MISSISSIPPI POWER & LIGHT COMPANY
Helping Build Mississippi
P. O. BOX 1640, JACKSON, MISSISSIPPI 39205

September 28, 1981

NUCLEAR PRODUCTION DEPARTMENT

U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, D.C. 20555

Attention: Mr. Harold R. Denton, Director

Dear Mr. Denton:

SUBJECT: Grand Gulf Nuclear Station
Units 1 and 2
Docket Nos. 50-416 and 50-417
File 0260/3700
GGNS Class A Model
AECM-81/350

Mississippi Power & Light Company (MP&L) submitted a preliminary description of the Grand Gulf Nuclear Station (GGNS) Backup Meteorological System and Class A Model to the Commission by letter AECM-81/103, dated April 10, 1981. In response to the requirements of NUREG-0737 and NUREG-0654, we are now submitting a more detailed description of the Class A Model that will be utilized at GGNS.

Our current plans call for both the Backup Meteorological System and the Class A Model to be operational on or before October 1, 1982. In the event these two systems are not operational prior to fuel load (currently scheduled for December 31, 1981), the compensating actions required by NUREG-0654, and outlined in letter AECM-81/327, dated August 28, 1981, will be implemented until these systems are operational.

Since preliminary design work on the Class A Model has been complete, and the actual development of the Model is now imminent, please provide us with your comments, if any, as soon as possible. If you have any questions concerning this information, please contact this office.

Yours truly,

L. F. Dale
Manager of Nuclear Services

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GOS/LRM/JDR:lm
Attachment

cc: (See Next Page)

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cc: Mr. N. L. Stampley
Mr. G. B. Taylor
Mr. R. B. McGehee
Mr. T. B. Conner

Mr. Victor Stello, Jr., Director
Office of Inspection & Enforcement
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

GRAND GULF NUCLEAR STATION

CLASS A MODEL

FOR THE

EMERGENCY RESPONSE FACILITY INFORMATION SYSTEM

SECTION 1.0
INTRODUCTION

A Class A atmospheric dispersion model is appropriate for use in estimating plume behavior for the first 10 miles of the Emergency Preparedness Zone (EPZ). It provides dosage estimates and a plume characterization (including plume dimensions and locations, magnitude of and arrival time of peak relative concentrations) within the EPZ or for travel periods of three hours.

The approach used by the Grand Gulf Nuclear Station (GGNS) is to develop the model in modular form running on a real time basis with a batch processing program to provide periodic reports from archived data. The model consists of a sampling and activation module, an accidental release module, and a display module and will be integrated to the existing Emergency Response Facility Information System (ERFIS) as shown in Figure 1.

This model will supply meaningful data to control room personnel within 15 minutes of an alert to aid in responding to the emergency situation. Additionally the model will perform a simple validation of the meteorological input data and alert the operators of a possible meteorological tower malfunction.

Calculations will be performed by using a puff advection model for atmospheric dispersion and standard dosage equations for radiological dose assessments. The approach is to use the primary meteorological tower to characterize site meteorology with the puff advection model to provide a realistic dispersion estimation of effluents released from the GGNS. This model will be made site specific by:

- o incorporating the split sigma approach,
- o using site specific power laws to estimate missing wind speeds,
- o applying an approach for using σ_θ under stable conditions and light winds,

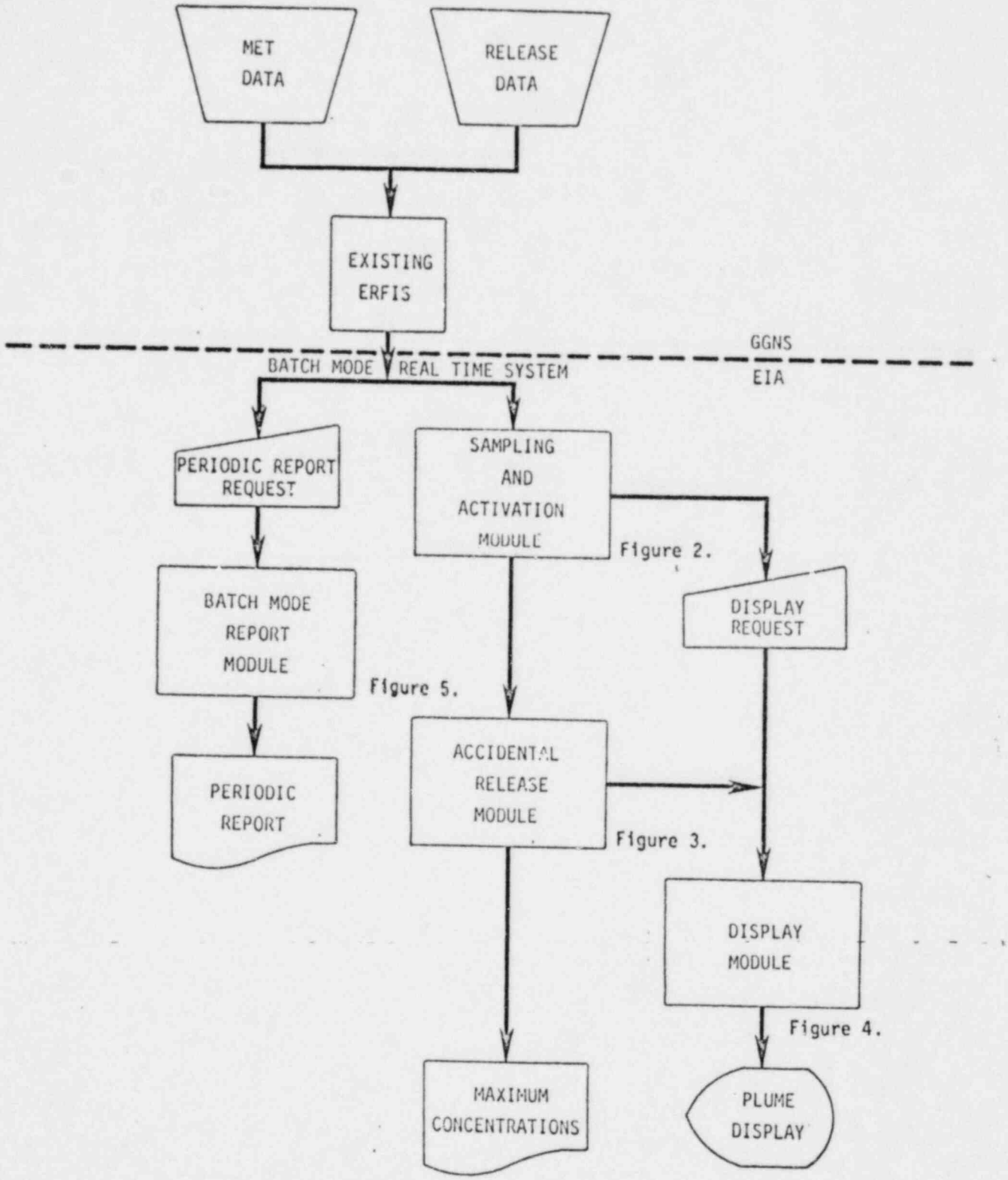

Figure 1. Upper Tier Representation of the Proposed System

- incorporating site specific building wake parameters and source characteristics.

The puff model is discussed in more detail in Section 3.0.

All dosage calculations will be based on standard equations. However the whole body dose rate calculations will be performed by defining kernel functions allowing simple alegebraic solutions to complex integral equations. Likewise, skin immersion, inhalation and ground deposition calculations will be simplified computationally whenever possible. These equations are discussed in Section 4.0.

SECTION 2.0
GGNS' CLASS A MODEL FUNCTIONAL DESCRIPTION

The GGNS Class A model consists of three modules to monitor radiological releases and alert station personnel when limits are exceeded. In addition, one batch mode program to generate periodic reports will also be supplied. Functional flow charts of each module and the report generation program are shown in Figures 2 through 5. Each module and program is discussed below.

2.1 SAMPLING AND ACTIVATION MODULE

The function of this module is to sample and process both meteorological data and release data (i.e., raw or refined data used to determine the source term) and determine if an emergency situation exists.

It also allows for an 'on command' graphical display of a plume, resulting from either an actual release (not violating the criteria) or as input data to the system, without indicating an alert condition. Its functional form is shown in Figure 2.

This module continuously performs calculations to obtain 10-minute averages of the incoming meteorological data and 2- and 30-minute averages of the release data. Principal components of this module are subroutines which:

- Perform the meteorological data averaging
- Calculate running 2- and 30-minute averages of Q and χ/Q
- Check for site or general alert conditions as per NUREG 0654
- Calculate plume parameters for 'on command' graphical display (not alert status)

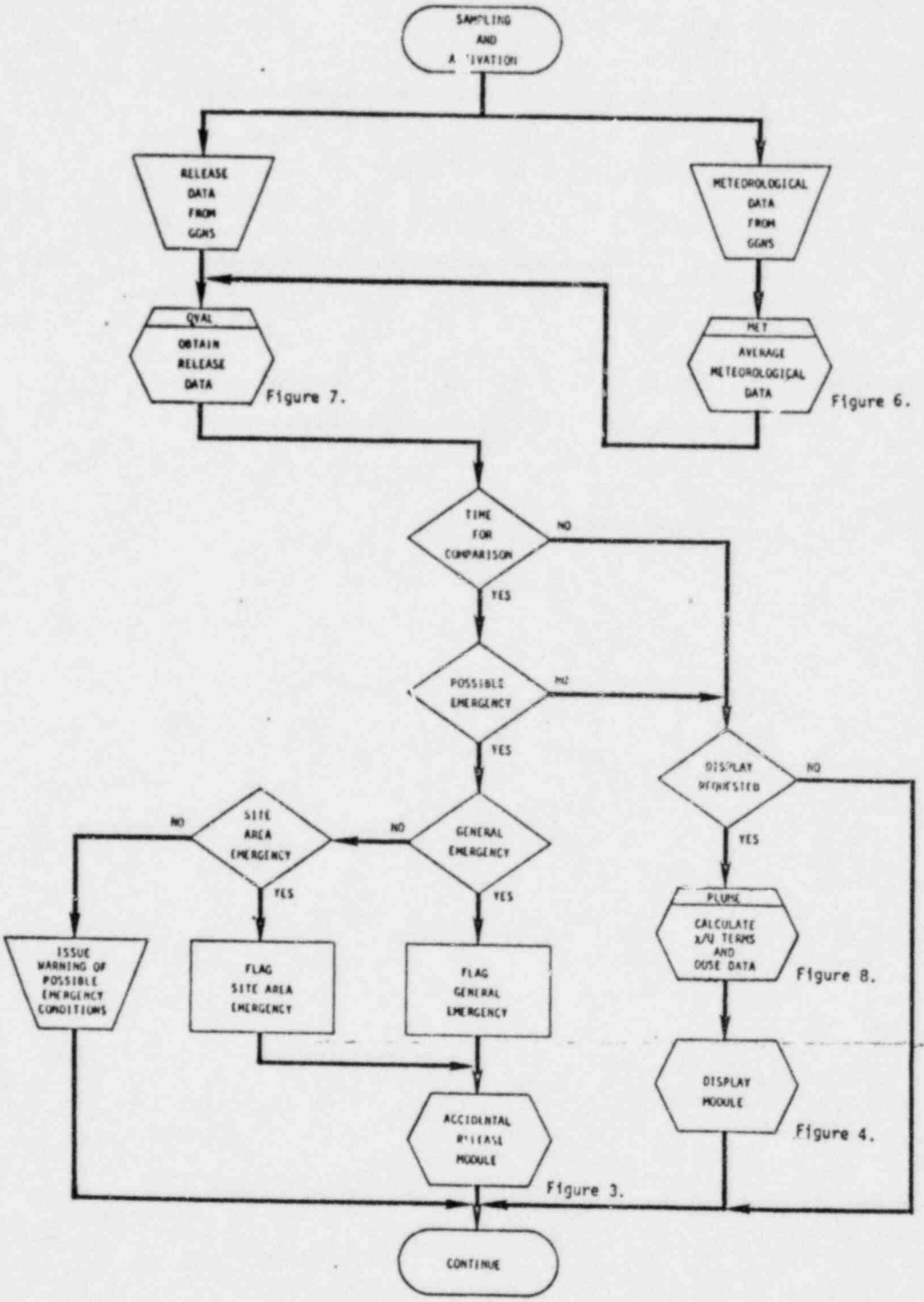

Figure 2. Functional Flowcha.. of the Sampling and Activation Module

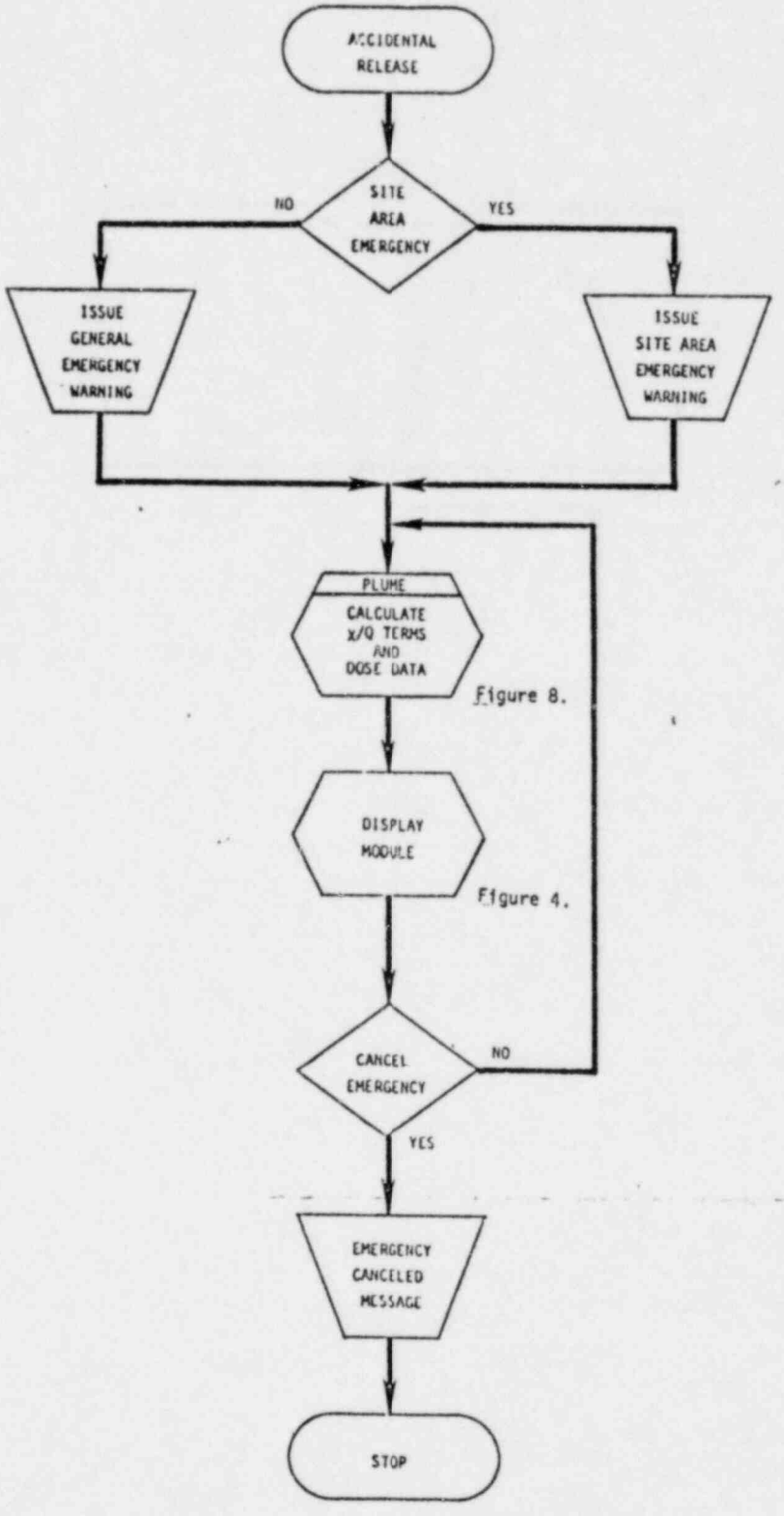

Figure 3. Functional Flowchart of the Accidental Release Module

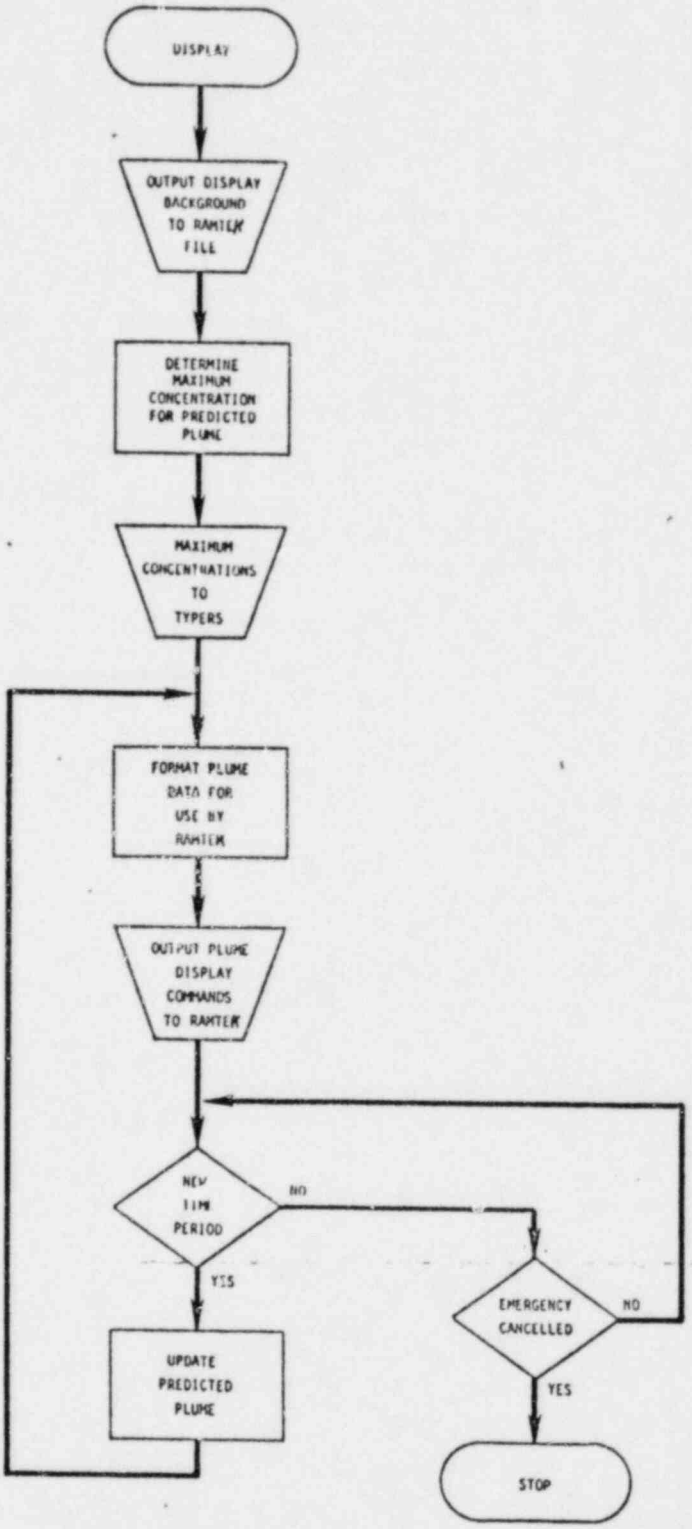

Figure 4. Functional Flowchart of the Display Module

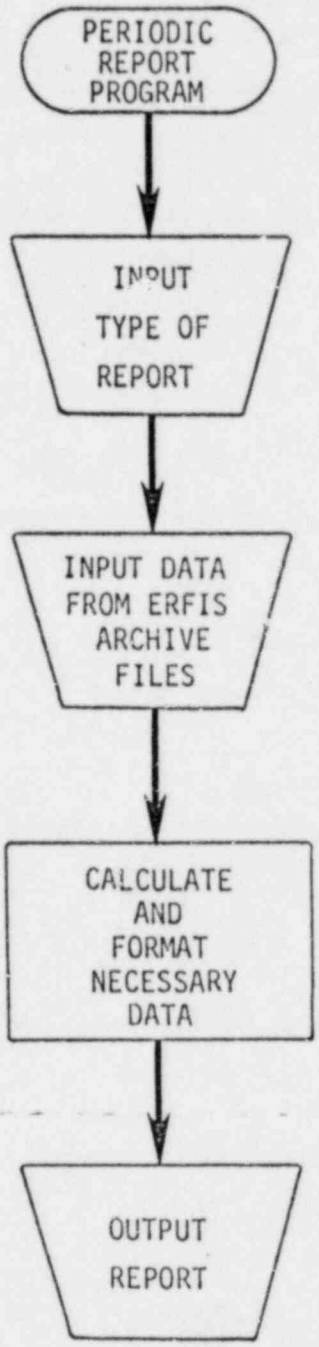

Figure 5. Functional Flowchart of the Batch Mode Periodic Report Program

To process the meteorological data a subroutine (Figure 6) continuously accepts this data from the existing ERFIS system and performs preliminary calculations in preparation for the 10-minute averages. Additionally, σ_θ is computed on a running 2-minute average based upon wind direction data.

Two checks are performed on this data to ensure proper operation of the system.

1. Check to assure a minimum sample size is used to calculate the 10-minute averages.

   - o If the test is failed, a missing data indicator is placed in the output file without notification to the plant operator.

   - o If the test is passed, the 10-minute averages are calculated for the meteorological data.

2. Comparison of all 10-minute meteorological averages with the average calculated for the preceding three hours.

   - o If no change has occurred, over the past three hours according to the limits set in Table 1, then the plant operator is notified that a possible malfunction exists at the meteorological tower.

   - o If a change has occurred, then update the 3-hour comparison parameter.

All meteorological data, whether missing, valid or invalid, is stored in a working file for three hours and updated once every 10 minutes. All data is flagged as to its validity and made available to the existing ERFIS data logging system as necessary.

In addition to the 10-minute meteorological data averages the sampling and activation module also computes a 2- and 30-minute averages of noble gas

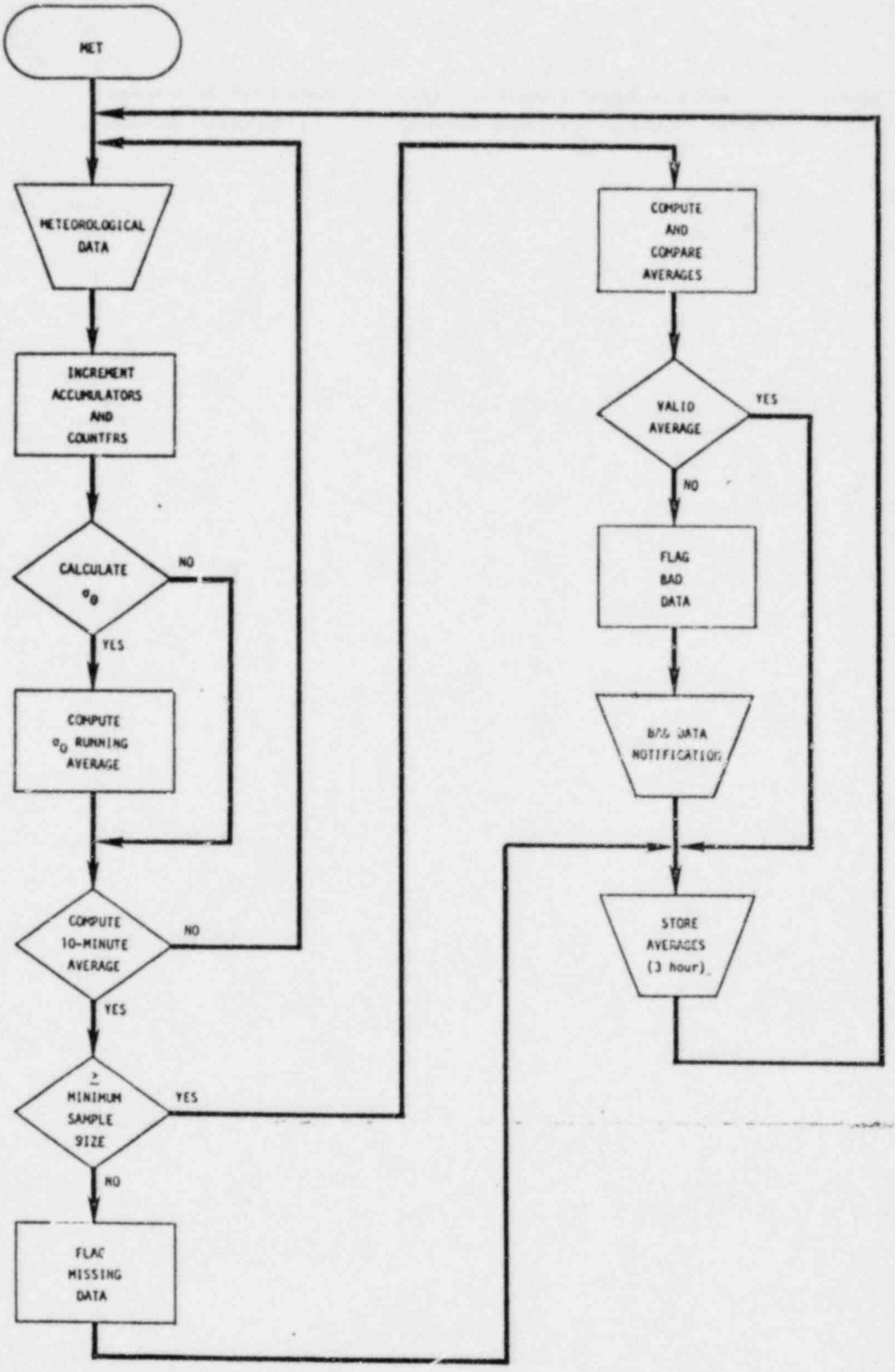

Figure 6. Functional Flowchart of the Meteorological Data Averaging Routine

TABLE 1

SPECIFICATIONS FOR METEOROLOGICAL DATA AVERAGING

Parameter	Sampling Frequency (seconds)	Minimum Number of Samples Required*	Averaging Time (minutes)	3-Hour Valid Average Limits of Variation
Wind Speed	5	32	10	±0.2 m/s
Wind Direction	5	32	10	±5°
Temperature	60	6	10	±0.5°C
Differential Temperature	60	6	10	±0.15°C
σ_θ	N/A	12**	2†	N/A

* Minimum number of samples required for each 10-minute period. They need not be consecutive samples.

** Minimum number of wind direction samples required.

† Computed as a 2-minute running average.

releases (using a fictional nuclide with a half-life of 30 minutes and $\bar{E}_\gamma$ of 0.8 MeV) via principal effluent pathways. This is depicted in Figure 7. These values are compared to predetermined criteria which serve as an indication of an emergency condition. Should these criteria be exceeded a possible site area emergency exists under adverse meteorology or the EPA Protective Action Guidelines are projected to be exceeded outside the site boundary. If this occurs, the offsite dose rate is calculated from the 2-minute emission rate averages and actual 10-minute average meteorology. This information is then passed back to the main routine of this module.

It should be noted that this subroutine uses real time meteorological and release (i.e., source term) data but has the provision of inputting projected release or meteorological data. This gives on-site personnel the capability of predicting dispersion of radionuclides due to controlled or uncontrolled releases with actual or predicted meteorology.

As shown in Figure 2 the final function performed by this module is to determine if an emergency exists. This is accomplished by:

1. Determining if the calculated dose rate using actual meteorology indicates a general emergency (1 rem/hr whole body or 5 rem/hr thyroid). If so, a general emergency is initiated by setting a software flag which indicates a general emergency and activates the accidential release module.

2. If there is no general emergency, then determine if EPA Protective Action Guidelines are projected to be exceeded or adverse meteorology (as per NRC) exists. If so, a site area emergency is initiated similar to the general emergency case.

3. If neither a site area nor general emergency is in progress but the criteria have been exceeded, then the conditions exist for these emergencies. Therefore, notify the operator that possible emergency conditions exist with the message:

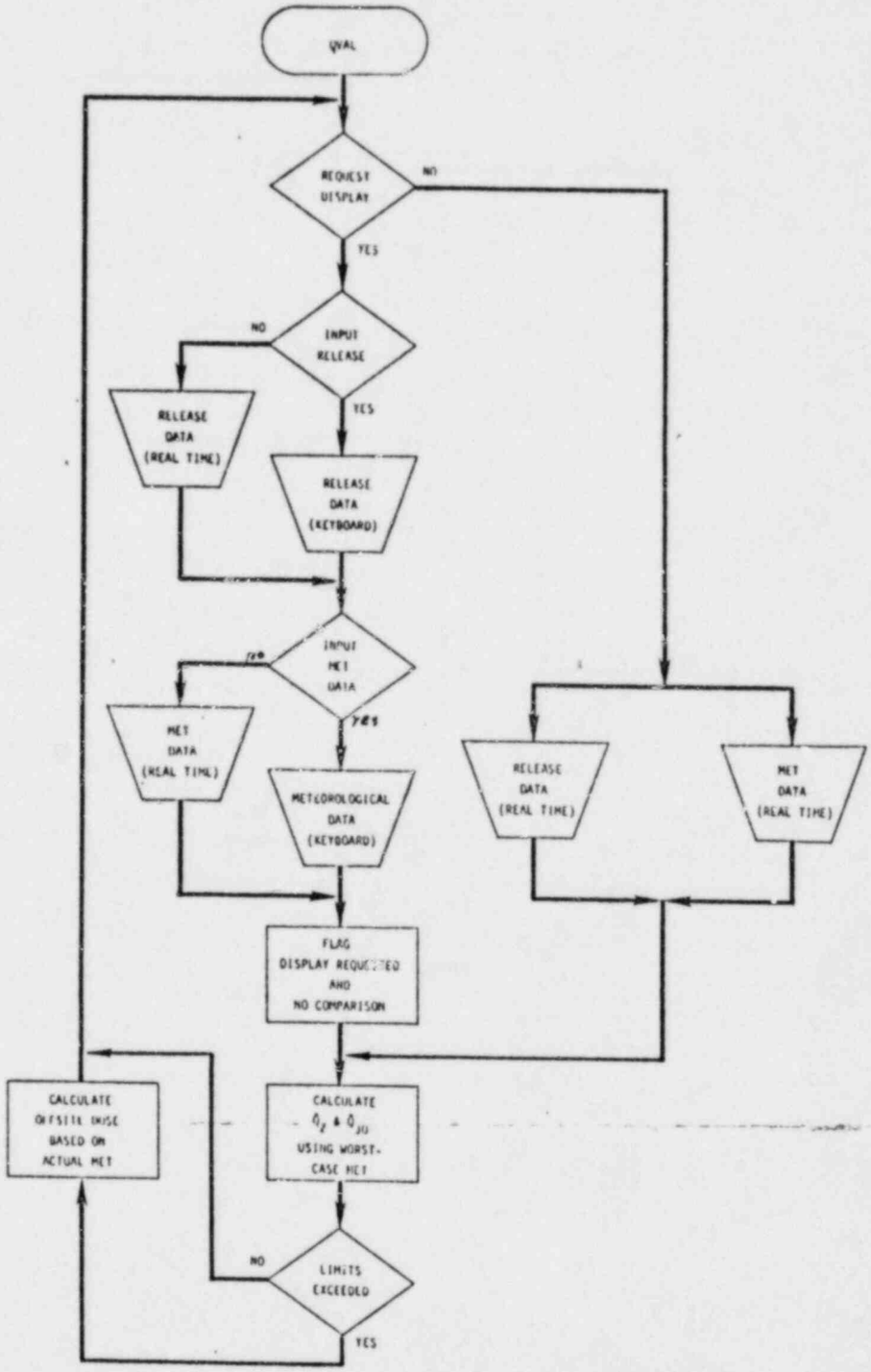

Figure 7. Functional Flowchart of the Emission Rate and Dose Calculation Routine

- WARNING: Conditions are conducive to causing a site area or general emergency.

This module then recycles for another 2-, 10- and 30-minute average calculation.

2.2 ACCIDENTAL RELEASE MODULE

The function of this module is to perform χ/Q calculations and radiological dose assessments through out the emergency situation.

The functional form of this module is shown in Figure 3 and its purpose is threefold:

1. To notify the plant operators that an emergency exists and to log the start and stop times (as well as maximum concentrations) on hard copy computer terminals.

2. Assess the plume dispersion pattern via a puff model and calculate the dosages for the isotopes listed in Table 2.

3. Activate the display module and supply it with updated information on plume dispersion and dosage.

This module is activated by the sampling and activation module and notifies the operators of the type of emergency condition and the maximum estimated concentration.

The principal component of this module is a subroutine (see Figure 8) which:

- Calculates the χ/Q values for the sector of interest using a puff model and on-site meteorology for 10-minute, 1-hour and 8-hour (using sector averages for 8 hours) time periods.

TABLE 2

LISTING OF RADIONUCLIDES TO BE CONSIDERED FOR THE GGNS

		Pathways Considered			
Type	Radionuclide	Whole Body	Skin Immersion	Inhalation	Ground Deposition
Noble gases	Kr - 83 m	x	x		
	Kr - 85 m	x	x		
	Kr - 85	x	x		
	Kr - 87	x	x		
	Kr - 88	x	x		
	Kr - 89	x	x		
	Xe - 131 m	x	x		
	Xe - 133 m	x	x		
	Xe - 133	x	x		
	Xe - 135	x	x		
	Xe - 137	x	x		
	Xe - 138	x	x		
	Fictional nuclide ($T_{1/2} \simeq 30$ min & $\bar{E}_\gamma = 0.8$ MeV)	x	x		
Iodines	I - 131	x	x	x	x
	I - 132	x	x	x	
	I - 133	x	x	x	
	I - 134	x	x	x	
	I - 135	x	x	x	
Telurium	Te - 132	x	x	x	
Cesium	Cs - 134				x
	Cs - 136				x
	Cs - 137				x
Strontium	Sr - 89				x
	Sr - 90				x

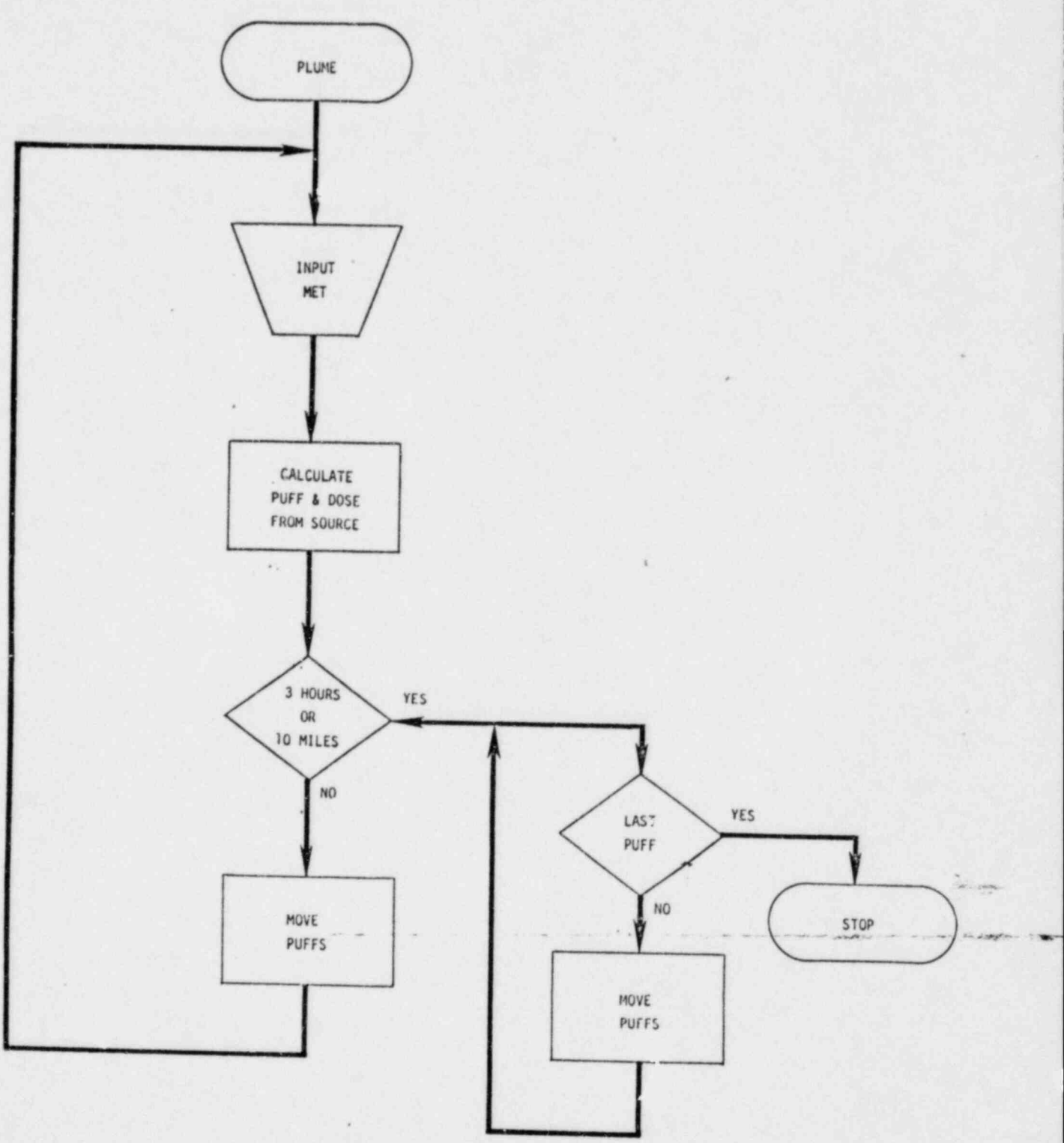

Figure 8. Functional Flowchart of the Plume Routine

- o Uses these values to determine:

  - whole body dose due to immersion in cloud. γ dose from noble gases and iodires;

  - skin dose due to immer ion in cloud. β dose from noble gases and iodines plus part of γ dose from noble gases and iodines;

  - inhalation dose due to immersion in cloud (iodine, tellurium and cesium doses to specific organs including thyroid, bone and lung);

  - whole body doses due to activity deposited on ground (iodines, telluriums and cesiums);

  - ground deposited concentrations of I-131, Cs-137, Sr-90 and Sr-89 for comparison with Protective Action Guideline's (PAG) for food pathway.

- o Constant tracking of puff to develop the plume dispersion pattern with updating calculations, whenever fresh data is available, for the duration of the emergency.

2.3 DISPLAY MODULE

This module (shown in functional form in Figure 4) acts as a formatting routine between the other modules and the RAMTEK video display unit. It is accessible to both the sampling and activation module in the 'on command' mode of operation and the accidential release module during emergency conditions.

Operational characteristics of this module include:

- o Creation of a file containing the required display information;

- Graphical map output of the area showing key landmarks and the plume for both 'time from emergency initiation' and predicted 1-, 2- and 3-hour (or 10-mile) plume travel;

- Selection of graphical display or tabular form of data for various radionuclides or pathways (whole body, skin dose, etc.). Tabular data includes a listing of radionuclides and their current emission rates or a listing of population centers (and other points of interest) and the predicted concentrations for 1-, 2- and 3-hour periods;

- Automatic updating of the graphical display during emergency conditions as new data become available.

2.4 BATCH MODE PERIODIC REPORT PROGRAM

This is a stand-alone program to be run whenever a report of either gaseous radioactive releases or meteorological data is required. Input data is taken from the archived files created by the existing ERFIS. The data is then processed to conform to the guidelines found in the US NRC Regulatory Guide 1.21. A functional flow chart of this program is shown in Figure 5.

SECTION 3.0
PUFF ADVECTION MODEL

This section provides detailed information on the proposed formulation of a puff advection model to be used in the Class A model for the Emergency Response Facility Information System at the Grand Gulf Nuclear Station. The puff advection concept is ideal for use in the Class A model for the following reasons:

1. It provides a realistic representation of the plume advection and diffusion processes in a variable meteorological field.

2. It retains a memory of plume history from one time period to the next.

3. It can easily be upgraded to a Class B model if necessary.

3.1 PUFF ADVECTION CONCEPT

The puff advection concept assumes that a continuous plume can be broken into an infinite number of individual puffs of infinitesimal source strength which have been serially released. The advection of the continuous plume is defined by the movement of each component puff. This movement is in turn controlled by a wind field which can vary in both time and space. Diffusion of the continuous plume is defined by the growth of each component puff. The concentration at a specific receptor point is obtained through the integration of the contribution of all puffs in the vicinity of the point.

Mathematically, the puff concept can be expressed as:

$$\chi(x_g,y_g,t) = \int_{-\infty}^{t} \chi(x_g,y_g,t,\tau)\, d\tau \qquad (1)$$

where $\chi(x_g,y_g,t)$ is the ground level concentration at a grid point with coordinates, (x_g,y_g), at time t, and $\chi(x_g,y_g,t,\tau)\,d\tau$ is the contribution of the puff released at time τ to this concentration.

The puff advection concept is typically implemented in models which make the following sequence of calculations:

1. puff release
2. puff advection
3. puff diffusion
4. calculation of concentration

In the past, the following two techniques have been used to implement the puff advection concept in nuclear applications:

1. the simulated release of individual puffs, and
2. the simulated release of plume segments.

In both techniques the release advection and diffusion processes are calculated by tracking individual puffs which are sequentially released. The basic difference between the two techniques lies in the calculation of the concentration field. A numerical integration (a sum of individual puff contributions) is used to calculate concentration in the first technique, while an analytical integration is used in the second technique.

EIA proposes to use simulated release of plume segments to implement the puff advection concept in the GGNS Class A model. The rationale for the decision is that plume segment method eliminates the need for the numerical integration and associated problems related to the impact of the puff release rate upon the accuracy of the integration.

3.2 MODEL FORMULATION

3.2.1 OVERVIEW

The model will be formulated to operate in a real time mode and in a predictive mode. The real time mode will provide the current estimate of the plume position, magnitude and location of maximum relative concentration and relative concentration at selected receptors which correspond to areas of special interest such as population centers, etc. The predictive mode will provide identical output for one, two and three hours into the future. In addition, the predictive mode will provide the magnitude and time of arrival of the maximum relative concentration at each receptor point. These predictions will be based upon the current plume position and estimates of wind speed, wind direction and stability class over the prediction period. These estimates will be based upon the observed meteorology during the prior 3-hour period. An option will be included to allow key board input of predicted meteorology.

The model will incorporate building wake effects in the initialization of each puff. Ground deposition and plume depletion will be included in the model. Wet deposition will not be considered. The following sections provide additional details on the model formulation.

3.2.2 PLUME ADVECTION

Plume advection will be calculated using 10-minute averages of wind speed and wind direction from the lowest level of the GGNS primary meteorological system. If this data is missing then the following replacement procedures will be used. If wind speed is missing, then in order of preference either

1. the backup system wind speed will be used, or

2. an upper level wind speed will be used in conjunction with a site specific wind power law to estimate the lower level wind.

If wind direction is missing then in order of preference either

1. the backup system wind direction will be used, or

2. an upper level wind direction will be used in conjunction with site specific vertical wind shear value to estimate the lower level wind direction.

The power law and shear estmate will incorporate an index of stability class and will be based upon a statisitcal analysis of at least one year of on-site data. Following U.S. Nuclear Regulator Guide 1.111, a wind speed of half the anemometer starting speed will be assigned to calm conditions.

Horizontal variation of the wind field in the vicinity of the emergency plan-zone will not be considered in the calculation of plume advection. The rationale for this decision is contained in a detailed study of the representativeness of the Grand Gulf Meteorological site.* The referenced study states that while drainage flow and channeling in the river area were observed "prediction of downwind radioactive concentrations and time of transport of gaseous radioactive effluents using the meteorological data from the permanent tower should not be significantly affected." That study concludes that "the meteorological characteristics at the existing tower site closely represent that of the plant site and its vicinity. Meteorological data from the tower will be sufficient and adequate for performing atmospheric dispersion calculations for the emergency planning zone (16 km radius circle of the plant)."

Puffs will be released at 10-minute intervals and tracked to calculated plume advection. The classical puff advection model using a numerical integration over puffs to calculate concentration requires puffs to be released more frequently than models using the plume segment technique. A 10-minute release interval is appropriate for the plume segment model while a 2-minute release is appropriate for the numerical technique. Puff coordinates will be referenced to a cartesian system centered on the plant (0,0) and oriented with northerly (y) and easterly (x) axes.

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* Study of the Representativeness of the Grand Gulf Meteorological Site for Mississippi Power & Light, Bechtel Power Corporation, February 1981.

Puff coordinates will be updated using the following equations:

$$x_N = x_0 + U\,\Delta t \qquad (2)$$

$$y_N = y_0 + V\,\Delta t \qquad (3)$$

where x is the easterly coordinate, y is the northerly coordinate, the subscripts N and 0 represent new and old, respectively, U is the easterly wind speed component, V is the northerly wind speed component and Δt is the length of the advection step (10 minutes in this case).

3.2.3 PLUME DIFFUSION

The diffusion of the continuous plume will be calculated in terms of the growth of puffs which are released every 10 minutes. The growth of each puff will be calculated using the following equation:

$$\sigma_N = \sigma_S\,(x_v + \Delta x,\ i) \qquad (4)$$

where σ represents either σ_y or σ_z, x_v represents the virtual plume dispersion distance, i represents the current stability class, Δx represents the distance the puff has traveled during the advection step (e.g., $(U^2 + V^2)^{1/2}\,\Delta t$). The subscrips N and S represent new and standard, respectively; σ_S represents the standard NRC Pasquill-Gifford dispersion curves. The virtual distance used in equation (3) is defined by:

$$x_v = F(\sigma_0,\ i) \qquad (5)$$

where F is the functional inverse of σ_s and σ_0 is plume dispersion parameter at the end of the prior advection step.

The vertical dispersion parameter, σ_z, will be modified for the building wake effect prior to the calculation of relative concentration using the following equation:

$$\Sigma_z = \text{MIN}((\sigma_z^2 + 0.5\ D^2/\pi)^{\frac{1}{2}},\ \sqrt{3}\ \sigma_z) \qquad (6)$$

where Σ_z is the modified value and D is the maximum adjacent building height in the vicinity of release.

It should be noted that the split sigma approach to the calculation of stability class will be used. Standard NRC criteria for $\Delta T/\Delta Z$ will be used to determine the stability class for the calculation of σ_z. The calculation of σ_y will be based upon the stability class determined from σ_θ. Criteria will be incorporated which will allow the use of the σ_θ stability class in the calculation of σ_y during very stable low wind speed conditions. This will be accomplished by using a smaller averaging time in the calculation of σ_θ.

3.2.4 CALCULATION OF RELATIVE CONCENTRATION

The locus of the centers of all puffs released at 10-minute intervals defines the plume centerline. The portion of the plume centerline between one puff and the next puff is referred to as a plume segment. The relative concentration at a particular receptor point (x_g, y_g) is calculated as the sum of the contributions of each plume segment to the receptor point.

In this application the contribution of a plume segment to the receptor point (x_g, y_g) will be calculated using the following equation.

$$\frac{\chi}{Q} = \frac{1}{\pi\sigma_y\sigma_z V} \exp\left\{-0.5\left(\frac{y_g'}{\sigma_y}\right)^2\right\} G \qquad (7)$$

where G is an edge effect term given by:

$$G = 0.5\left\{\text{erf}\left(\frac{x_g'}{\sqrt{2}\ \sigma_y}\right) + \text{erf}\left(\frac{D - x_g'}{\sqrt{2}\ \sigma_y}\right)\right\} \qquad (8)$$

where (x_g', y_g') represents the coordinates of the receptor point in a new coordinate system which has been translated to the coordinates of the puff which define the start of the plume segment and has been rotated in a manner which orients the x' axis with the plume centerline in the downwind direction. V represents the wind speed at the time the plume segment was released, D represents the length of the plume segment and σ_y and σ_z are the horizontal and vertical dispersion parameters. The variation of the disperson parameters along the plume segment centerline will be calculated using the values of the dispersion parameters of the puffs which bound the plume segment. It is anticipated that this calculation will be made using a power law interpolation. Equation 7 is valid for a ground level release and includes a consideration of ground level reflection.

Plume depletion estimates and deposition rate estimates for use in the dose calculation will be calculated by multiplying the results obtained using equation 6 by the factors contained in U.S. NRC Regulatory Guide 1.111. Outputs of relative concentration, decayed relative concentration and depleted relative concentration and deposition rate will be output as appropriate for use in the dosage calculations.

The maximum relative concentration value will occur along the plume centerline because a ground level release is being modeled. Because the puff advection model includes a history of the wind speed when the plume was released the location of maximum concentration may not occur at the site boundary. The maximum concentration and its location will be estimated by an application of equation 6 to the center points of the puff centers.

SECTION 4.0
RADIATION DOSE CONSIDERATIONS

The methodology for calculation of radiation doses in the offsite environs of the Grand Gulf Nuclear Station (GGNS) near Port Gibson, Mississippi resulting from releases of radioactive materials from the facility are outlined in this section. The radiation dose rates will be used in the accidental release module of the Emergency Response Facility Information System of the Grand Gulf Nuclear Station. This module permits predictive impact assessment of releases as well as an analytical indicator of the general plant/site status.

The methodology will enable assessments of radiation dose impact in the off-site environs based upon input describing the characterization of the release and the site meteorological conditions at the time of the release. The methodology permits the assessment of the major types of radiation dose: gamma or wholebody dose, beta or skin dose and intake dose resulting from inhalation or ingestion. The methodology will cover releases of all important radionuclides from the station under accident conditions including the noble gases, iodines, telluriums, cesiums and strontium nuclides. Based upon the meteorological methodology, the radiation assessment package will also permit analysis of the potential ground deposition and resultant dose rates that can be used in conjunction with the FDA Protective Action Guides. The basic methodology for these assessments is presented in the following pages. Numerical values and other supporting equations will be developed during the course of the program to allow both numerical and graphical display of all important information.

4.1 GAMMA DOSE

The gamma dose rate from a point monoenergetic source is given by:

$$D'_{\gamma} = [0.0404\ \mu_a q E_{\gamma}(1+k\mu r)\exp(-\mu r)]/r^2 \qquad (9)$$

where

D'_γ = tissue dose rate due to a point source in air

E_γ = gamma ray energy release per disintegration

r = distance between the point source and the receptor

μ_a = gamma ray energy absorption coefficient for air

μ = gamma ray total absorption coefficient for air

q = source strength at point source in air

$k = (\mu-\mu_a)/\mu_a$

The differential unit source strength in the plume is given by:

$$dq = Q(\chi/Q)dxdydz \tag{10}$$

where

dq = source strength per unit volume

Q = release rate of radioactivity

$dxdydz$ = a differential volume element

χ/Q = relative concentration at receptor point

The differential dose rate at any point (x_o) at ground level along the centerline of the plume travel direction for a volume element of the plume at any point may then be obtained from equations 9 and 10 above.

$$d\,D'_\gamma = 0.0404\ \mu_a Q(\chi/Q)E_\gamma(1+k\mu r)\ \exp(-\mu r)r^{-2}\ dxdydz \tag{11}$$

where $r = ((x-x_o)^2 + y^2 + z^2)^{\frac{1}{2}}$ (12)

The total dose may then be obtained by integrating equation 11 over the full extent of the plume.

The total dose is then the summation of the dose rates for each gamma energy represented in the plume. The model also accounts for decay during downwind transit of the radioactive material. Accordingly,

$$D'_{\gamma\ TOTAL} = \sum_{i=1}^{n} D'_{\gamma_n} \exp(-\lambda R/u) \qquad (13)$$

where

λ = decay constant of radioactive material of a given gamma ray energy
R = distance from release point to receptor
u = wind speed

4.2 SKIN DOSE

The dose rate to the skin is due from two components: gamma rays and beta particles. The gamma component can be obtained from equation 13 with appropriate corrections for energy deposition in skin. The beta component can be obtained from:

$$D'_{\beta} = \frac{1}{8760} \sum_{i} \bar{L}_i \, (\chi/Q) \, Q'_i \exp(-\lambda R/u)$$

where

D'_{β} = skin does rate from beta radiation
$\bar{L}_i$ = skin dose factor due to beta radiation
χ/Q = relative effluent concentration
Q'_i = release rate from the source
λ = decay constant for radionuclide
R = distance between receptor and release point
u = wind speed

The skin dose is not integrated over the entire plume as was the case for gamma radiation since the mean free path of beta particles is generally small in relation to the plume dimensions.

4.3 INTAKE DOSE

The intake dose is due to the intake of radioactive materials into the body by either inhalation or ingestion. The dose rate in the case of intake must be calculated as a dose commitment (i.e., the total dose from the time a radioactive material enters the body until it is eliminated from the body). Tables of dose commitment per unit of substance intake are available for various organs and radionuclides based on biological and physical data Thus the dose rate can be written as:

$$D_I' = R_a \sum DCF_i(\chi/Q)\, Q_i' \exp(-\lambda R/u)$$

where

D_I' = the dose rate to a specific organ
DCF_i = dose conversion factor
χ/Q = relative source strength
Q_i' = release rate of radionuclide
λ = decay constant
R = distance from release point to receptor
u = wind speed