronto and Montreal to the energy-rich western provinces. The site of the derailment is depicted on the local map shown in Fig. 1; the distance from this site to Lake Ontario is about 5 km. The accident occurred at 11:45 p.m. on Saturday,

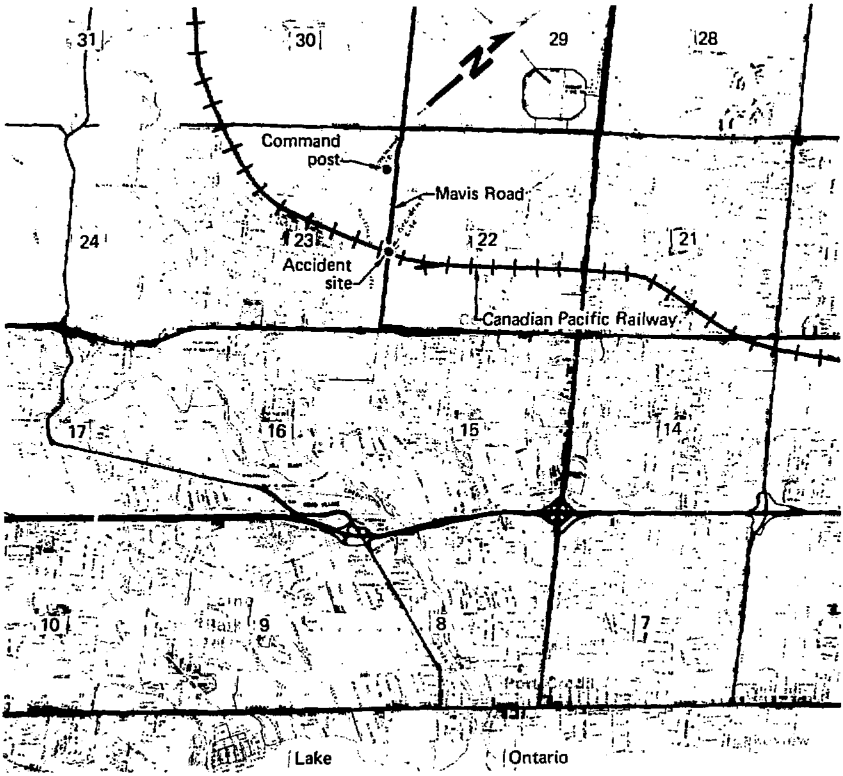

FIG. 1. "Map of Mississauga, Ontario, Canada, showing site of train derailment, command post, and evacuated areas (see text)."

November 11, 1979, in a sparsely populated section of Mississauga. The wind was from the northwest and towards Lake Ontario. The derailment and the subsequent pile of scrambled cars of propane, chlorine, butane, caustic soda, and styrene occurred precisely at the intersection of the railway and Mavis Road, a major north–south artery paralleled by a large water pipeline. If the accident had taken place a few minutes earlier or later, the explosion would have occurred in an area adjacent to residential portions of the town.

THE PRE-EVENT CONDITIONS

"Mississauga has been the site of previous accidents: two aircraft accidents and a petroleum-refinery fire; during both the police of the Peel region performed *ad hoc* evacuation of nearby residents. The sensitivity of the populace and authorities to these 'warning' events resulted in emergency planning being implemented by focusing at the provincial and local levels. Peel Region of the Province of Ontario was prepared for that night in

November; they had an emergency-action plan for this type of accident; a staged evacuation plan had been developed; and the local and auxiliary police resources were identified for implementation of the evacuation plan. Prior to the accident, the performance of local leaders was clearly very professional. They again proved their professionalism in the management experience of this event.

"The message from Mississauga is that effective management of emergencies is rooted in focused planning, in staged evacuation plans adaptable to peculiar situations, and in clear definition of individual roles. As will become clear, chance produced a number of lucky and favorable factors that aided the management of the emergency. But as Pasteur stated, 'Chance favors the prepared.' Pasteur might have added, 'The unprepared have little chance.'

THE EVENT

"The derailment resulted in a scrambled pile of cars that contained, among other things, propane and chlorine next to one another. The initial, propane-produced explosion resulted in the rupture of a chlorine car and the entrainment of 60 to 70 tons, of the available 90 tons, of chlorine into the explosion cloud. This cloud, containing most of the chlorine, rose to a height of a few thousand feet. One of the diffusion modelers from the Ministry of the Environment heard the first explosion and subsequently saw the fire-column plume of the second explosion. This first-hand experience, coupled with fragmentary data on the quantities of materials involved, allowed the modeler to make reasonable assumptions on the fate of the 60 to 70 tons of chlorine that went up with the explosion. These reasonable inputs permitted him to estimate the required evacuation zone as being 16 miles downwind.

"Early in the emergency, a second car with liquid fuel, presumably with a minor rupture on one end, was ignited. Its subsequent behavior resembled that of a rocket being launched, with the car coming to rest one-half mile from the derailment site. The pseudo-rocket impact area was fortuitously uninhabited or else the scale of the accident and its severity would have escalated in a delta fashion.

"The water pipeline adjacent to Mavis Road provided water for the cooling of cars with potential problems and certainly assisted in minimizing the number of cars involved. A heroic brakeman is credited with decoupling and moving many cars still on the track, both ahead and behind the accident; these cars had the potential for involvement if not decoupled and moved. During its early stages, the accident was managed by local authorities, including the first evacuation of squares 22, 23, 15, and 16 (see Fig. 1).

METEOROLOGICAL AND ENVIRONMENTAL SUPPORT

"The Ministry of Environment (MOE) of the provincial government coordinated and interpreted the air quality and meteorological information. The TAGA (trace atmospheric-gas analysis) systems of the MOE were capable of accurate chlorine-gas-concentration measurements and were deployed in two mobile trucks in a pattern downwind of the accident site. Their readings were communicated by radio to the command post for analysis and display. Meteorological information was supplied by the regional office of the federal Atmospheric Environment Service. On-site minisonde wind and temperature profiles were obtained by a team from the Air Quality Branch of that service. Modeling of the toxic gas release was performed by the provincial government agency in cooperation with the chemical companies. Potentially hazardous corrective operations (e.g., pumping of chlorine) were conducted *only* when the wind conditions were deemed favorable. It is abundantly clear that at Mississauga there was a coordinated and planned use of real-time environmental data to manage and reduce hazards to the public during remedial actions.

THE FIRST EVACUATION

"The local police and fire chiefs made the early decision to evacuate, for preventative reasons, the close-in population (squares 22, 23, 15, and 16, see Fig. 1), starting from the inside out. Persons refusing to leave had a clear mark placed in front of their homes so that a swift sweep could be made if forced evacuation were required. Local authorities remained in charge until the arrival of provincial relief, requested by local authorities to the Province of Ontario. Thereafter, the Solicitor General of the

Province was in charge of the emergency. A command center was established upwind, in the local telephone headquarters building and 2 km from the derailment site. The telephone company furnished full and adequate communication from this location throughout the emergency. The company provided rooms in the building as were required: most notably, a conference room for media and press to assemble and where the *single* commander issued clear statements about the emergency, starting from the initial establishment of the media room. The provincial plan clearly contained a reasoned section on the management of information flow from a single authority.

THE SUBSEQUENT EVACUATION

"On the basis of model calculations and site information on materials involved in the explosion, further evacuation was advised by the provincial authorities. Squares 21, 14, 7, 8, 9, 10, 17, and 24 (see Fig. 1) were evacuated from the outside to the inside of the established perimeter, presumably using techniques similar to those of the first stage of evacuation. For two days, while propane tanks burned, adjacent chlorine cars were kept cool by spraying them with water. The Solicitor General established a 'Control Council' that managed the emergency under his chairmanship: constituents were the Mayor of Mississauga, provincial police officials, Deputy Minister for Environment, Dr. Fitch from the Ministry of Labour (for evacuation of hospitals, homes, etc.), and others not identified specifically.

THE RETURN OF THE EVACUEES

"When the propane fires were controlled and the potential for toxic releases was deemed null, the evacuees were allowed to return in a staged and systematic manner (starting with those from the outside regions and going inward) as well as under surveillance to control potential crime. Looting involved a few cases at most, an incidence deemed small in present societal conditions and in view of the large number of people involved. In this aspect, it was apparent that successful planning was the strategic element.

THE FAVORABLE FACTORS

"The responsible on-site commander, Mr. Cross, indicated that, beginning with time zero, innumerable favorable factors (some of which we have already mentioned) aided in the management of this emergency: the close-in regions to the derailment site were clear of people and housing, a major water-supply line paralleled Mavis Road, a sand supply was nearby, the initial wind was towards Lake Ontario rather than towards Toronto, a diffusion modeler saw the explosion-produced cloud, Mavis Road provided excellent access to the derailment site from both sides, the close proximity of the telephone building that served as command and communication center, the landing of the jet-propelled propane car in an uninhabited area, and the moving by the brakeman of the two ends of the train (still on the track) away from the fire.

THE LEGACY FOR CHANGE

"Major accidents serve as traumatic learning experiences for man and, as such, impact on his institutions and management structures. The learning experience of Mississauga will undoubtedly result, everywhere, in some required changes in procedures for accident prevention and response as a result of this significant event in emergency-response planning. Transportation rules will, no doubt, be questioned; the existing car-spacing rules regarding loads of both propane and toxic materials on the same train are clearly to be reexamined in the months ahead by Canadian government committees. It is not unreasonable to assume that the emergency response plan that served so well in the actual emergency will nevertheless be examined for its adequacy and for places of improvement. The U.S. transportation community should, and no doubt will, learn from these findings and should consider train makeup formulae for these and other kinds of materials.

"But the emergency response community, one the author is much more familiar and involved with, should take special note of the milestone of emergency-response planning symbolized by Mississauga. The success scored at Mississauga should serve as a positive example of the benefits of awareness, appropriate planning, and appropriate management structures that are understood, tested, and in readiness to protect public health and safety. 'Chance favors the prepared!'

DISCLAIMER

"Any errors of fact or interpretation belong to the author and not to the Canadian officials who generously gave of their time to talk about Mississauga and who received and improved the manuscript in its early form."

Looking back at TMI and Mississauga, it appears essential in emergency-response management for command control of the response, remedial actions, and preventative or forced evacuation to be at the state and local level. Local knowledge of rapidly occurring events, of the availability of resources and supplies, and of the personnel involved in the decision-making processes contributes to this recommendation. The Federal government can, through various agencies, assist with special measurement capabilities, assessment tools, advisory information, and needed expertise. These resources from the larger national pool can be effectively integrated into the local decision-making processes by local and state authorities in the context of a tested, proven, and scalable emergency-response plan. The crucial message from the Mississauga experience is that local and state authorities need the command control and authority to deal with response management with assistance, advice, and expertise from the Federal government as needed and requested. Criteria for requesting Federal assistance should, of course, be clearly defined and understood by all parties before an emergency occurs so that valuable time can be saved.

REFERENCES

1. M. H. Dickerson and R. C. Orphan, "Atmospheric Release Advisory Capability," *Nuclear Safety* **17**, 281-289 (1976).
2. B. S. Lawver and R. C. Orphan, *Operators Guide: Atmospheric Release Advisory Capability (ARAC) Site Facility*, Lawrence Livermore Laboratory, Livermore, California, UCID-17490 (1977).
3. C. A. Sherman, "A Mass-Consistent Model for Wind Fields Over Complex Terrain," *J. Appl. Meteor* **17**, 312-319 (1978).
4. R. Lange, "ADPIC—A Three-Dimensional Particle-in-Cell Model for the Disperal of Atmospheric Pollutants and Its Comparison to Regional Tracer Studies," *J. Appl. Meteor* **17**, 320-329 (1978).

JBK/ceb

*LLL: 1980/9