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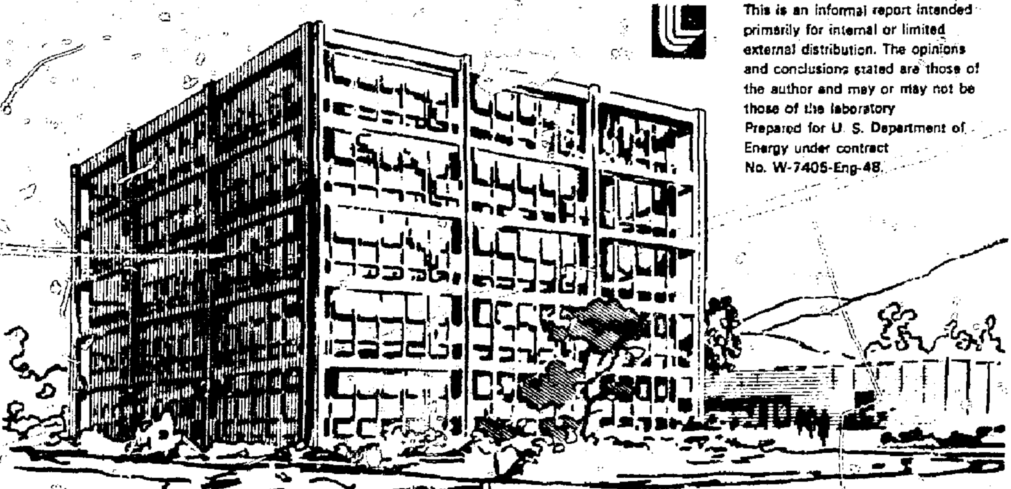

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ABSTRACT

Computer codes have been written which estimate toxic aerosol resuspension based on computed deposition from a primary source, wind and surface characteristics. The primary deposition pattern and the transport, diffusion and redeposition of the resuspended toxic aerosol are calculated using a mass-consistent wind field model including topography (MATHEW) and a particle-in-cell diffusion and transport model (ADPIC) which were developed by Sherman, Dickerson and Lange at LLL. The source term for resuspended toxic aerosol is determined by multiplying the total aerosol flux as a function of wind speed by the area of highest concentration and the fraction of suspended material estimated to be toxic. Preliminary calculations based on a test problem at the Nevada Test Site determined an hourly averaged maximum resuspension factor of 10^{-4} for a 15 m/sec wind which is within an admittedly large range of resuspension factor measurements using experimental data.

INTRODUCTION

The Atmospheric Release Advisory Capability (ARAC) at LLL has the responsibility to analyze downwind transport, diffusion and impact of real and simulated atmospheric releases of toxic gases and particles.[1] On two occasions meteorological and ground surface conditions were such that recuspension could occur. Fortunately, the first situation involved only a small release of non-radioactive beryllium and the second was only a test. However, the possibility exists for a situation involving large quantities of toxic suspendible material to be deposited on a surface when resuspension conditions exist. For a long term release eventually enough material could be built up on the soil to make it a secondary source under high wind conditions of equal or greater magnitude than the primary source. Of course, when the primary source is contained, resuspension is the only source remaining. So it is important to estimate the magnitude and history of the secondary resuspension source in certain circumstances. The word estimate is used because resuspension sources cannot be quantified to any accuracy comparable to the primary source. Measurements of resuspension rates vary by orders of magnitude for very subtle changes in wind and surface conditions. However, enough experience has been gained to allow reasonable estimates of resuspension to be made for a range of soil types and wind speeds.

The experience accumulated comes in two forms. The first is from studies of resuspension of radioactive particles (principally plutonium) from varied surfaces by wind or mechanical disturbance.[2-4] These studies have been limited however by the very small quantities of material usually involved. Tracer studies using distinguishable non-radioactive particles have also been conducted on a limited variety of surfaces.[5] The second source of information comes from studies of wind blown dust itself.[6-9] These studies have been conducted on a much wider variety of surface soil types and meteorological conditions and since the blown dust itself is the source term small quantities of material is seldom a problem.

The approach I have taken in this work is to combine these two sources of information by creating a source term for resuspension for total suspension of aerosol from different surfaces and winds and estimating the proportion of toxic aerosol to soil dust from measurements or empirically from predicted surface concentrations. Resuspension then becomes a secondary source whose fate is determined using MATHEW-ADPIC computer codes. MATHEW[10] is a mass-consistent wind field model including topography and ADPIC[11] is a particle-in-cell diffusion and transport code. The deposition pattern, location and concentration predicted by ADPIC using the wind field determined by MATHEW is used for determining the area and toxic to non-toxic aerosol proportionality. This area then becomes an area source with a source strength determined as a function of friction velocity and surface type. In the present preliminary form of the model, soil types are simply divided into sandy, loam-like, or clay-like soils. MATHEW-ADPIC codes are run again with resuspension as the source term and the results compared to the original source calculations for integrated air, instant air and redeposition concentrations. A sample problem has been run using a deposition pattern derived from a unit release for a test situation at the Nevada Test

Site. The resulting resuspension air concentrations showed an integrated maximum concentration resuspension factor for 15m/sec winds of $\sim 10^{-4}$ (i.e. maximum integrated air concentration at 2m divided by the maximum ground concentration). This is within the relatively wide range of experimentally determined resuspension factors found for similar situations.[12]

THEORY

Since the basis for the calculations which follow is the relation of total dust suspended from different surfaces to the friction velocity (u_*), the question to be answered first is whether any dust will be suspended. Figure 1 shows a simple flow diagram which can be used to determine whether a potential for suspension exists. These depend on surface wetness, surface vegetation, soil type (or snow type), and wind speed. Ordinarily, the wind speeds available to ARAC are 15 minute to 1 hour average winds, so threshold winds for suspension are lower because the periods may contain many periods of much higher winds. It should also be kept in mind that the surface criteria are for normal high wind speeds (< 20m/sec), during very high wind conditions (> 20m/sec) it may be possible to get significant suspension from even a wet vegetated surface. Once suspension has begun, two transport mechanisms occur, horizontal saltation and vertical suspension. Under normal circumstances, only vertical suspension has a potential for long range transport of respirable size particles. Table 1 shows empirically derived values for horizontal and vertical flux (F_H and F_V) of soil particles and snow as a function of the friction velocity from experimental studies by Gillette[13] and Mellor[14] respectively. The very steep exponential relationships with friction velocity (5th to 7th power) have been independently verified with very fast response instrumentation[15] and over longer periods.[5] The u_*^3 relationship for horizontal sand transport was derived over forty years ago by Bagnold.[16] The vertical flux over snow was assumed to behave similarly to the horizontal mass flux of snow derived by Mellor and coincidentally the same as the vertical flux over sandy soil derived by Gillette.

Since vertical aerosol flux (F_v) contributes smaller particles with higher potentials for long range transport and being respirable, we will base our resuspension source term on the fraction of the mass flux F_v which contains suspendible toxic particles. Ideally, F_v and the mixing ratio of suspendible toxic to surface particles on the ground (m_g) and in the air (m_a) should be measured. However, lacking that information, the assumption is made that the mixing ratio in air is the same as that on the ground. Measurements of resuspended plutonium and dust at the Nevada Test Site[3] and Rocky Flats[17] support this first order approximation for aged deposits when dilution from upwind uncontaminated sources is accounted for. For fresh deposits the recently deposited material may have a greater propensity for suspension, but no data exits to establish this. For lighter materials such as total carbon there can be as much as a 50 times enhancement in m_a over the ratio at the surface.[18] m_g can be estimated as the ratio of the fraction of suspendible toxic particles calculated to be deposited on the ground C_f divided by the surface density D_s ($\sim 1.5 gm/cm^3$ for soil and $1 gm/cm^3$ for snow).

$$m_g = C_f/D_s \qquad 1.$$

Therefore the resuspension source term is

$$Q_{RO} = m_g F_v A \qquad 2.$$

where A is the area over which the toxic particles are distributed. For sandy soils the resuspension source term becomes

$$Q_{RO} = M_g A F_o \ (u_*/30cm/sec)^7 \qquad 3.$$

where u_* is the friction velocity. For a prairie surface u_* is equivalent to the wind speed at 2m multiplied by the square root of the roughness coefficient C_D(= .0028).[19]

Since the source term is a function of the surface concentration it will decay exponentially with time

$$Q_R(t) = Q_{RO} \ e - \frac{Q_{RO}}{A\ C_f} \ t \qquad 4.$$

Combining Equations 1) and 2), the decay function

$$\frac{Q_{RO}}{A\ C_f} = \frac{F_V}{D_S}$$

which is independent of the area and surface concentration and depends only on the wind and surface type.

In most cases the decay rate will be very slow unless the surface wind speed is very high. For the example discussed in the next section, the time needed for $Q_R(t)$ to reach 37% of Q_{RO} would be 1.64×10^6 seconds or 456 hours for a 15m/sec wind speed. A constant source term over 1 hour is therefore justifiable even in very high wind conditions.

The assumptions used to derive inputs to the numerical models described in this section were all chosen conservatively as worse case estimates with a minimum of information at the accident site. As more information is available about soil type and conditions become available, more reliable estimates can be made using more detailed soil erosion data such as provided by Gillette, et al.[20] who has studied a wide variety of soils; their crustal integrity and size mixture.

RESULTS

Figure 2 shows a deposition pattern for a unit release calculated by MATHEW-ADPIC for a test problem at the Nevada Test Site. Figure 3 shows the 10% contour around the maximum concentration location. From this contour the location, area and average concentration was calculated. For this example the location of the maximum concentration in Universal Transverse Mercator (UTM) units was 560.63km east, 4065.38km north. The area enclosed by the contour was $.562km^2$, and the calculated average concentration was $2.57x10^{-7}gm/m^2$. For this test an explosive Pu size distribution was assumed with only 25% of deposited material suspendible. Since no measurements were possible as this was only a test, m_a was assumed to equal $1.7x10^{-11}$ which was determined from Equation 1. F_V was determined for a sandy soil with a roughness coefficient of 0.0028 for prairie land.[19] With these assumptions the source term for resuspension, Q_R can be determined as a function of the wind speed over threshold at 2m (u_{2m}) as

$$Q_R = 1.28x10^{-30} (u_{2m})^7$$

The source height was assumed to equal 2m as this is the height for which the F_V values in Table 1 were calculated.

Figure 4 shows the wind field assumed over flat topography. An average wind of 15m/s was assumed from the east, northeast. Neutral stability and a Monin-Obukov length of zero were assumed for these high wind conditions. These winds yield a source term Q_R of 2.18×10^{-8}gm/sec. Clay soils suspend much less material than sandy soils because of the relative lack of large particle bounce to ballistically produce a small particle flux.[7] Had we assumed a clay surface Q_R would have been reduced to 2.42×10^{-11}gm/sec.

Figures 5, 6 and 7 show the computer generated particles for the particle-in-cell calculations for ADPIC for three different assumptions about the resuspension source term. Figure 5 shows the horizontal profile particle flow assuming no particle settling or deposition velocity. Figure 6 shows the same profile with settling velocities associated with a logrithmic Pu particle size distribution associated with high explosive detonation only and no deposition velocity. Figure 7 shows the same profile with both settling velocities and an assumed deposition velocity of 1cm/sec. It is obvious from these figures that depositing and settling are needed to remove the physically unreasonable lack of particles near the surface far downwind of the resuspension source. Figure 7 shows a striking resemblance to how a single eroding field looks during a dust storm.

Figures 8, 9 and 10 show the pattern of 1 hour integrated air concentrations from the resuspension source with the assumed source characteristics used to generate Figures 5, 6 and 7 respectively. Figure 11 shows the redeposition pattern assuming both particle settling and deposition. The ratio of maximum integrated air concentrations to the maximum original surface concentration (Figures 2 and 3) in all these cases is of the order of 10^{-4} which is within the wide range of published resuspension factors.

CONCLUSIONS

Computer codes have been written which interface with MATHEW-ADPIC numerical transport models to estimate the effect of resuspension of deposited toxic aerosol. These codes were tested on computations of the deposition pattern from a supposed unit release of plutonium from a test problem for the Nevada Test Site. The following results were obtained assuming meteorologic conditions associated with a 15m/s wind:

1. A reasonable maximum resuspension factor of about 10^{-4} was obtained.
2. Particle settling and deposition velocities are important for physically reasonable downwind numerical particle-in-cell transport profiles from flat terrain.
3. A decay time of 456 hours for this situation allows calculations to be based on a constant source term over the period of an hour.

This tool should prove useful in emergency response situations for ARAC as well as guidance for where and what kind of measurements should be made during a potential resuspension event. It should, however, be emphasized that these results are preliminary and much more work should be done to improve the code manipulation required and to test the codes both parametrically and against real data.

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Table 1. Parameters for vertical and horizontal dust flux.

Flux Direction	Suspension Mechanisms	General Limit of Particle Diameters	Surface Type	Aerosol Flux F_o ($g/sec\ cm^2$)	Relationship with u_* ($=U2m\sqrt{C_D}$)
1. Horizontal	Surface Creep	>1000 m	Sand		
			Loam	$\sim 10^{-3}$	$F_H = 10^{-6}\ u_*^2(u_* - 18)$
	Saltation	50-1000 m	Clay		
			Snow		$F_H = 10^{-3}(u_*/30cm/sec)^7$
2. Vertical	Suspension	<50 m	Sand	10^{-9}	$F_V = F_o(u_*/30cm/sec)^7$
			Loam	$5x10^{-10}$	
			Clay	10^{-10}	$F_V = F_o(u_*/50cm/sec)^5$
			Snow	10^{-9}	$F_V = F_o(u_*/30cm/sec)^7$

FIGURE CAPTIONS

Figure 1. Wind suspension decision flow diagram.

Figure 2. Deposition pattern from a test problem at the Nevada Test Site before resuspension.

Figure 3. Location and size of 90% concentration area determined from Fig. 2 again before resuspension.

Figure 4. Fifteen metre per second wind field assumed to initiate resuspension.

Figure 5. Numerically generated particles for ADPIC calculations assuming no particle settling and deposition velocity.

Figure 6. Same as Fig. 5 with settling velocities of Pu particles with a size distribution associated with explosive generation.

Figure 7. Same as Fig. 6 with an assumed deposition velocity of 1 cm/sec.

Figure 8. Integrated air concentrations for 1 hour after resuspension with no particle settling and deposition velocity.

Figure 9. Same as Fig. 8 with particle settling.

Figure 10. Same as Fig. 8 with particle settling and deposition velocity.

Figure 11. Redeposition pattern after two hours from resuspension of deposited Pu in Figure 3.

WIND SUSPENSION DECISION FLOW DIAGRAM

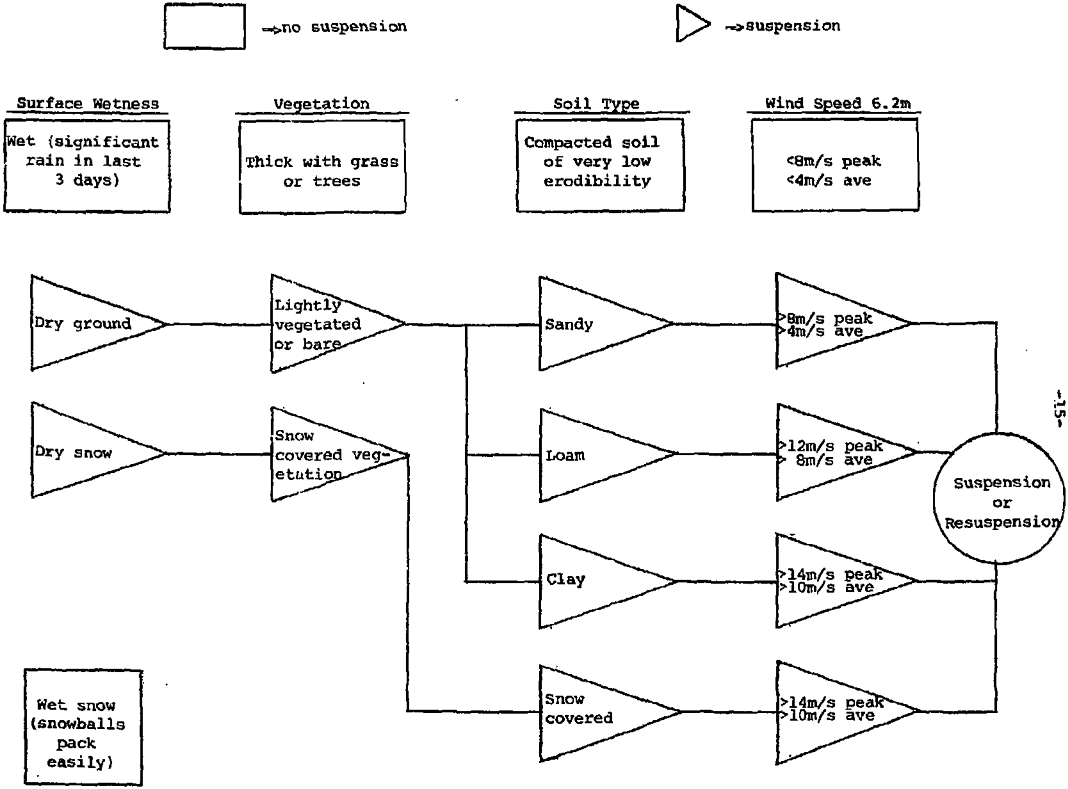
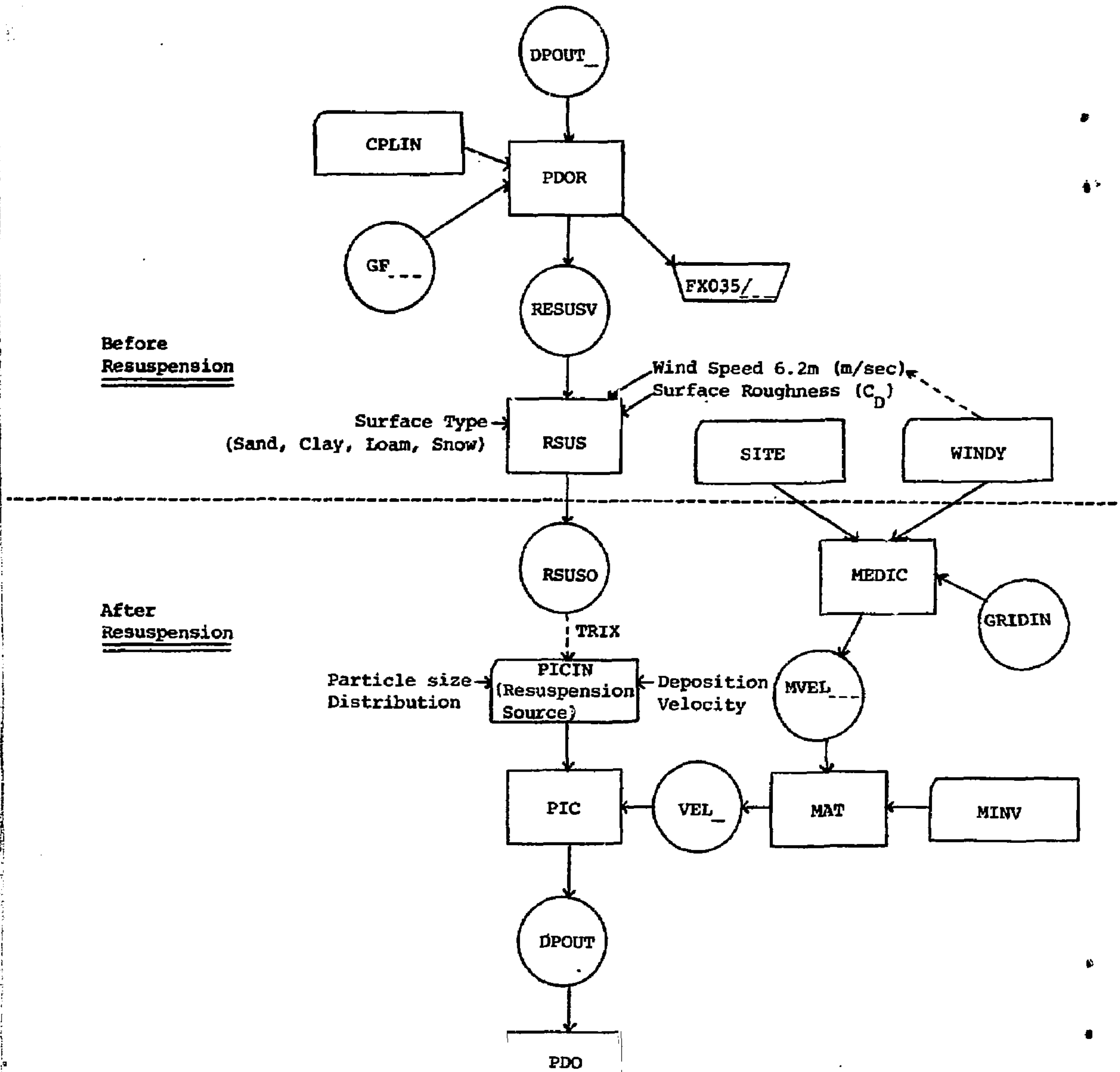
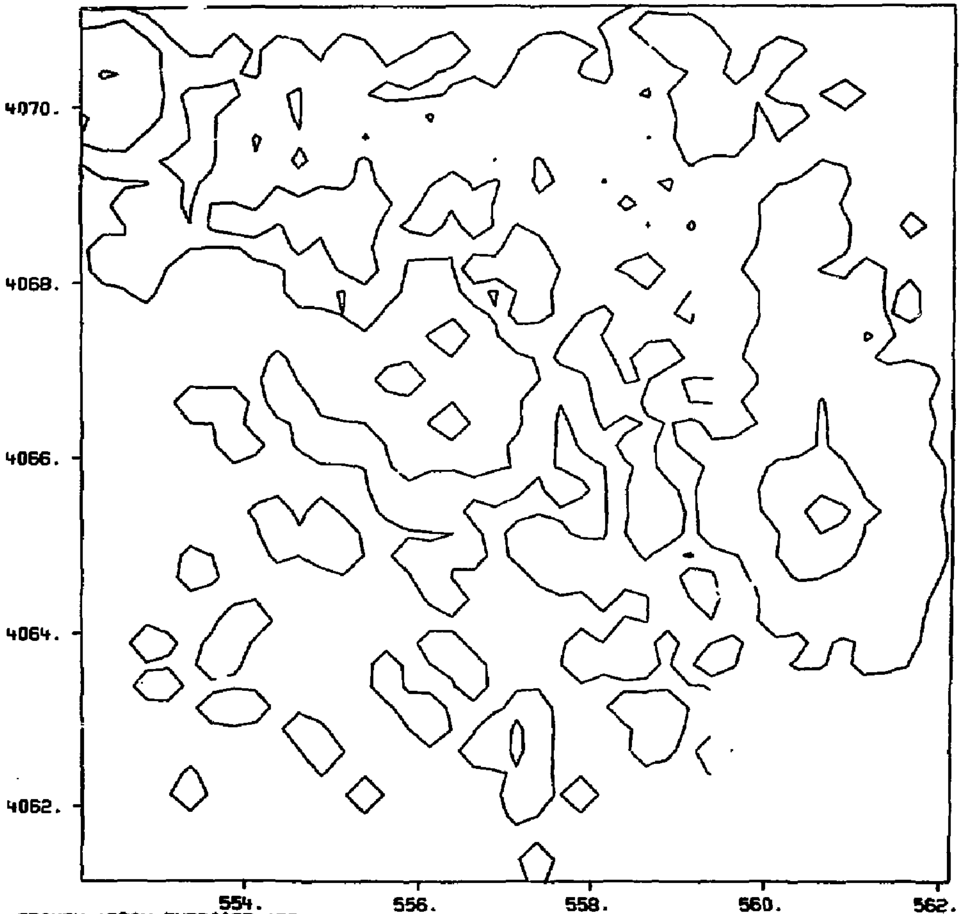


Figure 1

FLOW CHART FOR RESUSPENSION CALCULATIONS





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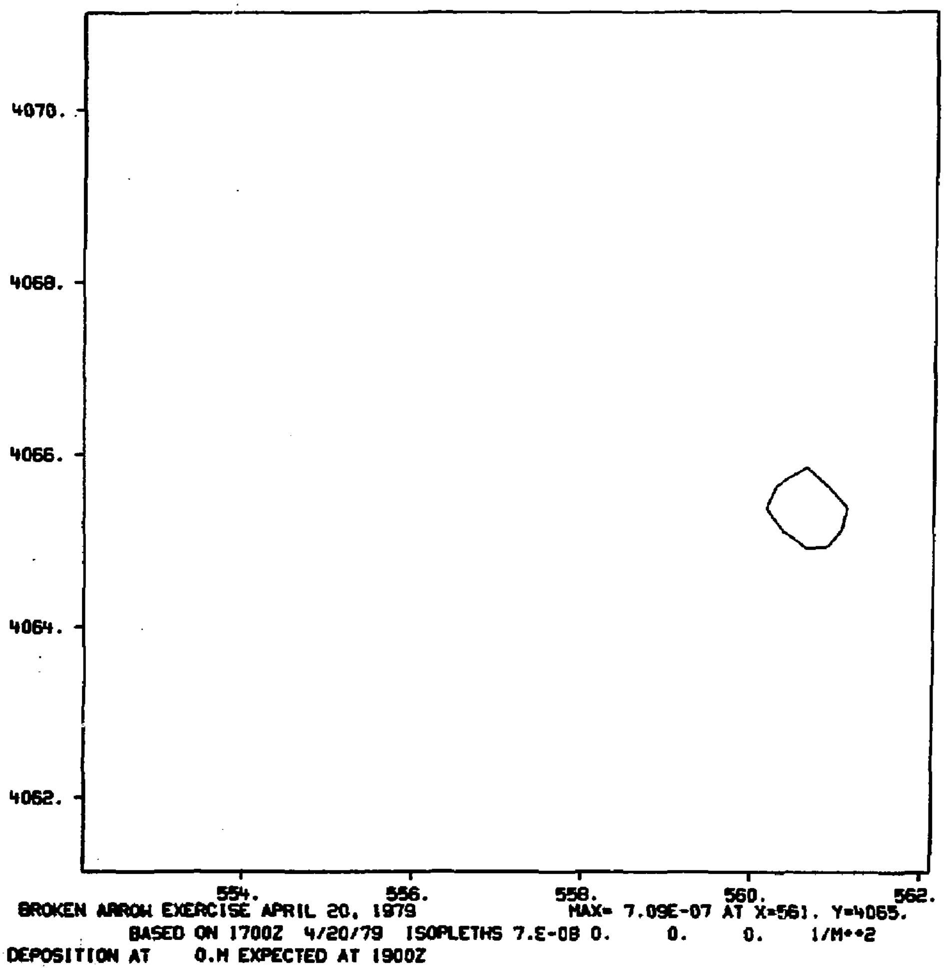
DEPOSITION AT 0.M EXPECTED AT 1900Z

Figure 2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4068.
4066.
4064.
4062.
554.
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558.
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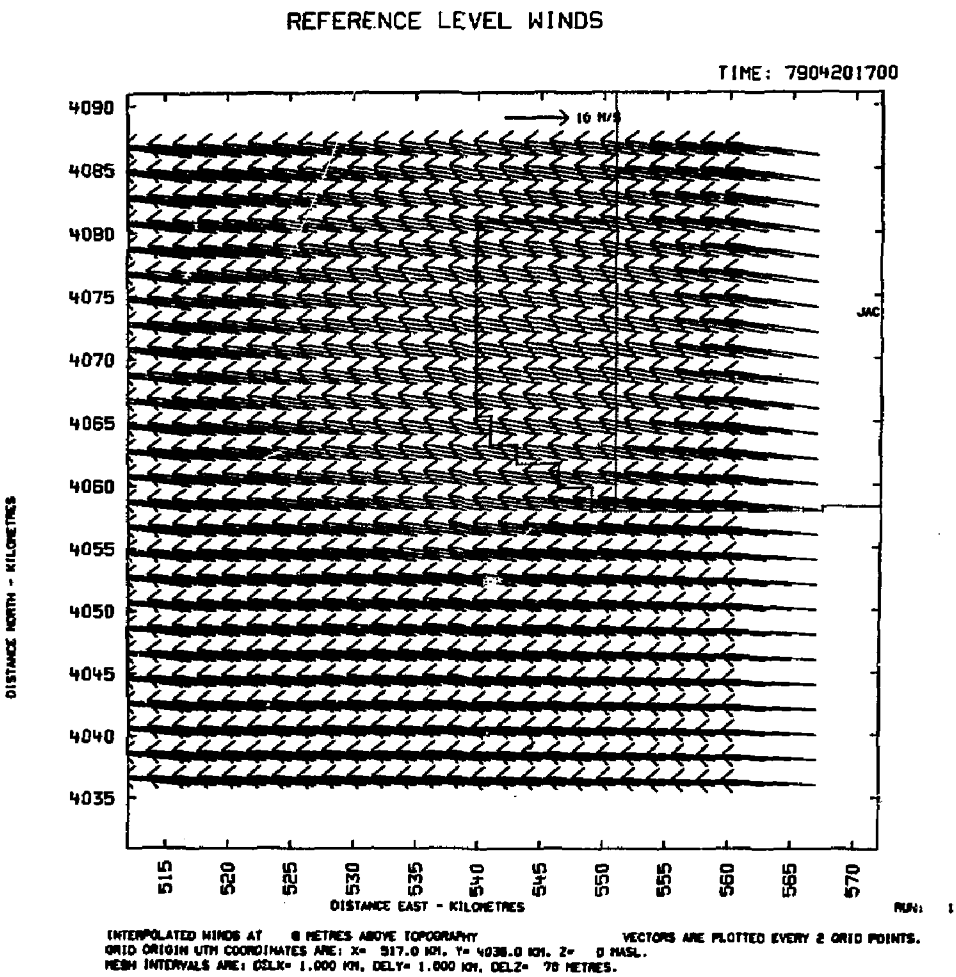
MAX= 7.09E-07 AT X=561. Y=4065.
BASED ON 1700Z 4/20/79 ISOPLETHS 7.E-08 0. 0. 0. 1/M**2
DEPOSITION AT 0.M EXPECTED AT 1900Z

Figure 3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TIME: 7904201700
10 M/S
JAC
4090
4085
4080
4075
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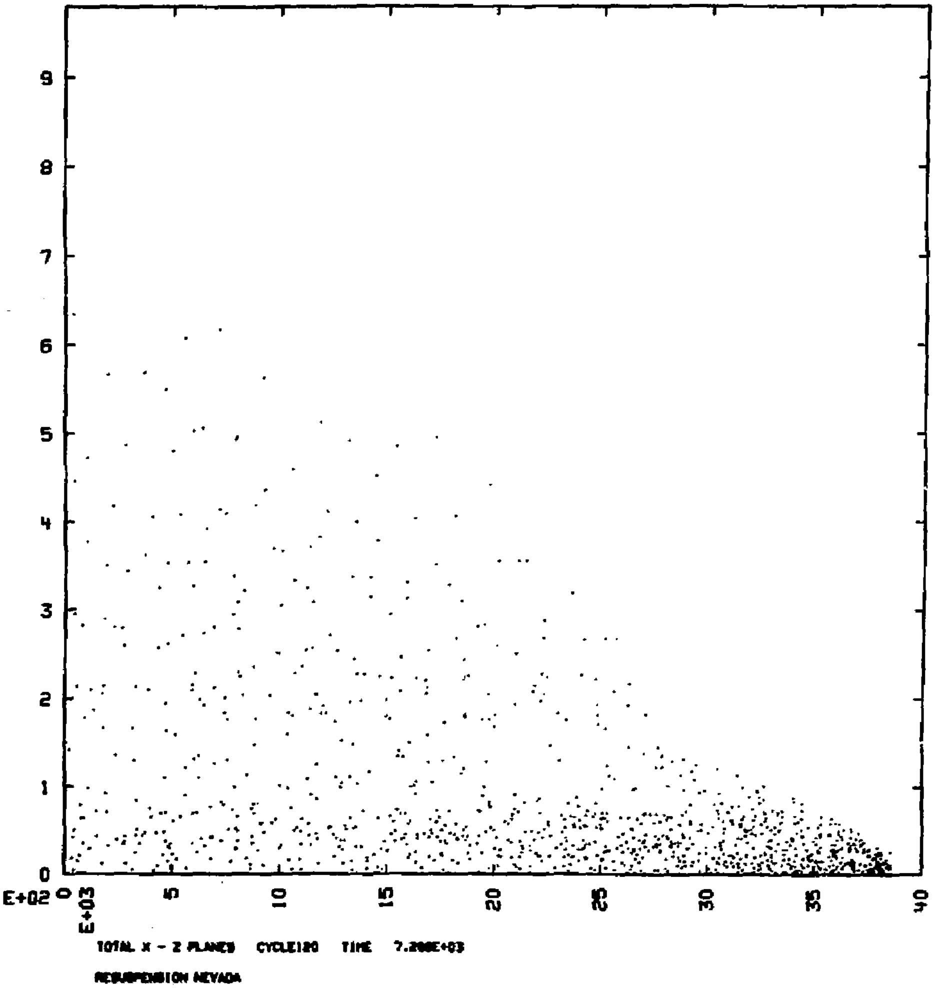
4065
4060
4055
4050
4045
4040
4035
DISTANCE NORTH - KILOMETRES
515
520
525
530
535
540
545
550
555
560
565
570
DISTANCE EAST - KILOMETRES
RUN: 1
INTERPOLATED WINDS AT 0 METRES ABOVE TOPOGRAPHY
VECTORS ARE PLOTTED EVERY 2 GRID POINTS.
GRID ORIGIN UTM COORDINATES ARE: X= 517.0 KM, Y= 4038.0 KM, Z= 0 MASL.
MESH INTERVALS ARE: DELX= 1.000 KM, DELY= 1.000 KM, DELZ= 70 METRES.

Figure 4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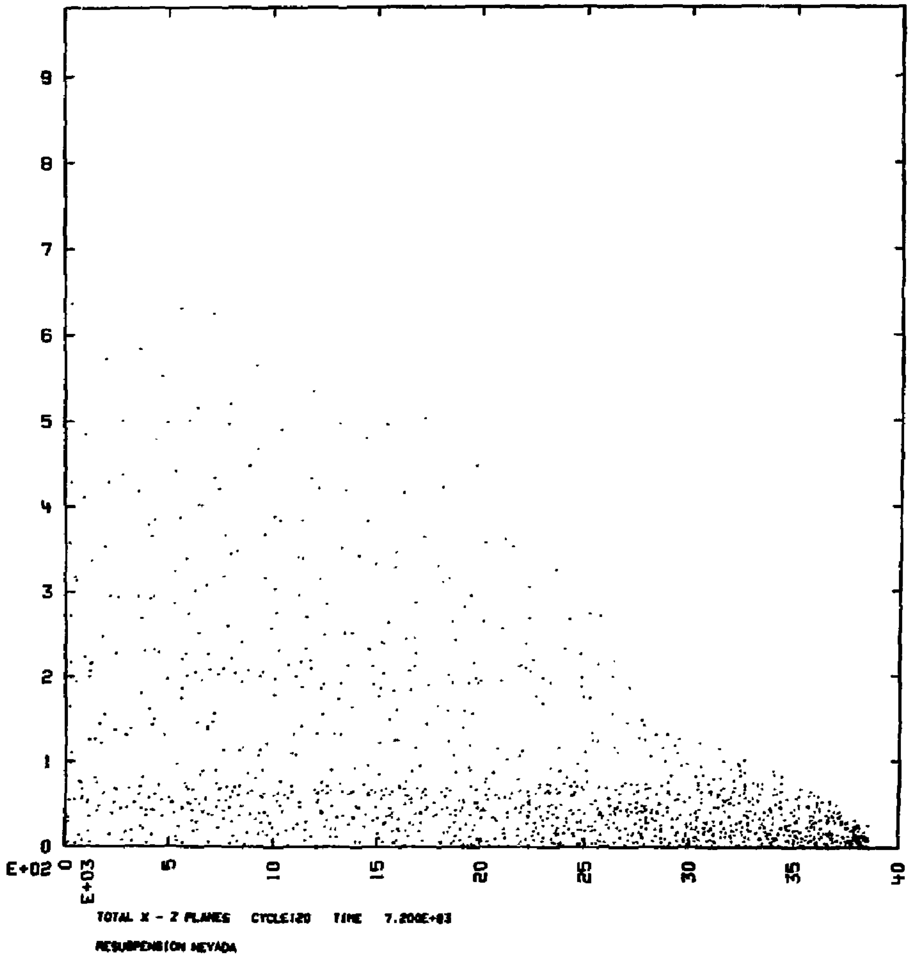
E+03
TOTAL X - Z PLANES CYCLE120 TIME 7.200E+03
RESUSPENSION NEVADA

Figure 5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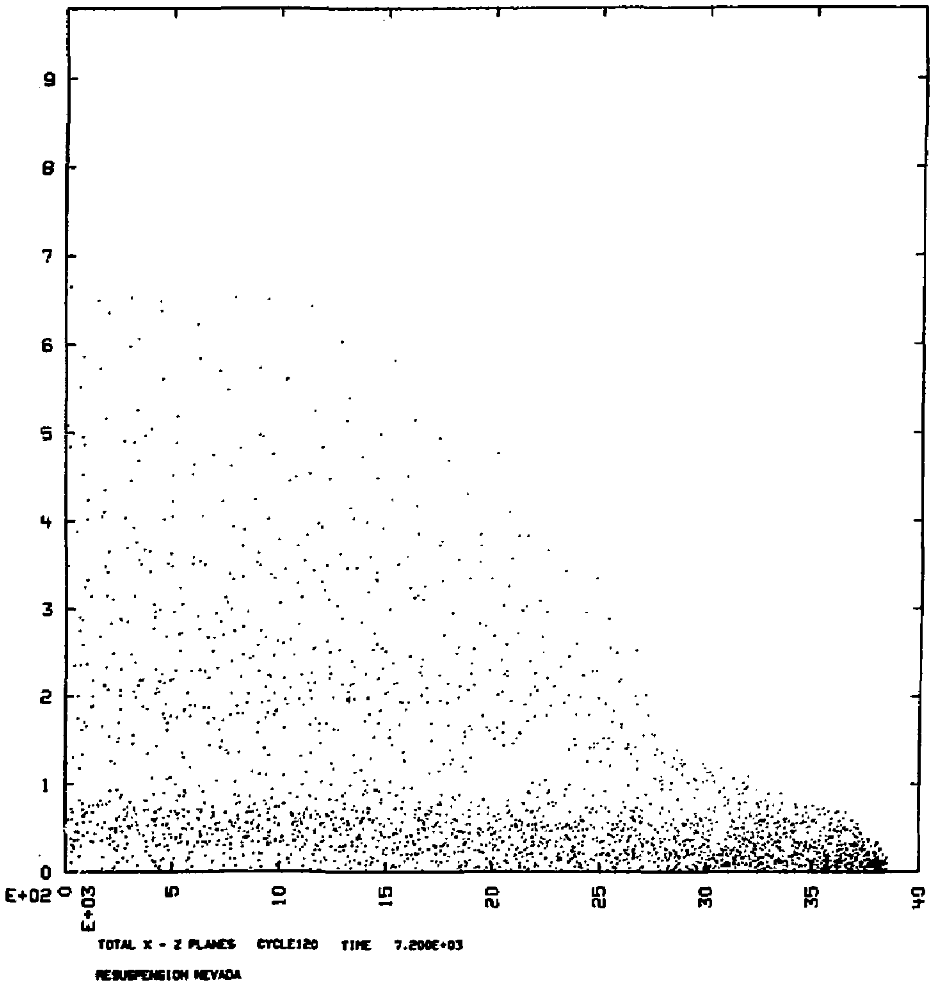
TOTAL X - Z PLANES CYCLE120 TIME 7.200E+03
RESUSPENSION NEVADA

Figure 6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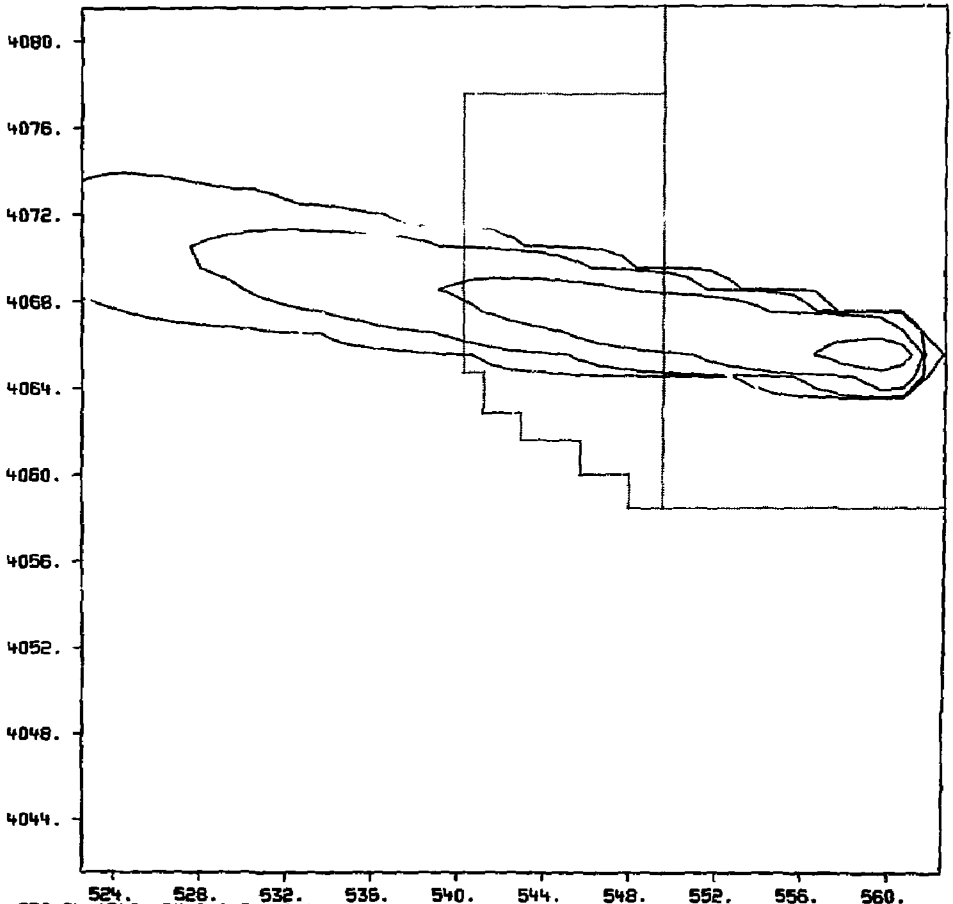
E+03
TOTAL X - Z PLANES CYCLE120 TIME 7.200E+03
RESUSPENSION NEVADA

Figure 7



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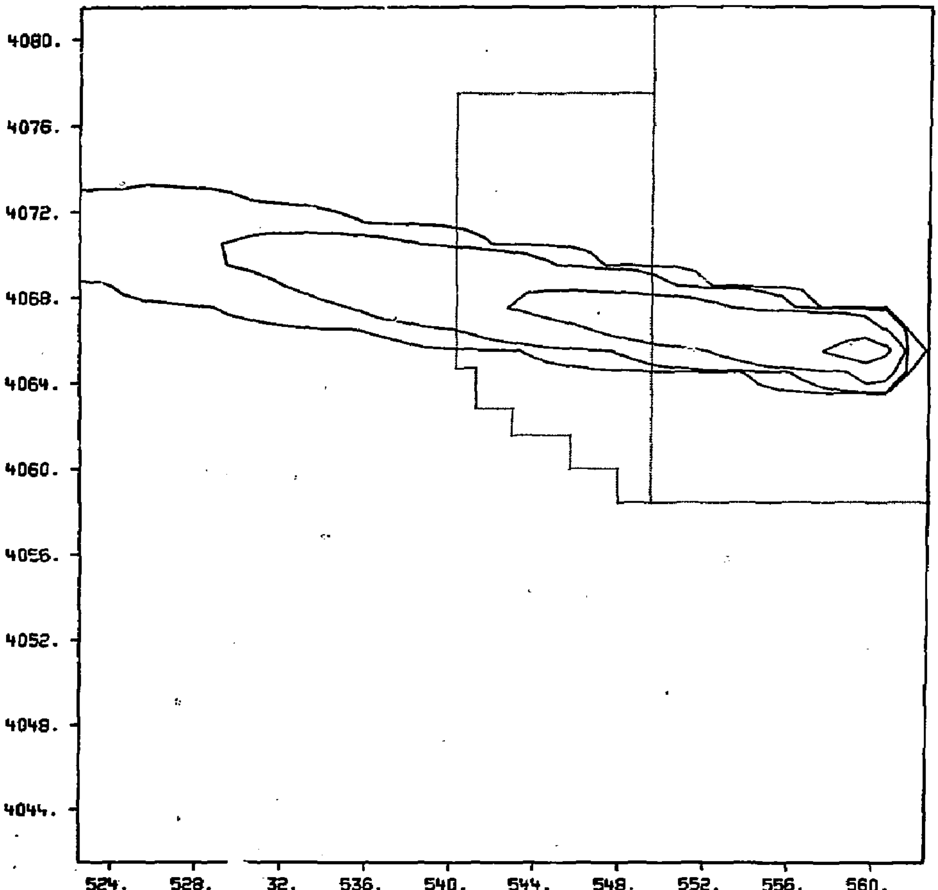
INTEGRATED AT 2.M EXPECTED AT 2000Z

Figure 8



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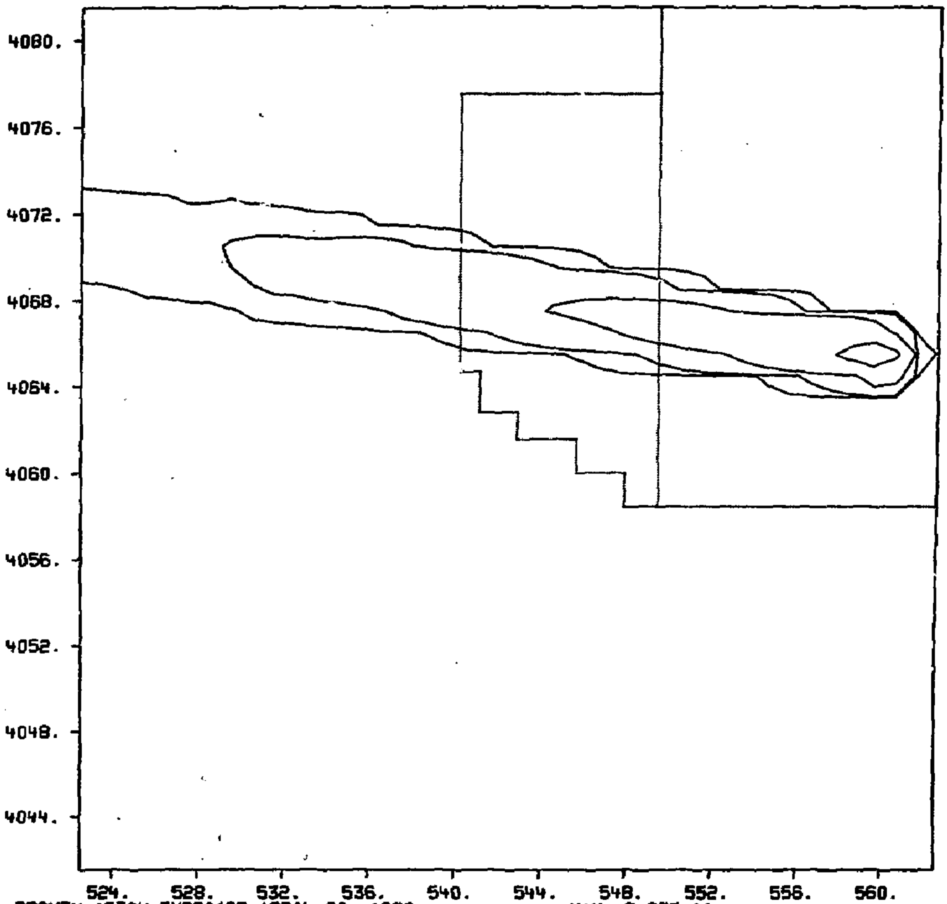
INTEGRATED AT 2.M EXPECTED AT 2000Z

Figure 9



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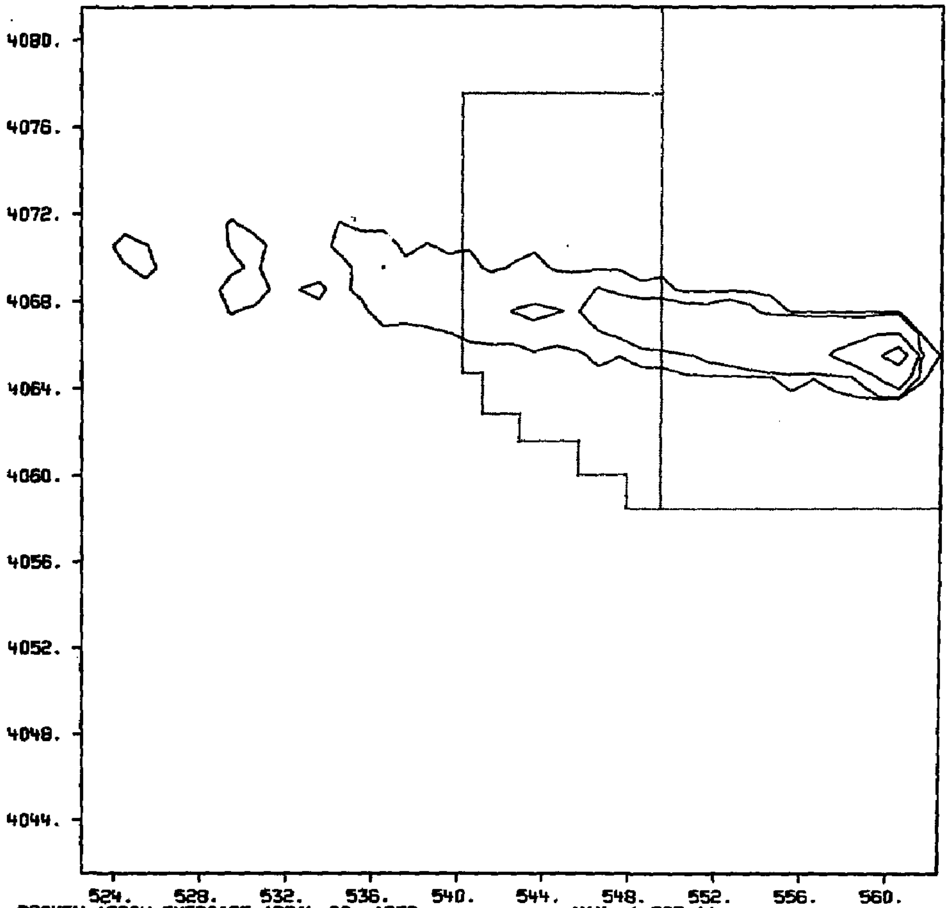
INTEGRATED AT 2.M EXPECTED AT 2000Z

Figure 10



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PU BASED ON 1700Z 4/20/79 ISOPLETHS 1.E-11 1.E-12 1.E-13 1.E-14 1/M**2
DEPOSITION AT 0.M EXPECTED AT 2000Z

Figure 11

APPENDIX A

Code Manipulation

After MATHEW-ADPIC codes are run for an ARAC problem a file called DPOUT_ is generated and a code called PDO is used to plot air concentration and deposition. This code has been modified for resuspension studies and called PDOR. This code finds the location, size and average concentration within a 10% concentration contour around the point of maximum deposition concentration and sends this information to a file called RESUSV and plots the 10% contour. A file called RSUS is then opened with TRIX AC to insert wind speeds, surface type and surface roughness. RSUS is then run and a file RESUSO is produced using these values and the values determined from RESUSV. RESUSO produces all the values necessary to modify PICIN which is the input file for PIC which performs the particle-in-cell transport, diffusion and redeposition calculations. As the winds change, new WINDY files are created as input to MAT the mass-consistent wind field model with topography and new VEL_ files are created. PIC is then run with these new files and PICIN modified by the resuspension calculations to include a new area resuspension source and new DPOUT_ files are created. Figure 1A shows a flow chart of this process. RSUS and output samples are available in a library file called LFROTAR.