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LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California

ATMOSPHERIC RELEASE ADVISORY CAPABILITY (ARAC)

Marvin H. Dickerson

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Marvin H. Dickerson

Lawrence Livermore Laboratory, University of California,
Livermore, CA 94550

INTRODUCTION

Facilities handling toxic materials have an obligation for the protection of both their operating personnel and the public at large. The advent of nuclear materials has introduced new forms of hazard subject to controversy and often misunderstood by the layman. Continuation of a favorable nuclear safety record depends not only on strict adherence to standards and regulations, but also an extensive effort at the local level to foresee any potential occurrences and to plan protective emergency actions.

Although the growing nuclear power industry, on the whole, is engaging this problem, the Energy Research and Development Administration (ERDA) nuclear sites (research and production facilities) have found a special responsibility in this regard. ERDA is in the process of establishing a means of assisting the management at ERDA nuclear sites in responding to accidental releases of hazardous material and to routine operating releases and their impact on the surrounding environment. Under the cognizance of the Division of Biological and Environmental Research (DBER) program, Lawrence Livermore Laboratory (LLL) has developed a centralized service to provide nuclear sites with real-time predictions of the consequences of an atmospheric release of toxic material. This service is called Atmospheric Release Advisory Capability (ARAC).[1,2]

Since 1973, when the concept was introduced, a joint feasibility study by LLL and the Savannah River Laboratory has proved its workability and LLL has built and is now operating an ARAC component. During the next three years, ERDA intends to implement ARAC service for several of its nuclear facilities which means installing a central facility at LLL for acquiring, processing and transmitting data; linking this facility with national meteorological services; and installing local data-acquisition, assessment and communication facilities at the individual sites. By 1979, ARAC is expected to provide its service to the ERDA nuclear facilities on a 24 hour-a-day basis.

PURPOSE

The chief purpose of ARAC is to provide site officials, who are responsible for ensuring maximum health protection for the endangered site personnel and public, with estimates of the effects of atmospheric releases of hazardous material as rapidly and accurately as possible. ARAC would develop and send a series of advisories to assist the site in rapidly choosing its optimum alternative.

While the primary function of ARAC is to assist a site in emergency response, there are additional routine uses intended for this service. Some examples are:

- Calculate and maintain an inventory of radioactivity in the source.
- Maintain an updated inventory of routine releases and their location in the environment.
- Calculate doses from routine operations.
- Perform sensitivity studies to ascertain changes in pathway drives that determine the biological impact possible from changes in site operations and in site location for projected facilities.

For a particular site, the ARAC service offers the following advantages:

- *Predictive capability based on a local automated system.* The ARAC site equipment would provide the means for locally applying atmospheric modeling techniques for close-in distances (~ 5 km).
- *Links with advanced state-of-the-art predictive capability* The ARAC central facility would provide the result of newly developed regional modeling techniques and dose conversion data in real-time. Access to large scale computer systems and modern efficient data handling would permit protective planning based on information products not readily available at an individual site.
- *Emergency backup links.* In the event of an accidental release, protective planning could also be conducted away from the local site. Graphic display of data at several remote locations would permit coordination and alternative options.
- *Minimal costs.* The centralized basis of ARAC would permit economies not practical for individual sites.

When implemented, the ARAC would support the present ERDA role for assistance to operating nuclear sites in several important ways. These include, but are not limited to, the following:

- The quality of information and radiological advisories from ERDA would be improved due to the availability of real-time data and regional information.
- The predicted off-site radiological effects would include transient regional transport processes.
- Any off-site protective actions and postemergency cleanup operations would have a basis for iterative improvement as actual radiological information is received.
- ARAC would serve as a focal point to develop future improvements in the assistance and advisories provided by ERDA

ARAC OPERATION

The ARAC system is built upon a communication and data acquisition network that allows each user to have rapid access to the central advisory products which in turn are based upon environmental data from and surrounding the local site. A complete description of the component parts of the ARAC system can be found in Dickerson and Orphan (1975)[2] and will not be discussed in detail here. In summary, any number of nuclear or chemical facilities within the U. S. can be serviced within the network. Each ARAC-serviced site will have a mini-computer furnishing data acquisition, assessment and communication capabilities. Meteorological service provided by the National Weather Service (NWS) and the Air Force Global Weather Central (AFGWC) supplies meteorological data (observational data, analysis, forecasts) that are pertinent to each site assessment. The ARAC central facility, through data and voice telecommunication links, provides the site with regional advisories that are calculated on 7600 class computers. In the remainder of this paper we emphasize the regional models which are central to the ARAC service and their role in providing the real-time advisories and periodic assessments for normal operations.

Major ARAC Three-Dimensional Numerical Models

MATHEW, ADPIC and DOSCON are the numerical models used to provide the real-time regional, out to 100 km, advisories and assessments for normal operations. For short distances, up to approximately 5 km, the minicomputer at each site provides a Gaussian diffusion calculation, based on current meteorology measured locally, for quick response assessment. This calculation is always available to the site operator for display and is continually updated as current meteorological data are multiplexed and averaged. A trajectory out to approximately 100 km, calculated at the central facility, and based on local meteorological measurements at the site and regional weather data reported by the NWS and AFGWC would be available to the site personnel within 5 minutes after notification. Supplemental data, as from private industry or other government agencies, would also be used to update and improve this calculation.

MATHEW is a meteorological adjustment model that has been developed to provide a pollutant transport model (ADPIC, see below) with input wind fields that are mass-consistent, three-dimensional and representative of the available meteorological measurements. Interpolated three-dimensional winds are adjusted in a weighted least-squares sense to satisfy the continuity equation within the volume specified.[3,4] The upper and lateral boundaries above topography are assumed to be open air and thus allow mass flow through the boundaries. The bottom boundary (assumed to be solid) is determined by the topographic elevations of the area of interest.

The theoretical basis for this model was developed by Sasaki.[5-7] For this model a difference functional is needed, minimizing the deviation of the adjusted wind field from the measured field subject to the strong constraint that the adjusted field is nondivergent. The observed data needed for the adjustment are provided within the code by an interpolation-extrapolation scheme using information available at a given site to determine the observed velocity components at each grid point above the topography. These observed velocities are assumed to be a fair and reasonable representation of the actual wind field and only need to be minimally adjusted to significantly reduce the remaining divergence.

The current implementation of this model adjusts the three-dimensional winds at approximately 30,000 grid points. It must be emphasized that this computer code does not forecast the wind fields but uses existing wind measurements over the region to produce wind fields based on persistence.

ADPIC[8-10] is a hybrid, Lagrangian-Eulerian, three-dimensional particle-in-cell code for calculating the transport and anisotropic diffusion of a pollutant from its source to its temporal and regional distribution at arbitrary times. This computer code has the capability to simulate: speed and directional wind shear; occurrence of calms; space-variable surface roughness; wet and dry deposition; radioactive decay; gravitational settling; space- and time-dependent eddy diffusion parameters; and single or multiple sources of either continuous or instantaneous nature. ADPIC solves the three-dimensional advection diffusion equation in flux-conservative form using a pseudovelocity technique for a given regional mass-consistent advection field (supplied by MATHEW) in three-space dimensions and in time.

In this method, the Lagrangian particles represent the activity distribution and concentration associated with the aerosol within the structure of an Eulerian grid. The chief advantages of this approach are (1) the artificial diffusion inherent in purely Eulerian finite-difference codes is practically eliminated and (2) the Lagrangian particles can be tagged with their coordinates, mass or activity, age, and other properties that a particular pollutant might exhibit.

ADPIC has undergone extensive validation tests against closed analytic solutions and also regional tracer studies. Against selected analytic solutions ADPIC compares to within a 5% error. Against Methyl-Iodine tracer studies at the Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho, and ^{41}Ar plumes at Savannah River Plant (SRP), South Carolina, agreement is remarkably consistent. In Fig. 1 we have shown that ADPIC concentrations are within a measured factor of two 60% of the time and over 90% of the time within an order of magnitude.[10]

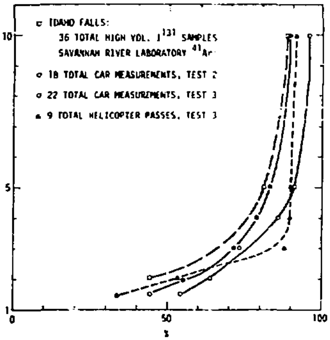

FIGURE 1. Percentage of time that ADPIC results are within a factor of N of field data.

MATHEW and ADPIC are now available to run operationally on the Livermore CDC 7600 computers (see next section). These codes can estimate air concentrations and ground deposition for any proposed site by inputting the local topography, potential source term(s), and location of available meteorological data. "Tuning" these models for each site is not necessary.

The ADPIC-calculated regional distribution of surface air concentrations and surface deposition of specific radionuclides of interest may be input to a dose-conversion computer code (DOSCON) for deriving the individual and population whole-body or organ doses via the inhalation, external, and ingestion pathways. By using the ICRP Task Group on Lung Dynamics Model,[11] one can compute the dose to various organs of the respiratory tract provided the aerodynamic particle size and the chemical and physical characteristics of the specific radionuclides are known. External exposures caused by direct gamma radiation from gaseous plumes may be evaluated by integrating the activity over the volume of the plume. This has been demonstrated by Clarke[12] and in the case of noble gases by Kahn and Blanchard[13] as well as by Russell and Galpin.[14] External exposures caused by surface deposition of gamma-emitted radionuclides can be derived on the basis of the calculated photon flux per unit source strength and the flux-to-exposure-rate conversion factors presented by Beck, et al.[15] The calculation of dose from ingestion of food, however, requires the use of reconcentration factors of radionuclides by biological processes to determine the activity of specific radionuclides in each food. These factors may be obtained from the data of Thompson, et al.[16] Numerous models are available for the calculation of the ingestion dose through specific food-chain pathways. Most noted are the results of Ng, et al.[17] and Killough, et al.[18] We plan to include these dose models in the ARAC system by June 1976.

ARAC Operational Numerical Models

In Fig. 2 we show a schematic of the operational numerical models used to provide ARAC advisories and regional assessments out to approximately 100 km. The three basic models (MATHEW, ADPIC and DOSCON are discussed above) coupled with site topographical, geographical, demographical and land use data bases provide the advisories which site personnel can use to

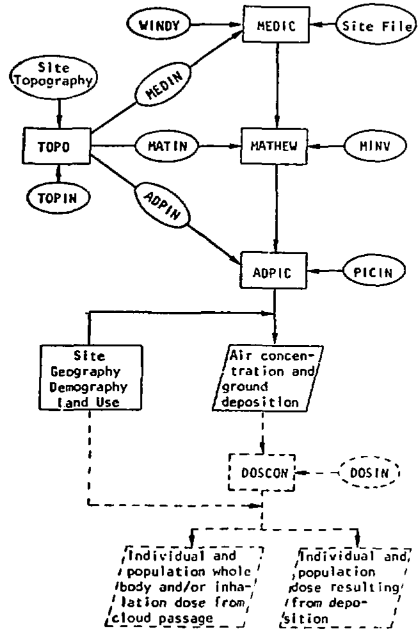

FIGURE 2. Schematic of ARAC Operational Models.

choose their optimum protective actions. Dashed lines in this figure are used to indicate that DOSCON is not presently included in the operational set of models.

As we stated above the basic models are site independent, i.e., they can be compiled and stored on the computer in a manner where they can be used for any site location provided the appropriate local input files and data bases are available.

MEDIC is a meteorological data interpolation computer code used to interpolate horizontal wind measurements to grid points at a fixed height above topography. WINDY is an input file that contains the horizontal winds and temperatures measured locally at the site in addition to measurements in the surrounding area reported by the NWS and other sources such as municipalities and industries. The Site File supplies the coordinate locations of the meteorological measurements. New input files to MEDIC can be made up as often as additional information becomes available in time or space. Output from MEDIC is used by MATHEW to calculate a three-dimensional non-divergent regional wind field which is used by ADPIC to advect the pollutants. MINV and PICIN are site specific input files that are generated each time conditions at a specific site change. For example, PICIN furnishes ADPIC with information related to the source term, i.e., height above topography, constituents, buoyancy and strength, if known. It is not required that the source strength be known since we can assume a unit source strength and adjust the final calculations with estimates of the source term as they are available.

TOPO is used to set-up the MEDIN, MATIN and ADPIN input files that contain topography and graphical coordinates for MEDIC, MATHEW and ADPIC respectively. Since it is unlikely that the entire 100 km radius area surrounding a site would be required for any one calculation, TOPO selects the topography for the area of interest from the site topography data base and the grid origins for the three computer codes. In addition, TOPO calculates the lower topographic boundary conditions for MATHEW and ADPIC.

When the ARAC central facility becomes operational within the next year the site specific input files can be constructed in real-time at the central facility mini-computer using interactive graphic techniques. These techniques allow the user to quickly display the data in a way that makes it easy to check, modify and construct the input files. As these data are constructed they can be formatted and directly input to the large computers.

ARAC Advisories and Assessments

The digitized geography, demography and land use data bases are used as background for overlaying ADPIC and/or DOSCON calculations. Also the digitized demography and land use data bases can be used to calculate population dose when they are coupled with output from DOSCON. These data bases offer a flexibility that provides various options for graphically displaying the concentration estimates from ADPIC or dose estimates from DOSCON. Design of the advisories can be such that they are easily interpreted by persons charged with issuing countermeasures. For example, individual inhalation and whole body dose from the airborne radioactive cloud passage can be overlayed on the demography of a region to estimate the exposure of individuals within the area of concern and at the same time locate critical exposure regions with large population densities. These same dose contours can be overlayed on the geography of the area to help determine what protective actions should be implemented. Any combination of calculations and backgrounds from digitized data bases can be supplied to the individuals in charge of assessment and issuance of countermeasure actions. Presently we are working with persons at LLL and other ERDA sites to design our model output so it can be accurately interpreted to provide a timely assessment. We estimate that advisories based on the models shown in Fig. 2 can be available at the site approximately 35 minutes after notification.

Advisories for emergencies generated by the accidental release of radioactivity to the atmosphere can be enhanced by feed-back between ARAC and other capabilities discussed today, namely, on-site and off-site emergency radiological monitoring systems and the ARMS capability. On-site and off-site radiological measurements, if they are telemetered to the ARAC site facility in real-time can help provide an immediate validation of the ARAC model output and supply a basis for interative improvement in the calculations by updating the source term. Since most model calculations will be based on a unit release the source term and the calculations can be updated as this information becomes available without rerunning the computer codes. For any remote or mobile measurements, ARAC would provide an estimate of the geographical area of concern thereby reducing the time required for deploying the measurements. As measurements from the mobile stations become available they can also be used to help validate the model calculations and source term estimate.

If the ARMS aircraft is called upon for aerial surveillance a period of time would be required before it could arrive at the site. During this time ARAC would be calculating and updating advisories. When the aircraft arrives, information from the ARAC advisories transmitted to the personnel on board would considerably limit the area of search and allow the aircraft to locate the airborne material in an expeditious manner. This continual feed-back between model calculations and measurements provides a means to efficiently interface several capabilities. During the December 1975 diffusion tests at the Savannah River Plant this feed-back between ARAC numerical model calculations and measurements will be further tested as the EG & G aircraft measures ^{41}Ar and SF_6 and LLL is simultaneously estimating concentrations of these materials in real-time. With this experiment we hope to gain additional experience which will allow us to proceed to a more sophisticated method for interfacing and utilizing measurement and calculational data.

Although ARAC was originally designed to assist the site and local personnel with planning during emergencies, the system is capable of providing each site with an assessment based on its normal operations. All meteorological and radiological data measured locally at each site and meteorological measurements reported by the NWS in the surrounding area can be data banked at the central facility and used for periodic assessments. These assessments can be calculated with a version of the models shown in Fig. 2 that has the capability of dealing with large amounts of data. In many cases assessments based on the use of these models would be more realistic than those calculated by standard wind-rose techniques since the ARAC models can account for coupling between local topography and time and space varying wind fields. By utilizing ARAC for regional assessments in addition to its emergency response capabilities, ARAC becomes a cost effective service for ERDA nuclear facilities as well as the nuclear industry as a whole.

CONCLUSION

ARAC is in the initial stages of being implemented and is therefore susceptible to changes before it reaches its final form. However the concept of ARAC is fully developed and was successfully demonstrated during a feasibility study conducted in June 1974, as a joint effort between the Savannah River Laboratory (SRL) and LLL. Additional tests between SRL and LLL are scheduled for December 1975. While our immediate goal is the application of ARAC to assist a limited number of ERDA sites, the system is designed with sufficient flexibility to permit expanding the service to a large number of sites. Success in ARAC application should provide nuclear facilities with a means to handle better the urgent questions concerning the potential accidental hazards from atmospheric releases in addition to providing the sites with a capability to assess the effort of their normal operations.

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