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An Assessment of Offsite, Real-Time Dose Measurement Systems for Emergency Situations

Prepared by W. J. Maeck, L. G. Hoffman, B. A. Staples, J. H. Keller

Exxon Nuclear Idaho Co., Inc.

Prepared for
**U.S. Nuclear Regulatory
Commission**

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ABSTRACT

An evaluation is made of the effectiveness of fixed, real-time monitoring systems around nuclear power stations in determining the magnitude of unmonitored releases. The effects of meteorological conditions on the accuracy with which the magnitude of unmonitored releases is determined and the uncertainties inherent in defining these meteorological conditions are discussed. The number and placement of fixed field detectors in a system is discussed, and the data processing equipment required to convert field detector output data into release rate information is described. Cost data relative to the purchase and installation of specific systems are given, as well as the characteristics and information return for a system purchased at an arbitrary cost.

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SUMMARY

The Nuclear Regulatory Commission has been considering a requirement that each operating commercial nuclear power station be fitted with an offsite real-time emergency monitoring system. Currently, several power stations have installed, or are in the process of installing, monitoring systems of varying degrees of complexity and sophistication.

Prior to deciding whether to require all stations to install an offsite real-time emergency monitoring system, the NRC requested an independent evaluation of the usefulness of such a system and an assessment of the validity of the information obtained from the system. The information provided by this study will be used to aid the NRC in their determination of whether or not to require that fixed offsite real-time emergency monitoring systems be installed at all operating and planned commercial nuclear power stations.

This study addresses several aspects of the offsite real-time emergency monitoring system concept. The primary items receiving attention in this study are:

1. The ability of a fixed real-time monitoring system to detect and quantify monitored and unmonitored releases.
2. The ability of the system to detect and quantify an unmonitored release in the presence of a known release.
3. An assessment of the uncertainties associated with estimating the magnitude of an unmonitored release.
4. The number of stations required to detect a release and the uncertainty associated with the detected value.
5. The availability, cost, and the instrumentation requirements for a system.

An augmented effort of the study was to determine the characteristics and information return that might be obtained from a close-in (0.5 mile) system with capital costs limited to \$500,000.

A matrix approach was used in this evaluation in which the three major parameters were, 1) the measurement range of the detector, 2) the accuracy of the final results, and 3) the costs.

The general conclusions from this study are presented below. The uncertainty estimates are based on the use of simple error analyses of the meteorological expressions required to describe plume shapes and atmospheric transport.

1. While a ring of detectors around a nuclear power station can provide the means for monitoring releases; the number of stations required for two detectors to provide information within a factor of 5 of each other can be as large as 50 or more for one installation.
2. The use of short-time (15 min) data from a fixed offsite monitoring system to project downwind dose rates is a complex and highly uncertain process. Based on our study the uncertainty associated with a projected value is at least a factor of 10 or more.
3. The use of a fixed offsite monitoring system to determine the magnitude of an unmonitored release in the presence of a monitored release is highly questionable. Depending on the ratio of the unmonitored release to the monitored release, uncertainties of factors of 25 and 50 are common.
4. Several vendors of monitoring equipment were contacted relative to cost and performance characteristics of the available instrumentation. In addition, we contacted several power stations and state agencies involved in the installation of fixed real-time environmental monitoring systems. While the cost factors

for the instrumentation were relatively fixed, the installation costs were highly variable. Based on this study the cost per monitoring station ranges from \$25,000 to \$65,000. Depending upon the specific site characteristics the cost for a 32 station system could easily exceed \$1,000,000 while only providing data with uncertainties in the range of factors of 10 to 50.

5. The placement of a simple limited (\$500,000) detector system in proximity (0.5 mi) to a reactor may not provide reliable information in the case of an emergency for several reasons. Of prime importance is the limited number of stations (8-16) that could be installed and the consequence that a plume might go undetected. A second serious problem, especially in the case of a BWR, is the building shine factor which could give a sufficiently high background signal to negate detection of the plume radiation.

In general, it is highly questionable that a fixed station (16-32 units) emergency monitoring system can provide sufficiently reliable technical information to be of use in a decision-making process in the event of an emergency situation.

This conclusion should not preclude consideration of the installation of such a system. A monitoring system could be used to develop site specific meteorological information and could develop improved public relations with the populace. It should be emphasized, however, that the stations should be judiciously placed so as not to convey false information.

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1.0 INTRODUCTION

1.1 Background

It has been recommended that systems of offsite, real-time environmental monitors be installed around nuclear power stations. The premise is that the data obtained from such a system could, when coupled with meteorological data, provide information relative to unmonitored, as well as monitored radioactive effluent releases, and provide the basis for making downwind dose rate projections during an emergency accident situation.

1.2 Objective

The purpose of this study is to evaluate this proposal and to provide information to aid the NRC in determining whether or not to require that a fixed offsite monitoring system be installed at all nuclear power stations.

The primary items considered in this study are:

- 1) The ability and related accuracy of a fixed real-time monitoring system to detect monitored and unmonitored releases.
- 2) The ability of a fixed real-time monitoring system and associated calculational methods to detect and quantify the magnitude of an unmonitored release in the presense of a known release.
- 3) To provide an estimate of the credibility (uncertainty) of the information associated with the estimated value of an unmonitored release.
- 4) To determine, using calculational methods, the number of fixed stations required to detect a release and to provide an estimate of the uncertainty in the measured dose as a function of the number of stations.

- 5) To provide cost data relative to the installation, operation, and maintenance of a fixed real-time monitoring system.
- 6) To determine the characteristics and information return for an 800 m (0.5 mile) (probably onsite) emergency system with capital cost limited to \$500,000.

1.3 Evaluation Criteria

The variables to be considered in this evaluation are listed below and shown in a matrix array in Figure 1.

Range of Detector (Assume Background of 10 μ R/hr)	a. (0.1 x background) to 10 R/hr b. (1.0 x background) to 10 R/hr c. (10 x background) to 10 R/hr d. (100 x background) to 10 R/hr
Accuracy of Dose to:	a. $\pm$ factor of 2 b. $\pm$ factor of 5 c. $\pm$ factor of 10 d. $\pm$ factor of 50 e. $\pm$ factor of 250
Order of Magnitude Costs for Installed System (Excluding Costs for Detectors)	a. \$ 250,000 b. \$ 750,000 c. \$2,000,000

The following assumptions are used throughout the evaluation:

1. The detectors will be available as "off the shelf" items and will have the sensitivity to make the required measurements. Calibration procedures will be available to assure a detector response accurate to $\pm$ 25%.

2. The monitoring stations will be located within 3200 m (2 miles) of the plant and the measurements will be averaged on a 15-minute time scale. The costs of the detectors will not be considered; but costs for signal averaging, transmission, and correction for background will be included.
3. Meteorological information requirements will be those required to satisfy NUREG-0654, Regulatory Guide 1.97 and the Proposed Revision to the Regulatory Guide 1.23.
4. Computerized analysis of the detector and meteorological input will use in-house or "off the shelf" hardware and software to provide accurate and intelligible output for use in control room decisions. For offsite, real-time monitoring system output to be intelligible, the information presented to the operator in the control room must describe in real time the significant features of the release, such as dose distribution and contours within two miles and characterization of the source. In addition, the computer analysis must provide for downwind dose prediction capability beyond two miles.
5. The source term to be evaluated will be limited to mixtures of radionuclides which are nondepositing, i.e., only the noble gases without radioactive daughters.

Figure 1. Matrix Parameters

2.0 QUANTIFICATION AND ASSESSMENT OF THE UNCERTAINTIES ASSOCIATED WITH THE MEASUREMENT OF AN UNMONITORED RELEASE

To provide an evaluation of the accuracy which might be obtained from a fixed offsite real-time monitoring system we used simple statistical methods of error analysis. Of particular concern was the quality and credibility of the values obtained for an unmonitored release in the presence of a known release.

The model used for this evaluation is shown in Figure 2, in which

D_B is dose related to background,
 R_1 is the known or monitored release,
 R_2 is the unknown release,
 D_1 is the dose related to R_1 ,
 D_2 is the dose related to R_2 , and
 D_T is the total dose measured by the receptor.

Thus, the total dose, D_T , is the sum of D_1 , D_2 and D_B which are in some form proportional to R_1 and R_2 .

$$D_T = D_1 + D_2 + D_B \quad (1)$$

$$\begin{aligned} \text{where } D_1 &\propto R_1 \\ \text{and } D_2 &\propto R_2 \end{aligned}$$

To obtain a value for the unmonitored release in the presence of a known release, the following procedure is used. First, the measured value for R_1 is converted to a dose, D_1 , using the equations given in Section 2.1. Second, the calculated value D_1 is subtracted from the measured value D_T to give a value for D_2 . Third, the value D_2 is then converted to a value for R_2 , using the same equations to obtain D_1 . It is assumed that D_B is small in comparison to D_1 and D_2 and can therefore be ignored.

The following is a discussion of the errors associated with each step in the calculational procedure and an assessment of the uncertainty in the value of R_2 .

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Figure 2. Model to Evaluate the Estimate of an Unmonitored Release in the Presence of a Known Release

2.1 Prediction of Downwind Atmospheric Concentration Values

The first calculational step involved in the model given in Figure 2 is conversion of the measured release R_1 to a dose D_1 . The most commonly used method for calculating the exposure to a receptor involves converting the known release value to an atmospheric concentration value at some downwind distance and then integrating the concentration over the volume of the plume. The exposure is then proportional to the product of the integrated concentration and the decay energy of the radio-nuclides present in the plume, expressed as an exposure rate per unit release $(R/hr)/(Ci/s)$ at 1 m/s wind speed. The detector response calculated in this study is in exposure rate. However, in the remainder of this report the authors equate exposure rate and "dose rate" as is common practice.

The atmospheric concentration value at some downwind distance is usually calculated using the Gaussian plume equation. This is an empirical diffusion formula which assumes constant wind speed, no wind shear, and flat topography. The equation for a continuous point source release is:

$$\chi(x,y,z) = \frac{QG(z)}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left(-\frac{1}{2}(y/\sigma_y)^2\right) \quad (2)$$

where:

- χ = atmospheric concentration at a calculated point (x,y,z) for a release point h meters above the ground, Ci/m³
- Q = source term (release rate), Ci/seconds
- $G(z) = \exp -\frac{1}{2}((z-h)/\sigma_z)^2 + \exp -\frac{1}{2}((z+h)/\sigma_z)^2$
- σ_y = horizontal atmospheric diffusion parameter, m
- σ_z = vertical atmospheric diffusion parameter, m
- $\bar{u}$ = average wind speed, m/sec
- y = cross wind distance, m
- h = release height, m
- x,y,z = coordinates of the point where the concentration is calculated

In this relationship the most critical terms are the values for σ_y and σ_z . Both of these terms carry a different value for each class of atmospheric stability and downwind distance. Unfortunately, the values for σ_y and σ_z are not explicitly mathematically defined and as such must be determined empirically. A number of different field experiments have been conducted to determine σ_y and σ_z as functions of atmospheric stability conditions (weather class) and downwind distances.

Currently, the most widely used data sets for σ_y and σ_z are those based on the Pasquill-Gifford¹ model for atmospheric diffusion. Several methods have been used to establish the atmospheric stability class which must be determined prior to obtaining the values for σ_y and σ_z . One general classifying scheme is based on isolation, cloud cover, and wind speed. The standard deviation of the horizontal wind direction is also used to establish the stability class. Another method, recommended by the NRC² (Reg. Guide 1.23) uses the temperature gradient between 10 and 60 m (or the release height) above the ground to determine the stability classification. None of these methods are without uncertainties, and in many cases the selection of the proper atmospheric stability class may be in error by one or more classes.

Assuming an error of one stability class in the assignment process (i.e. - assigning class D for a real class E conditions), we determined the error which would be introduced in the value for χ based on the Pasquill-Gifford curves³ for adjacent atmospheric stability classes. The effect on the value for χ at distances of 1000 m and 3000 m for release heights of 10 m and 100 m is given in Tables I and II, respectively. For a near ground-level release, the error in the predicted groundlevel average concentration could range from a factor of 2 to 10 for a one unit misassignment of the stability class. For a 100 m release the errors can be much larger.

To establish the frequency with which the stability class may be in question, four months of meteorological data for an inland nuclear power station were evaluated. For this station, both the standard deviation of the horizontal wind direction and the temperature gradient data were available on an hourly basis. An analysis of these data indicates that the assigned stability class based on these two methods differed by one class 43% of the time, and by two classes, up to 25% of the time. The results shown in Table III indicate that the stability class assignment based on the two methods differed about 60% of the time. Thus, the downwind ground-concentration value could be in error by a factor of 5 about half of the time just from this source.

Table I. ERRORS IN X (GROUND-LEVEL AVERAGE CONCENTRATION)
FOR A ONE UNIT ASSIGNMENT ERROR IN STABILITY CLASS

Release Height 10 m

<u>True Class</u>	<u>Assigned Class</u>	<u>Error Factors</u>			
		<u>D = 1000 m</u>		<u>D = 3000 m</u>	
		<u>Over-predict</u>	<u>Under-predict</u>	<u>Over-predict</u>	<u>Under-predict</u>
A	B	5		10	
B	A		5		10
B	C	3		4	
C	B		3		4
C	D	3		4	
D	C		3		4
D	E	2		2	
E	D		2		2
E	F	2		2	
F	E		2		2

Example: If the true stability class is C and the assigned class is D, the Gaussian plume model using Pasquill-Gifford diffusion values for class D at 3000 m over-predicts the ground-level average concentration by a factor of 4.

Table II. ERRORS IN X (GROUND-LEVEL AVERAGE CONCENTRATION)
FOR A ONE UNIT ASSIGNMENT ERROR IN STABILITY CLASS

Release Height, 100 m

Error Factors

True Class	Assigned Class	D = 1000 m		D = 3000 m	
		<u>Over-predict</u>	<u>Under-predict</u>	<u>Over-predict</u>	<u>Under-predict</u>
A	B	5		30	
B	A		5		30
B	C	1		6	
C	B		1		6
C	D		12	1	
D	C	12			1
D	E		15		2
E	D	15		2	
E	F		800		33
F	E	800		33	

Table III. VARIABILITY IN STABILITY CLASS ASSIGNMENT
BASED ON TWO DIFFERENT MEASUREMENT METHODS

<u>Date</u>	<u>No. Observation</u>	<u>One Class Difference</u>	<u>Two Class Difference</u>
June-1974	640 ^a	274 (43%) ^b	39 (6%)
July-1974	430	186 (43%)	113 (26%)
Aug.-1974	613	262 (43%)	76 (12%)
Sept.-1974	661	281 (43%)	152 (23%)

a) Number of hourly observations for which both wind variability and temperature differential data were available.

b) Percentage of the time that the stability class assignments were different.

At this point it might be well to recognize that the Gaussian plume equation only provides concentration estimates and not dose estimates. In general, the uncertainties in the dose values are not as variable as the ground-level concentration values, because the cloud gamma dose is an integrated value as opposed to a point concentration value. This fact, however, should not preclude consideration of the uncertainties in concentration values predicted by the Gaussian plume equation because the ground-level concentration values are more important with respect to the beta dose factor, the inhalation dose factor, and the ground-level concentration value for radioiodine, which may be the dominant factor in an accident case. The uncertainties associated only with the dose values will be treated in detail later in this Section.

Another item which must be considered regarding the uncertainties associated with the Gaussian plume equation and ground-level concentration values, is the validity of the primary diffusion data based on the Pasquill scheme. The basic Pasquill diffusion data were derived from tracer experiments which involved a ground-level release over very flat terrain with sampling periods of a few minutes at distances of up to about 1 km. Unfortunately through time and widespread usage, the

original nature of the experiment seems to have been forgotten by many users of the data, and the original results have been extrapolated to include elevated release points (up to 100 m) and to distances of up to 100 km. Pasquill diffusion parameters are primarily applicable to short term releases at or near ground-level over relatively short distances (1 km) and quite flat terrain.

Because of the restrictive nature of the Pasquill scheme, more recent experiments have been conducted to attempt to better quantify the diffusion parameters for the more realistic cases (i.e. hills, rough terrain, forests, metropolitan areas, and elevated releases). Some examples are given in References 4, 5, and 6. Vogt⁷ and Brenk⁸ have reviewed these experiments in some detail and compared the diffusion parameters derived from these experiments to each other and to Pasquill. In some cases the downwind concentration values may differ by factors of 10 to 1000, depending upon the stability class involved.

Figures 3, 4 and 5 taken from Brenk⁸ give comparisons of the short-term diffusion factors for the various experimental results for stability classes A, D, and F as a function of distance, for a release height of 100 m. For class A, unstable diffusion, the data are in good agreement. However, with increasing atmospheric stability, significant differences are evident (Figures 4, 5). For class D stability at a distance of 1000 m, the difference between the Pasquill diffusion factor and the majority of the other systems is a factor of 10 to 15. At 3000 m the difference is about a factor of 5.

For class F stability there is little agreement in the diffusion factors for the various systems and differences of a factor of 100 to 1000 are common.

These data are presented not to dwell on the large differences between the various systems, but rather to emphasize the need for selecting the most applicable system for a given site. Ideally, the preferred situation is to develop site specific data. Unfortunately, experiments of this type are difficult and expensive to conduct. Brief descriptions

Figure 3. Comparison of Short-Term Diffusion Factors (Stability Class A) Depicted for 6 Different Diffusion Parameter Systems (From Brenk, ref. 8)

Figure 4. Comparison of Short-Term Diffusion Factors (Stability Class D) Depicted for 6 Different Diffusion Parameter Systems (From Brenk, ref. 8)

**Figure 5. Comparison of Short-Term Diffusion Factors (Stability Class F)
Depicted for 6 Different Diffusion Parameter Systems (From Brenk, ref. 8)**

and the result and data obtained from some recent experimental programs are given in Appendix A. Included are reviews of the Savannah River ^{85}Kr experiment,⁹ the ORNL assessment of the Hanford experiment¹⁰, excerpts from a Workshop on the Evaluation of Models Used for the Environmental Assessment of Radionuclide Releases,¹¹ and results of a survey of programs used for radiological dose computations.¹²

Presently, it is virtually impossible to give a definitive estimate of the overall uncertainty to be associated with the prediction of downwind concentration values, especially for data related to short time periods. However, based on our study and those of others^{9,10,11,12} we believe that a predicted value which may vary by a factor of 10 to 25 from the true downwind concentration is not unreasonable. Even this estimate may be low if site specific diffusion parameters are not available.

2.2 Prediction of Downwind Atmospheric Dose Values

The calculation of the cloud gamma exposure from a plume is a two-step process. First, the radionuclide concentration of the plume is calculated using the Gaussian plume dispersion equation given in Section 2.1 (Eq. 2). Second, the total cloud gamma exposure rate at the detector is calculated by using a point source approximation and integrating over the source distribution (i.e. the volume of the plume). Both components of the exposure rate calculation have been incorporated into a code developed by Science Application, Inc.,¹³ which was used in this study to establish detector response values.

The assumptions and parameters used to calculate the cloud gamma values presented in this report are given below.

1. The Gaussian plume equation given in Section 2.1 (Eq. 2) was used to establish the plume dispersion and downwind concentration values. The values used for σ_y and σ_z are given in Appendix-II.

2. The cloud gamma exposure rate at a receptor was obtained by using a point source approximation and integrating over the volume of the plume. This involved an extensive numerical summation of small volume elements. Although this is a lengthy process, we believe the results are more representative than those obtained from the use of infinite or semi-infinite cloud approximations. The following is the methodology used to calculate the cloud gamma exposure rate to a receptor.

$$\text{exposure rate } D \left(\frac{R}{h} \right) = C \frac{\mu_a}{\rho} EB(\mu R) \Gamma \quad (3)$$

where

$$C = 6.87 \times 10^{-5} \frac{R-g-s}{\text{MeV-h}}$$

$$\frac{\mu_a}{\rho} = \text{mass absorption coefficient for air at energy } E \text{ (m}^2/\text{g)}$$

$$E = \text{energy per photon MeV/photon}$$

$$B(\mu R) = \text{buildup factor}$$

$$\Gamma = \text{photon flux } \left(\frac{\text{photons}}{\text{m}^2\text{-s}} \right)$$

$$\text{photon flux } \Gamma \left(\frac{\text{photons}}{\text{m}^2\text{-s}} \right) = \frac{s}{4\pi r^2} e^{-\mu r} \quad (4)$$

where

$$s = \text{photon emission rate (photons/s)}$$

$$r = \text{distance from source (m)}$$

$$\mu = \text{total linear attenuation coefficient for air (m}^{-1}\text{)}$$

The photon emission rate, s , was determined by assuming a small volume, dV , at concentration χ as follows:

$$S \text{ (photons/s)} = 3.7 \times 10^{10} \chi I_K dV \quad (5)$$

where

3.7×10^{10} = the the number of disintegrations per second per curie

χ = radionuclide concentration in the small volume element dV (Ci/m³)

I_K = number of photons of energy E per disintegration

dV = volume element considered (m³)

Combining equations 4 and 5

$$\dot{D} \left(\frac{R}{h} \right) = \frac{2.54 \times 10^6}{4\pi r^2} \frac{\mu_a}{\rho} E I_K \chi e^{-\mu r} B(\mu r) dV \quad (6)$$

Equation 6 is the contribution to the exposure rate at the detector due to the small volume element dV . The total exposure rate was obtained by integration over the volume of the plume. When using the code, $\chi \bar{\mu}/Q$ was used in equation 6 instead of χ to subsequently give results in terms of $\dot{D} \bar{\mu}/Q$ or exposure rate per unit release rate (R/h)/(Ci/s) at 1 meter per second wind speed.

Several calculations were made to evaluate the dose rate to a receptor as a function of stability class, distance, and release height. The dose rate as a function of distance for several stability classes for a ground level release is shown in Figure 6. At a distance of 3200 m (2 miles), the centerline dose can vary by at least four orders of magnitude over the extreme stability class range of A to F. The uncertainty in the dose as a function of adjacent stability classes can also be estimated from Figure 6. For example, at a distance of two miles the difference in the maximum centerline dose between stability class B and C is approximately 8, and between stability class C and D, approximately 3. These values are for an average gamma ray energy of 80 keV (^{133}Xe). The differences are only slightly less for an average energy of 250 keV.

The effect of the release height on the dose rate as a function of distance for three different stability classes is shown in Figure 7. For the worst case, class F, the dose rate at short distances (500-1000 m) can vary a factor of 6-12 between a release height of 0 to 100 m. This difference decreases as a function of distance. At 3200 m the difference is approximately 2.5.

In the discussions presented up to this point, we have assumed that the centerline of the plume has passed directly over the receptor, thereby giving the maximum dose value. The probability of this happening is quite remote. The number of detectors and their placement required to give accurate dose readings will be discussed in detail in Section 3.

Based on the calculated data given in Figures 6 and 7 and the problems presented with respect to an accurate assessment of the prevailing weather class and to a knowledge of the location of the source term, it is our opinion that the calculated downwind dose value must carry an associated uncertainty of at least a factor of 10 or more.

Figure 6. Projected Center Line Dose as a Function of Stability Class and Distance For a Ground Level Release

Figure 7. Effect of Release Height on Dose Rate as a Function of Distance for Stability Class B, D, and F

2.3 Uncertainties Associated with the Quantification of an Unmonitored Release

The uncertainties and range of values associated with quantifying the magnitude of an unmonitored release (R_2) in the presence of a known release (R_1) were calculated based on the model given in Figure 2 and the relationship,

$$D_T = D_1 + D_2$$

$$\text{where } D_1 \propto R_1, \text{ and} \\ D_2 \propto R_2.$$

The calculation of the expected error in R_2 assumed the following conditions:

1. R_2 (constant)	1	1	1
R_1 (variable)	10	1	0.1

2. The uncertainties assigned to D_1 were:

$\pm$ factor of 2	(200%)
$\pm$ factor of 5	(500%)
$\pm$ factor of 10	(1000%)
$\pm$ factor of 25	(2500%)

3. The same uncertainties were assigned to D_2 ; however, in many cases the uncertainty associated with D_2 may be larger than D_1 because the height of the release is probably unknown.

4. No significant error was assumed in the measured dose, D_T .

5. The background contribution is small. If the background is significant with respect to the measured D_T value the resultant error will increase.

The results of the error analysis are given graphically in Figure 8 and listed in Table IV. In Figure 8, the range in the values for R_2 as a function of the ratio R_1/R_2 are given for a family of uncertainty assignments for D_1 and D_2 . From this simple error analysis it is concluded that uncertainties of factors of 10 to 25 are possible for the calculated value for the unmonitored release, especially when the magnitude of the unmonitored release is equal to or smaller than the known release. For the case where the unmonitored release is large with respect to the known release the uncertainty in the unmonitored release will approach the error associated with the values for D_1 and D_2 .

For example, in the case where the known release and the unmonitored release, R_1 and R_2 respectively, are of equal magnitude (in this case, 1) and the assumed uncertainty in the calculated values for D_1 and D_2 is a factor of 10, the value for R_2 can have a range of 0 to 19 for a true value of 1. For the case where the unmonitored release is 10 times larger than the known release and the uncertainty in D_1 and D_2 is a factor of 10, the value of R_2 can have a range of 0 to 11 for a true value of 1. For the case where R_2 is only one-tenth of R_1 the uncertainty in the value 1 for R_2 increases dramatically, having a range of 0 to 100 for an uncertainty of a factor of 10 in D_1 and D_2 .

This error analysis only presents the range of relative values to be associated with an unmonitored release having an assigned value of 1. It does not provide an estimate of the true value of the unmonitored value. The accuracy of the true value for the unmonitored release depends on the location of the plume relative to the detector. If the plume centerline is several degrees removed from the detector, the measured value for D_T could be low by a factor of 2 to 10 depending on the proximity of the plume to the detector. This effect is discussed in detail in Section 3.

Figure 8. Uncertainty in Calculated Values of an Unmonitored Release in the Presence of a Monitored Release

Table IV RANGE OF UNCERTAINTIES WHICH CAN BE ASSOCIATED WITH
AN UNMONITORED RELEASE HAVING A TRUE VALUE = 1.

<u>CASE: 1</u>	<u>UNCERTAINTY</u> <u>D₁, D₂</u>	<u>RANGE IN CALCULATED</u> <u>VALUE OF R₂</u>
R ₁ = 10	200%	12 to -4.5
R ₂ = 1	500%	45 to -7.8
R _T = 11	1000%	100 to -8.9
	2500%	265 to -9.6
 <u>CASE: 2</u>		
R ₁ = 1	200%	3 to 0
R ₂ = 1	500%	9 to -0.6
R _T = 2	1000%	19 to -0.8
	2500%	49 to -0.9
 <u>CASE: 3</u>		
R ₁ = 0.1	200%	2.1 to 0.5
R ₂ = 1	500%	5.4 to 0.1
R _T = 1.1	1000%	10.9 to 0.01
	2500%	27.4 to -0.1

3.0 DETECTOR PLACEMENT AND REQUIREMENTS

3.1 Detector Placement and Response Functions

The response functions and requirements for a ring of detectors were determined by calculating the dose rate from a plume at various distances from the plume centerline. Figure 9 gives the dose rates at 1600 m for three different stability classes (A, C, and F) as a function of distance from the plume centerline for a ground level release of 1 Ci/s. The curves given in Figure 9 describe one-half of the plume shape; from the centerline to one edge. The plume shapes and dose rates were calculated for 80 keV gamma rays (^{133}Xe) using the equation and input factors given in Section 2.2.

The number of detectors required for two adjacent detectors to give responses within factors of 2, 3, 5, and 10 of each other was determined based on the plume shape (i.e., the width of the plume). For the plume shape corresponding to stability class C (Fig. 9), the lateral distance from the plume centerline which gives a signal equal to one-half of the maximum was determined to be $\sqrt{7.8}$ degrees. Dividing a 360 degree circle by this value gives a value of 46, which is the number of detectors required for two adjacent detectors to give a response within a factor of two of each other. The same process was used to establish the number of detectors required to give readings within factors of 3, 5, and 10 of each other for each stability class. In all cases, it was assumed that the plume centerline was directly over one detector. This is the worst case situation.

Figure 10 shows the number of detectors at 1600 m required to give responses agreeing within 200%, 300%, and 500% as a function of stability class. These results are for straight line meteorology, a release height of 100 m, and an average gamma ray energy of 80 keV. For class F weather (the worst case) about 85 detectors are required for two adjacent detectors to give signals within a factor of two of each other. For a ground-level release, approximately 100 detectors would be required for a factor of two agreement. Even for class B weather and a release height of 100 m, about 36 detectors would be required for agreement within a factor of two.

Figure 9. Plume Shape Analysis for Determining Detector Requirements

Figure 10. Number of Detectors Required at 1600 m to give Response within 200, 300, and 500%

Figure 11. Detector Requirements as a Function of Cloud Dose Gamma Ray Energy

Table V. DETECTOR REQUIREMENTS

			WEATHER CLASS					
DISTANCE, m	RELEASE HEIGHT, m	AGREEMENT BETWEEN TWO DETECTORS	A	B	C	D	E	F
NUMBER OF DETECTORS								
800	0	x 2	23	30	40	58	69	90
		x 5	15	19	25	36	42	51
		x 10	--	16	20	28	33	38
800	100	x 2	25	30	39	43	46	58
		x 5	16	19	24	26	29	30
		x 10	--	16	19	21	23	24
1600	0	x 2	24	32	42	65	--	100
1600	100	x 2	23	34	45	62	72	86
		x 3	18	28	36	49	57	64
		x 5	15	23	30	40	46	50
3200	0	x 2	--	44	55	69	103	138
		x 5	--	34	40	46	65	80
		x 10	--	32	36	40	55	66

Table V gives additional data for distances ranging from 800 m to 3200 m. As expected, the number of required stations increases with distance. These data also show the dependence on release height, with the worst case being a ground level release.

The effect of more energetic gamma rays from shorter-lived noble gas nuclides on the number of detector requirements has been evaluated. Plume shape and detector requirement calculations similar to those shown in Figure 9, page 26, were made for three different gamma ray energies: 80keV, 250keV, and 1500keV. The conditions assumed were class C weather stability, and a release height of 100m. The results given in Figure 11 show little change in the overall plume shape with respect to gamma ray energy and hence, little significant difference in the number of detectors required to give responses within factors of two or five of each other.

Based on the results of these calculations, it is quite evident that offsite real-time monitoring systems consisting of 16 or even 32 units may not provide information on centerline dose values and plume location because of the limited number of detectors. In some cases, especially for extremely narrow plumes (stability classes E and F), the plume might pass between two detectors and go undetected, or if detected, the magnitude of the dose associated with the plume could be greatly underestimated unless it passed directly over one of the sparsely placed detectors. Conversely, in our opinion, the installation of a 100 unit detector system is not practical, feasible or cost effective.

3.2 Building Shine and Background

Some consideration has been given to the installation of real-time monitoring systems within the confines of the site boundary; distances of 500-800 m are typical. In the event of an accident, it is quite probable that the background resulting from building shine could result in a significant signal to near-by detectors. To evaluate the magnitude of this component we calculated the dose to a receptor as a function of distance for the following condition:

1. 100% of the Krypton and Xenon isotopes and 50% of the iodine isotopes were released from the core.
2. Of these amounts 1% of each leaked to the reactor building.
3. The following reactor building contents (based on WASH-1400⁽¹⁴⁾ for a 12 hr decay period).

⁸⁷ Kr	2.4 Ci	¹³¹ I	1.2×10^5 Ci
⁸⁸ Kr	1×10^4 Ci	¹³² I	4.8×10^3 Ci
¹³³ Xe	4.8×10^5 Ci	¹³³ I	1.7×10^5 Ci
¹³⁵ Xe	4.1×10^4 Ci	¹³⁴ I	22 Ci
		¹³⁵ I	6.5×10^4 Ci

4. No significant shielding (BWR).
5. Building volume = 5×10^4 m³.

Using the building contents given above, the dose rate from this source was calculated for various distances from the building using the code ISOSHL-D-II⁽¹⁵⁾. The results for the rare gas and iodine components are given separately in Figure 12. These data indicate a significant increase in the normal background level (0.01 mR/hr) due to the contents of the building, especially at distances of less than 1000 m.

The question of shielding the detectors from this source has not, in our opinion been adequately resolved. Complete shielding of the detector from this source would only negate the signal from a plume. The value of partial shielding in the direction of the building shine is questionable considering the scattered radiation from the building.

To evaluate the impact of the building shine on a signal from a passing plume we have included in Figure 12 the contribution from a plume of ¹³³Xe based on the building contents given above and a leak rate of 1%/day, giving a source term of 0.055 Ci/s. Also assumed was class E weather, a wind speed of 1 m/s, a release height of 100m, and that the bulk of the iodine was retained in the reactor building or trapped by the filter system and therefore had no significant contribution to the plume dose.

Figure 12. Effect of Building Shine on Detector Response

The results of this calculation clearly show the significance of the building shine factor relative to the plume dose. For the accident case where significant quantities of the volatile radioactive products are in the reactor building, little or no information regarding the plume dose could be obtained from detectors located close to the reactor building.

4.0 INSTRUMENTATION REQUIREMENTS, AVAILABILITY AND SYSTEM COSTS

The basic components of an offsite real-time monitoring system are shown in Figure 13. Also identified, are the major cost areas to be considered in establishing an offsite, real-time monitoring system. Currently, virtually all of the existing real-time monitoring systems which have been installed are for the purpose of monitoring routine releases rather than for use in emergency situations. Although the immediate use is different, the equipment and costs should be similar. Because many of these systems have only recently been installed or are in the installation stage, little information or cost figures are available in the open literature.

To obtain the information necessary to establish an estimate of the costs involved in the installation of a system for use in an emergency situation, several utility stations and state agencies were contacted. These conversations ranged from rather open discussions to quite guarded comments, and in some cases, a reluctance to quote cost values. Also vendors of potentially useful instrumentation were contacted.

A review of the instrumentation requirements and availability of real-time monitoring systems is given in Section 4.1. Section 4.2 gives a review of total system cost and an estimate of the installation costs based on information gathered for existing or planned systems.

4.1 Instrument Description and Requirements

The basic requirements for an offsite, real-time monitoring system are listed below and shown diagrammatically in Figure 13.

4.1.1 Field Stations. Field Stations will consist of radiation detecting devices and associated electronics. The stations would preferably have the capability of signal averaging and onsite readout. The radiation detection system should be capable of measuring dose rates

OFFSITE, REAL-TIME MONITORING SYSTEM

MAJOR COST AREAS

MAJOR COMPONENTS

Figure 13. Schematic of Offsite Monitoring System Basic Components

from $1\mu\text{R/hr}$ to 10 R/hr with reasonable accuracy ($\pm 10\%$) and respond in a relatively flat manner to photons of 50 to 3000 keV. The detector(s) should be weather proof and the associated electronics enclosure maintained at suitable operating conditions. This may require heating or cooling depending on site conditions. For the winter of 1981-2, the heating requirement could be significant. A provision for backup power should be made.

Additional instrumentation, such as meteorological sensors and iodine sampling devices may be added to the field stations. This additional instrumentation may provide useful data but the cost per field station will be increased.

4.1.2 Data Transmission. Three practical methods exist for transmitting data from the field stations to the central processing unit and commands from the central processing unit to the field stations. These include direct hard wire connections, dedicated telephone lines and radiotelemetry. The choice for specific site will depend on economic and environmental factors. The selected system must be capable of:

1. Bidirectional operation,
2. Error detection and correction,
3. A useful transmission rate, and
4. A transmission structure compatible with the accumulated data.

Direct wire connections often provide the most reliable connections. However it may be impractical to use hardwire connections over water or at distances greater than one mile.

Telephone systems using voice grade lines for data and command transmission can be installed by and then leased from telephone companies. Bidirectional transmission is preferred, although half-duplex is adequate.

Several commercial vendors including those of real-time environmental monitoring systems supply compatible telemetry systems. Line of sight transmission of up to one mile can be performed using an FM system.

As with other field stations electronics, transmitters and encoders must be protected from the environment and, at colder sites, heated.

4.1.3 Central Processing Unit (CPU). The CPU performs the acquisition, reduction and storage of data describing radiation dose rate conditions existing at each field station. The CPU also performs the following functions: 1) diagnostic testing of these data to provide dose rate and meteorological condition time average values for each station, 2) the comparison of radiation data to alarm points, 3) compilation of historical data files, and 4) polls the field stations for radiation dose rate levels at requested intervals. The CPU also should have an interface for transferring the acquired data to an external computer for plume analysis, characterizations, and the ultimate prediction of downwind dose values. Hardware required for these tasks include:

1. Data receiver and decoder
2. Microprocessor,
3. Data storage device,
4. Printer,
5. Command entry device, and
6. Back-up power supply.

4.2 Instrument Availability

The capital costs of obtaining and installing an emergency monitoring system were estimated from costs of existing routine monitoring systems. To prepare capital cost estimates for an emergency monitoring system, three vendors of routine monitoring systems (GCA Corporation, Harshaw Chemical Company and Reuter-Stokes) were contacted. None of these vendors offer systems which are capable of simultaneously monitoring routine radiation releases and meteorological conditions, transmitting this information to a CPU which subsequently models the release and provides dose rate characteristics. The existing systems provide real time remote location dose rate data which is transmitted to a CPU and converted to information such as count or dose rate averages, anomalies and alarm points. All three vendors offer a CPU which can be interfaced with an external computer for characterizing and predicting dose rates. It is interesting to note that the only external computer that each of the three vendors recommends interfacing to their CPU is the Digital Equipment Corporations PDP-11/34. Details of the features, capabilities and price for each of the three systems are discussed below and summarized in Table XI.

GCA Corporation

The GCA Corporation has installed several of their "Guardian" systems at power stations in the United Kingdom for the purpose of providing routine real-time environmental monitoring. The "Guardian" system employs two GM detectors (low range, 10^{-6} - 10^{-2} R/hr, and high range 10^{-3} - 10 R/hr) at each field station for radiation detection. In addition, a "Maypac" particulate and iodine filter system with constant air pump can also be placed at each field station. Data transmission from the field stations to the central processing unit is usually performed by VHF radiotelemetry, but other methods are possible. The "Guardian" CPU provides immediate hard copy and visual display of current field station readings, system diagnostics, and data logging. Although the "Guardian" system has been marketed in the USA since 1981 it has not been installed and operated at any power station in this country. Installation costs and operational characteristics of this system can be obtained by contacting power station personnel in the U. K.

The Harshaw Chemical Company

The Harshaw TASC-4 systems may be used for routine real time environmental radiation monitoring. This system uses two scintillation detectors per field station to give monitoring capabilities over seven decades of signal. Data transmission from the field stations to the CPU is by dedicated hard wire systems because generally the units are used inside of buildings where the distances are short. An advantage of the Harshaw TASC-4 system is that all field station electronics, except the preamplifier, can be placed in the CPU thus minimizing the effects of weather on the system, lowering the potential for tampering at the field stations, and centralizing much of the maintenance. Components of the CPUs of these systems also include counter-timers, printer, and computer interface modules. To date none of these systems have been installed to function as routine real time monitoring devices at distances being considered in this study.

Reuter-Stokes

The Reuter-Stokes Senti-1011 system, designed specifically for real time routine radiation monitoring, has been installed at several nuclear power stations in the USA. The field stations of the Senti 1011 systems are equipped with high range (10^{-3} - 10 R/hr) and low range (10^{-6} - 10^{-2} R/hr) pressurized ion chamber detectors and associated instrumentation. Reuter-Stokes is presently developing a single detector to provide accurate monitoring over seven decades of signal which should result in a reduction of a capital cost and installation. Data transmission from the field station to the CPU of the Senti-1011 system can be accomplished by radiotelemetry, dedicated telephone lines, or hard wire. The Senti-1011 CPU performs field station data reduction, system diagnostics, and data logging. Historical information can be obtained in hard copy and the unit contains an interface port for an external computer.

Reuter-Stokes is the only vendor which offers a compatible meteorological accessory package for their field stations. This package, the "3-D Wind System," is marketed by Climatronics and is described in Table VII.

4.3 System Costs

Several commercial power reactor stations and state radiological monitoring agencies were contacted relative to obtaining cost information regarding the purchase and installation of offsite, real-time monitoring systems. Although the systems which have or are being installed are for the purpose of monitoring routine releases, the basic instrumentation and cost data should be similar for an emergency monitoring system. In some cases, detailed cost information was not available because the systems were still being installed or existing systems were being modified or expanded. Information regarding date of installation, number of fixed stations, distance from the source, and type of data transmission is given in Table VIII. All of these systems are using the Reuter Stokes Sentry-1011 monitoring system.

The cost factors for these systems are quite variable because of varying degrees of instrumentation complexity and whether a subcontractor was involved in the design, purchase, and installation of the system. The range in the costs per monitoring unit is approximately from \$20,000 to \$40,000/unit. In general, the higher priced systems included a meteorological sensing component and/or additional subcontractor costs. For purposes of this survey an average cost of about \$30,000 per unit appears reasonable. This value includes the costs of all monitoring and data transmission instrumentation. The cost of a central data processing unit and a computer for extended data handling and reducing capabilities is variable depending on whether dedicated or existing hardware is used for this purpose.

A much more ambiguous cost is that regarding the installation of the field units. If the monitoring unit is installed on existing supports (power transmission poles) and the power source is readily available, the installation costs may only amount to a few thousand dollars (\$3,000 - 5,000) per unit. Conversely, if special supports are required

or if the units are installed over water, the average station costs could increase five fold (\$25,000/unit). Additional cost would also be incurred if special power lines and installation are required. For example, use of uninterrupted power from the Auxiliary Building could add several hundred thousand dollars to the overall costs.

Other costs which must be considered but are difficult to quantify include design and engineering, purchase of land if necessary, depreciation, routine maintenance, dedicated telephone line leasing fees, and operating cost. The last item could be significant if a group of dedicated operators (meteorologists) were assigned to operate the system and evaluate the data.

Based on the data currently available, the following range of cost figures are given for a 16 unit station at a distance of 2 miles.

	<u>Range of Costs (000)</u>
1. Instrumentation \$20-40K/unit	400 - 640
2. Data Collection and processing equip.	40 - 110
3. Installation \$5-25K/unit	80 - 400
4. Design and Engineering	50 - 200
5. Contingency	<u>100</u> - <u>200</u>
	\$670 - \$1,610

The lower cost figure does not insure uniform placement of the monitoring units because existing support poles are considered for use. Thus, it is quite probable that a release could go undetected if it consisted of a compact plume (stability class E or F). Considering that we are only referencing a 16 unit system this same comment could apply even if the monitoring units were uniformly spaced on a ring. Therefore, one could raise a question regarding the technological validity of the entire concept. To increase the number of stations to give highly reliable measurements would result in increasing the overall cost of a system by several million dollars.

TABLE VI
VENDOR DATA FOR REAL-TIME MONITORING SYSTEMS

	<u>Field Station Detector Electronics</u>	<u>Data Transmission</u>	<u>Central Processing Unit (CPU)</u>
Harshaw Chemical Co. TASC-11			
Features	Two weatherproofed CaF ₂ (Eu) Scintillation detectors. Wired power backup.	Hard wire.	All field station electronics except preamplifier are at CPU.
Capabilities	Two detectors span seven decades of signal (1 μ R/hr - 10 R/hr). and withstand tempera- ture variations of 15°C/hr.	Hard wire use demonstrated up to one mile.	Field station electronics at CPU record and print out monitoring data. External computer required for other data reductions and dis- plays.
1981 Prices	\$7K per station including electronics.	Included in field station price.	\$4.2K for CPU consisting of com- puter interface, data recorders, counter and timer.

TABLE VI (Cont'd)
VENDOR DATA FOR REAL-TIME MONITORING SYSTEMS

	<u>Field Station Detector Electronics</u>	<u>Data Transmission</u>	<u>Central Processing Unit (CPU)</u>
GCA Corporation "Guardian"			
Features	Two weatherproofed GM detectors, digital display, detector range changer, solar powered battery backup and "Maypac" particulate and iodine filters. Automatic detector range changer.	RF telemetry, dedicated telephone, hard wire.	CPU has teletype printer, visual data display, data storage, alarm and status system, and external computer interface.
Capabilities	Two detectors span seven decades of signal (1 μ R/hr - 10 R/hr) with + 5% accuracy at 10 μ R/hr. Energy response between 60 KeV and 3 MeV is $\pm$ 20%. Temperature operating range -10°C to +60°C.	Hard wire or dedicated phone line possible.	Processes data from up to 31 field stations. Field stations scanned at 5 second intervals in system alarm mode, 5 minute intervals in non-alarm mode.
1981 Prices	\$15K per station with telemetry \$10K per station with hard wire or telephone.	Included in station cost	\$50K

TABLE VI (Cont'd)
VENDOR DATA FOR REAL-TIME MONITORING SYSTEMS

	<u>Field Station Detector Electronics</u>	<u>Data Transmission</u>	<u>Central Processing Unit (CPU)</u>
Reuter - Stokes Sentry 1011			
Features	Two weatherproofed pressurized ion chamber detectors. Digital display, strip chart recorder, 8-hour battery power backup, serial readout and automatic detector range charger.	Hard wire, dedicated telephone, or RF telemetry.	Basic CPU processes input from 16 field stations, reduces and stores exposure rate data. CPU also has alarm and system diagnostics, and external computer interface.
Capabilities	Two detectors span seven decades of signal (1 μ R/hr - 10 R/hr) with + 5% accuracy at low levels. Temperature operating range is -25°C to + 55°C.		Basic CPU can be upgraded to process input from up to 48 field stations. Scan of field stations can be done at 5 second to 5 minute intervals.
1981 Prices	\$11.3K per station (detectors cost \$3K a piece)	\$3.5K per station for telemetry. Hard wire about \$2K per station at 0.5 miles.	\$39K to process input from 16 stations. \$70K to process input from 48 stations.

TABLE VII
Climatronics "3-D" Meteorological Monitoring System

	<u>Field Station Electronics</u>	<u>Data Transmission</u>	<u>Central Processing Unit (CPU)</u>
Features	Sensor package inputs to field computer to determine θ and ϕ . Can use dedicated telemetry for radiation detection electronics for transmission. Ten meter tower, sensor heater and electronics housing required.	Dedicated 2-way telemetry system recommended for real-time monitoring but telephone and hard wire is possible.	Field computer output transmitted directly to modeling system to determine stability class.
Capabilities	Solar power, temperature dew point sensors also available.	Two-way RF can relay commands to station such as time averages and scan times.	Station sensors used with doppler monitor for forecasting would give more information for modeling.
Cost ^a	\$10K/station for the above features and capabilities.	\$3.5K/Station for 2-way RF telemetry	\$3K for RF central processing unit

^a1981 purchase prices

TABLE VIII
REAL-TIME INSTALLED MONITORING SYSTEMS

<u>Facility (Owner)</u>	<u>Installation Date</u>	<u>Number of Monitoring Units</u>	<u>Distance from Sources (miles)</u>	<u>Data Transmission</u>
Diablo Canyon ^a (PG & E)	1981	12	5-10	Phone
La Salle (Comm. Ed)	1980	8 ^b	2	Phone
Berwick (Penn. P & L)	1980	2 ^c	15-26	None
Virgil C. Summer ^a (SC G & E)	1981	8	0.5	Hardwire
Three-Mile Is. (Metro. Ed)	1980	12	0.1-4	Phone
Indian Pt. -2 ^a (Con. Ed.)	1980	16	0.5-2.5	Telemetry
San Onofre (So. Cal. Ed.)	1981	9 ^d	0.6	Phone

a) Field stations include meteorological accessories

b) When completed system will have 16 field units

c) Complete system will have 7 field units

d) Complete system will have two rings of 9 stations each. One at 1000m and the other at 2000m.

5.0 MATRIX EVALUATION

One of the primary objectives of this program is to evaluate the concept and usefulness of an offsite real-time monitoring system in the light of a matrix array and associated parameters. The matrix and its three major components, accuracy, cost, and detector sensitivity were presented in Section 1. Based on the review and studies conducted in the prior sections of this report our evaluation of the matrix is as follows. For ease of reference the matrix array is reproduced on page 51 as Figure 14.

Accuracy - The accuracy level was evaluated based on the uncertainty associated with the quantification of an unmonitored release in the presence of a monitored release. Based on our study we propose eliminating all conditions associated with accuracy values for factors of 2, 5 and 10. In some cases, especially for the case where the unmonitored release is small compared to the monitored release, even the accuracy factor of 50 for the unmonitored release may be a question.

Detector Range - The requirement for detectors sensitive to the measurement of a quantity of radiation equivalent to 0.1 background (1 μ R) cannot be justified, especially when the background can fluctuate more than this amount. A similar argument can be made for detector systems having a lower range equivalent to background (10 μ R/hr) because the uncertainty in the signal would be large and a reading equivalent to background in an emergency situation would not be significant relative to the initiating protective action in the surrounding areas. One might make a case for the use of detectors having a lower range of 10 μ R/hr in establishing site specific diffusion models based

on the monitoring of normal releases. However, if the detectors are placed at a two-mile distance from the plant, the dose rate from normal releases would be so small as to be garbled in the normal background fluctuations. In our opinion, detectors with a lower range of 10 times the background level or 0.1 mR/hr should be adequate for an offsite real-time monitoring system, because readings of less than 0.1 mR/hr are of little significance from a hazard standpoint. This is a point which should be presented as part of the public relations effort of the utility. This conclusion eliminates the two lower levels of the matrix.

Cost Factors - This item is more difficult to assess because of the wide range of values associated with the installation costs. We can, however, make some general comments. If a low cost system is installed with a minimum (8-12) number of stations, there is a high probability of missing a plume, in which case the system has little technological value. To install a minimum system with detectors only near population centers may have appeal from a public relations standpoint but it does not provide the technical data which is necessary to assess the impact of a plume to the rural areas which could be populated by grazing milk cows. Also, if the detectors were not uniformly spaced near the population centers, false information relative to the intensity of the plume dose could result.

We do not support the installation of a minimum system, which we are associating with a \$250,000 cost value, because the technical information obtained from such a system would be of questionable use in a decision making process.

Similar arguments can be made for a \$750,000 system; however, at this level each installation would have to be evaluated on an individual basis because of site specific characteristics. Obviously the requirements for a monitoring system in a flat terrain situation is different from one involving water, off-shore and on-shore breezes etc. In some cases, a system constructed for a cost of \$750,000 might provide reasonable technical information. Thus, we have decided to leave this area of the matrix open but emphasize the site specific characteristic of the case.

For \$2,000,000 one might construct a reasonable system, but in no case would information accurate to a factor of 5 or 10 be obtained. In fact, almost no sum of money would insure obtaining dose values to this level of accuracy.

Based on the above discussion and evaluation, the bulk of the matrix has been eliminated. The remaining areas which we feel identify the potential benefits and associated uncertainties from the installation of a fixed off-site real-time monitoring system are shown in gray in Figure 14. While it is acknowledged that our conclusions are argumentative, we believe they are representative of the current state the of art.

Figure 14. Matrix Parameters

6.0 MINIMUM-COST EMERGENCY SYSTEM

An augmented effort to the general program involved the characterization and evaluation of a specific, minimum cost emergency system with close proximity to the plant. The constraints to be applied to the evaluation of such a system are as follows:

1. Total system cost - not to exceed \$500,000,
2. Detector assembly cost - not to exceed \$7,000/unit
3. Detector distance - no further than 800 m (0.5 mi),
4. Detector sensitivity - 0.1 mR/hr to 10 R/hr, and
5. Accuracy - within a factor of 10.

Using the cost data presented in Section 4, the following values were used to establish the magnitude of the system which could be installed within the \$500,000 constraint.

Fixed Costs

Central Processor (with modeling, 48 station capacity)	\$110,000
Design and Engineering	<u>40,000</u>
	\$150,000

This leaves a balance of \$350,000 which can be allocated to the cost of the detector assembly, data transmission, and installation. The cost per station is estimated as follows:

Dectector Assembly	\$ 7,000
Data Transmission/Unit	8,000 ^a
Installation/Unit	<u>3-15,000^b</u>
Total/Unit	\$18-30,000

a Includes capital cost and installation

b highly variable depending on specific location

For this exercise it was assumed that the data transmission would involve a telemetry system because the cost of installing hardwired or dedicated phone systems is highly variable. For example, climatic factors may dictate the burial and/or the use of special materials in each of these data transmission systems. The installation costs are based on simple units all installed on flat solid terrain. If uniform placement of the detector assemblies required installation in cooling ponds, rivers, or other bodies of water, the installation costs would increase significantly, perhaps by as much as a factor of five for those units in such a location. Another significant expense item is the power source. If an uninterrupted power supply from the Auxiliary Building is used the cost per station would be significantly more, especially if underground or underwater lines were used.

Based on an after fixed-cost balance of \$350,000 which can be allocated to the detector units, and a range of average station costs of \$18,000 - \$30,000, from 12 to 20 detector units could be installed depending on the actual placement of the units.

The 12 unit system would insure equal placement of the units regardless of the location. The 20 unit system could have voids in the monitoring grid and be operated with normal power sources.

The estimate appears reasonable based on information obtained from two utilities which provided cost information for a comparable system. One station which recently completed installation of an 8 unit system at a distance of 800 m (0.5 mi) quoted a cost of about \$435,000 for the purchase and installation of the package. In this case, each unit also included a meteorology station and the output from the unit was hard-wired to the control station and coupled to an existing HP-1000 data processor. Thus, the total cost per unit is approximately \$54,000.

The overall cost would increase if a dedicated CPU were used and probably decrease if some other form of data transmission were used. The cost per unit would also decreasing if meteorology sensors were not installed with each unit, but the validity of any down-wind projection would also decrease.

A second utility while not providing complete capital cost data did provide sufficient information to estimate the cost for a ring of nine units at a distance of 1000 m. The central processing unit for this system has not been purchased. However, the purchase cost of the nine field stations was about \$135,000, or about \$15,000 per station. For the nine unit system using a dedicated phone system for data transmission, the installation cost per unit was quoted at about \$23,000 per unit or about \$200,000 for the system. This is somewhat higher than our estimate but gives some idea of the costs involved just for installation. Assuming fixed costs of \$150,000 for design, engineering, and a central data processor, about \$135,000 for instrumentation and \$200,000 for installation gives a sum within the \$500,000 constraint. The unit cost for the nine detector system is about \$55,000, which is similar to the first system discussed.

To estimate the credibility of the data which could be expected from an 8 to 20 unit system we first considered the data given in Table V. Based on these data, a minimum of $\sqrt{90}$ equally spaced stations would be required for two adjacent units to give a reading within a factor of 2 of each other when the release was at ground level

and the stability class was F. For two units to agree within a factor of 10 would require a system of 35-40 units. About 30 detectors would be required for more common class D weather. These numbers are based on the assumption that the centerline of the plume passes directly over one of the stations. This is a highly improbable event. The passage of a plume between two detectors would give a response which underestimates the true magnitude of the release.

A second factor which must be considered for a 500-800 m system, is the effect of the building shine factor, especially for a BWR. For the case given in Figure 12, the plume dose at 800m for a leak rate of 1% per day of the building noble gas inventory is considerably less than the building shine background. The effect of building shine will be much less for a PWR.

The effect of building wake and dispersion of the flow regime by other buildings (other than the reactor building) is a third factor which should be considered. This effect could significantly alter the measurement of the true dose from the plume.

While a close-in detector system might in some instances provide some information in an emergency situation, the ability to extrapolate and project the information to give concentration or dose values at some extended downwind distance (5-10 mi) is highly questionable. This could only be done with a reasonable degree of confidence if site specific modeling and additional downwind meteorological data were available.

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APPENDIX - A

BRIEF SUMMARY OF EXPERIMENTAL RESULTS TO
COMPARE MEASURED AND PREDICTED GROUND LEVEL CONCENTRATION VALUES

A.1 ⁸⁵Kr Experiment at Savannah River Plant⁹

In this experiment, the release of ⁸⁵Kr from the Savannah River Plant chemical separations facility was monitored for over a year at six sites within 10 km of the release points. Using the Gaussian plume model for a continuous source, the ratio of the predicted concentration to the measured concentration was determined. The dispersion parameters were those based on the ideal case of flat terrain, short distance, and steady meteorological conditions.

The general results showed that the annual average concentrations were over-predicted by a factor of 2 to 4 compared to the measured values. For the short-term (10 hours), the predicted values were within about a factor of 10, and in many cases, particularly in calm or stable conditions, measurable concentrations were predicted when none were observed. The results of the short-term data are shown in Figure A-1 from Reference 9.

A.2 ORNL Assessment of Hanford Experiment¹⁰

As part of a DOE sponsored program associated with the Breeder Reactor Program, ORNL is evaluating experimental data obtained from an experiment conducted at Hanford in which zinc sulfide fluorescent particles were released from a height of 111 m over relatively smooth terrain. Crosswind-integrated ground-level air concentration measurements were compared with predicted values using a Gaussian plume atmospheric dispersion model. Of interest was the use of three different sets of measurements to calculate the atmospheric stability class.

- a. The vertical temperature difference between 10 and 122 m above ground-level,
- b. The standard deviation of the wind direction measure at a height of 122 m, and

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Figure A-1. Measured to Predicted ^{85}Kr Concentrations (ref. 9)

c. A combination of a and b.

For the Hanford data, methods a and b, with one exception, indicate Pasquill stability classes E or F, while method c always indicates class D.

In this study ORNL compared the results obtained as a function of the dispersion factor, σ_z , based on five different sets of diffusion models. Basically, these include those data sets previously discussed and reviewed by Brenk⁸ (Pasquill, St. Louis, Briggs' Rural, Brookhaven, and Julich-100 m). Separate comparisons were made between measured and predicted concentration values using each of the five sets of σ_z values and three stability class determinations. A summary of the observed and predicted concentrations values is given in Table A-1.

These data (Table A-1) show that the predicted values differ from the measured values by a factor of 5 to 10 more than 50% of the time and that the predicted value may be more or less than the measured value depending on the dispersion system used and the associated dispersion factors. About 40% of the time the difference between the predicted and observed values can be a factor of 10 or greater; again in either direction.

These data tend to support our initial comments regarding uncertainties associated with the use of the standard Pasquill factors and the need to develop site specific data.

A.3 Excerpts from a Workshop on the Evaluation of Models Used for Environmental Assessment of Radionuclide Releases¹¹

The working group suggested some tentative accuracy statements on the estimation of airborne concentrations. These statements are largely based on scientific judgement; there are not enough data upon which to base a reliable statistical estimate. For the ideal situation of a highly instrumented flat-field site from which previous data on meteorology

Table A-1. EVALUATION OF HANFORD EXPERIMENT BY ORNL.

Stability Assignment Method*	% of Observations Exceeding Limits					
	<u>Factor of 5 or Greater</u>		<u>Factor of 10 or Greater</u>			
	<u>(a)</u>	<u>(b)</u>	<u>(a)</u>		<u>(b)</u>	
Pasquill-Gifford	62%	52%	43%	UP**	38%	UP
St. Louis (Smith)	62%	57%	38%	UP	38%	UP
Briggs' rural	43%	48%	29%	UP	33%	UP
Brookhaven	62%	52%	52%	OP	52%	OP
Julich (100 m)	62%	62%	43%	OP	38%	OP

* (a) Stability class based on vertical temperature difference between 10 and 122 m above ground level.

(b) The standard deviation of the wind direction measured at a height of 122 m

** UP - Model underpredicts ground level concentration relative to observed values (i.e. $\frac{\text{obs.}}{\text{pred.}} > 1$ majority of time).

OP - Model overpredicts ground level concentration relative to observed values (i.e. $\frac{\text{obs.}}{\text{pred.}} < 1$ majority of time).

and airborne concentrations were available, it should be possible to estimate to within $\pm 20\%$ the ground-level centerline concentrations from a continuous point source at downwind distances of less than 10 km.

For a specific hour and downwind receptor point, the accuracy is very dependent on the calculation of the exact plume trajectory during a short period. For flat terrain and relatively steady meteorological conditions and distances of 10 km or less, the airborne concentrations for an individual case should be estimated to within about a factor of ± 10 . For annual average concentrations values, the accuracy estimate is about a factor of 2.

For a complex terrain or meteorological situations (e.g., sea breeze regimes) a few experiments have indicated departures from estimates from the Pasquill-Gifford curves of more than a factor of 10. However, there are insufficient data upon which to base even a "scientific judgement" estimate of accuracy.

A.4 Results of a Survey of Programs for Radiological Dose Computations¹²

A standard accident release problem was presented to several nuclear facilities with the request that the cloud gamma dose be calculated as a function of distance. The same input data were used by all participants. The results of the various calculations using identical input are shown in Figures A-2 and A-3. The range in the calculated values is a factor of $\sqrt{10}$ at the 1000-3000 m distance. Considering that there are no absolute standards by which to judge the accuracy of the dose calculations, one might question, "how close is the range of values presented by these calculations to the true absolute value?"

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Figure A-2. Comparison of Different Dose Calculation Models, Class F (ref. 12)

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Figure A-3. Comparison of Different Dose Calculation Models, Class C (ref. 12)

APPENDIX B

VALUES FOR σ_y AND σ_z USED IN DOSE CALCULATIONS

,

TABLE B-1

VALUES FOR σ_y AND σ_z USED IN DOSE CALCULATIONS^a

Stability Class	Distance							
	500 m		800 m		1600 m		3200 m	
	σ_y	σ_z	σ_y	σ_z	σ_y	σ_z	σ_y	σ_z
A	106	128	164	326	312	1530 ^b	586	8294 ^b
B	80	53	125	98	239	278	449	920
C	57	35	88	54	167	99	313	176
D	37	19	57	27	108	45	204	71
E	28	14	43	20	81	31	151	47
F	19	9	30	12	56	19	105	27

^a Listed data are calculated values based on an equation developed⁽¹³⁾ to fit the data given in Reference 3.

^b Values greater than 1000 are not realistic because the mixing layer depth ($\sim 1000\text{m}$) can restrict vertical plume growth.

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