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ARAC: A CENTRALIZED COMPUTER ASSISTED EMERGENCY PLANNING, RESPONSE, AND ASSESSMENT SYSTEM FOR ATMOSPHERIC RELEASES OF TOXIC MATERIAL

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ARAC: A CENTRALIZED COMPUTER ASSISTED EMERGENCY PLANNING, RESPONSE, AND ASSESSMENT SYSTEM FOR ATMOSPHERIC RELEASES OF TOXIC MATERIAL

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ABSTRACT The Atmospheric Release Advisory Capability (ARAC) is an emergency planning, response, and assessment service, developed by the U. S. Departments of Energy and Defense, and focused, thus far, on atmospheric releases of nuclear material. For the past 14 years ARAC has responded to over 150 accidents, potential accidents, and major exercises. The most notable accident responses are the COSMOS 954 reentry, the Three Mile Island (TMI-2) accident and subsequent purge of ^{85}Kr from the containment vessel, the recent UF_6 accident at the Kerr-McGee Plant, Gore, Oklahoma, and the Chernobyl nuclear reactor accident in the Soviet Union. Based on experience in the area of emergency response, developed during the past 14 years, this paper describes the cost effectiveness and other advantages of a centralized emergency planning, response, and assessment service for atmospheric releases of nuclear material.

I. INTRODUCTION

The Atmospheric Release Advisory Capability (ARAC), (Dickerson et al., 1985) has developed over the past 14 years from merely a concept in 1972 to its present role as a federal emergency planning, response, and assessment resource. From the beginning, ARAC was designed to be a centralized resource of a highly trained and specialized staff devoted to all aspects of emergency response, and to reduce duplication of capabilities, software development, and maintenance. This concept was not intended to replace local functions or responsibilities; in fact, it was designed to compliment and enhance local emergency response capabilities of individual nuclear facilities.

During the development and implementation of ARAC, the Department of Energy (DOE) and Department of Defense (DOD) have been major supporters and users of the service. Presently there are approximately 50 DOE and DOD facilities connected directly to ARAC, each having on-line databases for terrain, geography, and meteorological measurement locations pertinent to their own facility. In addition to these facilities, ARAC supports the DOE response to any nuclear event capable of releasing radionuclides into the atmosphere, the Nuclear Regularatory Commission (NRC) response to nuclear power plant accidents, the Federal Aviation Administration (FAA) response to incidents in which aircraft might intercept radioactive material, and the Environmental Protection Agency (EPA) response to incidents in which radioactive material has left or might leave facility boundaries.

Advantages of a centralized emergency planning, response, and assessment system are that it:

- Avoids duplication of resources, and provides a state-of-the-art, proven response capability;
- Provides experienced staff devoted to emergency preparedness, response, and assessment;
- Is cost effective when applied to a large number of nuclear facilities and integrated into the federal emergency preparedness programs;
- Provides a standard (or criterion) for emergency response assessments while maintaining flexibility to meet site-specific and agency requirements;
- Focuses research and development on timely improvement and evaluation of emergency response resources; and
- Applies integrated research and development resources to specialized emergency response requirements in real-time, e.g., Cosmos 954, TMI, Gore, (Oklahoma), and Chernobyl events.

On the other hand, the disadvantages of a centralized system are that it:

- Is cost effective only when applied to a broad base of nuclear facility and federal agency requirements;

- *Can be viewed by local authorities as a "threat"* to their capabilities and responsibilities; and
- Can be viewed by local authorities as a mechanism for reducing or eliminating their responsibilities.

During the development and implementation phases of ARAC, a balance between the advantages and disadvantages of a centralized system has emerged. As stated earlier, ARAC now serves as a national emergency response resource for several federal agencies. It has developed an extensive background in emergency response by responding to over 150 accidents, potential accidents, and major exercises. The most notable ARAC responses are:

- Savannah River Plant (SRP) Tritium Release, 1974
- Train accident involving UF_6, 1976
- Chinese 200 kt and 4 mt atmospheric tests, 1978
- COSMOS 954 *reentry*, 1978
- TMI Nuclear Power Plant accident, 1979
- Titan II accident, 1980[a]
- SRP H_2S leak and transfer, 1981[a]
- Ginna Nuclear Power Plant accident, 1982
- Gore, Oklahoma, UF_6 accident, 1986[a]
- Chernobyl USSR Nuclear Power Plant accident, 1986

The remainder of this paper will discuss the role research and development has played in responding to accidents, both in real-time and in the model evaluation area—two significant attributes of a research and development group co-located with an operational emergency response center.

II. RESEARCH CONTRIBUTIONS TO REAL-TIME EMERGENCY RESPONSES

The various roles ARAC played during and after the TMI accident response provide an excellent basis for describing how the system is used, and the value of closely associated research and development. The five basic roles ARAC filled during and after the accident are that it:

- Provided guidance on deployment of radiological measurement systems;
- Helped interpret surface and airborne radiological measurements,
- Estimated the ^{133}Xe source term;
- Provided guidance to the FAA for air traffic safety in and out of the Harrisburg airport; and
- Estimated total population dose for the President's Commission on TMI.

A few of these roles, such as advising the measurement teams and the FAA, were relatively straightforward. Estimating the source term and modifying the MATHEW/ADPIC (Sherman, 1978; Lange, 1978a) models to estimate "man-rem" for the President's Commission required model modifications and interpretations of data by the research staff. To estimate the source term required a knowledge of both the response *function of the instruments used in the aircraft to measure* the ^{133}X, and of the characteristics of the ADPIC transport and diffusion estimates, which use particles to simulate radioactivity. This coupling of information led to estimates of the source term that were made available during the first four days of the accident. Later a comparison of the model calculated source term with a source term estimate provided by the President's Commission showed agreement within a factor of two to three.

During the ARAC response to the Soviet Cosmos 954 satellite reentry into Canada, the ARAC research team was able to modify a nuclear weapons fallout model (KDFOC2) (Serduke, 1978) so that it could be used to simulate the depositional "footprint" of radioactive particles generated with varying densities at altitudes between 20 and 60 km. These "footprint' simulations, together with the ground measurements, were used to define and to limit the search areas to manageable sizes. For this event, ARAC also provided guidance on the appropriate time and positioning for launching a balloon-borne measurement system into the stratosphere to observe the amount of fine particulate material (i.e., the material that remained for months in the stratospheric circulation regime). This guidance served to eliminate costly and prematurely arranged balloon flights when the regularly scheduled future flights would provide the required concentration measurements.

For the UF_6 release at the Gore, Oklahoma facility of Kerr McGee, the ARAC research team worked with LLNL chemists, Oak Ridge National Laboratory, and the Atmospheric Turbulence Diffusion Division (NOAA) scientists to define the chemical and physical characteristics of the source term and the dispersion processes. These input data were used to define and parameterize the amount of HF and UO_2F_2 released in the process, the cloud rise due to exothermic reactions, and the particle size attributed to the UO_2F_2. Without this research support, the ARAC response to this accident would not have been as timely and useful as it was to the NRC on-site assessment team.

The Chernobyl accident, because of its magnitude and limited information, has provided the largest challenge to date for the ARAC research and development team. The team was "called on" to (1) expand the MATHEW/ADPIC grid from a horizonal size of 200 × 200 km to 1920 × 1920 km, (2) estimate the vertical extent, time history, and magnitude of the source, and (3) retrieve a global particle-in-cell model (PATRIC), (Lange, 1978b) which was originally developed for estimating transport and diffusion in the stratosphere, from 6 years of storage and modify the model to simulate the upper level (tropospheric) release created by the initial explosion and fire at Chernobyl.

The first part of the MATHEW/ADPIC calculation covered a 200 × 200 km region centered on the Chernobyl reactor site (Figure 1a); it became apparent that this calculation was insufficient to answer the questions arising from the spread of radioactivity across the Soviet boundaries into the rest of Europe. Thus, the first

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[a] Toxic Chemical Releases

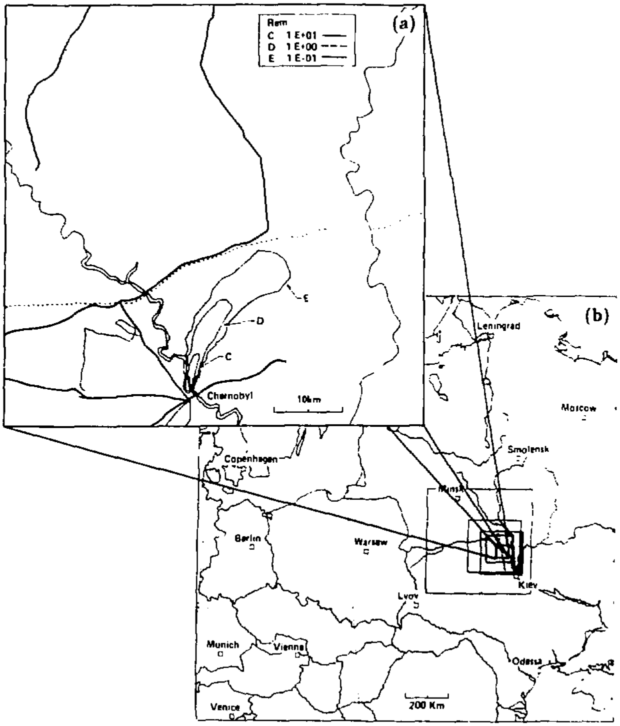

Figure 1. The calculational grids used for the MATHEW/ADPIC models: a) the calculated infant thyroid dose due to ^{131}I inhalation for a six-hour period on 29 April shown on a 60 km expanded subregion of the 200 km grid; b) the final 1920 × 1920 km grid (48 km cells) with the nested subgrids (3 km, 6 km, 12 km, and 24 km cells) outlined and the initial grid (200 × 200 km) shaded.

MATHEW/ADPIC modeling effort was terminated, as part of our ARAC response, and a second, larger-scale simulation was initiated, covering the largest area possible within the limitations of the model and available computer resources.

The MATHEW/ADPIC grid chosen was 1920 km on a side, and extended 2100 m vertically. The horizontal grid mesh was 48 km and the vertical grid spacing was 150 m. This particular grid size was chosen because it represented the largest grid that could be used for the MATHEW/ADPIC models without a major revision of the computer codes. In addition, this grid allowed for coverage of a reasonably sized area of interest for the initial dose and deposition calculations. In Figure 1b, a nested sampling grid is shown around the source (Chernobyl) for horizontal cell sizes of 3 km, 6 km, 12 km, and 24 km, respectively. These nested grids were used to sample the particles that produced surface air concentration and ground deposition estimates near the reactor site.

The source term for the reactor accident was divided into two parts, a lower and an upper cloud. The lower cloud was assumed to be produced over a period of six days as a result of heat from the burning reactor. The upper cloud was assumed to be produced by one or more of the following: explosions followed by a hot fire for several hours, convective activity near the Chernobyl reactor site associated with thunderstorms, or lifting over a warm front located between Chernobyl and the Baltic Sea. One major part of the ARAC effort during the first two weeks following the accident was associated with the determination of a lower level source term and the associated consequences.

Employing both the grid shown in Figure 1b and the initial source estimate derived from the environmental

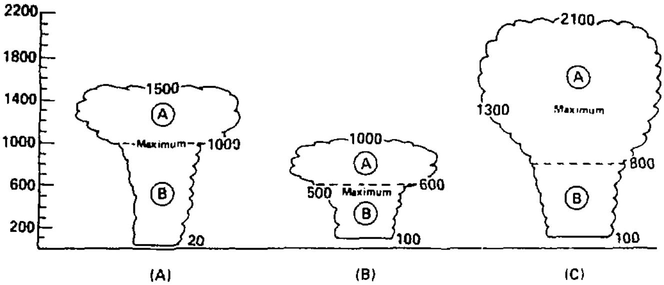

Figure 2. Depictions of the vertical distribution of source material (explosion and fire cloud): a) average distribution as used in the ADPIC calculations; b) the night and c) day, respectively, vertical distributions calculated with a non-hydrostatic cloud model.

measurements of ^{137}Cs and ^{131}I in Scandinavia and Europe, the MATHEW/ADPIC model was used to refine initial estimates of the low level source term for the first six days of the accident. Providing a reasonable description of this source term required a vertical distribution of the radioactivity, as well as a time dependence of the release.

Figure 2a shows the vertical distribution of material used to define the lower level source term in the MATHEW/ADPIC calculations. This estimate was based on prior experience simulating heated plumes within air masses—air masses which contained vertical temperature distributions similar to those shown by vertical atmospheric soundings near Chernobyl. Eighty per cent (80%) of the released material was assumed to reside between 1000 m and 1500 m, with the remaining 20% located between the surface and 1000 m. The maximum concentration was at 1000 m.

Toward the end of the two-week period immediately following the accident, the vertical distribution of the low level source term was quantitatively estimated by a two-dimensional, high resolution, non-hydrostatic cloud model. This model was originally developed to simulate thunderstorms but, more recently, has been applied to simulate plumes of smoke induced by large-scale urban fires. The estimated source strength for the model calculations was 62 megawatts, about the resident heat energy expected from the shut-down of a 3200 mw thermal reactor. Figures 2b and 2c show the vertical distribution of material, calculated by this model, for both nighttime and daytime atmospheric soundings taken near the Chernobyl reactor site near the time of the accident. During the nighttime (Figure 2b), the model estimated that 80% of the material was contained between 600 m and 1000 m. The remaining 20% of the material was located between 100 m and 600 m with the maximum concentration located at 500 m. For the daytime (Figure 2c), 80% of the material was determined to be between 800 m and 2100 m, with the remaining 20% between 100 m and 800 m. The maximum value for this case was at 1300 m. Differences between dose and deposition estimates, based on the distribution of material in the original source term estimate (Figure 2a) and the non-hydrostatic model estimate (Figures 2b, 2c), would not be large, particularly at distances of several hundred kilometers and beyond. For this reason, the dose and deposition estimates were not recalculated using the quantitatively-modeled vertical distributions of material (Figure 2).

From the PATRIC hemispheric scale model calculations, it rapidly became apparent that some radioactive material was convected or lofted (or both) to much higher altitudes than that assumed for the MATHEW/ADPIC calculations (described above). A series of calculations with material placed at 2500, 4200, and 5500 m failed to transport contamination to Japan and North America even close to the recorded arrival times—if at all. While limitations of the model reduce some of the precision desired, it presently appears that at least some material had to be injected to altitudes above 5500 m in order to account for airborne air concentration and surface rainwater and milk measurements of the radioactivity in Japan and the USA. Original estimates of dose and deposition from ^{131}I and ^{137}Cs, made during the first 3 weeks of the accident, for eastern and western Europe using the MATHEW/ADPIC model and global estimates of dispersion with the PATRIC model, are reported by Dickerson and Sullivan, 1986. Further refinements of these estimates have recently been reported by Gudiksen and Lange, 1986.

III. MODEL EVALUATION STUDIES

One of the most significant continuing research and development efforts has been in the area of model evaluation and improvement. Over the past several years, better diffusion parameterizations utilizing space varying surface roughness heights, and the use of multiple vertical wind profiles and nested grids for better con-

EXPERIMENT	TERRAIN	METEOROLOGY STABILITY	 WINDSPEED (m/s)	TRACER MEASUREMENTS (km)
INEL 1971	ROLLING	C	2-6	7-80
SRP 1974	ROLLING	F-C	1-4	3-30
TMI 1980	ROLLING	F-C	1-4	40-60
ASCOT 1980	COMPLEX	F-E	0-4	1-8
ASCOT 1981	COMPLEX	F-E	0-4	1-10
EPRI 1981	FLAT	F-A	1-5	1-50
SRP MATS 1983	ROLLING	D-B	1-8	~ 20
MONTALTO 1983	COASTAL	C-B	1-6	1-6

Table 1. Summary of MATHEW/ADPIC Model Evaluation Studies

centration estimates near the source point have contributed to improving the MATHEW/ADPIC models. Many of these improvements were designed and implemented as a result of model evaluation studies which were done to define the expected accuracy of the models under various terrain and meteorological situations. Table 1 lists the evaluation studies conducted with the MATHEW/ADPIC models during the past 12 years. Contained in these studies are 26 individual experiments conducted in 6 different geographical areas. They represent approximately 3000 tracer measurements spanning a wide variety of diffusion categories. (Dickerson and Lange, 1986) The experiments shown in Table 1 utilized a multitude of tracers, including routine emissions of ^{41}Ar from the SRP nuclear reactors, the controlled venting of ^{85}Kr from the TMI containment, ^{131}I releases at the Idaho National Engineering Laboratory (INEL), sulfur hexafluoride releases from the SRP, the Montalto, and Kincaid power plant sites, and perfluorocarbon and heavy methane releases that were part of the ASCOT experiments. The releases occurred from the 62 m stacks at the SRP and TMI, and from the 187 m stack at the Kincaid power plant. The remaining releases generally occurred near the surface, except for one heavy methane tracer that was released at 60 m during the 1980 ASCOT experiments, and one perfluorocarbon tracer released in a cooling tower plume during the 1981 ASCOT experiments. The duration of the releases varied from 15 minutes to several hours. Extensive surface sampling networks were employed in each series of experiments. Maximum distances were 80 km for the 1971 INEL studies, 50-60 km for the EPRI and TMI studies, 30 km for the MATS experiments, 10 km for the ASCOT experiments, and approximately 6 km for the studies at Montalto, Italy. The experiments were supported by a variety of surface and upper air meteorological observations; data was provided by measurements ranging from normal meteorological coverage provided by the National Weather Service (NWS), to a local site tower and an extra upper air sounding during the TMI purge of ^{85}Kr. Data were supplied by a wide spectrum of measurement systems, including acoustic sounders, tethersondes, rawinsondes, optical anemometers, and towers that were an integral part of the ASCOT experiments.

It is difficult to devise a statistical process that adequately describes a model's performance when compared to tracer field data, particularly when the field data span a broad spectrum of release and sampling times, sampling distances, terrain, and meteorology. For example, the standard correlation coefficient is used sometimes; however, one point at the high end of the scale can influence the entire data set. Early on, a rigid technique, but one considered a standard, was chosen for comparisons of tracer measurements to the MATHEW/APDPIC model calculations. A factor R is computed for each pair of measurements (C_m) and model calculations (C_c) which represents the whole - number ratio between the two. For each experiment the percent of comparisons within a factor R are plotted as a function of R. The definition of R is R = $(C_m + B)/(C_c + B)$, except if (R < 1,) then R = $(C_c + B)/(C_m + B)$, and B is background.

Figure 3, based on the factor R, depicts a summary of the performance of the MATHEW/APIC models to date. The *best* simulation of the experimental data is given by the upper curve, which is associated with rolling terrain and near-surface tracer releases. The most *difficult* simulation is associated with complex terrain and elevated releases. Other situations provide results that are intermediate to these curves. Hence, the best results indicate that the calculated concentrations are within a factor of 2 for 50% of the measured concentrations and within a factor of 5 for 75% of the comparisons. This performance degrades to 20% and 35% for factors for 2 and 5, respectively, for the comparisons associated with elevated releases in complex terrain. This degradation of results in complex terrain is due to a variety of factors, such as the limited representativeness of measurements in complex terrain, the limited spatial resolution afforded by the models, and the turbulence parameterizations used to derive the eddy diffusivities.

IV. FUTURE RESEARCH OPPORTUNITIES

The most significant improvement in emergency response can be attained by the development and implementation of an operational mesoscale (out to 200 km) time-dependent forecast model. Technology is available today to develop a model that can be applied to a range

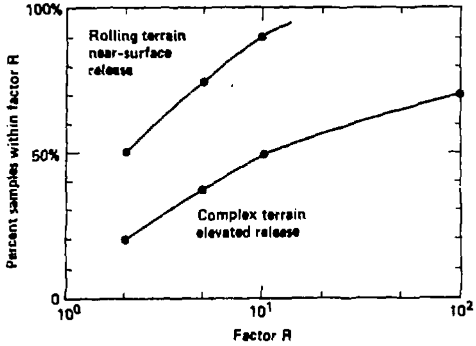

Figure 3. Percent of computed air concentrations within a factor R of measured values. The figure provides a measure of the spectrum of model evaluation results that span from near-surface tracer releases in rolling terrain to elevated releases in complex terrain.

of forecast problems and consequently would be useful (but not all inclusive) for emergency response purposes. This is definitely a high pay-off, low risk area of research and development. Chernobyl has shown the value of having the capability of simulating rainout in the transport and diffusion models. The state-of-the-science in this area has advanced to the point where rainout is technically feasible to implement, although additional research would be required to improve the simulations and make them more realistic. A logistical problem remains which involves obtaining spacially varying rainrate data, and providing a mechanism for including these data directly into the transport-diffusion models.

ARAC does provide a foundation for addressing toxic chemical response as a centralized system; however, many more technical unknowns are involved in dealing with toxic chemicals as opposed to radioactive material. Also the frequency of accidents and the number of chemicals are considerably greater and the health effects are known to a lesser degree than for nuclear material. In general, toxic chemical releases can be divided into four classes based on their physical and chemical reactivity and their density with respect to density of the ambient air. These 4 classes are: non-reactive chemical/ambient air density, non-reactive chemical/heavier-than-air density, reactive chemical/ambient air density, and reactive chemical/heavier-than-air density. Given a toxic chemical release where the chemical is non-reactive and whose density is approximately that of ambient air, the MATHEW/ADPIC models would be expected to perform as well as they do for nuclear material. If the released material is non-reactive and heavier-than-air, models are available to estimate consequences; however, considerable effort would be required to place them in an operational environment. (Gudiksen et al., 1986)

Chemically toxic releases that are both chemically and physically reactive at the source point and during the dispersion processes, would require a large research effort before the environmental consequences can be modeled with confidence. A joint research and development and implementation effort is required before ARAC or any other centralized or local emergency response system can be expected to address a range of accidental releases of toxic chemicals with any degree of confidence.

V. ACKNOWLEDGEMENT

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