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2DPUF-A SEQUENTIAL GAUSSIAN PUFF MODEL (U)

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2DPUF

A SEQUENTIAL GAUSSIAN PUFF MODEL

ENVIRONMENTAL TECHNOLOGY SECTION

SAVANNAH RIVER LABORATORY

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CONTENTS

Summary	3
Introduction	3
Dispersion in 2DPUF	
Sequential Puffs	4
Dispersion Equations	4
Dispersion Parameters	5
Mixing Depth	6
2DPUF Wind Field	
Regional Wind Field Input Data	6
Wind Field Grid	7
Interpolation of SAOs and SGLs	8
Local Wind Field	8
Uniform Regional Wind Field	9
Forecast Winds (MOS)	9
Transport Grid	9
Radioactive Decay and Individual Dose Estimates	
General	9
ICRP 30 Dose Factors for Individuals	10
Acknowledgements	12
References	13
Figures	
1. Effect of Time Dependent Wind on Dose Estimates	14
2. Regional Wind Field Grid	15
3. 2DPUF Module Flow Diagram	16
4. Graphical Output from 2DPUF	17
Appendix A: Dispersion Equations for a Gaussian Puff	18
Appendix B: Upper Limit for Vertical Dispersion	19
Appendix C: NWS Stations Providing SAOs and SGLs for 2DPUF.	20
Appendix D: Description of 2DPUF Subroutines	22

SUMMARY

This report documents the Environmental Transport Section's (ETS) two-dimensional, sequential gaussian puff transport and dispersion model for emergency response. The sequential puff scheme is described, and the dispersion equations are presented. The advantages of this model over the ETS's PUFF/PLUME model are discussed. Options for calculating a two-dimensional wind field, interpolation procedures, and the wind field grid are described. The various grid systems for puff transport calculations and dose estimates are also described. A flow diagram for the modules comprising the 2DPUF code and a description of each module is presented.

INTRODUCTION

Atmospheric transport and dispersion models are important tools for emergency response to radioactive atmospheric releases. Rapid predictions of where the released material will go, how quickly it will get there, and estimates of the expected radiation doses are vital for timely management decisions. This is an inherent forecasting problem. Ultimately, the success of any emergency response program depends upon the ability to forecast the wind field and turbulence over a given region. At this time a forecast of *local* wind and turbulence at Savannah River Site (SRS) is provided by the National Weather Service (NWS) through their Model Output Statistics (MOS) program. This forecast is based on NWS large-scale model results and SRS meteorological tower data (persistence).

The Savannah River Laboratory (SRL) Wind Information and Display System (WINDS) uses this MOS forecast in a gaussian trajectory model, PUFF/PLUME, for emergency response to atmospheric releases. PUFF/PLUME gives timely predictions appropriate for the support of immediate management responses. For a short term or "puff" release, the trajectory can be calculated in the presence of strongly time-dependent wind direction and speed. Of course, the validity of this trajectory becomes less reliable with distance from the site because the MOS forecast only applies at SRS. For releases of more than one to two hours in duration, use of PUFF/PLUME may be inappropriate because of changes in the wind direction. This is true even if the local wind forecast is valid at all points along the trajectory. Such changes may require the use of multiple trajectories, a feature not available with PUFF/PLUME. When significant wind changes occur during long releases, PUFF/PLUME overestimates doses. This effect is illustrated in Figure 1.

A sequential gaussian puff model, 2DPUF, has been developed to alleviate this problem of long-term releases into a time dependent wind field. Atmospheric releases are treated as a sequence of gaussian puffs by 2DPUF, which are advected and dispersed by the wind field. Changes in the wind field during the period in which material is released to the atmosphere are taken into account by assigning to each puff its own trajectory. Each puff is transported by the wind field and dispersed as a reflected gaussian puff.

The wind field may be local or regional. A local wind field is determined solely by SRS meteorological tower data and the MOS forecast. However, this local wind may (with caution) be applied uniformly over a regional extent if desired. A spatially varying regional wind field can be calculated from NWS radiosonde and airport wind data, as well as the SRS tower wind data. The winds are interpo-

lated with exponential weighting onto a horizontal, rectangular wind field grid measuring 17 by 19 grid points, with 40 km lateral grid size. In the vertical there are 11 levels; the lowest level is 100 meters, and above that level are 10 equally spaced levels from 200 to 2000 meters. For actual transport calculations, the interpolated wind field is averaged vertically to produce a two-dimensional horizontal wind field. Since the MOS forecast is valid only at SRS, persistence alone is used to provide a predictive capability in the regional calculation.

Puffs are created every 15 minutes for the duration of the release. A release rate is specified for each hour and distributed uniformly over the four puffs created during the hour. Puff transport calculations are performed on a 151 by 151 grid. The wind field on this transport grid is linearly interpolated from the 17 by 19 wind field grid, which it overlays. The transport grid has a lateral grid size of 0.5 km for a local calculation, and a 5.0 km grid size for a regional calculation.

Instantaneous surface concentrations and cumulative individual doses are calculated on a polar grid centered on the release location for each one degree and one kilometer (radius) intersection. This calculation extends to 30 km for a local calculation and 300 km for a regional calculation. Doses are also calculated at each puff center location every 2 km (radius) for a local calculation and every 20 km for a regional calculation. The maximum dose at each of these radial distances is reported as the centerline maximum. The individual doses for each 1 km (local) or 10 km (regional) in 16 sectors of 22.5° are also calculated.

DISPERSION IN 2DPUF

Sequential Puffs

The 2DPUF Program is a sequential gaussian puff model. Atmospheric emissions are simulated by a series of puffs released from the source every 15 minutes for the duration of the emission. The emission rate is specified for each hour and distributed uniformly over each puff released during the hour. As each puff is released, it is transported and dispersed at each time step on a transport grid using the hourly wind field. The surface concentration and individual dose estimates are calculated on a polar grid, adding the effects of each puff at each grid point.

Dispersion Equations

Each puff is assumed to be a reflected gaussian. The dispersion equation for the puffs is the same as that used for puffs in PUFF/PLUME and are described in Garrett and Murphy.¹

$$X = \frac{2Q}{(2\pi)^{3/2}\sigma^2\sigma_z} \exp\left(-\frac{d^2}{2\sigma^2} - \frac{h^2}{2\sigma_z^2}\right)$$

where:

X = the pollutant concentration (gm/m^3 or Ci/m^3)

Q = the amount of pollutant in the puff

h = release height

d = the horizontal distance from the puff center

σ_x = the horizontal standard deviation of the puff along the direction of motion

σ_y = the horizontal standard deviation of the puff transverse to the direction of motion

σ_z = the vertical standard deviation of the puff

It is assumed that $\sigma_x = \sigma_y = \sigma$

Expressions for σ and σ_z are obtained from observations of σ_a and σ_e , the standard deviations of the azimuth and elevation of the wind vector, as obtained from bivanes and anemometers. This is discussed in the next section.

Dispersion Parameters

The σ and σ_z are calculated from measurements of σ_a and σ_e , using expressions developed by F. B. Smith and documented by Pasquill.² These are the same expressions used in PUFF/PLUME.¹

$$\sigma = 0.22\sigma_a s$$

$$\sigma_z = 0.22\sigma_e s$$

where σ_a is the standard deviation of the azimuth, σ_e is the standard deviation of the elevation, and both are in radians. The downwind distance is denoted by s . The maximum mixed depth for the entire calculation period of σ_z is constrained to be no larger than 80 percent (see Appendix B). This restriction essentially forces uniform mixing within the mixed layer when σ_z is large.

In addition, if the mixed depth starts to decrease during the calculation period, the puff σ_z does not decrease. This prevents unrealistic recovery of dispersed material during development of a stable layer. (An additional constraint exists in PUFF/PLUME. Namely, the puff dispersion parameters are not allowed to exceed those of a plume. This condition does not exist in 2DPUF.)

Mixing Depth

The mixing depth is calculated by taking the larger of:

$$\text{Mixing Depth (m)} = 125 \times \text{speed (m/s)}$$

or daily climatological values (in Greenwich Mean Time):

<u>m</u>	<u>GMT</u>	<u>m</u>	<u>GMT</u>
600	for 00	700	15
500	01	900	16
400	02	1000	17 - 20
300	03 - 11	900	21
350	12	800	22
400	13	700	23
500	14		

2DPUF WIND FIELD

Regional Wind Field Input Data

A regional wind field is generated using data from the National Weather Service observing network of stations in the southeastern United States, as well as wind data from the SRS area towers. The NWS data is available in real-time on the NWS Automated Field Operations and Services computer network (AFOS). When the data is received by the AFOS located in SRL's Weather Center Analysis Laboratory (WCAL), it is immediately transmitted to the WCAL VAX computer and is available for use by 2DPUF.

The NWS wind data consists of hourly surface aviation observations (SAOs) and radiosounding atmospheric observations (called RAOB), both usually taken at airports. The wind information obtained in an SAO is a one minute averaged speed and azimuth taken on the hour at a height of 10 meters. The RAOBs are balloon soundings of the atmosphere taken every 12 hours. The data from the RAOBs are significant level data (SGLs). Wind speed and azimuth are observed by an instrument package attached to a helium filled balloon as the balloon ascends.

Data from 66 NWS stations generating SAOs and 12 stations generating SGLs is received regularly on AFOS and subsequently sent to the VAX. If Florida is excluded from the grid the number of SAOs decreases from 66 to 41 and the SGLs from 12 to 8. The list of the stations providing SAOs and SGLs appears in Appendix C.

The SAOs are observed hourly and are received for use in the model within a few minutes of the observation being taken, usually within about 10 minutes. If no data is available for periods, the missing data is replaced by one of three methods:

1. For data missing at the beginning (or end) of the period of interest, the first (or last) available data at that station is used to replace all the missing data up to (or beyond) the first (or last) available observation. Persistence is assumed.
2. If only two observations surround a missing observation, then linear interpolation in time is used to determine a replacement for the missing observation.
3. If three observations surround a missing observation, a quadratic time interpolation is performed to replace the missing value.

The interpolations are conducted on the u and v components of the wind vector. In this manner 24 hourly values of the wind field are available.

The SAO from Augusta's Bush field airport is replaced by the space average mean (SAM) obtained from SRS's towers. SAM is a vector average of the eight 62 meter area towers and an interpolated 62 meter value on the WJBF TV tower located nearby. The 10 m wind data of the SAOs and the 62 meter SAM wind are converted to 100 m data using Pasquill's "power law":

$$U(100 \text{ m}) = U(10 \text{ m}) \times 10^P$$

where $P = 0.17$ for A and B

0.20 for C

0.27 for D

0.38 for E

0.61 for F (and G)

The different values of P correspond to different atmospheric stability classes.²

The SGLs are observed every 12 hours at 00 and 12 Greenwich Mean Time (7 p.m. and 7 a.m. EST). The SGLs are usually available within an hour or two of the beginning of the balloon sounding. The SGLs are linearly interpolated to 10 levels from 200 m to 2000 m at 200 m increments. Three consecutive soundings (SGLs) for each of the RAOB stations are used to generate the 24 hour wind field. The time of the first sounding is based on the current time and the start time of the release (see the description of subroutine MDZCALZ). A quadratic time interpolation is then performed on the three periods at each of the 10 levels for each station to generate hourly values. If forecast information is required (as it usually is in an emergency response), then persistence is assumed. Checks on SGL data availability, consistency, and methods for handling data problems can be found in the description of the interpolation subroutine TIMINT.

Wind Field Grid

The SAOs and SGLs are interpolated onto a wind field grid 17 by 19 grid points in the horizontal (17 east-west, 19 north-south), and 11 grid points in the vertical. The southwest and northeast corners of the wind field grid have coordinates (1,1) and (17,19), respectively. Each horizontal grid spacing is

0.4289° longitude by 0.3597° latitude. This is approximately 40 km by 40 km at 33° latitude; thus, the total wind field is 640 km east-west by 720 km north-south. The default location of the center of the wind field grid is at the center of the SRS at grid location (9.000, 10.000) or (33.25140°, -81.6250°). When the SRS is centered on the grid, the latitude-longitude coordinates of the southwest corner of the wind field grid default to (30.01410°, -85.05620°), and those of the northeast corner default to latitude-longitude coordinates (36.48870°, -78.19380°). Under these conditions the user may opt to exclude from the wind field the 4 SGLs and 25 SAOs from Florida since most of this data would not be within the wind field grid. A map of the Southeast, showing the regional extent of the wind field grid and locations of the SAOs and SGLs, is given in Figure 2.

The latitude and longitude of the grid points of the wind field centered on SRS are given by

$$\text{LAT (I,J)} = 30.0141 + (J-1) \times \Delta Y$$

$$\text{LONG (I,J)} = 85.0562 - (I-1) \times \Delta X$$

where $\Delta Y = 0.3597$ and $\Delta X = 0.4289$

The user may chose to center the wind field grid elsewhere in the southeastern United States by defining the desired latitude and longitude of the grid. If a location is chosen further south, the Florida SAOs and SGLs may be included.

Interpolation of SAOs and SGLs

Interpolation onto the 17 by 19 wind field grid for the 100 m values at each SAO station is calculated first. Then for each upper level (200..., 2000 m) the values from each station are interpolated onto the 17 by 19 grid. Interpolation is achieved by giving each station a weighting for each grid point. The weightings are exponential:

$$W(I,J,K) = \exp \left\{ - \left(\frac{R(I,J,K)}{D} \right)^2 \right\}$$

where $W(I,J,K)$ = the weighting factor for station K at grid point (I,J)

$R(I,J,K)$ = the distance between station K and grid point (I,J)

D = a measure of the average station spacing (a normalizing factor)

If only one station reports at any particular level, that value is assumed for the entire grid.

Local Wind Field

A "local" wind field calculation uses the SRS SAM winds along with MOS forecast information, "canned winds", or manual input data to compute puff trajectories. If the scale of the calculation is also assumed to be local, then the puffs are advected on a 151 by 151 grid with a 0.5 km grid size. It should be emphasized that this calculation, while strictly local in extent, has forecast capability (MOS) well beyond mere persistence (i.e., greater than three hours).

In an emergency response situation, archived wind data from SRS towers will generally be used to calculate puff trajectories for the first 15 minutes to one hour after the release. After this "response time" the MOS forecast is used to predict the wind and turbulence. Because there is always the possibility that the MOS forecast and the tower data might not agree at the end of the response period, the first and second pieces of MOS data are altered to smoothly merge the tower and forecast wind. This is done in subroutine SMTH.

Uniform Regional Wind Field

The local wind may also be used to construct a spatially uniform wind field of regional extent, if desired. Whether this assumption is valid or not will depend on the overall (synoptic) state of the atmosphere. Note that this wind field will still be time dependent. The puff trajectories on a regional scale are calculated on a 151 by 151 grid with a 5 km grid spacing.

Forecast Winds

Forecast winds using Model Output Statistics (MOS) are calculated by the National Weather Service every 12 hours. MOS uses linear regression equations to predict the local wind and turbulence based on output from the NWS Limited Fine Mesh model and SRS tower measurements at three and six hours before the forecast is received at SRS.³ The forecast wind information is provided in three hourly intervals. This data is then interpolated using a quadratic scheme to generate 24 hourly forecasts of wind azimuth, speed, σ_z and σ_y .

Transport Grid

Four puffs are created per hour for the duration of the release. Each puff is transported and dispersed on a transport grid for the duration of the calculation using the wind data from the wind field grid. The minimum calculation duration is the release duration plus four hours with a maximum of 23 hours.

A 151 by 151 transport grid is overlayed on the 17 by 19 wind field grid. The center of the grid is located at (76.0, 76.0). The transport grid unit size is 0.5 km for a local calculation, and 5.0 km for a regional calculation (the wind field grid unit size is 40.0 km). The horizontal components of the wind field (u, v) are linearly interpolated in two dimensions onto the transport grid. This enables the location of each puff to be identified on the transport grid.

The wind components are found for the current hour and the next hour. A time interpolation for the current time step is then performed. This is done for each puff at each time step.

RADIOACTIVE DECAY AND INDIVIDUAL DOSE ESTIMATES

General

Instantaneous concentrations are calculated for each puff at each time step. Doses are then calculated for each grid point on a polar grid which is (360 degrees by 300 km). Doses are also calculated at puff center locations for specified radial distances from the source (every 2 km for a local calcula-

tion; every 20 km for a regional calculation). The maximum dose at each of these distances is reported on output as the centerline maximum. In addition, the doses for every 1 km (every 10 km regional) are reported for each of the 16 sectors beginning with the north sector. Graphics in the form of isopleths at the ground level overlayed with the location of the centerline maximums are also part of the output. An example of the graphical output from 2DPUF is shown in Figure 4.

ICRP 30 Dose Factors for Individuals

The "effective dose equivalent" equates organ doses to an equivalent total body dose. The effective dose equivalent is the sum of the product of individual organ doses and organ weighting factors. The effective dose equivalent dose factors (DSF) are the 50 year dose commitment factors for an active man based on Department of Energy-published ICRP 30. The breathing rate (BR) is $3.81\text{E-}04 \text{ m}^3/\text{s}$.

The DSF and DSF x BR are given in Table 1 below. HTO includes absorption through the skin. HT is the dose factor based on the lungs as critical organs to keep from submersion. Breathing rate is not considered in deriving dose factors for elemental gas. The dose is calculated as

$$\text{DOSE (x,y)} = X(x,y) \times \text{DSF} \times \text{BR} \times \text{DEL T} \times N$$

where:

DOSE (x,y) = whole body ground level dose at (x,y) [rem]

X (x,y) = ground level concentration of radionuclide [Ci/m³]

DSF = 50 year whole body dose commitment factor [rem/Ci]

BR = active adult breathing rate [m³/s]

DEL T = model time step [s]

N = number of time steps between calculation

Table 1

<u>Radioisotope</u>	<u>Dose Factor</u> <u>DSF x BR</u> <i>(rem/Ci)(m3/s)</i>	<u>Half Life</u>		<u>Critical Organ</u>
		<i>(S)</i>	<i>(y,d,h)</i>	
1 Pu-238	1.75E05	2.77E09	87.7 y	bone surf.
2 Pu-239	1.94E05	7.60E11	24100 y	bone surf.
3 Cf-252	4.95E04	8.33E07	2.64 y	lungs
4 Cm-244	1.03E05	5.71E08	18.11 y	bone surf.
5 Co-60	5.71E01	1.66E08	5.27 y	lungs
6 HTO	3.62E-2	3.89E08	12.33 y	soft tissue
7 HT	1.22E-6	3.89E08	12.33 y	lungs
8 I-130	9.53E-1	4.45E07	12.36 h	thyroid
9 I-131	1.22E01	6.95E05	8.04 d	thyroid
10 I-132	1.26E-1	8.24E03	2.29 h	thyroid
11 I-133	2.06E00	7.49E04	20.8 h	thyroid
12 I-135	4.19E-1	2.38E04	6.6 h	thyroid
13 Ru-103	2.97E00	3.40E06	39.4 d	lungs
14 Ru-106	1.68E02	3.18E07	368 d	lungs
15 Cs-137	1.22E01	9.51E08	30.17 y	LLI wall
16 Sr-90	4.95E01	9.15E08	29 y	lungs

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Figure 1. The Effect of Wind Changing with Time on a Sequence of Puffs

Figure 2. Regional Domain for 2DPUF

Figure 3. 2DPUF Module Flow Diagram

Figure 4. Graphical Output from 2DPUF for a One Hour Release of HTO
(10,000,000 Ci)

13-JUN-91 2-D SEQUENTIAL PUFF MODEL 11:48 AM DT

HTO DOSE #
TOTAL DOSE #
K AREA 6/13/91
REL. START 11:45AM
REL. END 12:45PM

TV

MAXIMUM DOSES *

DIST. DOSE
(MI) (MREM)

1	1.3E+03
2	3.7E+02
3	1.8E+02
4	1.1E+02
5	7.9E+01
6	6.4E+01
7	5.4E+01
8	4.6E+01
9	4.1E+01
10	3.7E+01
12	3.1E+01
14	2.7E+01
16	2.3E+01
18	2.0E+01
20	1.8E+01

ISOPLETHS (MREM)

—	2.0E+02
---	5.0E+01
----	1.0E+01
-----	8.0E-01
-----	1.0E-02

EFFECTIVE DOSE EQUIVALENT FROM PLUME
SHINE AND/OR INHALATION

Appendix A: Dispersion Equations for a Gaussian Puff

The model 2DPUF simulates a prolonged release to the atmosphere by a series of discrete puffs released sequentially. Following Gifford's example, as discussed in Pasquill,² the shape of the concentration distribution within each puff is assumed to be gaussian.

$$X = \frac{Q}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp \left(-\frac{(x-x')^2}{2\sigma_x^2} - \frac{(y-y')^2}{2\sigma_y^2} \right) \times \left\{ \exp \frac{-(z-z')^2}{2\sigma_z^2} + \exp \frac{-(z+z')^2}{2\sigma_z^2} \right\}$$

The final term in the equation is an image term that accounts for the reflection of the puff at the ground.

The puff center location (x', y', z') is a function of time. The horizontal position of each puff is determined by the trajectory of each puff,

$$x' = \bar{U} \times t \quad y' = \bar{V} \times t$$

where $\bar{U}$ and $\bar{V}$ represent the mean wind components.

For an effective release height of h , and assuming no vertical motion for the center of the puff, z' may be replaced by h in the above equation. The concentration (or dose) at the ground ($z=0$) is then given by:

$$X = \frac{2Q}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp \left(-\frac{(x-x')^2}{2\sigma_x^2} - \frac{(y-y')^2}{2\sigma_y^2} \right) \times \exp \frac{-h^2}{2\sigma_z^2}$$

If horizontal dispersion is assumed to be symmetric (i.e., $\sigma_x = \sigma_y = \sigma$), then:

$$X = \frac{2Q}{(2\pi)^{3/2} \sigma^2 \sigma_z} \exp \left(-\frac{d^2}{2\sigma^2} - \frac{h^2}{2\sigma_z^2} \right)$$

where $d = [(x-x')^2 + (y-y')^2]^{1/2}$ is the lateral distance from the center of the puff.

The ground level concentration (or dose) at the center of the puff is given by:

$$X = \frac{2Q}{(2\pi)^{3/2} \sigma^2 \sigma_z} \exp \left(-\frac{h^2}{2\sigma_z^2} \right)$$

Expressions for σ and σ_z are given in the "Dispersion Parameters" section of this report.

Appendix B: Upper Limit For Vertical Dispersions

The top of the mixed layer retards vertical dispersion of airborne pollutants. To prevent σ_z from growing to unrealistic values, an upper limit is placed on its value. It is assumed that when σ_z grows to 80% of the mixed layer depth (H), the puff is uniformly mixed over the mixed layer depth and σ_z remains constant. This restriction on σ_z is obtained in the following manner:

For a uniform distribution vertically between 0 and H, and a gaussian distribution horizontally,

$$X = \frac{Q}{2\pi \sigma_x \sigma_y H} \exp \left(-\frac{(x-x')^2}{2\sigma_x^2} - \frac{(y-y')^2}{2\sigma_y^2} \right)$$

Since the concentration is uniform vertically, the ground level concentration for the surface reflected gaussian puff can be equated to the above concentration to obtain a relation for σ_z involving H and the release height h.

$$\sigma_z = \frac{2}{\sqrt{2\pi}} H \exp \frac{-h^2}{2\sigma_z^2}$$

For $h/\sigma_z \ll 1$, $\sigma_z = 0.798 H$. In other words, when $\sigma_z = 0.798 H$, the ground level concentration in the reflected gaussian puff is approximately equal to the concentration in a vertically homogeneous mixture.

Appendix C: NWS Stations Providing SAOs and SGLs for 2DPUF

The 12 stations supplying SGLs are:

Athens, GA (AHN)
Waycross, GA (AYS)
Charleston, SC (CHS)
Greensboro, NC (GSO)
Hatteras, NC (HAT)
Centreville, AL (CKL)

Apalachicola, FL (AQQ)
Cape Canaveral AFS, FL (XMR)
Eglin AFB, Valparaiso, FL (VPS)
Tampa Bay-Ruskin, FL (TBW)
West Palm Beach, FL (PBI)
Nashville, TN (BNA)

The 66 stations supplying SAOs are:

Albany, GA (ABY)
Alma, GA (AMG)
Athens, GA (AHN)
Atlanta, GA (ATL)
Augusta, GA (AGS)
Brunswick, GA (SSI)

Columbus, GA (CSG)
Rome, GA (RMG)
Savannah, GA (SAV)
Valdosta, GA (VLD)
Warner Robins AFB, Macon, GA (WRB)

Anderson, SC (AND)
Beaufort MCAS, SC (NBC)
Charleston, SC (CHS)
Columbia, SC (CAE)

Florence, SC (FLO)
Greer, SC (GSP)
Myrtle Beach, SC (MYR)
Shaw AFB, Sumter, SC (SSC)

Asheville, NC (AVL)
Charlotte, NC (CLT)
New Bern, NC (EWN)
Fayetteville, NC (FAY)
Greensboro, NC (GSO)

Hatteras, NC (HAT)
Hickory, NC (HKY)
Raleigh-Durham, NC (RDU)
Rocky Mount, NC (RWI)
Wilmington, NC (ILM)

Bristol, TN (TRI)
Chattanooga, TN (CHA)
Crossville, TN (CSV)

Knoxville, TN (TYS)
Nashville, TN (BNA)

Birmingham, AL (BHM)
Dothan, AL (DHN)

Huntsville, AL (HSV)
Montgomery, AL (MGM)

Avon Park AUX AFB, FL (AGR)
Cape Canaveral AFS, FL (XMR)
Crestview, FL (CEW)
Cross City, FL (CTY)

Orlando, FL (MCO)
Orlando, FL (ORL)
Patrick AFB, Cocoa, FL (COF)
Panama City, FL (PFN)

Daytona Beach, FL (DAB)
Eglin AFB, Valparaiso, FL (VPS)
Fort Myers, FL (FMY)
Gainesville, FL (GNV)
Homestead AFB, FL (HST)
Jacksonville, FL (JAX)
Mary Esther, FL (HRT)
Melbourne, FL (MLB)
Miami, FL (MIA)
NASA Shuttle Landing Facility,
Titusville, FL (X68)

Pensacola, FL (PNS)
Pensacola NAS, Milton, FL (NPA)
Sanford, FL (SFB)
Sarasota/Bradenton, FL (SRQ)
Tallahassee, FL (TLH)
Tampa, FL (TPA)
Tyndall AFB, Panama City, FL (PAM)
Vero Beach, FL (VRB)
West Palm Beach, FL (PBI)
Whiting Fields NAS, FL (NSE)

Appendix D: Description of 2DPUF Subroutines

2DPUF_MAIN.FOR

The main program for 2DPUF code. It determines terminal type and calls subroutines TWOD_INPUT (data input), GWINDS (wind field calculation), and TWODPUF (trajectory and dose calculations).

2D_INPUT.FOR (Subroutine TWOD_INPUT)

Primary subroutine for user to interactively input data about the release: time (start and end); height; location; radioisotope; source term; whether *local* or *regional* calculation is needed; duration of model calculation; whether automatic, latest, canned, or manual winds. All of this is required by TWODPUF and GWINDS. TWOD_INPUT calls PUFFIN and WINDAT to obtain input information, SAM winds (or local area winds), and determines release time and calculation time. The information is written into a file for GWINDS and TWODPUF programs.

PUFFIN.FOR

Subroutine to obtain information interactively for TWOD_INPUT. The input case data is release time (start and end); height; location; radioisotope; source term; whether *local* or *regional* calculation; duration of model calculation; whether automatic, latest, canned, or manual winds. From this information the grid coordinates and latitude or longitude are determined, the duration of the calculation, as well as the correct dose factors, and half-life obtained.

WINDAT.FOR

Calls SAMDAT and reads the MOS file (mosout.dat) for 24 hours of local tower wind data including past, present, and forecast starting with the start time of the release. Forecast and tower (SAM) data are smoothly merged by a call to subroutine SMTH. If canned wind data is to be used, then WINDIN is called to read the appropriate data file. Canned data files are also created in WINDAT by a call to WINDIN. WINDAT calculates the mixed depth for each hour: the larger of $125 \times \text{SPD}$ (in m/s), and hourly climatological values. The total calculation time, *icaldur*, is calculated in this subroutine.

SAMDAT.FOR

SAMDAT returns observed data up through the current hour. Past data is hourly to the nearest 15 minutes. Current data is hourly using the last 4 x 15 minute averaged data. Maximum data returned is 24 hours. SAMDAT uses Wind Archive System routines ARCGET and SAMGET to obtain on-line archived tower data. *However, the requested data time period is not checked to ensure it is contained within the online records.* This can lead to incorrect data being obtained.

SMTH.FOR

This subroutine smooths the data in transition from observed to forecast information. Two different weighting factors are used depending on the number of forecast points in the met data arrays used to

fill the arrays after the observed data is entered. If there are at least three forecast points the weighting factors are 0.25 and 0.5. The equations for smoothing are:

$$x(l)=0.5xx(k)+0.25xx(l)+0.25xx(n)$$
$$x(m)=0.25xx(k)+0.25xx(m)+0.5xx(n)$$

where

- k - is the last piece of observed data
- l - is the 1st piece of forecast data
- m - is the 2nd piece of forecast data
- n - is the 3rd piece of forecast data.

If there are less than 3 pieces of forecast data the weighting factors are 0.33 and 0.67. The equations for smoothing are

$$x(l)=0.67xx(k)+0.33xx(l)$$
$$x(m)=0.33xx(k)+0.76xx(m)$$

where

- k - is the last piece of observed data
- l - is the 1st piece of forecast data
- m - is the 2nd piece of forecast data

WINDIN.FOR

This module reads a file of "canned" data (stored in metric units), or allows manual input of wind data in either English or metric units. Section 1 reads a data file; Section 2 prompts and accepts data for up to 24 hours.

MDYJUL.FOR

Convert MO-DY-YR to a Julian sequence number.

GWINDS.FOR

Reads 24 hours of local wind data, release time, calculation duration, etc., from a file written in TWOD_INPUT. It then calls GWINDS2 to create a gridded wind field.

GWINDS2.FOR

If uniform TWOD wind field based on the 24 hour SAM/MOS wind is desired, GWINDS2 simply calls MAKEUNIF to create this field and then returns to 2DPUF_MAIN.

If a regional wind field based on SAOs and SGLs is desired, then SGLDAT and SFCDAT are called to obtain this data. The start time for collecting the SGL data is determined by a call to MDZCALC. Time and vertical interpolation of the SGL data are produced by calls to TIMINT and VINT respectively. Data checks are made in TIMINT for the SGLs and MISSFC for the surface data. The subroutine PASQUILL is called to obtain 100 m wind speed from the 10 m surface velocities.

Using the above NWS site data, a three-dimensional wind is created by an exponentially weighted interpolation procedure in the subroutine OBJ. This wind field will be defined on a grid centered at SRS's center with latitude-longitude coordinates of (33.2514, -81.6250), or optionally, at a user defined location. The grid is 640km west to east by 720km south to north. In metric units it is a 17 by 19 grid with grid blocks of approximately 40km by 40 km. The lower left corner has coordinates (1,1) with x increasing to the right (west to east) and y increasing up (south to north). Eleven levels in the vertical are created.

Finally, the subroutine TPORT is called to produce a vertically averaged TWOD wind field for use in the transport calculations and for plotting in PLOTMEAN.

MAKEUNIF.FOR

This program creates a wind field for a regional study based on local winds (i.e., automatic SRS winds, manually input local winds, or canned local winds). It may be used when no SGL data is available for a study, or if local winds are desired for the entire region.

MDZCALC.FOR

MDZ_CALC is the first hour of 24 hours for which SGL and SAO data is collected for generating a regional gridded wind field. This variable must end in 00 or 12 in order to be compatible with SGL sounding times. It must also be at least 25 hours prior to the current time.

SFCDAT.FOR

This routine gets the AFOS surface data (10m NWS) for the period of interest from online files.

MISSFC.FOR

This subroutine checks for periods of missing surface data and replaces missing values with estimates by one of three methods as follows:

1. If data is missing at the beginning (or end) of the time period of interest, the first (or last) available data is used to replace the missing data.
2. Linear interpolation is used to determine values to replace missing data if only two observations are available surrounding the period of missing data.
3. Time using a quadratic is used to determine values if enough data is available surrounding the time period of missing data.

TIMINT.FOR

TIMINT is designed to perform a quadratic time interpolation of sounding data for each of three z-times and up to 12 stations. It also checks for and flags missing SGL data.

TPORT.FOR

This calculates a vertically averaged two-dimensional transport wind field from the three-dimensional field created in OBJ. The U and V components are linearly interpolated to the midpoint of adjoining levels, and the result is weighted by the vertical displacement between the two levels in the averaging calculation.

VINT.FOR

VINT performs a vertical interpolation of irregularly spaced data for each sounding to obtain regularly spaced data at 10 levels up to 2000m.

PASQUILL.FOR

This routine will modify wind speeds according to the Pasquill classification of atmospheric stability using the "power law" relationship:

$$U(z)=U(z_0) \times (z/z_0)^P$$

LOCAT.FOR

This subroutine provides the latitude and longitude values for the reporting stations, both surface and upper air, for the automatic wind input.

STIME.FOR

Subroutine to perform a quadratic time interpolation of surface data.

OBJANAL.FOR (Subroutine OBJ)

Interpolates SAO and SGL data to a THREED wind field grid (17 by 18 by 11). The interpolation is exponentially weighted by the square of the distance between the grid point and the data point.

GETLATLONG.FOR

Subroutine to return the three-letter ID of the desired met station and the latitude and longitude coordinates of the station.

SGLPRT.FOR

This is the diagnostic routine to dump SGL data at any point in program.

SGLDAT.FOR

SGLDAT.FOR is in [AFOS_PROJ.SRC.PROJ.LIBRARY]

This routine places three periods of SGL data for 12 stations in large arrays, and returns them in a common block. Arrays NTEMP and NWIND will be 0 for a particular station and period if data is

not available. For example, if $NTEMP(2,1) = NWIND(2,1) = 0$, then no AHN data (see Appendix C) was stored for the second period.

Data is collected from the starting period (MMDDZZ) specified by the calling program, and must end in either 00 or 12. Data arrays are structured as follows:

VARIABLE (Period, Station, Observation)

3 periods: MMDDZZ, MMDDZZ + (1 period), MMDDZZ + (2 periods)

12 stations:	1 = AHN	2 = AYS	3 = CHS	4 = HAT
	5 = GSO	6 = BNA	7 = AQQ	8 = CKL
	9 = VPS	10 = PBI	11 = TBW	12 = XMR

32 observations maximum for each variable, period, and station.

SAODAT.FOR

SAODAT.FOR is in [AFOS_PROJ.SRC.PROJ.LIBRARY]

SAO data is received from AFOS by program AFOSRD and decoded and written into a data file SAO.DAT by subroutine SAOSUB. Subroutine SAODAT places pressure, temperature, dewpoint, wind direction and speed, and decimal station coordinates for all stations in a COMMON buffer which can be accessed by calling programs. The arrays returned in the COMMON block contain this information for xx stations for a 13 hour span beginning with the MMDDZZ time specified by the user. It also contains the latitude and longitude of the surface stations.

2DPUF.FOR (Subroutine TWODPUF)

This subroutine is the main program for trajectory, dispersion, and dose calculations. SAM is called to perform the analysis, print the input, model output data, and plot the plume. If the release is a regional calculation, PLOTMEAN is called to plot the mean transport wind field, and the soundings, if desired.

PLOTMEAN.FOR

PLOTMEAN is the routine to plot the TWOD wind field produced in either MAKEUNIF or TPORT for the start, middle, and end of the study period.

SAM.FOR

The subroutine SAM creates the puffs and calculates their trajectories. Information for this calculation (and others) is obtained by reading data files created in TWOD_INPUT and GWINDS2. The subroutine READ_INPUT performs this function. The initial conditions (radius, location and total material) are set, and then the puffs are advected by linearly interpolated winds. The time step is varied from one to five minutes over the first seven hours, and remains five minutes thereafter. The location of each puff center along with σ (horizontal) and σ_z are stored at each time step. With this

information, NEWCALC is called to calculate the dose at each point on a radial grid centered at the release location. The grid points on the radial grid (360 deg by 1 km) are calculated in terms of the transport grid by the subroutine XYPTS. In addition, an "effective" centerline dose is computed by calls to CENTERLINE_DOSE and MAX_DOSE. Calls to PRINT_INPUT, NEWTBL and MAX_LIST produce hard copy of the input information, dose information on the polar grid (sectors), and centerline doses, respectively. Finally, CONTOUR_VALUES and POLAR_CONTUR are called to determine and plot five dose contour levels.

READ_INPUT.FOR

This routine is called by SAM to read input information and data from files created by 2D_INPUT and GWINDS (for regional calculations).

PUFFS.FOR

PUFFS is the subroutine to calculate puffs per hour, total number of puffs, fraction of an hour for any time over an integer number of hours from the release time, and the number of puffs released during this fraction of an hour. This subroutine is called by SAM.

INTERP.FOR

INTERP performs both a spatial and time interpolation of wind components from the mean wind field grid (17 by 19) to a given puff center location. The spatial interpolation involves the four wind field grid points nearest the puff location. The time interpolation involves the two hourly wind field values encompassing the current integration time. Both interpolations are linear.

RGNL_CENTERLOCS.FOR/CENTERLOCS

These are the routines to determine the intersection of each puff trajectory with a set of specified radial distances from the release location. RGNL_CENTERLOCS is called if the scope of the calculation is regional, and CENTERLOCS if the scope is local. For a regional calculation the radial distances are 20 to 300 km. in increments of 20 km. For a local calculation the radial distances are 2 to 30 km in increments of 2 km.

CENTERLINE_DOSE.FOR

For each individual puff trajectory, this routine calculates the dose along the trajectory (15 fixed radial distances) due to *all* puffs. The radial distances are from 2 to 30 km in increments of 2 km for a local calculation, and 20 to 200 km in increments of 20 km for a regional calculation.

NEWCALC.FOR

This calculates doses at grid points on a radial grid centered at the release point. The grid points are defined by the intersection of each M degree and N km radius, where M=1 to 360 and N=1,2,3,—,30 (local) or 300 (regional). The calculation is actually done over all puffs at each time step, evaluating the dose only at those grid points within 3σ of each puff center. The resulting spatial dose distribution is then contoured in POLAR_CONTUR.

POPDOSE.FOR

POPDOSE reads a population table for a polar grid centered at the release point and calculates average individual doses corresponding to the given population zones. The product of population and individual dose is then formed and presented in tabular form. POPDOSE is called from SAM and reads a population file named POPxx.DAT, where x denotes the letter of the release point. The results are stored in a concise tabular form in a file named POPDOSE.DAT

MAX_DOSE.FOR

MAX_DOSE takes the centerline doses at each specified radial distance (see CENTERLINE_DOSE) and finds the maximum dose. For each radial distance the maximum dose is saved and returned to the calling program, SAM. These are considered the maximum centerline doses which are printed out as hard copy, and the locations are overlayed on the isopleths of dose for the graphic output.

PRINT_INPUT.FOR

This subroutine prints the input information and makes hard copies. PRINT is called from SAM.

NEWTBL.FOR

NEWTBL is a subroutine designed to determine the maximum dose in each of 16 sectors at various radial distances from the grid's center. The center defaults to latitude-longitude coordinates for the release site. The sectors are the 16 compass directions—N, NNE, NE, ENE, ..., NNW. NNE is sector one at 22.5 degrees. Zero degrees is due north. For each radial distance the doses at each degree line within the sector are compared to obtain the maximum dose. Doses in array dose are from the release site out to 300 km in increments of 1 km each. If the desired output is English, a linear interpolation to the mile distances is done.

MAX_LIST.FOR

MAX_LIST makes a hard copy of the maximum centerline doses and the radial distances from the release site. These distances are straight line distances *not* downwind distances.

XYPTS.FOR

This calculates transport grid coordinates for the polar coordinate positions of the dose array.

CONTOUR_VALUES.FOR

The CONTOUR_VALUES subroutine determines contour values based on the individual doses. Five contour levels are chosen. The largest contour value is generally chosen to be a significant fraction of the maximum grid point dose. The other four values are a progressive order of magnitude lower. This procedure is quite arbitrary and can easily be changed by the user.

POLAR_CONTUR

This draws contours of spatial dose distribution calculated in NEWCALC. These contours are drawn on a background map, which is produced by a call to PLOT2D. All plotting is done in a Lambert coordinate system. These coordinates are obtained by calls to CONPROJ. Graphics are produced by Tektronix IGL commands.

CONPROJ.FOR

CONPROJ converts locations on the appropriate transport grid to latitude and longitude coordinates, and then to Lambert meters by a call to subroutine LAMBERT_LAT_LON_EASTING. These coordinates are used for plotting dose contours in POLAR_CONTUR.

PLOT2D.FOR

This subroutine is used for plotting the background map and setting graphics parameters for the dose contours plotted in POLAR_CONTUR.

END

**DATE
FILMED**

4/22/92