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ADPIC: A Tool for the NEST On-Scene-Commander

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ABSTRACT

The Atmospheric Release Advisory Capability (ARAC) code ADPIC is used to calculate dose and ground deposition from mitigated and unmitigated high explosive (HE) detonation of a radiation dispersal device (RDD). Comparisons are made assuming differing particle size and activity distributions associated with the mitigation effort.

INTRODUCTION

In early March of 1982 the NEST Damage Limitation Working Group (DLWG) conducted a containment exercise in a building south of the Sandia Laboratories technical area near Albuquerque, New Mexico. The DLWG made estimates of the amount of containment that could be achieved on a radiation dispersal device (RDD) using one of their containment options. Although no actual explosive devices were used in the exercise the actual physical containment option was employed.

Assuming the containment option would accomplish the desired objectives the next thing to estimate was the integrated dose and the potential clean up problem, items fundamental to an on-scene commander's decision making process. ARAC was asked by the DLWG to make such calculations. This paper describes the calculation performed, discusses the assumptions made and the calculational results and their implications.

DESCRIPTION OF COMPUTER MODELS

A suite of three-dimensional computer codes was used to prepare the dose isopleth patterns presented in this report. The two major codes in this suite are MATHEW,¹ a program that adjusts observed horizontal winds, using variational

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analysis methods,² to conserve mass from cell to cell, and ADPIC,³ a Cartesian particle-in-cell code used to calculate the transport and diffusion of effluents on a regional scale. ADPIC can handle diffusion with both horizontal and vertical wind shears, variable surface roughness, dry and wet deposition, radioactive decay, and space- and time-variable diffusion parameters. Particles, simulating pollutants (up to 25,000 can be generated), move in a Lagrangian reference frame through an Eulerian grid. The main advantage of particle-in-cell techniques is that the problem of artificial diffusion, common to most Eulerian grids, is eliminated. ADPIC calculations have agreed within 5% of existing closed-form analytic solution. Using observed site-specific meteorological data, ADPIC calculations have agreed within factors of two or three of surface and helicopter observations. The deviations between calculations and observations are due to both meteorological and sampling errors, as well as to uncertainties about nonmeteorological input parameters, such as surface roughness and deposition velocity.

In past studies, calculations using the MATHEW-ADPIC suite of codes for flat terrain have agreed within a factor of three with continuous-point-source Gaussian diffusion (CPS)⁴ results for plume centerline doses. Off-axis estimates usually deviate more; the MATHEW-ADPIC results have agreed better than CPS with past tracer studies.

While MATHEW-ADPIC does have the capability to include the influence of terrain it also has the capability to define a flat grid. A flat grid (i.e. no terrain) was used in these calculations to facilitate the comparison of the study (i.e. comparisons of mitigated versus unmitigated detonation effects on dose and ground deposition of toxic material).

INPUT DATA

Material Release Rates

In this containment scenario the device (simulated) was an RDD containing Plutonium Dioxide (PuO_2). It was assumed that the device in its operational configuration would yield, upon high explosive (HE) detonation, 3.7 kilograms of PuO_2 with a stable cloud top height of 240 metres. It was further assumed that the containment option used would reduce the source yield to 1.75 kilograms of PuO_2 and yield a cloud top of 140 metres. It was assumed in both cases that cloud stabilization would occur in the first two minutes.

Physical Parameters

The activity distribution within the HE detonation debris cloud is modeled in two distinct parts, an upper part containing 24 percent of the activity and a lower part containing the remaining 76 percent of the activity. The model assumes that the activity in both the top and bottom portions of the cloud have separate "normal" distributions. For comparison a separate calculation was made assuming that the material in the mitigated debris cloud was uniformly distributed throughout the cloud.

The particle size distribution (PSD) was assumed to be log-normal throughout the debris cloud both for the mitigated and unmitigated cases. Two distinct log-normal particle size distributions were used i.e. both mitigated and unmitigated calculations were made for each PSD including the additional calculation assuming a uniform distribution of particles throughout the cloud. PSD I was provided by the DLWG. Its standard geometric deviation (SGD) is $1.5 \mu\text{m}$ and its median radius is $12 \mu\text{m}$. PSD II is the particle size distribution derived from the "Roller Coaster" data and is the standard PSD used by ARAC for hypothetical HE detonation accident assessments involving PU 239. PSD II's SGD is $5.71 \mu\text{m}$ and its median radius is $20 \mu\text{m}$.

The calculational grid was flat and 40 kilometres by 40 kilometres in the horizontal and 700 metres in the vertical. The horizontal grid cell size was one kilometre (x and y) and the vertical cell size was 50 metres.

Meteorology

One "canned" set of winds was used for these calculations, i.e., one surface wind and one vertical profile thru the grid top. Surface winds (10 metres) were from 200 degrees at three metres per second while grid top winds were from 230 degrees at five metres per second. A surface roughness height of 3 metres was used to simulate the urban environment. The stability was assumed to be neutral and the mixing depth was 650 metres.

Dose Conversion Constants

Doses calculated were via the inhalation pathway and were 50 year committed doses. The 50 year Rem/Ci inhaled dose constant is 2.9×10^8 . The specific activity of PuO_2 is $6.14 \times 10^{-8} \text{ Ci}/\mu\text{g}$ so that for $3.7 \times 10^9 \mu\text{g}$ of PuO_2 the activity is $2.27 \times 10^2 \text{ Ci}$. Using this and a 50 year committed lung dose

conversion factor of $9.66 \times 10^4 \frac{\text{Rem m}^3}{\text{Ci sec}}$ the ARAC dose conversion constant (DCON) becomes 4.38×10^6 . When used with the ARAC codes the dose units are in REM. Also factored into the DCON is the fact that only 20% of the particles are respirable.

RESULTS

Figures 1-6 depict the two hour integrated inhalation lung dose calculations for both PSD I and PSD II, Figures 1-3 for PSD I and figures 4-6 for PSD II. Figure 1 and Figure 4 are the unmitigated calculations (i.e. source = 3.7 kg PuO_2 and cloud top at 240 m). Figures 2 and 5 are the corresponding mitigated calculations (i.e. source = 1.75 kg and cloud top at 140 m). Figures 3 and 6 are both mitigation calculations for PSD I and PSD II respectfully; however the calculations assume a uniform distribution of particles within the cloud.

Figures 7-12 depict in a similar fashion the cumulative deposition calculations unmitigated, and mitigated for both PSD I and PSD II and including the PSD I and PSD II calculations for the uniform distribution.

Discussion

The purpose of the calculations in this study was to provide the DLWG a quantitative idea of how successful the containment option chosen for their test might be. A secondary result of the calculations has been to provide a qualitative "feel" for how sensitive the ADPIC code is to some of the input parameters. In this case the particle size distribution and the distribution of material within the debris cloud. A visual examination of Figures 1-3 for PSD I and Figures 4-6 for PSD II reveal a relative decrease of area affected. The areal change (e.g., area enclosed by isopleth D) is a 28% decrease from the unmitigated to the mitigated (Fig. 1 and 2) for PSD I and comparing the unmitigated (Fig. 1) to the mitigated uniform distribution calculation (Fig. 3) shows better than a 50% decrease. Also as expected one notes an increase in dose close to the source.

Inspection of the deposition calculations Figures 7-12 show similar results, e.g. a 51% decrease in total areal extent from the unmitigated PSD II calculation (Fig. 10) to the mitigated uniform distribution (Fig. 12). For PSD I the decrease is 53 percent (Fig. 7 vs Fig. 9).

If one assumes that all the basic assumptions made for these calculations are valid then the most dramatic comparisons are between Figures 1, 13 and 14 and Figures 7, 15 and 16. Figure 1 depicts the unmitigated 50 year

commitment lung dose for PSD I. If one further assumes that the particular containment option used would "filter" out small particles and yield PSD II (still with 20% of the particles respirable) the percent change in areal extent is an overall decrease of 32% (Fig. 1 vs Fig. 13) and if one assumes that the final debris cloud is uniformly distributed (Fig. 14) the decrease is 50 percent. Similarly for the deposition calculations comparison of Fig. 7 to Fig. 15 and 16 show overall decrease of 37% and 55% respectively.

It should be kept in mind that these comparisons are at most valid only in a qualitative sense unless it can be shown that PSD II is a valid direct result of a particular containment option. It should also be noted that the uniform distribution assumption has no basis in experimental data. It is no more than an intuitive "guesstimate."

This study has shown in a qualitative sense that the ADPIC code is sensitive enough to provide useful model calculational guidance provided that useful input data exists. If experiments demonstrate that a particular containment option can in fact achieve the assumed mitigation results then the overall dose effects and surface contamination can be reduced significantly as the ADPIC model calculations have shown.

More importantly the study shows that the data base must be improved if the DLWG is expected to provide quantitative answers to what can be expected from their containment options. The particle size distribution resulting from each class of containment option must be better defined. Additionally the activity distribution must have a basis in more than one real data point. More study is also required on how the particular containment options affect the overall debris cloud, not only the particle size and the activity distributions but the cloud's physical dimensions as well.

SUMMARY

It has been demonstrated that given valid input regarding particle size, and activity distributions and cloud geometry the ADPIC code is a viable tool to supplement the NEST DLWG and to provide meaningful information to the NEST on-scene-commander and other NEST officials should the need arise. Most important is the fact that not enough is known about how a particular containment option affects the source term. Better information is needed on particle size distributions, activity distributions and cloud geometry of debris clouds resulting from containment options.

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FIGURE 1

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