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SUMMARY OF MATHEW/ADPIC MODEL EVALUATION STUDIES

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ABSTRACT

This report summarizes model evaluation studies conducted for the MATHEW/ADPIC transport and diffusion models during the past ten years. These models support the U.S. Department of Energy Atmospheric Release Advisory Capability, an emergency response service for atmospheric releases of nuclear material. Field campaigns involving tracer releases used in these studies cover a broad range of meteorology, terrain and tracer release heights, the three most important aspects of estimating air concentration values resulting from airborne releases of toxic material. Results of these studies show that these models can estimate air concentration values within a factor of 2, 20% to 50% of the time and a factor of 5, 40% to 80% of the time. As the meteorology and terrain become more complex and the release height of the tracer is increased the accuracy of the model calculations degrades. This band of uncertainty appears to correctly represent the capability of these models at this time.

1. INTRODUCTION

The MATHEW/ADPIC (M/A) models are used as the major operational models for the Atmospheric Release Advisory Capability (ARAC), an emergency response service developed by the Lawrence Livermore National Laboratory (LLNL) for the U.S. Departments of Energy (DOE) and Defense (DOD) [1,2,3]. The ARAC service provides guidance to crisis managers and on-scene commanders that deal with potential or actual atmospheric releases of radioactive material. Assessment products calculated by the M/A models provide the crisis managers and on-scene commanders with estimates of the public health and safety effects of an atmospheric release of toxic material.

In addition to the ARAC service, these models are used now by approximately 10 other countries involved in developing or implementing emergency response services. This broad usage of the models implies an importance for maintaining and expanding statistical data bases on model performance. For the past ten years LLNL has evaluated the models against tracer and meteorological data bases for 6 different geographical locations for a total of 26 field campaigns. These field campaigns encompass rolling and complex terrain areas under a variety of meteorological conditions. Other countries, e.g., Italy and Japan, have also evaluated the models against data from field campaigns. Other data sets are presently being analyzed by LLNL and other users for future model evaluation studies. This paper summarizes the model evaluation studies completed to date and plans for future studies.

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2. FIELD CAMPAIGNS

The wide variety of terrain types, tracer release heights and sampler placements and meteorology represented by these model evaluation studies is discussed below. The specific field campaigns used to evaluate the M/A models are:

INEL 1971 [2]	SRP 1974 [2]	TMI 1980 [3]
ASCOT 1980 [4]	ASCOT 1981 [4]	Montalto 1984 [7]
EPRI 1981 [5]	SRP 1983 [6]	

2.1 Terrain Types

Figure 1 shows a computer generated plot of the terrain at the DOE Savannah River Plant (SRP) site. This figure was generated using 62 m horizonal resolution terrain data [8]. (Similar plots of terrain data resolved on a 500 m resolution grid can be generated in real-time, in color, for any location within the United States and several foreign countries.) This figure shows the rolling terrain features around the SRP site with small channels leading to the Savannah River valley shown in the southwest corner of the figure. During stable atmospheric conditions these channels can effect the lower level transport winds by directing the flow toward the river. Wind instruments located in these valleys sometimes require special interpretations. Topographic relief in the area is approximately 60 m.

Figure 2 shows the rolling terrain around the TMI nuclear power plant site. The Susquehanna River flows along the generally northwest-southeast channel. Hills along the river in the north-south section where the power plant site is located, can influence the boundary layer flow during periods of stable or near-stable flows by diverting northerly flow at the reactor to northeast flow south of the site. Terrain variations near the TMI reactor complex are on the order of 100 m.

The Geysers Geothermal Resource Area of northern California is shown in Figure 3. This area is particularly complex with terrain variations of 800 m. The bowl shaped region (Anderson Springs Valley), descending toward the southeast corner of the figure was used as the study site for the 1980 DOE Atmospheric Studies in Complex Terrain (ASCOT) program experiments [6]. The valley, located just to the west of this area and oriented towards the north, was used for a series of ASCOT experiments conducted in 1981 [6]. Figure 4 shows the Brush Creek area of western Colorado, the location of the 1984 ASCOT campaigns. This area is extremely complex with terrain variations from the valley floor to the mesa top on the order of the 1000 m. Data from these campaigns will be used in the near future to further evaluate the M/A models. The remaining experimental sites (not shown) were relatively flat with no significant terrain features near the tracer release points or tracer sampler locations. Experiments at the Montalto nuclear power plant site were conducted on a coastal plain, 100 km northwest of Rome, Italy [7].

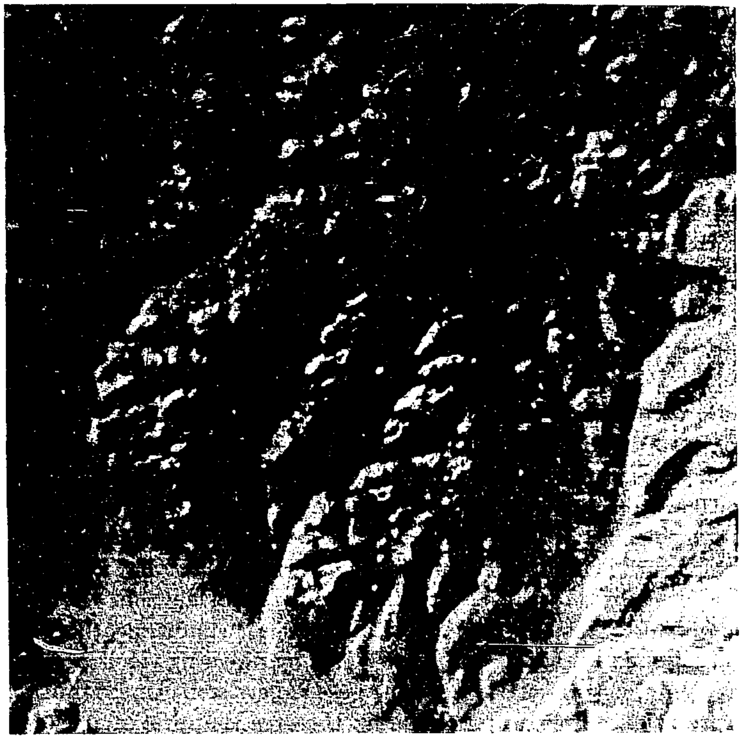

FIGURE 1. Computer generated terrain for a 40 × 40 km area centered on the DOE Savannah River Plant, Aiken SC. The Savannah River basin is located in the southwest corner. Terrain variations are about 60 m.

2.2 Tracer Releases

A variety of tracers, release heights and sampling techniques were used for these studies. Air concentration values, produced by tracer releases of opportunity from 60 m stack releases at the SRP operating reactors (SRP 1974) and purge of ^{85}Kr from the TMI containment vessel (TMI 1980), were measured at distances from 2 to 40 km by sodium iodide crystal and high volume sampler techniques. Instrumentation was mounted in automobiles and aircraft as well as fixed sampling locations. These continuous releases had known, variable source terms.

Tracers released during the ASCOT field campaigns were used as part of the overall experimental designs. The majority of the releases were near surfaces (1–5 m). For the 1980 experiment one heavy methane was released at 60 m and one tracer was placed in a cooling tower plume for the 1981 experiments. Most tracer air concentration measurements were made near surface, supported by one or two vertical profiles. Release rates were constant for 1 hour and samplers were placed from 500 m to 10 km from the release points.

FIGURE 2. Same as Figure 1 for the area around TMI, near Harrisburg, PA. The Susquehanna River flows along the channel from northwest to southeast. Terrain variations are about 100 m.

The EPRI study used SF_6 released through a tall stack associated with a coal-fired power plant in flat terrain. Thermal bouyancy, coupled with wind speed and thermal structure of the atmosphere produced a viable plume height stabilization level several hundred meters above the 160 m stack. A dense array of surface air samplers were located up to 40 km downward from the stack.

The Montalto and SRP 1983 MATS regional transport studies were conducted with SF_6 as the tracer. Samplers for the MATS experiments were located in an arc approximately 20 km from the source point. The Montalto experiment sampled in two arcs from 1 to 6 km from the release point. Tracer release heights for these experiments varied from 10 to 60 m. Volume samplers were used to measure 15 min integrated air concentration values. The INEL near surface tracer release of ^{131}I lasted for 3 hours. High volume samplers, located in 4 arcs 7 to 80 km from the release point, measured the average air concentration values over the plume passage time.

FIGURE 3. Computer generated terrain perspective view for the Geyers area, northern California. Terrain variations are on the order of 800 m.

2.3 Meteorological Conditions and Measurements

These model evaluation data bases also represent a wide variety of meteorological conditions and supporting measurement systems. Nighttime stable meteorological conditions are represented by the ASCOT experiments. In the western U.S., where these studies were conducted, the atmosphere is relatively dry, thus allowing the establishment of strong drainage winds due to high surface heat loss through the radiative processes. The EPRI field campaigns were conducted from the morning transition though the daytime unstable regions to the evening transition period. The TMI purge of ^{85}Kr was conducted on a 24 h/day basis for 12 days which covered most stability classes and calm wind conditions. The 14 SRP MATS studies were conducted during daytime hours when the atmospheric stability ranged from B to D with windspeeds ranging from 1–8 m/s.

For the field campaigns associated with atmospheric research studies, meteorological measurements were relatively numerous for both surface and upper air observations. For the TMI purge of ^{85}Kr meteorological measurements were adequate. A recent study, using the Geysers 1980 data set, shows how the M/A model performance degrades as a function of the density of the meteorological input data sets [9]. Although the

FIGURE 4. Same as Figure 3 for Brush Creek, western Colorado. Terrain variations are on the order of 1000 m.

comparisons of measured to calculated air concentration values degrade as the data set is reduced, a greater reduction is shown if the complexity of the model is reduced.

3. RESULTS

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. We have chosen a somewhat rigid technique but one that we consider a standard for comparisons of tracer measurements to the MATHEW/ADPIC model calculations. A factor is computed for each pair of measurements (Cm) and model calculations (Cc) 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.

Figure 5 shows results of model comparisons using data from the TMI, SRP 1974 and the INEL experiments. The model calculations were within a factor 2 for 50% of the comparisons and a factor of 5 for approximately

80%. These field campaigns were in areas of relatively flat terrain and included distances out to 80 km. Sampling times varied from 10 min for the ^{41}Ar measurements using instruments mounted in cars and airplanes to 3 hrs for the INEL study. Results shown in this figure are the best obtained by the models, thus far.

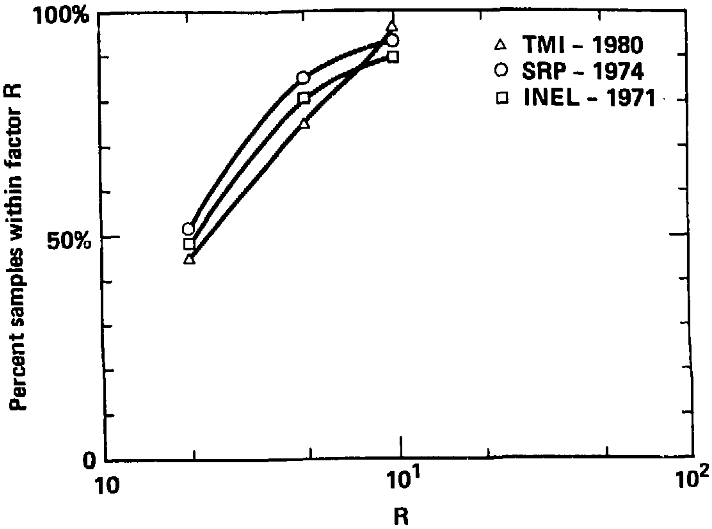

FIGURE 5. Percentage of computed air concentration values within a factor *R* of measured, for the TMI 1980, SRP 1974 and INEL 1981 tracer experiments.

Figure 6 shows results from the SRP 1983 MATS and Montalto studies. In this case we have shown comparisons with no adjustment of the model calculations to those where the model calculations have included a directional change that best matches the measured data. An example of how the unadjusted model calculations compare to measurements is shown in Figure 7. The shape of the two curves are similar, i.e., the diffusion is modeled well; however, the direction in this case is off by 7 degrees. This feature of these comparisons and others we have performed tend to indicate that the calculated concentration patterns are similar to those measured; however they are displaced by an error in either the wind direction measurements and/or the model adjusted wind fields. In any case, for both the Montalto and the SRP 1983 studies an average directional correction of 5° shifted the comparisons from the lower two curves to the upper two curves, resulting in the adjusted curves being similar to those shown in Figure 6.

Comparisons of model calculated air concentrations with the most complex field campaigns are shown in Figure 8. The ASCOT 1980 and 1981 surface releases of tracer material show similiar results; model calculations are within a factor of 2 about 25% and a factor of 5 about 50% of the time. These field studies were conducted in complex terrain (see Figure 3) and under stable nighttime conditions which account for much

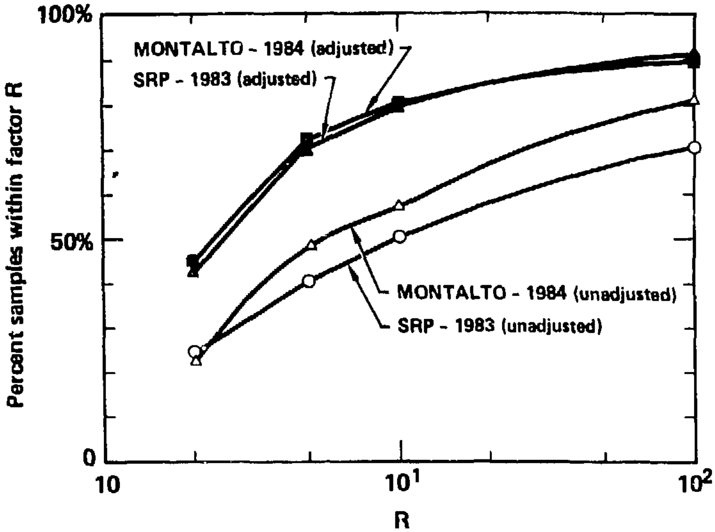

FIGURE 6. Same as Figure 5 for SRP 1983 MATS and Montalto 1984 tracer experiments.

of the degraded performance of the models. The EPRI study, although conducted in flat terrain, was associated with a power plant plume as the tracer release mechanism. For this study complicating factors were the measurement or modeling of the correct plumerise and the meteorology which varied from stable to unstable during the morning transition and through the daytime hours returning to stable during the evening transition [10].

The curves representing the ASCOT 1980 elevated heavy methane and the 1981 cooling tower releases represent complex terrain and elevated releases coupled with stable meteorological conditions [4]. Under these conditions the model results are further degraded by about 10% in the factor of 5 comparisons. Multiple stratification coupled with complex terrain and elevated release heights pose a complex combination of processes that stretch the physical limits of diagonsitic models.

In addition to the studies described above, researchers at the Japan Atomic Energy Research Institute (JAERI) have evaluated models similiar to MATHEW/ADPIC, for over 30 data sets during the past 4 years [12]. The two sites used for these studies were a flat coastal area and a mountain region. Meteorological conditions for the experiments were sea-land breeze for the coastal site and complex mountain winds for the complex site. Tracers for these experiments were released from heights that varied from 7 to 150 m and lasted from 30 to 90 min. Surface samplers were located out to 15 km in the horizontal and up to 300 m in the vertical directions. An array of meteorological measurements were made ranging from anemometers on towers to radiosondes and kitoons. Although reports on these studies have not been published in English (they have plans to do so in the future), qualitatively, graphs of comparisons between tracer measurements and model calculations appear to be similiar

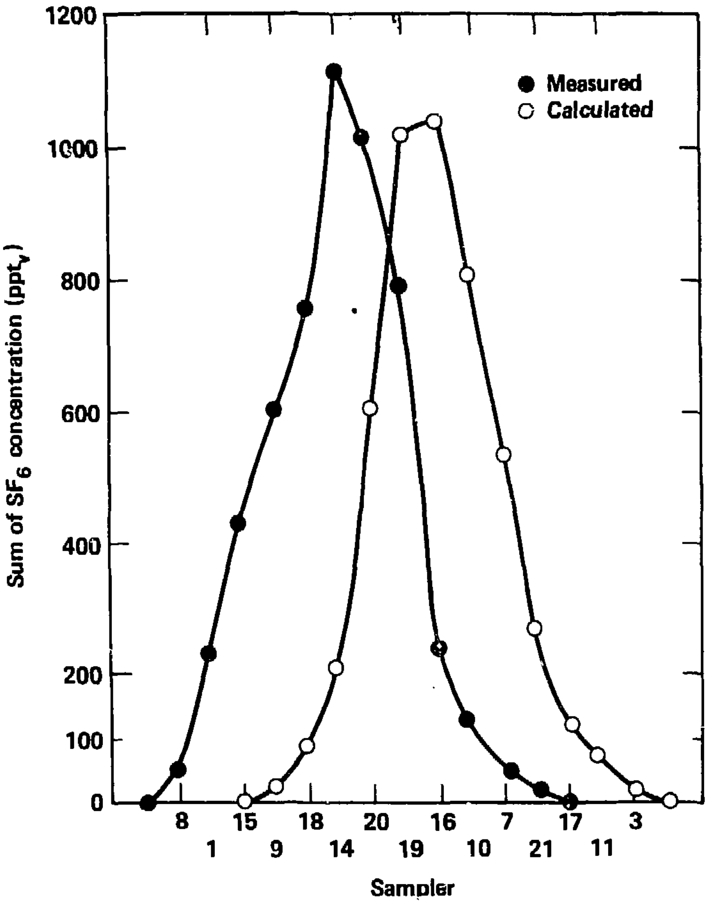

FIGURE 7. Measured and calculated air concentration values for the SRP 1983 MATS tracer experiment number 7.

to those discussed above for the SRP MATS and Montalo studies and for the ASCOT studies.

4. CONCLUSIONS

The M/A evaluation studies described in this article represent a broad range of terrain, meteorological conditions and tracer release heights. In general, the models perform best under the simpler terrain, meteorological, and tracer release height conditions. For relatively flat terrain and simple meteorological conditions the models can be expected to estimate air concentration values to within a factor of 2, 50% of the time, and a factor of 5, 80% of the time (Figure 5). Most of the discrepencies beyond a factor of 5 for these studies occurred near the plume edge where concentration values are relatively low and gradients are high. A small directional error under these conditions contributes to significant differences between model calculated and measured air concentration values.

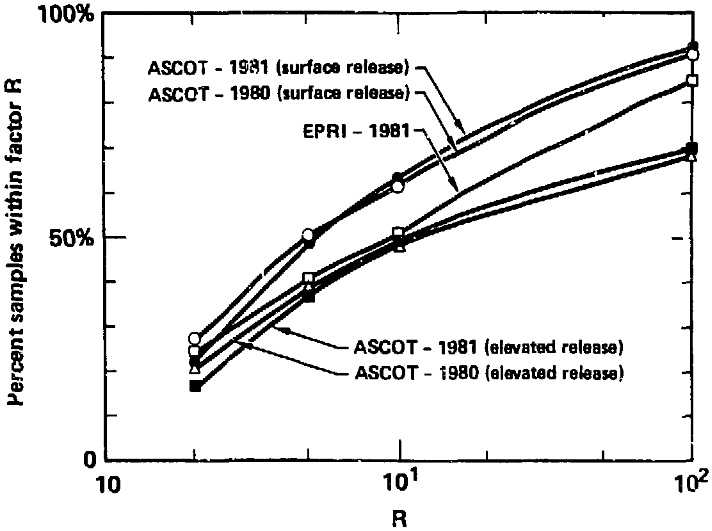

FIGURE 8. Same as Figure 5 for the ASCOT 1980 and 1981 surface and elevated tracer releases and the EPRI 1981 experiment.

Implications of small directional errors are more clearly shown in Figure 7 where an average change of 5° in the wind direction markedly improved the results of the comparisons. These results imply that the calculated patterns are similar to the measured concentration patterns; however, they are displaced by a relatively small directional error. For these experiments the samplers were placed in arcs focused on the release points which provided a basis for a simple wind direction adjustment scheme. The more random and scattered arrays represented by the other studies described in this report do not allow for a simple adjustment. For these studies a more complex method, e.g., successive corrections, would be required and is suggested for producing a maximum correlation between model calculations and measurements of tracer air concentration values.

The curves shown in Figure 8 represent the most complex set of conditions the M/A models have been evaluated against thus far. A factor of 5 is achieved only 40 to 50% of the time. Analysis of the 1980 ASCOT tracer data showed variations in 2 hr measured concentration values greater than a factor of 20 for samplers placed 50 to 60 m apart and located 1 km from the source points [13]. These large variations, caused by a combination of natural atmospheric variability and changes in physical characteristics of the boundary layer occurring over relatively short distances, stretch the physical basis and resolution of these models. The heavy methane and cooling tower data for the ASCOT experiments had an additional built-in complexity of an elevated release. This is apparent in the shift of the curves in Figure 8 to lower percentages.

The band of uncertainty established by these studies is considered a fair representation of the M/A performance levels. Additional studies in the future will be accomplished to add to this data base and to devise additional methodologies for evaluating the models, particularly for more complex arrays of samplers than simple arcs.

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