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THE CURRENT STATUS OF ARAC AND ITS APPLICATION TO THE CHERNOBYL EVENT

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Abstract

The Atmospheric Release Advisory Capability (ARAC) project, developed by the Lawrence Livermore National Laboratory (LLNL), provides real-time dose assessments and estimates of the extent of surface contamination that may result from an atmospheric release of radioactivity. It utilizes advanced computer-based data communication and processing systems to acquire the meteorological and source term information needed by the three-dimensional atmospheric dispersion models to derive the consequence assessments.

The ARAC responded to the recent Chernobyl reactor accident in the Soviet Union by estimating the source term and the radiation dose distribution due to exposure to the radioactive cloud over Europe and the Northern Hemisphere. This analysis revealed that approximately 50% of the estimated core inventories of I-131 and Cs-137 were released. The estimated committed effective dose equivalent due to inhalation of radioactivity during cloud passage is of the order of 10 mrem within parts of Scandinavia and eastern Europe, while most of the populations within central Europe were exposed to levels ranging from 1-10 mrem. The amount of Cs-137 released by the Chernobyl accident far exceeds that released by previous reactor accidents, but is only about 6% of the Cs-137 produced by the atmospheric weapon testing programs.

Introduction

The Atmospheric Release Advisory Capability (ARAC) project is a Department of Energy (DOE) sponsored emergency response service[1] available for use by both federal and state agencies in case of a potential or actual atmospheric release of nuclear material. The project was initiated in 1972 when the DOE's predecessor, the Atomic Energy Commission (AEC), realized that the response to nuclear accidents could be improved substantially by developing a centralized capability for estimation of the dispersion of radioactivity released into the atmosphere. The initial objective of the ARAC project was to provide real-time predictions of dose levels and extent of surface contamination resulting from the release of radionuclides from AEC facilities. This objective has since been expanded to include support to the DOE and the Department of Defense (DOD) by assessing the consequences of potential or actual releases of radionuclides resulting from a wide spectrum of accidents such as nuclear extortion threats, nuclear weapons accidents, nuclear power plant accidents, transportation accidents, and re-entry of nuclear powered satellites into the atmosphere. During the past decade the ARAC has responded to over 100 real-time situations, including exercises. The most notable responses include the Three Mile Island (TMI) accident and the subsequent venting of the Kr-85 from the containment, the Titan II missile accident in Arkansas, the re-entry of COSMOS-954 into the atmosphere, the Sequoyah Facility accident in Oklahoma, and most recently the Chernobyl reactor accident in the Soviet Union.

The ARAC presently supports the emergency preparedness plans at 50 DOD and DOE sites within the U. S., and also responds to events at "non-fixed" sites. The ARAC Center, located at the Lawrence Livermore National Laboratory, serves as the focal point for data acquisition, data analysis, and assessment activities during a response. The center utilizes a computer-based communications network for acquiring real-time meteorological data from the site and the surrounding region, as well as pertinent accident information for input to the MATHEW[2]/ADPIC[3] three-dimensional numerical atmospheric dispersion models that are used for the accident assessment. This paper provides an overview of the ARAC system and its utilization during the Chernobyl accident for deriving the source term and the global transport of the released radioactivity. Also included is a comparison of the radioactivity released by the Chernobyl event with the activity releases associated with the atmospheric nuclear weapons testing programs, as well as the Windscale and TMI nuclear reactor accidents.

The ARAC System

The core of the ARAC system is the ARAC Emergency Response Operating System (AEROS)[4] which is situated at LLNL. It was designed to provide a centralized emergency response service capable of responding to accidents at numerous potential accident sites. Specifically, the AEROS presently has the capability to:

- Perform impact assessments, using three-dimensional atmospheric dispersion models, which include the effects of complex meteorology and terrain.
- Support the emergency preparedness plans at approximately 100 nuclear facilities (on-line sites).
- Respond with timely impact assessments for accidents occurring at other than on-line sites.
- Produce initial assessments within one hour of notification for on-line sites during normal working hours. Planned expansion will reduce this to approximately 15 minutes.
- Produce high quality graphical displays of the assessments in the form of isopleths overlaid on a base map.
- Provide a simple user interface for information entry and system operation.

To ensure high reliability, ease of maintenance, and ready adaptability to improvements, AEROS was developed by using modern structured programming techniques and incorporates numerous back-up features. It also incorporates many automated features, related to meteorological data acquisition and processing functions as well as model calculations, to enable the operations staff to derive timely and high quality assessments.

The AEROS hardware configuration and its functions are shown in Figures 1 and 2. In the event of an accident at one of the on-line sites, the site emergency response personnel interact with the ARAC center by means of a small desk-top computer which is linked to the AEROS by means of a dial-up telephone line into one of three communications processors.

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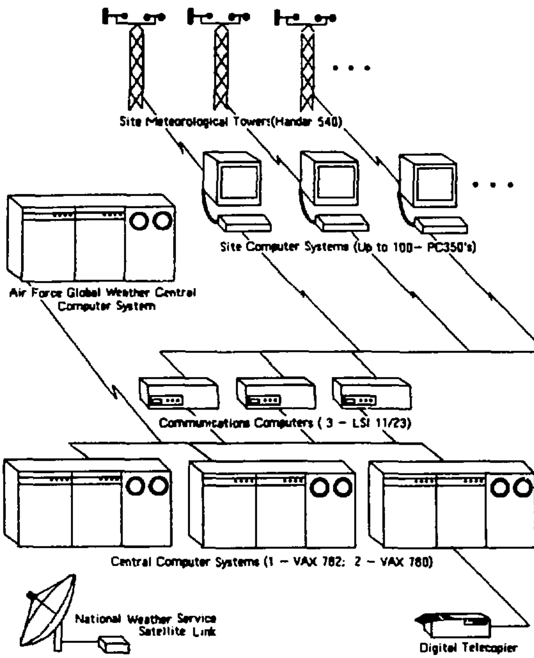

Fig. 1 A schematic diagram of the ARAC hardware system.

The site user fills out a problem questionnaire by entering pertinent accident information, such as time, location, description, and meteorological data from on-site towers, into the site computer. At some sites the computer is linked directly with the on-site meteorological tower. This information, when transmitted to the ARAC center, alerts the ARAC staff by initiating a page alarm. Additional meteorological data from the region surrounding the accident site is acquired from the U. S. Air Force Global Weather Central (AFGWC) over dedicated high speed communication lines (9600 BAUD) that are connected directly to the AEROS Digital Equipment Corporation (DEC) computers. To facilitate the preparation of input values for the dispersion models, default model parameter data bases for the on-line sites are resident on associated disk storage units. In addition, pre-prepared topographic and geographic data bases may be extracted rapidly for the on-line sites. Final preparation of these input files permits the operations staff to execute the dispersion models in order to calculate the time-dependent spatial distribution of radioactivity over the terrain. Time integration of these distributions, in conjunction with the dose conversion data base, leads to the estimation of the dose to the affected population centers and the resulting surface deposition. Graphical presentations overlaid on site maps may be transmitted and displayed on the site computer or transmitted to a digital telecopier. For accidents that occur at other than on-line sites, the process is similar, with the exception of the lack of a site computer; furthermore, the response will be slower due to the lack of the pre-prepared data bases.

The AEROS hardware includes a DEC-based VAX CLUSTER composed of a VAX 11/782 (8 Mb), a VAX 11/780 (16 Mb), and VAX 11/780 (4 Mb), and an HSC50 controlling three RA81 disk drives for 1.36 Gbytes of cluster-based storage. In addition, there are three RP06 disk drives (removable pack at 174 Mb), one RP07 (516 Mb), and one RM03 (67 Mb). The primary operational user interface to the AEROS system is via graphics terminals that include two TEKTRONIX 4125's, two 4208's, two DEC VSV-11's, and one QMS 2400 laser printer. The ARAC communications system consists of three LSI 11/23's, each with eleven dialup modems. The LSI's and local terminal servers are linked to the VAX CLUSTER via an ETHERNET Local Area Network (LAN). The site computer systems are DEC Professional Computer 350's (PC350) with 10 Mb hard disks, color monitors, 512 K memory, the Telephone Management System (TMS), LA50 dot matrix printers, and external DF112 modem if configured with a meteorological tower. One site operates on an upgraded PC380.

All the VAX computers run the VMS operating system; the LSI's run RSX-11S and the PC350/380's run POS. All the application software has been developed on the ARAC project using modern structured software development techniques. The primary language is PASCAL; FORTRAN is used for most of the complex models and some MACRO was required on the LSI's.

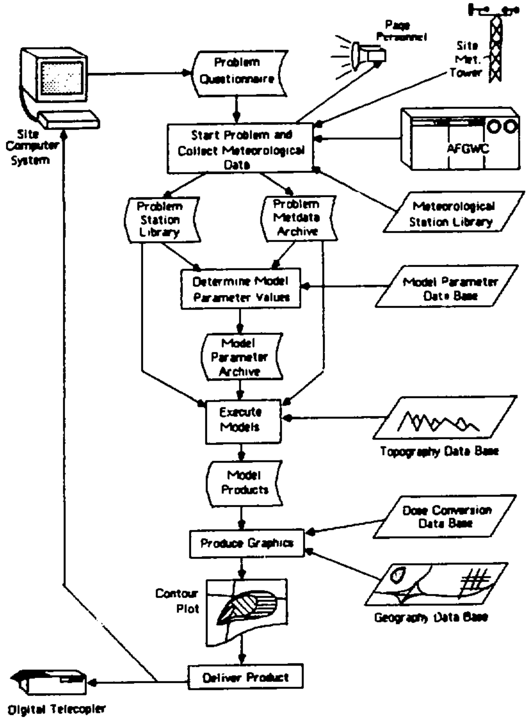

Fig. 2 An outline of the ARAC system functions.

ARAC Response to the Chernobyl Reactor Accident

The ARAC staff was requested by the DOE to assess the radiological impact of the Chernobyl event over the western Soviet Union, Europe, and the U. S. The resources to address an event of such a magnitude within the Soviet Union were not readily available since ARAC is primarily devoted to support domestic accidents on a regional scale of up to about 200 km. Hence, the ARAC staff needed to devote most of its efforts during the first several days to (1) acquiring meteorological data, from the AFGWC, for Europe and the Soviet Union as well as gridded wind fields for the Northern Hemisphere, and (2) expanding the spatial scale of the MATHEW/ADPIC models to approximately 2000 km, and modifying the PATRIC global scale model[5] to estimate the dispersion of radioactivity over the Northern Hemisphere. This allowed the construction of manually prepared air parcel trajectories from the Chernobyl area, which were used in conjunction with the 2BPUFF[6] two-dimensional long-range dispersion model for evaluating the activity as a function of time along the trajectories. By integrating these results with surface and upper air measurements of airborne radioactivity in Scandinavia, it was possible to obtain initial source term estimates of 40 MCi of I-131 and 3 MCi of Cs-137. This represents about 50% of the estimated core inventory of these radionuclides. Based on these release estimates, ARAC calculated the maximum concentration of I-131 in the milk in the U. S. would not exceed 9000 pCi/l, and more probably would not exceed 900 pCi/l. The more probable value included a factor of 10 reduction due to segments of the cloud being transported over Scandinavia and central Europe, and precipitation scavenging enroute to the U. S. In addition, the MATHEW/ADPIC models were used to calculate the time dependent spatial distribution of I-131 and Cs-137 activities over Europe, thus providing estimates of the dose commitment to the European populations from these two radionuclides. The adult thyroid dose due to inhalation of airborne I-131 was estimated to exceed 0.3 rem over an area extending into Sweden, Finland, Poland, and parts of the Soviet Union[7]; the inhalation dose due to Cs-137 was estimated to be about three orders of magnitude lower than that of I-131.

A more comprehensive series of calculations were made over Europe and the Northern Hemisphere, using the PATRIC model, upon the receipt of more detailed radiological data from Europe, Kuwait, Japan, and the U. S. This effort involved scaling of the calculated activity distributions with measurements of airborne radioactivity at about 20 sites in order to acquire a more definitive estimate of the activity released as a function of time and its initial vertical distribution in the atmosphere. The analysis, based on optimum agreement between the calculated and measured air concentrations, suggested that an

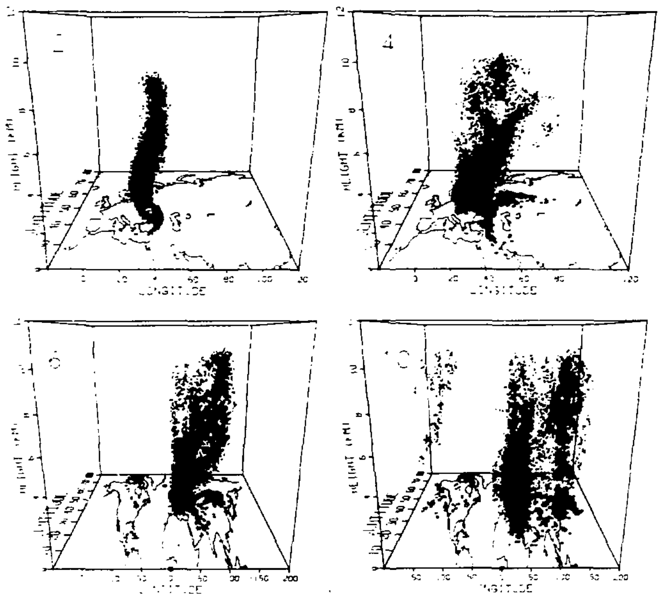

Fig. 3 Calculated spatial distribution of radioactivity 2, 4, 6, and 10 days after the initiation of the Chernobyl reactor accident on 26 April 1986.

upper and a lower level cloud of radioactivity were formed. The upper level cloud, which extended into the middle troposphere, was assumed to be due to the initial explosion, and implies that the major fraction of activity was released during the first day; the lower level cloud was assumed to be produced by the hot fire that continued to cause radioactive emissions during a six day period following the initial explosion. This optimum fit between the calculated and measured air concentrations required the upper level cloud to be centered at 4500 m with a vertical extent from 1500 to 7500 m, and included one-half of the total quantity of activity released; the lower level cloud was centered at 1300 m and extended from the surface to 1500 m. This combination of assumptions results in 65% of the total activity being released during the *first* day and the remaining 35% being emitted during the following five days. The estimated total activities released for a spectrum of fission product nuclides are given in Table 1. Since Xe-133 was not measured, its release rate was estimated by assuming the complete inventory was released. The inventory was based on an ORIGIN2 model[8] calculation, made by the Pacific Northwest Laboratories (PNL), on the basis of a fuel burn-up of 9000 MW-d/T. Note that the activities listed in Table 1 have been decay-corrected to 29 April 1986, three days after the initiation of the accident.

Using the above source term configuration in conjunction with the gridded hemispheric wind fields provided by the AFGWC, the PATRIC model derived the three-dimensional spatial distributions of radioactivity as a function of time, over Europe and the Northern Hemisphere. Detailed analysis of the time-varying spatial distributions indicated that the cloud became segmented during the first day, with the lower section heading toward Scandinavia and the upper part heading in a southeasterly direction with subsequent transport across Asia to Japan, the North Pacific, and the U. S. This is illustrated in the views of the cloud shown in Figure 3. Integrating the PATRIC-generated concentration distributions over the period 26 April to 13 May produced the unmitigated individual inhalation and immersion dose distributions due to exposure to the airborne radioactivity over Europe and the Northern Hemisphere. The spatial distribution for the inhalation pathway is shown in Figure 4a for Europe and in Figure 4b for the Northern Hemisphere. The isopleths represent the committed effective dose equivalent to an adult due to the inhalation of the radionuclides listed in Table 1. The dose distribution over Europe shows a region exceeding 10 mrem extending over the western USSR, northeastern Poland, and up into Sweden, while extending southward over the Ukraine and parts of eastern Europe. Most of central Europe, parts of northern Scandinavia, and the remainder of eastern Europe are situated between the 1 mrem and 10 mrem isopleths. Denmark, the United Kingdom, Spain, and northern Scandinavia received less than 1 mrem. About 80% of these values are due to the radioiodines, while the cesium, ruthenium, and tellurium radionuclides are the major contributors to the remaining 20%.

Because the spatial distributions for immersion in the radioactive cloud are essentially identical to those shown in Figure 4, one may obtain the corresponding effective dose equivalent by multiplying the isopleths in Figure 4 by 0.02. This factor, however, is spatially dependent within a factor of about two due to the time varying activity ratios of the radioiodines.

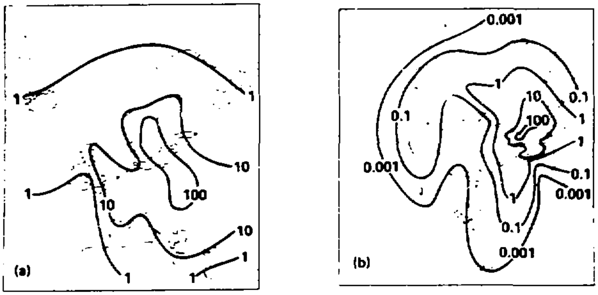

Fig. 4 The committed effective dose equivalent due to inhalation (10^{-4} rem) over (a) Europe and (b) the Northern Hemisphere.

Because the spatial distributions for immersion in the radioactive cloud are essentially identical to those shown in Figure 4, one may obtain the corresponding effective dose equivalent by multiplying the isopleths in Figure 4 by 0.02. This factor, however, is spatially dependent within a factor of about two due to the time varying activity ratios of the radioiodines. Because of the large spatial averaging inherent in these calculations, the radiation doses are greatly underestimated in the vicinity of the Chernobyl area. A more detailed assessment, based on an ADPIC calculation over a 400 km domain centered on the reactor site, revealed inhalation doses exceeding 3 rem within the first 10 km of the reactor.

Comparison of Chernobyl with Other Nuclear Events

In order to place the radioactivity released from the Chernobyl reactor in perspective with radioactivity releases corresponding to previous nuclear events, it is useful to compare the Chernobyl release with the radioactivity estimated to have been produced by the U. S. and the Soviet Union's atmospheric nuclear weapons testing programs, as well as with the releases associated with the TMI and the Windscale reactor accidents. However, the reader should be aware that a complete comparison of the radiological impact of the atmospheric weapon testing programs with the impact produced by the Chernobyl reactor accident is very difficult. This is partly due to the fact that weapon tests produce mixtures of radionuclides that are relatively more abundant in short lived radionuclides, with half-lives of less than a few days, in comparison with the mixture of radionuclides that may be found in the core of a reactor having been operated over periods ranging from months to years. In addition, the weapon tests injected a large fraction of the radioactivity into the stratosphere with the result that the activity was dispersed globally and did not reach the earth's surface for a year or more—allowing considerable time for radioactive decay. Furthermore, the weapon tests were conducted at several isolated test sites where, with only a few exceptions, no one was exposed to the immediate effects of the tests. This is in contrast to the Chernobyl event, which released principally noble gases and volatile radionuclides that were relatively more

Table 1. Estimated activity released by the Chernobyl reactor accident (decay — corrected to 29 April, 3 days after event initiation).

Nuclide	Activity Released (MCi)
Cs-137	2.4
Cs-136	0.47
Cs-134	1.3
I-131	36.0
I-133	9.1
Ce-141	0.23
Ce-144	0.14
Ba-140	1.0
La-140	1.0
Zr-95	0.23
Nb-95	0.23
Te-132	3.3
Ru-103	0.76
Ru-106	0.16
Xe-133	120.0

Table 2. Estimated activity released by atmospheric weapons tests, and the Windscale and TMI reactor accidents. Except for TMI, the activities have been decay-corrected to 3 days after the events.

	Activity Released (MCi)		
Nuclide	Weapon Tests	Windscale	TMI
Cs-137	40	0.0012	ND*
Cs-136	150	0.000041	ND
Cs-134	< 0.04	0.000032	ND
I-131	21000.0	0.016	0.00002
I-133	49000.0	0.0044	ND
Ce-141	12000.0	0.00019	ND
Ce-144	1300.0	0.00011	ND
Ba-140	28000.0	0.000017	ND
La-140	28000.0	0.000017	ND
Zr-95	6900.0	0.00020	ND
Nb-95	6900.0	0.00020	ND
Te-132	52000.0	0.016	ND
Ru-103	5600.0	0.0011	ND
Ru-106	85.0	0.0016	ND
Xe-133	56000.0	0.37	10

*Not detected

abundant in the long lived species such as Cs-137. The accident exposed operating personnel and emergency workers to radiation doses causing fatal injuries and acute radiation sickness, as well as exposing adjacent population centers to dose levels requiring evacuation. Nevertheless, it is still useful to compare the data in Table 2, which shows on a specific radionuclide basis the amount of activity released by the weapon tests as well as by the Windscale and the TMI reactor accidents. The Windscale reactor accident occurred in 1957 within the U. K. Except for TMI, the release estimates have been decay-corrected to three days after the events for ease of comparison. A comparison of the data given in Tables 1 and 2 clearly shows that the activity released by the Chernobyl accident is minor relative to the weapon test releases, which are based on 225 Mt of fission. The 2.4 MCi of Cs-137 released by the Chernobyl event is only 3% of the Cs-137 produced by the weapon tests, while all of the remaining radionuclide releases in Table 2 represent less than 1%, and in some instances considerably *less* than 1%, of the corresponding weapon test releases.

It is also of interest to reflect on a comparison between the Cs-137 surface deposition levels produced by the Chernobyl accident and the weapon test series. The Cs-137 deposition due to global fallout is approximately 100 mCi/km^2 within the middle latitude region of the Northern Hemisphere.[9] The deposition, however, does vary considerably due primarily to varying rainfall. Likewise, the Cs-137 deposition pattern resulting from the Chernobyl accident varies as a function of distance from the reactor and the occurrence of precipitation scavenging. According to informal data reports prepared by various individual scientific organizations, the highest deposition measurements reported within the Scandinavian countries ranged between 200 and 900 mCi/km^2, about 500 mCi/km^2 within West Germany, and approximately 100 mCi/km^2 in southeastern France. In contrast, about 2 mCi/km^2 of Cs-137 was deposited over the Tokyo area, and a range of 0.3 to 8 mCi/km^2 was measured within the U. S. as a result of the Chernobyl accident. The comparison of the Chernobyl releases with those associated with the Windscale and the TMI reactor accidents, shown in Table 2, clearly indicate that the Chernobyl release was greater by at least several orders of magnitude.

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