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REAL-TIME GLOBAL MUTUAL AID FOR ATMOSPHERIC RELEASES OF RADIOACTIVITY IS POSSIBLE TODAY

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ABSTRACT

Over the past 15 years, the Lawrence Livermore National Laboratory's Atmospheric Release Advisory Capability (ARAC) has developed and evolved a computer-based, real-time, radiological-dose-assessment service for the United States Departments of Energy and Defense. This service is built on the integrated components of real-time computer-acquired meteorological data, extensive computer databases, numerical atmospheric-dispersion models, graphical displays, and operational-assessment-staff expertise. The focus of ARAC is the off-site problem where regional meteorology and topography are dominant influences on transport and dispersion. Through application to numerous radiological accidents/releases on scales from small accidental ventings to the Chernobyl reactor disaster, ARAC has developed methods to provide emergency dose assessments from the local to the hemispheric scale.

As the power of computers has evolved inversely with respect to cost and size, ARAC has expanded its service and reduced the response time from hours to minutes for an accident within the United States. Concurrently the quality of the assessments has improved as more advanced models have been developed and incorporated into the ARAC system. Over the past six years, the number of facilities directly connected with ARAC has increased from 6 to 73. All major U.S. federal agencies now have access to ARAC via the Department of Energy as specified in the U.S. Federal Radiological Emergency Response Plan. This assures a level of consistency as well as experience. ARAC maintains its real-time skills by participation in approximately 150 exercises per year; ARAC also continuously validates its modeling systems by application to all available tracer experiments and data sets.

While the most recent major application of ARAC to a real accident event was the Chernobyl disaster, ARAC spent a considerable effort and was well prepared for the potential COSMOS 1900 reactor burnup. Preparation for events such as these provides the impulse for further improvement in data acquisition, databases, mapping, and models.

ARAC could provide significant assistance in support of a radiological accident anywhere in the world if requested/authorized by the U.S. Department of Energy. Modern telephone communications in combination with telefacsimile technology provides the possibility for contact between ARAC and appropriate national/international agencies or officials. With the recent addition of global topography and access to worldwide meteorological data, ARAC can rapidly provide emergency assessment calculations based upon a tested and verified system of models and databases.

INTRODUCTION

The Atmospheric Release Advisory Capability (ARAC)[1,2,3] is a United States government Department of Energy (DOE)-sponsored emergency-response service designed, developed, and established at Lawrence Livermore National Laboratory (LLNL) to provide real-time predictions of the radiation dose levels and the extent of surface contamination resulting from a broad range of possible occurrences or accidents that could involve the release of airborne radioactive material. During its 15-year lifetime, ARAC has responded to more than 300 real-time situations and exercises. Some of the most notable responses include the Three Mile Island (TMI) accident[4] in Pennsylvania, USA, the Titan II missile accident[5] in Arkansas, USA, the reentry of the U.S.S.R.'s COSMOS-954 into the atmosphere over Canada, the accidental release of uranium hexafluoride from the Sequoyah Fuels Facility accident[6] in Oklahoma, USA, and, most recently, the Chernobyl reactor accident[7,8] in the Soviet Union. On several occasions, ARAC has served on extended alerts, e.g., for COSMOS 1402 (1983) and COSMOS 1900 (1988), or served in an advisory and confirmatory role for the U.S. federal government, such as for the purge of Krypton 85 from the TMI containment in the summer of 1980.

ARAC currently supports the emergency preparedness plans and activities at Department of Defense (DOD) and DOE sites within the U.S., and also responds to any accidents that the U.S. has interest in, e.g., Chernobyl. Our ARAC center serves as the focal point for data acquisition, data analysis, and assessments during a response, using a computer-based communication network to acquire real-time weather data from the accident site (supported facilities) and the surrounding region, as well as pertinent accident information. Its three-dimensional models for atmospheric dispersion process all this information and produce the short-term (2–6 hour) projections used in accident assessment.

Our work has received international recognition and acceptance. In 1980, we transferred our ARAC models to the computer system of the Italian Nuclear and Alternate Energy Agency (ENEA), and we continue to cooperate with ENEA in the areas of model evaluation and system development.[9] In 1982, ENEA transferred our ARAC models to the computer system of the Japanese Atomic Energy Research Institute (JAERI), and we have developed a close working relationship with JAERI. In 1983 we transferred our ARAC models to the Swedish National Defense Institute (NDI), and we have since pursued model evaluation studies with NDI. We have provided consulting services with regard to emergency-response atmospheric models and computerized emergency-response methods to the International Atomic Energy Agency, and have presented a 2-1/2-day course in computerized emergency response for developing countries. In addition, we have provided our key models and various services to Spain, Korea, Brazil, Israel, West Germany, and India.

BACKGROUND

The Atmospheric Release Advisory Capability is a real-time emergency response and preparedness service developed at Lawrence Livermore National Laboratory. ARAC provides projections of dose level, concentration, and surface contamination resulting from a broad range of possible occurrences (e.g., accidents, spills, extortion threats involving nuclear material, reentry of nuclear-powered satellites, atmospheric nuclear tests) that could involve the release of airborne radioactive material. During the past 15 years, ARAC has responded to or participated in approximately 300 situations—mostly exercises, but also all major nuclear accidents/events.

The original concept, prototype development, and initial operations (1974–1982) were funded by the DOE. A major expansion, entailing redesign and increased automation, was accomplished (1983–1986) with major funding by the DOD. In 1987 a Memorandum of Understanding (MOU) was negotiated between the DOE and DOD for an even division of operational funds to support a 40 hour/week "immediate" and off-hours "as available" response service for the 50 then-supported/planned sites. Subsequent sites and services have been added on a pro rata cost-share basis so as not to jeopardize the basic service level of the MOU-covered sites.

The present ARAC is prepared to:

- Rapidly assess environmental impacts, using three-dimensional, atmospheric-dispersion models that include the effects of complex meteorological conditions and terrain;
- Support the emergency-preparedness plans at over 70 DOE and DOD facilities accessible through our computer system; and
- Provide timely impact assessments for accidents that occur at any location in the world.

Support for DOE is not only provided to specific sites/facilities, but also to its specialized emergency response and assessment organizations, i.e., the Accident Response Group (ARG) and the Federal Radiological Monitoring and Assessment Center (FRMAC). ARAC participates in most major exercises of these groups. DOD also receives ARAC support for its many major exercises, training courses, and accident manual/procedures development. Exercise preparation and development for DOE, DOD, and the Nuclear Regulatory Commission (NRC) is another frequently utilized aspect of the ARAC service.

DESCRIPTION OF ARAC

ARAC is both a service and a system. The ARAC emergency response and assessment service is the integral result of (1) the applied expertise of its 27-person operations and support staff, (2) extensive databases, (3) the application of sophisticated models, (4) an extreme emphasis on preparedness, and (5) a high degree of computer automation. The present staff composition is approximately half operations (assessment meteorologists, system operators, equipment support, etc.) and half computer programmers.

The ARAC emergency response and assessment system is a combined software/hardware structure based on a "central" system and distributed user-terminal support components. Such a design focuses the computational load (and power) at a central location (ARAC) and, through a communications system/network, supports a user terminal or mini-computer with site-specific information, local data, and central system-prepared advanced model calculations. The ARAC central system consists of clustered Digital Equipment Corporation (DEC) VAX-8550 and 780 computers (VMS), associated disk storage (approximately 12 Gbyte), and peripheral (graphic, text, and printer) devices. The communication system consists of two Micro-VAX II computers with 33 modems linked via DECNET to the main VAX cluster. Additionally, the remote user site system has been developed for a DEC Professional Computer 350/380 (PC-350/380) with the Professional Operating System (POS) and Telephone Management System (TMS) incorporating a proprietary communications protocol. At sites with a meteorological tower, dedicated microprocessors (HANDAR 540) manage the data collection and transmission of that data to the site computer.

The integrated system of hardware and software described above is called the ARAC Emergency Response Operating System (AEROS). Presently, as a result of the automation developed in AEROS, ARAC can:

- Produce initial emergency assessments within 25 minutes of notification during normal working hours, for sites connected to our computer system (future improvements of the system will reduce this response time to about 15 minutes);
- Produce high-quality graphical displays of the assessments of radioactivity in the form of isopleths (contour lines) on a map (see Fig. 1);
- Provide a simple user-friendly interface for data entry and system operation; and
- Manage multiple emergencies at a wide range of possible locations.

In developing AEROS, we used modern structured analysis and design programming techniques in order to make the system simpler to maintain and alter as evolution has required. AEROS incorporates many features that make it highly reliable, most notably, extensive variable-range checking and PASCAL language data-type checking. Its meteorological data-acquisition and processing functions, as well as its model-input-parameters selection process, are highly automated to reduce delays and human error. These latter features enable the system to reliably keep pace with changing developments in an emergency situation.

Figure 2 schematically outlines the hardware, which is essentially a network of computers and communication equipment. The AEROS system presently includes approximately 70 nuclear facilities. At each of these facilities, there is a meteorological tower and a DEC PC 350 or 380 with a hard disk, color monitor, telephone-management system, and dot-matrix printer. At some facilities the instruments on the meteorological tower transfer data directly into the on-site computer through a modem, while at the others an operator transfers the information manually. Information from the facility computer, together with detailed weather data for the surrounding area obtained from the U.S. Air Force Global Weather Central (Omaha, Nebraska), feeds directly into the ARAC central computer system at Livermore, California.

The flow of information and data for a response is depicted in Fig. 3. Operations staff at the ARAC central facility can initiate a response using an on-line questionnaire for entry of accident information received via telephone or telefax, collect meteorological data, simulate releases using complex dispersion models that account for the effects of local terrain, prepare graphical displays of all projections overlaying the local geography, and distribute these projections to on-site authorities.

Site computer users can initiate a response at the central facility by entering accident information into an on-line questionnaire. To report an accident, an operator at an ARAC-supported facility selects an "alert" or "emergency" condition on the local computer system menu. This action initiates a fully automated dialup connection task, transparent to the user. Immediately thereafter a problem questionnaire is displayed prompting the user for pertinent accident information such as time, location, description, and any supplemental meteorological data (primarily wind speeds and directions, although temperature, barometric pressure, and humidity can also be important). This information is automatically transmitted to the ARAC central facility. Receipt of an "off-normal" condition from a site immediately triggers a paging system that alerts the ARAC staff and sets in motion the data-acquisition system that gathers all available regional and site weather data for input into the model calculations.

MODELS

At the core of the ARAC system is a suite of diagnostic models, which are fully integrated into our emergency response environment, i.e., computers, communications, databases, etc. The primary model suite is actually a six-code stream:

- TOPOG (topography/grid generation)[10]
- MEDIC (meteorological data interpolation)[10]
- MATHEW (mass adjustment/balance)[11]
- ADPIC (atmospheric dispersion, particle-in-cell)[12]
- DOSE (dose factors)[10]
- PLOT CONTOUR (graphic contour plots)[10]

Upon initiation of a problem or emergency response, once the region of concern and problem scale have been determined, the terrain-grid-generation program (TOPOG) produces a 51-×-51-×-15 grid cell or block form rendition of the terrain features to serve as the lower boundary of the modeling domain. Immediately thereafter, the previously requested meteorological data, automatically decoded and processed, is input to a meteorological, spatial data interpolation program (MEDIC), which prepares a $1/R^2$, three-station-influenced, initial reference-level gridded wind field. This low-level grid is then matched/extrapolated vertically to fit a representative tall tower or upper-air wind profile, thus completely initializing the three-dimensional grid volume. Boundary layer and mixing layer depths, wind-profile power law exponents, stability, etc., are either entered by ARAC's assessment meteorologist or automatically selected by a hierarchy of algorithms. These initialized grid values are then passed to a mass-consistent, wind field model (MATHEW), which minimally adjusts the flow fields by removal of mass divergence, through horizontal and vertical wind-component balance, to satisfy the law of mass continuity. The resulting mass-balanced, terrain-influenced wind fields serve as the transport (flow) fields for the atmospheric-dispersion, particle-in-cell model (ADPIC); lateral and vertical dispersion/diffusion are treated by a K-theory, gradient diffusion scheme. The dispersing (toxic) hazard material (up to 9 different substances) is represented by a set of marker particles (maximum = 20,000) released either instantly (puff) or continuously (plume), with simulated properties of gases or particulates (with size distribution and gravitationally driven settling), time-variable source rate, half-life decay, deposition velocities, and washout/rainout interaction. The ADPIC model can be set to calculate instantaneous concentration, time-integrated concentration (dose), and time-accumulated deposition arrays (grids) for selected levels (surface and aloft), which can then be further processed with a dose conversion factors (DOSE) program and, individually or in combination, isoplethed and displayed with selectable contours (e.g., PAGs, EAGLs, DERLs) over geographical maps, and with appropriate legends, etc., by means of a graphics processing (PLOT CONTOUR) program. This model stream has been validated numerous times against field-program tracer studies and real-world accidents.

Prior to Chernobyl, ARAC had a minimally tested hemispheric code, PATRIC, which was derived from ADPIC. Though forced to use the PATRIC model for the real-time Chernobyl response, ARAC has since expanded and adapted a version of the full six-code suite to deal with large area (continental to hemispheric-scale) calculations through incorporation of gridded analysis and forecast data from the U.S. Air Force Global Weather Central (AFGWC). ARAC also has a sophisticated puff-diffusion model, 2BPUFF, and a nuclear explosion fallout model, KDFOC, as well as continuous- (plume) and instantaneous- (puff) point-source Gaussian models integrated into its emergency response system for application to relevant problems. For satellite reentry-type problems, ARAC has adapted an orbit prediction code (PREDICT) to calculate and display the orbital ground track of the vehicle, based upon orbital parameters available from NORAD (see Fig. 4).

DATABASES

One of the important inputs to the model calculation comes from topography databases. Terrain information is needed by the models so that material is dispersed in a manner consistent with the wind and temperature fields influenced by the underlying terrain[13]. In two to five minutes, ARAC operations staff create the essential files and call up images of the mountains, valleys, seashores, and plains for any part of the United States (from a 0.5-km database) and the world (from a 8-km database) on their computer screens. The topography databases used to construct these images are produced by the Defense Mapping Agency for the United States and by the National Ocean and Atmospheric Administration for the world.

Monthly, ARAC receives an updated list of all reporting meteorological stations (location, elevation, etc.) in the world and their reporting statistics. This information is loaded into a Master Station Library database from which ARAC software can automatically extract key information about all stations within a given radius of an accident/location, initiate automatic data requests, and locate the stations in three-dimensional space for model initialization.

Extensive geographic mapping databases exist[14] or are under development for a full spectrum of scales, i.e., detailed site maps to hemispheric/global maps. Sources of this data include the U.S. Geological Survey's (USGS) 1:2,000,000-scale Digital Line Graph (DLG) data, the Central Intelligence Agency's World Data Base II, and detailed site maps processed through an ARAC digitization process. ARAC intends to add USGS's newest product, the 1:100,000 DLG mapping data, as soon as possible.

In the past year, ARAC completed the implementation of an on-line Dose Factors database consisting of internal dose conversion factors published in the ICRP-30 report. For external dose conversion factors, we have incorporated those compiled by Kocher.[15,16] At some future date, ARAC anticipates the development of a substantial demographics database.

PREPAREDNESS

The underlying cornerstone of effective emergency response is preparedness, both in terms of the development and exercise of procedures, and in terms of the acquisition and cataloging/databasing of all possible static data. ARAC has developed and maintains "default" essential data files for all supported sites. Also, detailed site notebooks have been prepared for each site. A "potential accident site" library has been constructed for all U.S. potential accident sites, i.e., nuclear power plants, fuel cycle facilities, etc. ARAC is attempting to expand this library to include all sites worldwide. This information, in conjunction with the above mentioned terrain, mapping, meteorological station location, and dose factor databases, postures ARAC in a high state of readiness.

The extensive effort invested in the automation of all these essential databases and data acquisition processes, coupled with conversion of all possible manual tasks to automated functions, has resulted in reduction of ARAC's initial response time for an accident from $\sim$ 60 minutes to $\leq$ 25 minutes. With planned software changes this year, we anticipate a further reduction to a $\sim$ 15-minute response without further hardware upgrades (see Fig. 5).

Complementing this extensive data preparation and staging effort is an active exercise program, which finds ARAC constantly testing its entire system and assuring its readiness to perform (see Fig. 6). Tracer studies and other opportunistic events are used to evaluate and validate the entire system.

EVOLUTION

Technological changes, such as new generations of computers, communications systems, graphic (color) terminals, etc., have provided a continuous opportunity for system evolution in terms of performance speed, reliability, and appearance over the last decade. Likewise the application of new software development tools and methodologies has improved the reliability and management of this aspect of ARAC.

However, beyond these evolutions, each major accident/event over the life of ARAC has pointed out shortcomings of our emergency response service.[17] Many of these were somewhat compensated for by extensive real-time manpower efforts, albeit, usually at a significant cost in delay of our response. A "nested grid" version of ADPIC was developed and implemented to provide good spatial resolution for calculations near an accident location. As a result of these events, ARAC has developed an automated meteorological-data-request and management system that can acquire raw data immediately, and decoded or processed data within 20 minutes or less, for anywhere in the world. A continental

U.S. topographic database has been developed and implemented such that 0.5-km-scale data can be retrieved and processed within two minutes, for inclusion in ARAC's three-dimensional modeling system. Also, model product labels, legends, display areas, etc., have been changed to alleviate interpretation difficulties. Numerous in-house procedures have been developed, and many have been automated, to reduce the manual tasks, which could slow a response. A "nested grid" version of ADPIC was developed and implemented to provide good spatial resolution for calculations near an accident location.

In the model area, Chernobyl proved that the need for long-range transport and dispersion calculations existed, but ARAC was not immediately prepared to respond. After rapidly exceeding the 200-km range of our then existing regional-response capabilities, we defaulted operationally to simple hand and automated trajectory-puff calculations, while the systems development and support staff commenced four major expansion efforts. First, large three-hourly decoded data sets for all of Europe and the western Soviet Union were requested from Air Force Global Weather Central, then catalogued and prepared for model input. Second, the fundamental ARAC emergency-response models, MEDIC, MATHEW, ADPIC, and PLOT CONTOUR, were expanded to cover a 2000-km-square region and all the encompassed data stations (see Fig. 7). Third, after radioactivity was measured over Japan, an inactive hemispheric R & D model (PATRIC), derived from ADPIC, was rapidly brought to operational status and tested for applicability to the Chernobyl problem. And lastly, the procedures (requests, conversions, transforms, etc.) to receive and database the hemispheric gridded-data fields from AFGWC were developed and implemented such that hemispheric-scale calculations were available ten days after the accident started (see Fig. 8).

Operationally, today ARAC has its models adapted such that, if required, we could expand up to near-continental scale within a few hours or less. Data quantities, however, would be a problem because a high volume of reports would significantly slow the modeling initialization. At the next scale—hemispheric—we now have an operational version of the ADPIC model, and routinely (twice per day) receive gridded wind data from AFGWC for the northern hemisphere north of 20 degrees latitude. Calculations on this scale could commence in less than two hours, if required. A test of our model, mapping, and AFGWC data demonstrated that we have a capability in the southern hemisphere south of 20 degrees latitude. Since we do not routinely receive data for this region of the world, any response calculations in this hemisphere would require several hours to acquire the data sets. The tropics region from 20 degrees north to 20 degrees south is not presently covered by any ARAC gridded modeling/data system.

GLOBAL ADAPTATION

Considering the large number of nuclear power plants ($\sim$ 500) and research reactors ($\sim$ 250) throughout the world, and considering the grave response of the general public to the three nuclear reactor accidents with offsite consequences to date (Windscale, Three Mile Island, and Chernobyl), it seems prudent to apply the best available technical assessment tools/systems to nuclear-reactor-accident emergency response. Certainly a major issue for political leaders/governments as well as the nuclear industry is the provision of safe nuclear power for industrial development and support. This requires public support and acceptance, which is something greatly questioned since these accidents have occurred.

Proven emergency response systems/services such as ARAC can serve several key roles for national/international organizations confronting a nuclear reactor accident. The first is the provision of a rapid, early assessment of the immediate and near-term hazards in a consistent, uniform presentation based upon international standards. Second, local emergency response resources can be freed to acquire vital local-area measurements and concentrate on the collection, analysis, verification, and distribution of reliable data. Third, the full regional impacts can be derived from the combination of wide-area meteorological data, proven models, good accident information, and validated measurement data without tying up vital on-scene resources needed for accident management and public protection. An additional or fourth benefit is the training opportunity to provide public officials and facility managers with realistic, graphic visualizations of the consequences of plausible accidents, so that they are better prepared for the potential time and space scales of a real accident.

Modern telephone and telefacsimile communications make this type assistance available nearly worldwide in real-time. In order to actualize such a worldwide capability, an international organization such as the IAEA, UNDRO, WMO, WHO, IRC, etc., should request that the U.S. make ARAC an international resource. This could also provide some elevated level of confidence and assurance for the leadership of Less Developed Countries (LDCs) who recognize their very limited technological resource base and could project their complete overload in an accident situation.

In order to make such a service viable at a worthwhile level, a modest effort would need to be expended on data collection, i.e., preparedness, to curtail response time. Also, training–learning exercises should be conducted with the assistance of the appropriate international agencies in order to assure that the necessary communication links can be established, and to develop local site and regional government familiarity and confidence in the entire process. Once adequate training has taken place, the local news media should be advised and trained in understanding the products so that they can communicate this capability to the general public. This last step is the most important in developing and maintaining public confidence, particularly in the presence of a nuclear accident. Proper and confident use of a validated emergency response system will permit local, regional, and national officials to most effectively utilize their limited resources, communicate with the general public (through and with the media), and engender the vital confidence that public officials have adequate knowledge to make correct (and necessary) decisions in the event of an accident.

At the simplest level of global preparedness, telephone numbers, telefacsimile numbers, contact names, and training information should be gathered into an organized database and periodically tested. Perhaps either international agencies or technical/industry/scientific organizations could provide the leadership for such an effort. Eventually this could lead to routine checks of all communications links and possibly regular local exercises.

With the emerging computer and communications technologies, ARAC plans to develop a new generation, emergency response workstation with 3-D modeling capabilities, industry-standard color graphics, and low-cost dialup communications. If such workstations were installed at major reactor sites or emergency management centers, then a real-time, global, mutual aid system could evolve in place with the potential for support to come from several specialty centers, including specialists concerned with food and agriculture pathways, water systems, animal management, remediation, etc.

CONCLUSION AND SUMMARY

Fifteen years of evolution and experience with a wide spectrum of radiological accidents, two generations of computer technology, extensive databases, models, automation, and real-time meteorological data have led to the worldwide capable ARAC system that exists today. Requests for access to its capabilities by an international organization such as the IAEA, e.g., could make this proven emergency response technology available to the global community. There are no technical barriers to this end; only decisions and nominal support are needed to make this a reality.

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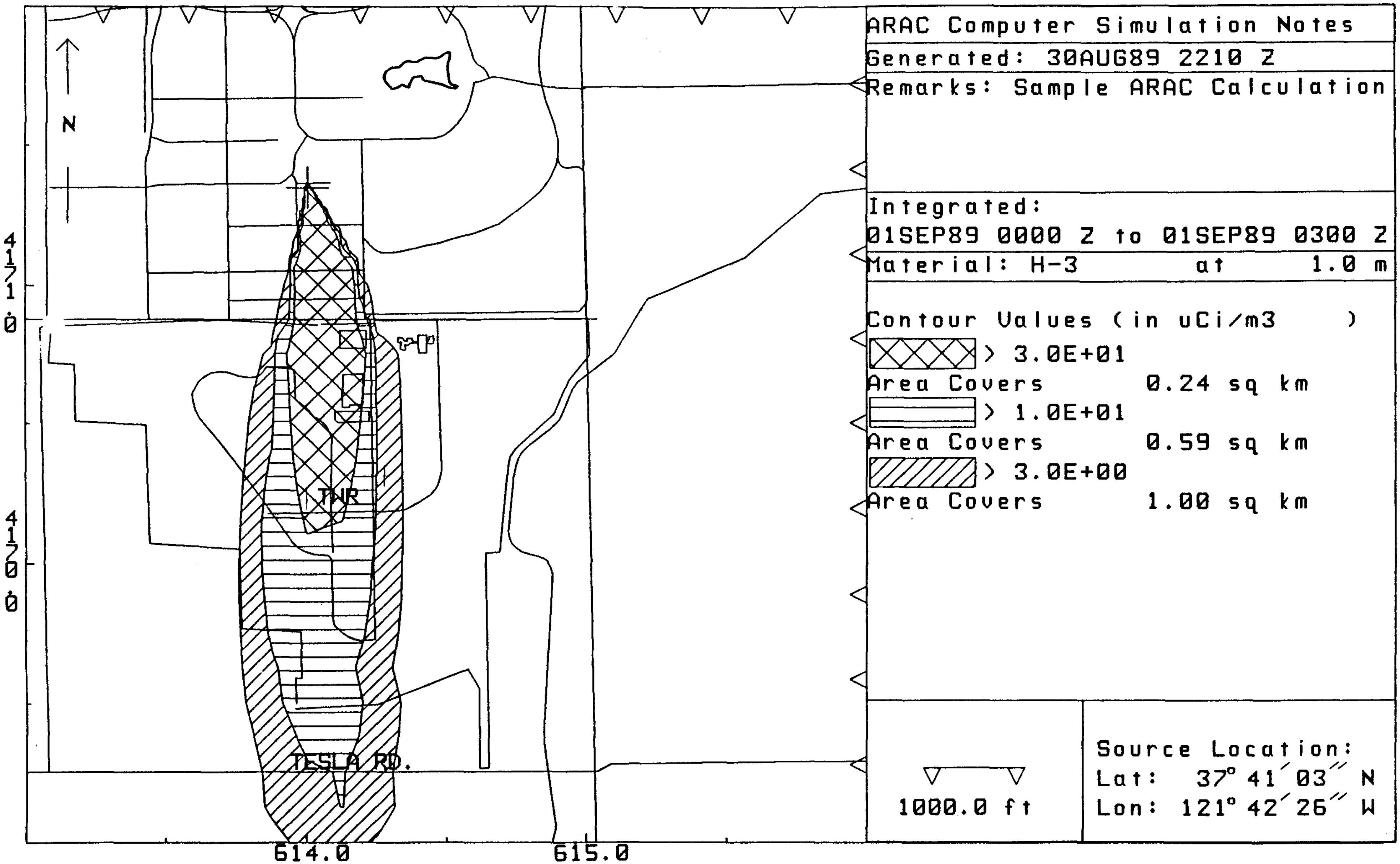

Figure 1. Illustration of a typical ARAC dose assessment plot (for a hypothetical release at Lawrence Livermore National Laboratory). Contour/area legends, calculation interval, species, units, etc., are all contained in the information legend. The depiction is always presented on a map background if the map is available.

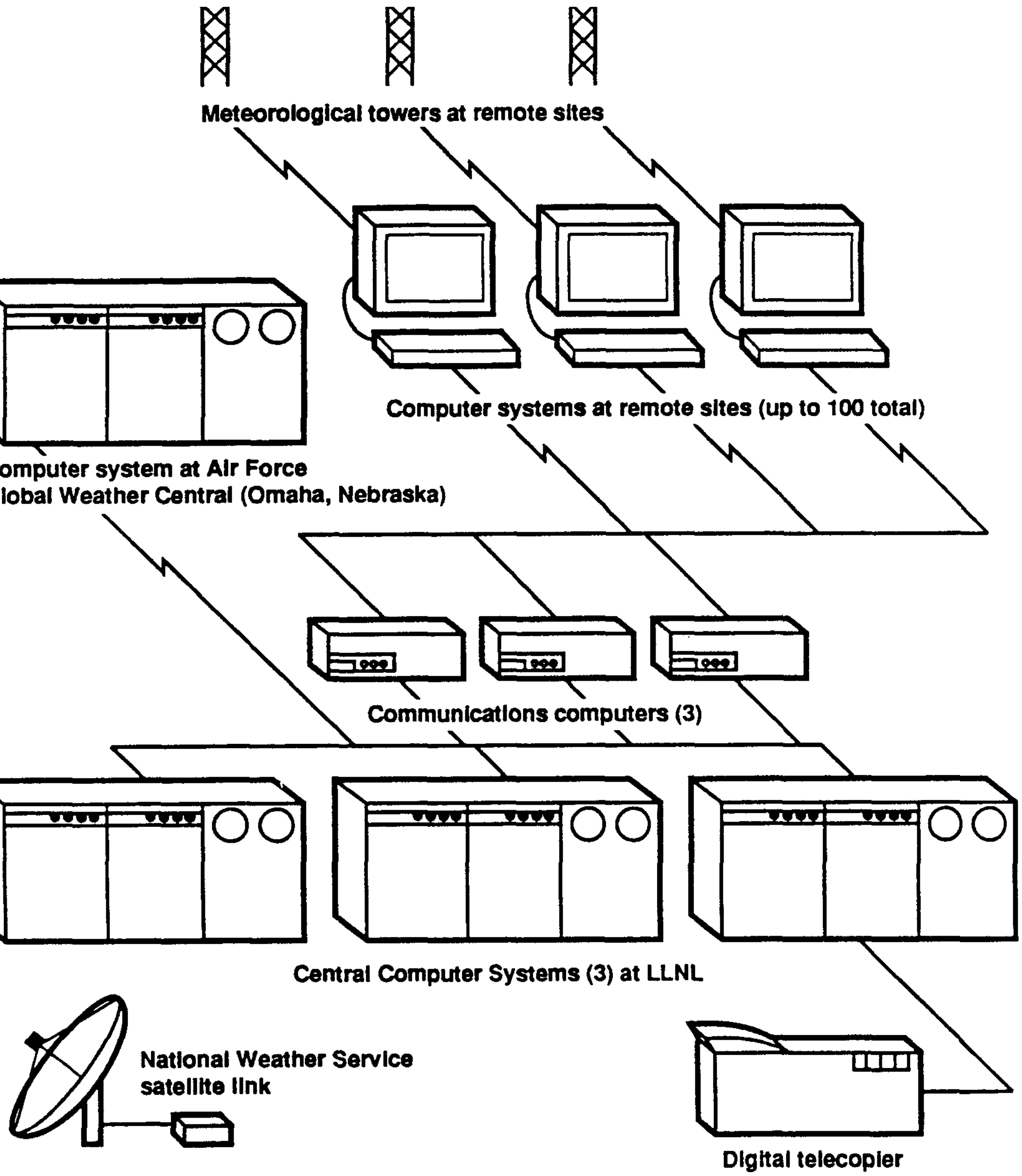

Figure 2. The AEROS network of computers that forms the core of the ARAC system. Each nuclear facility in the system has a desk-top computer for entering initial accident reports, and a meteorological tower to provide up-to-the-minute weather data. High-speed data links transmit this information to our computer center for use in atmospheric models.

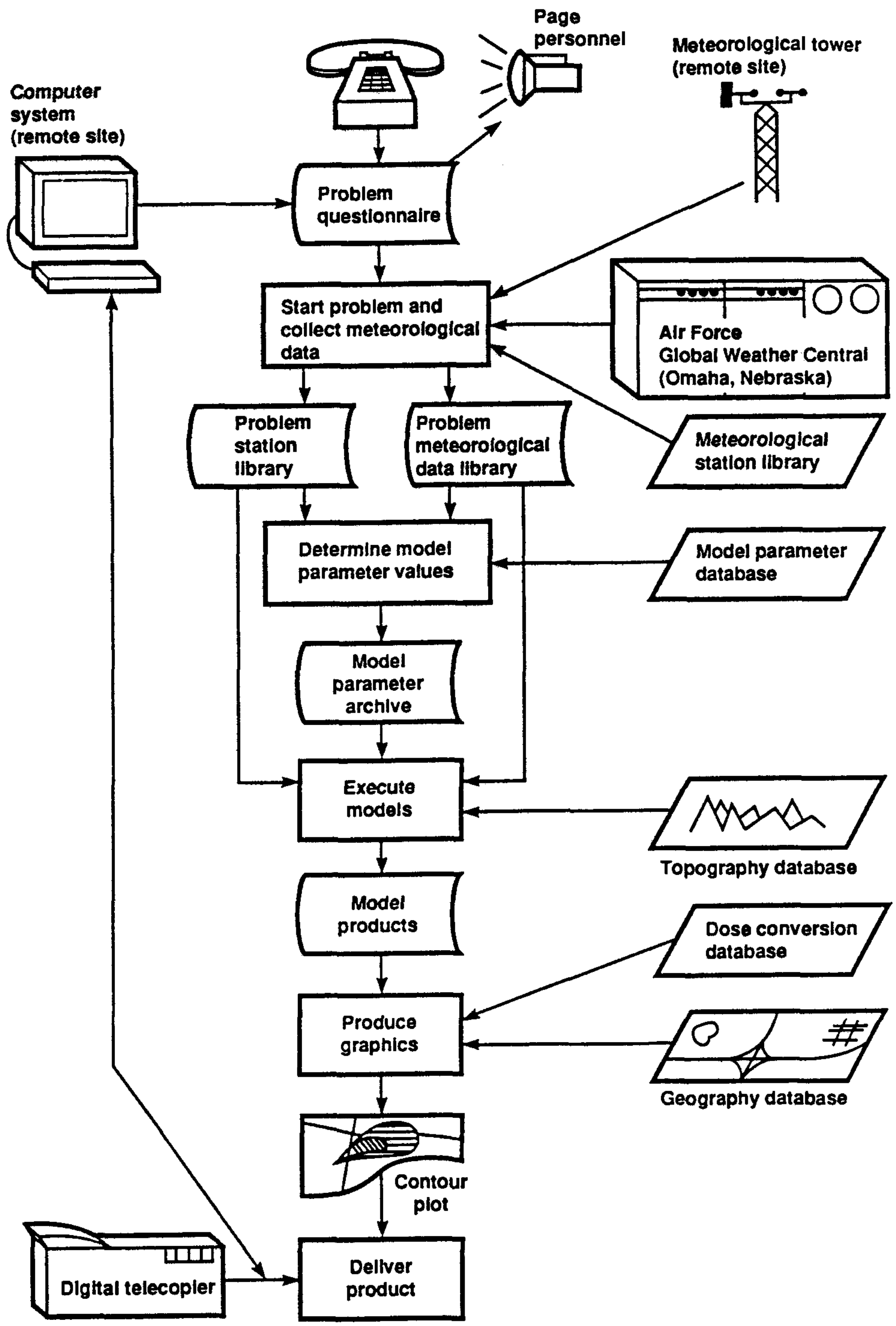

Figure 3. An outline of how the ARAC system functions. When an operator reporting an accident fills out a questionnaire on a computer located at one of the remote nuclear facilities, a paging system sounds at LLNL, alerting ARAC personnel and starting the collection of weather data from the nuclear facility's weather tower and from the Air Force Global Weather Central in Omaha, Nebraska. This information, combined with site-specific and problem-specific data from other libraries, is used to determine parameter values for use in the model. These values, together with information from our topography database, enable us to execute the models, produce graphics such as isodose plots, and distribute the results to crisis managers at ARAC and back at the site of the problem.

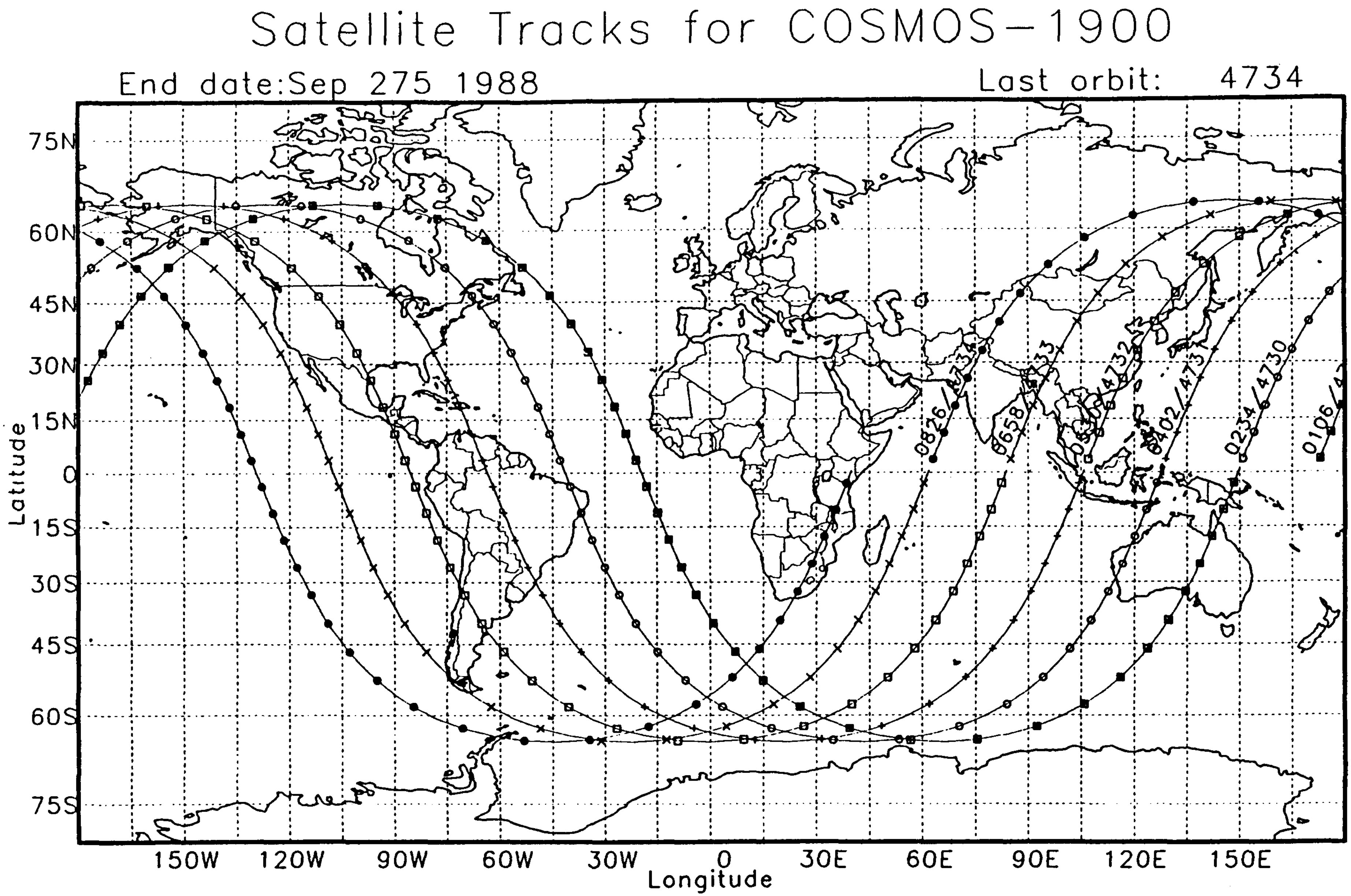

Figure 4. An example of five typical orbital paths of COSMOS 1900, illustrating the everchanging areas of concern until confirmation of reentry into the atmosphere.

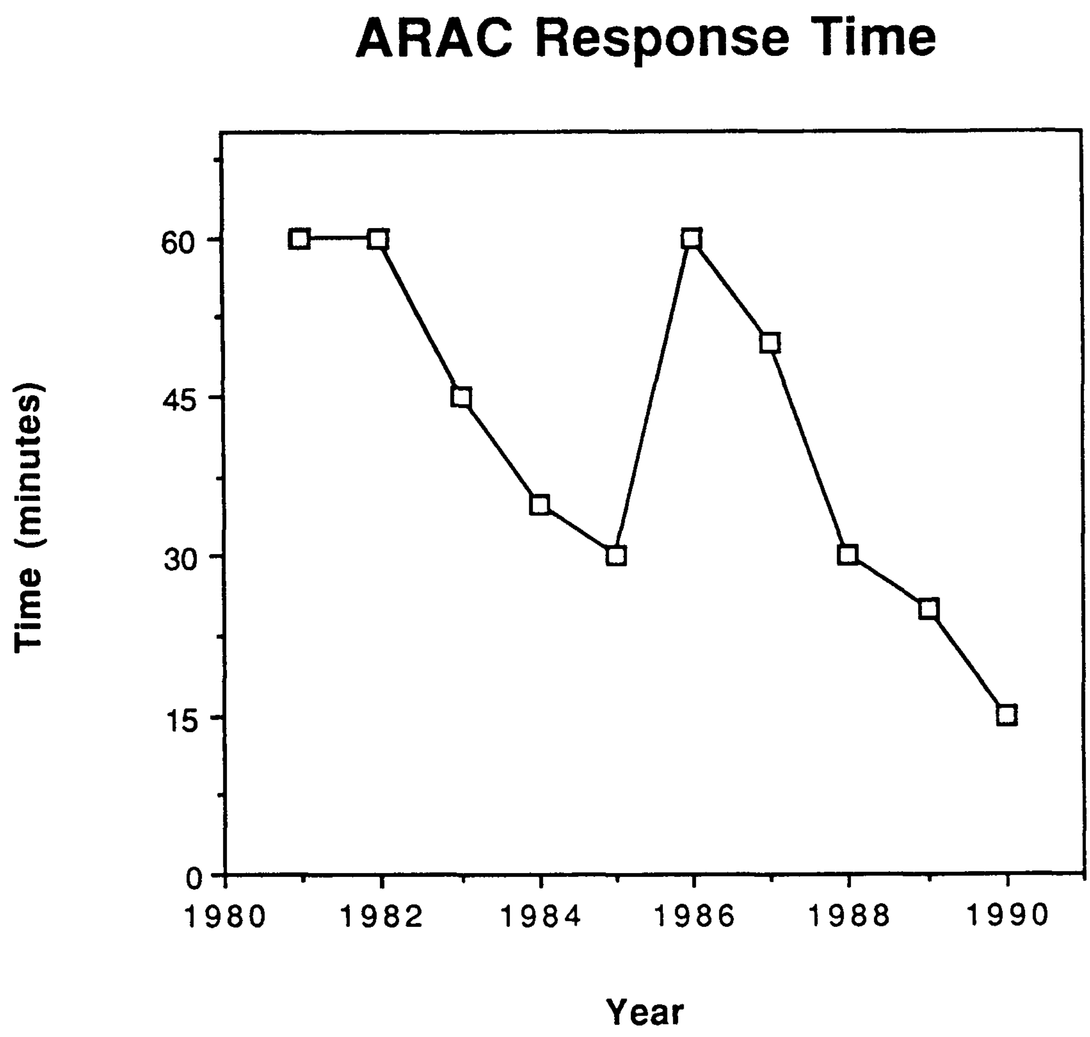

Figure 5. This plot shows how automation of the data acquisition process, databases, and manual tasks has steadily improved ARAC's initial response time. Note that ARAC moved from a CDC 7600 to a DEC VAX 782 in 1986 and to a VAX 8550 in 1988.

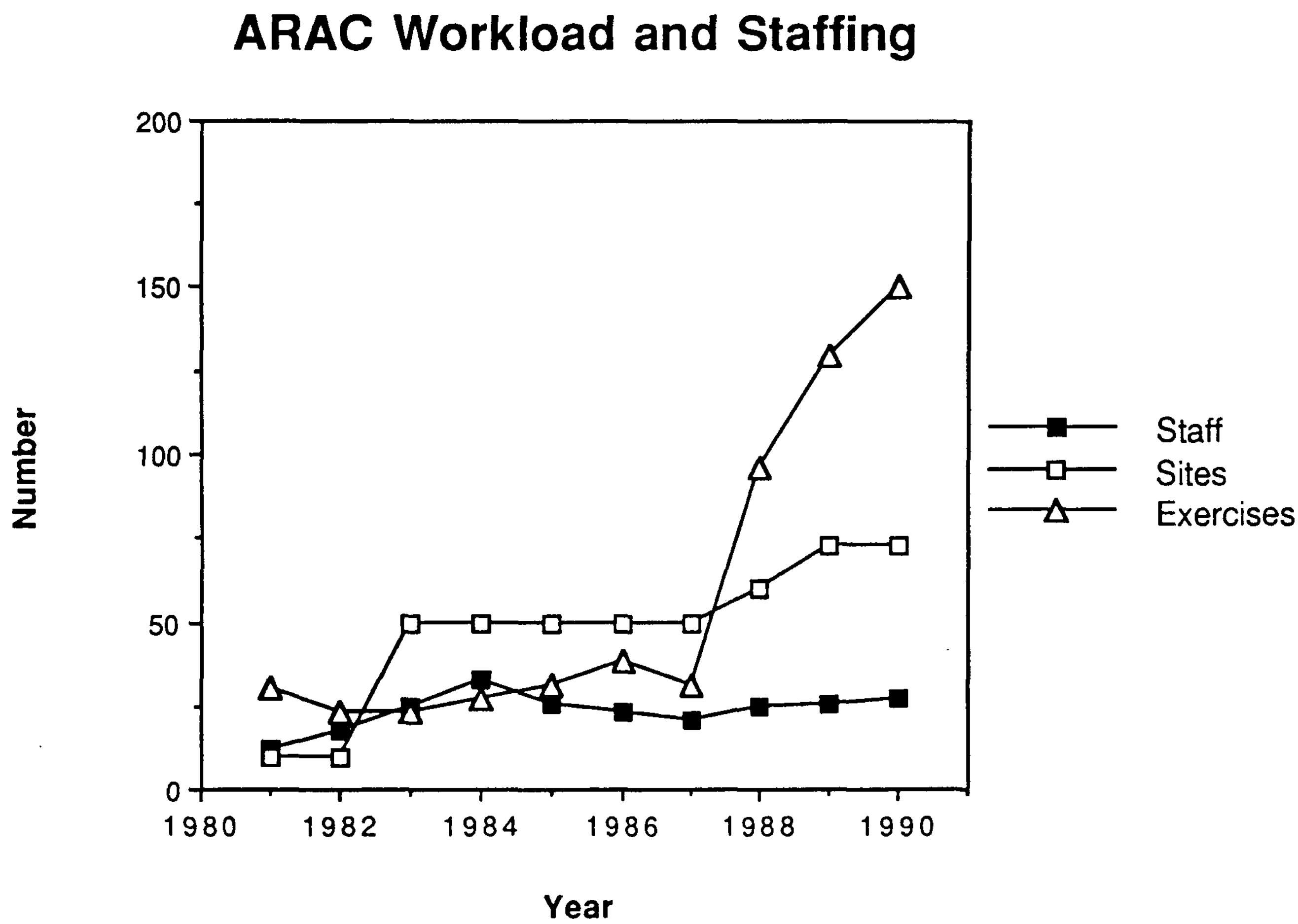

Figure 6. The benefits of automation to productivity are evident in this plot, which shows the chronology of the number of ARAC staff, the number of supported sites, and the number of training/preparedness exercises. It would not be possible to provide the ARAC service to the large number of supported sites and conduct so many exercises without the extensive automation and integration of capabilities as discussed in this report.

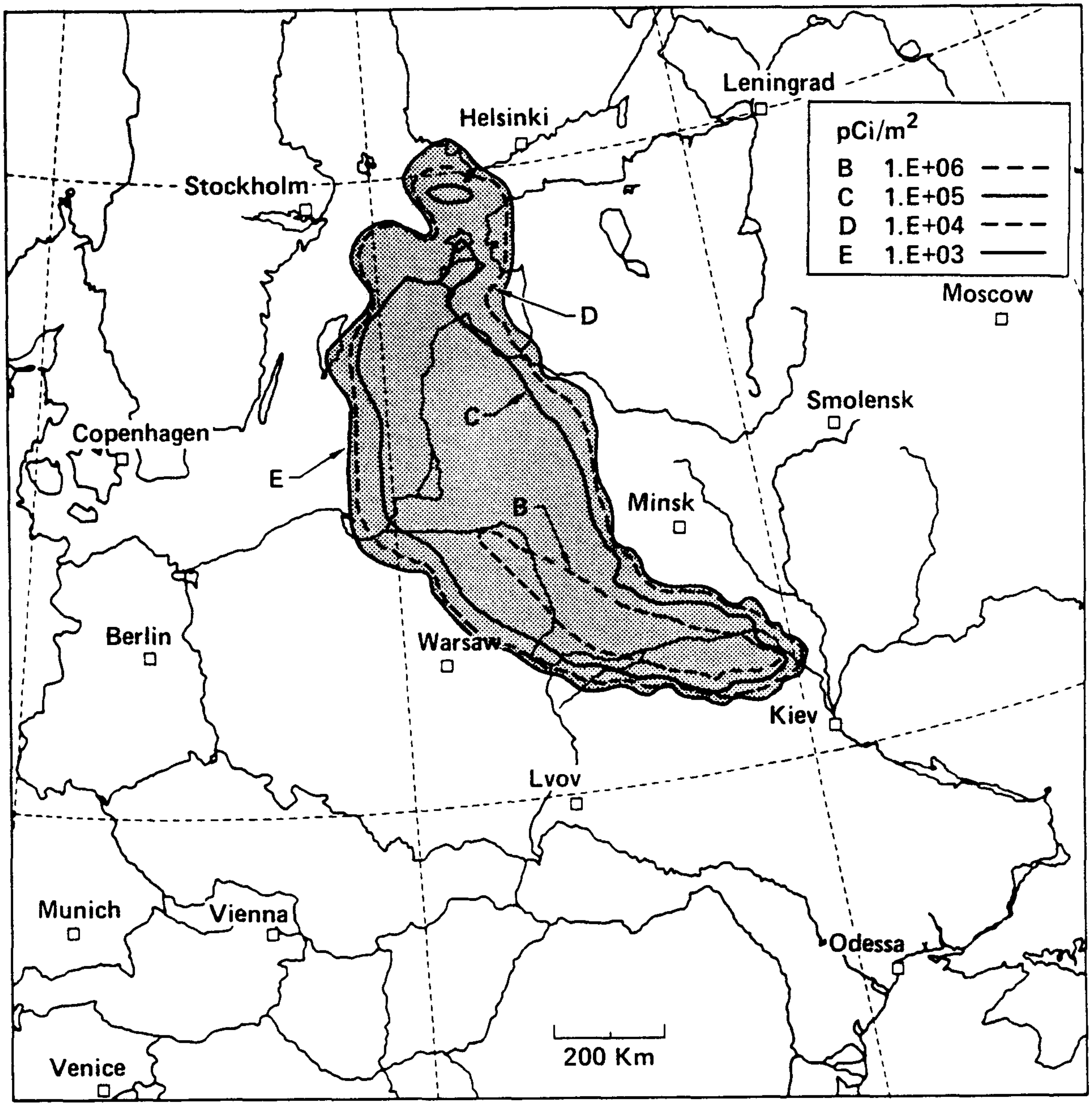

Figure 7. ARAC-calculated, Cesium-137 dry deposition isopleths after 48 hours of simulation, based upon an assumed source term for the Chernobyl accident. This plot shows the size of the area, and by inference, the regional meteorological data required to generate ARAC's initial asessments.

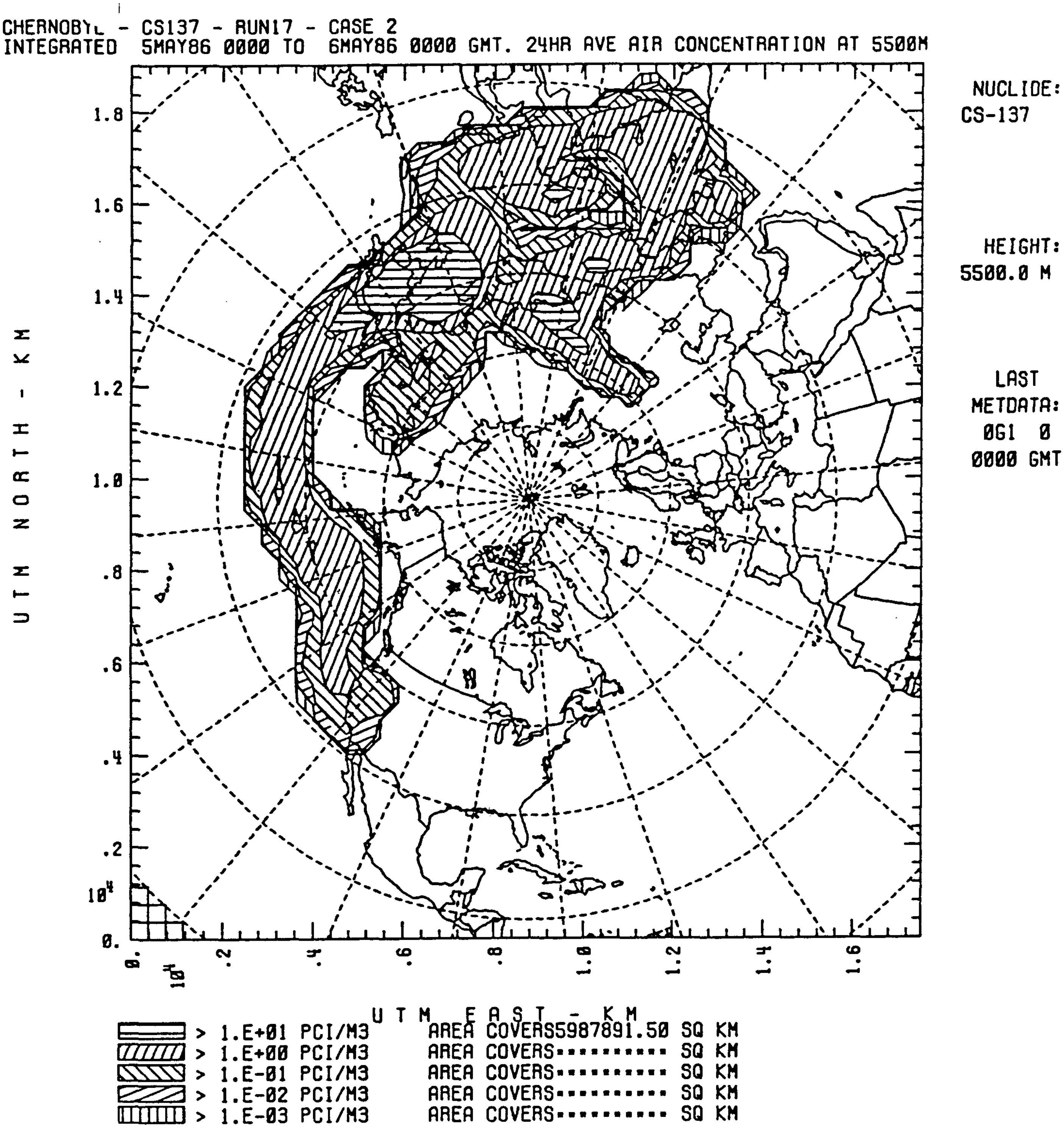

Figure 8. This is an example of a calculation for the Chernobyl accident of the 24-hour average concentration of Cesium-137 in pico-Curies m^{-2} for 5 May 1986 at 5500 m above sea level, produced by ARAC's operational hemispheric transport and dispersion model.