EPA-520/5-76-015

AIR PATHWAY EXPOSURE MODEL VALIDATION STUDY AT THE MONTICELLO NUCLEAR GENERATING PLANT

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

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September 1976

U. S. ENVIRONMENTAL PROTECTION AGENCY
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Washington, DC 20460

FOREWORD

The Office of Radiation Programs carries out a national program designed to evaluate the exposure of man to ionizing and nonionizing radiation, and to promote the development of controls necessary to protect the public health and safety and assure environmental quality.

Technical reports allow comprehensive and rapid publishing of the results of Office of Radiation Programs' intramural and contract projects. The reports are distributed to State and local radiological health offices, Office of Radiation Programs' technical and advisory committees, universities, laboratories, schools, the press, and other interested groups and individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

I encourage readers of these reports to inform the Office of Radiation Programs of any omissions or errors. Your additional comments or requests for further information are also solicited.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs

PREFACE

The Eastern Environmental Radiation Facility (EERF) participates in the identification of solutions to problem areas as defined by the Office of Radiation Programs. The Facility provides analytical capability for evaluation and assessment of radiation sources through environmental studies and surveillance and analysis. The EERF provides technical assistance to the State and local health departments in their radiological health programs and provides special analytical support for Environmental Protection Agency Regional Offices and other federal government agencies as requested.

This study is one of several current projects which the EERF is conducting to assess environmental radiation contributions from fixed nuclear facilities.

Charles R. Porter
Director
Eastern Environmental Radiation Facility

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ABSTRACT

The results of a study designed to improve the methodology for estimating the population exposures resulting from nuclear power plant gaseous effluents are given. The primary objective of this study was to validate a mathematical model (AIREM) for estimating radiation exposures due to atmospheric radioactive releases. This validation was accomplished by comparing the model predictions with actual field measurements made using pressurized ionization chambers and thermoluminescent dosimeters. Use of this model for predicting external exposures was shown to be quite acceptable for most applications. The usefulness of pressurized ionization chambers for making low-level exposure measurements was also demonstrated by this study.

I. Introduction

The proliferation of nuclear power plants, the increased cost of environmental monitoring, and the need to measure extremely low population exposure levels have necessitated the use of new and innovative techniques in nuclear power plant radiation surveillance. One such technique is the use of mathematical exposure models to supplement surveillance programs. These exposure models when used as an integral part of facility monitoring, hopefully will provide maximum necessary assurances with minimum expenditure of resources. The Office of Radiation Programs (ORP) of the Environmental Protection Agency (EPA) has a mathematical model (AIREM) for estimating the exposure to populations within 80 km of operating nuclear facilities due to atmospheric releases of radioactivity. The gaseous effluent data provided by each reactor in accordance with plant technical specifications are used as the basic input data for this model.

II. Objectives

The primary objective of this study was to validate the ORP mathematical model (AIREM) for estimating radiation exposures due to atmospheric radioactive releases. This validation was to be accomplished by comparing the model prediction with actual field measurements. The field measurements were made using pressurized ionization chambers and thermoluminescent dosimeters. The predictions obtained using the AIREM model were also compared to the predictions of several other existing models.

In addition to this primary objective, a secondary objective was to compare exposure measurements made using the pressurized ionization chambers (PIC's) and thermoluminescent dosimeters (TLD's).

The problem of dose rates from particulate releases was not addressed in this study. A model validation study based on particulates is intractable due to the extremely small quantity of particulates released.

III. Description of Facility and Site

The Monticello Nuclear Generating Plant is an operating boiling water reactor owned by the Northern States Power (NSP) Company and is located about 55 km northwest of Minneapolis - St. Paul, Minnesota (2). It has an authorized power level of approximately 545 MWe and started commercial operation in June 1971.

At the time of the study, the plant design allowed radioactive gaseous effluents to be held for approximately 30 minutes to permit decay of the short-lived noble gases and then filtered prior to release to the atmosphere from a 100-m stack. These effluents are also monitored prior to release. An extended holdup system (minimum 50 hours) has been installed to replace the 30-minute system (3).

The plant site is located about 5 km northwest of Monticello, Minnesota, (population approximately 2,000) on the south bank of the Mississippi River in Wright County, Minnesota. The nearest property boundary is 500 m south of the reactor building and the nearest house is 850 m to the south. St. Cloud, Minnesota, (population approximately 40,000) 35 km northwest of the site, is the nearest large city.

The land surrounding the site is predominantly rural. There are a few small communities within a 25-km radius of the site. The terrain is heavily wooded along the river while away from the river the terrain is relatively level and largely under cultivation.

IV. Study Design

To meet the objectives of this study, radiation exposure measurements, meteorological data, and gaseous release rates were obtained on a continuous basis for approximately 9 months. The data collection commenced on August 28, 1973, and continued until May 13, 1974. The reactor was shut down for refueling from March 15, 1974, through May 20, 1974.

A. Pressurized Ionization Chambers

The major portion of the field study consisted of continuous ambient radiation exposure measurements using pressurized ionization chambers (PIC's). The PIC's used in this study are commercially available instruments similar to those described by DeCampo, et al (4). The detector is a spherical stainless steel chamber, 25 cm in diameter with a wall thickness of 0.3 cm. The chamber is filled with argon to a pressure of 1900 cm Hg (0° C).

The ionization chambers were operated offsite at the locations shown in table 1 and figure 1. These locations were selected based on predominant wind directions and the points of maximum deposition.

Table 1

Monticello PIC site locations

Site	Distance from stack (km)	Direction from stack (degrees)
A	1.4	138
B	3.3	133
C	3.2	156
D	2.3	102

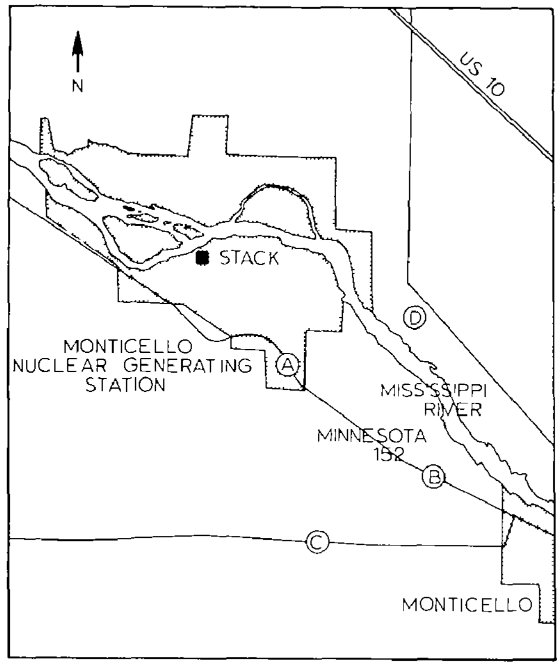

Figure 1. Pressurized ionization chamber locations

The instruments were housed in plywood boxes (figure 2) approximately 2 m above ground. All locations were supplied with AC power for operation of the instruments.

The readout of the instruments was in the form of a strip chart recording (figure 3). The strip chart operated at a speed of 10.16 cm per hour. The charts were collected and changed on a weekly basis and mailed to Eastern Environmental Radiation Facility (EERF) for data reduction.

Data reduction was accomplished by planimeter integration of the strip charts. The integral exposures were determined on 2-hour intervals. The plant contribution was determined by subtracting the natural background from each 2-hour integral.

During the latter portions of this study, a commercially available integrator module was adapted and tested by the EERF (5). The integrator, when used in conjunction with the PIC, can be used to determine integral exposures without the need for tedious planimeter integration.

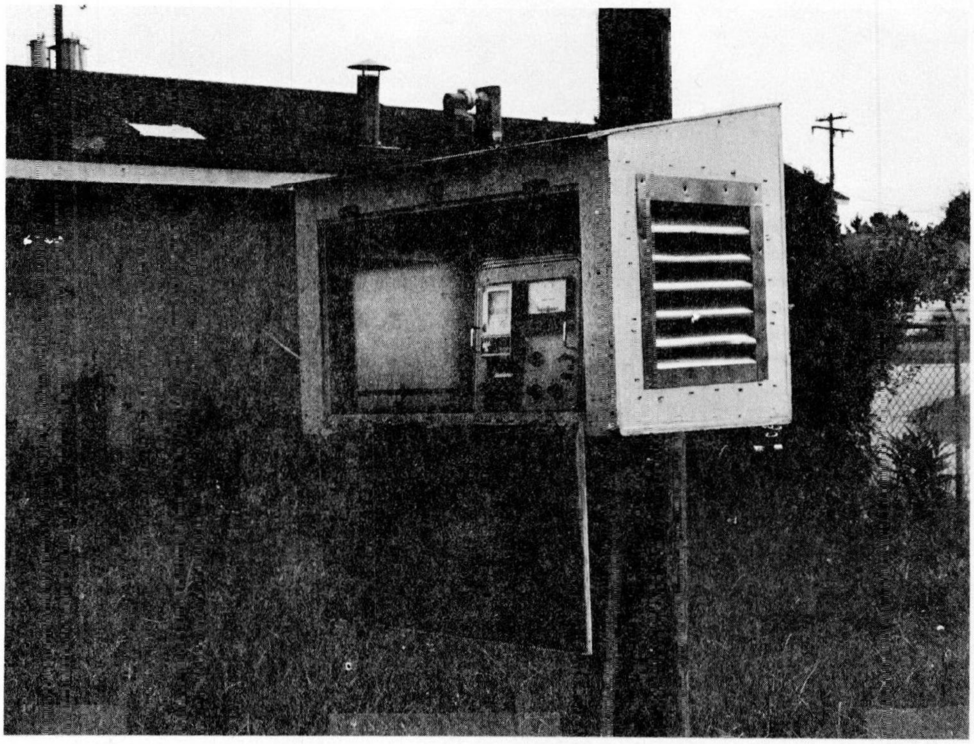

Figure 2. Instruments housed in plywood boxes

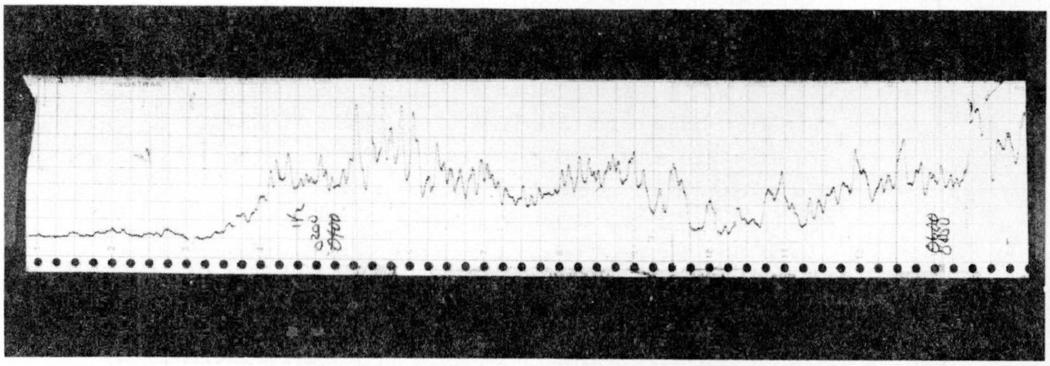

Figure 3. Strip chart recording

B. TLD Measurements

Additional radiation exposure measurements were made on a continuous basis using calcium fluoride:manganese activated (CaF_2:Mn) thermoluminescent dosimeters. These dosimeters are commercially available glass-bulb type dosimeters, complete with energy compensation shields to reduce the over response of CaF_2:Mn to low energy radiation (6,7).

Three TLD's were located inside the plywood boxes at each PIC site. The TLD's were read out on either a 1- or 2-month interval. All annealing and readout of dosimeters was performed in the field near the sites to avoid any errors that might be introduced by transporting the dosimeters.

TLD monitoring during the 2 months of reactor shutdown was used to approximate the natural background for each site. These background values were subsequently subtracted from TLD measurements taken during periods of plant operation to determine the net or facility contribution.

C. Meteorological and Gaseous Release Data

The meteorological data used were taken from the 42.6 m tower located approximately 1.0 km ESE of the 100 m release stack. Data taken at top of the tower consisted of strip chart recordings of wind speed and wind direction and were assumed representative of conditions at the stack release point. The mean wind direction, wind speed, and wind direction range were tabulated on 2-hour intervals as obtained from manual analysis of the strip charts. Temperature lapse rate data were not available on site and atmospheric stability classes were estimated from the 2-hour range of wind direction using the procedure described by Markee (8) and the tables of Turner (9).

During site visits, the wind direction recording equipment was observed to indicate winds 180° out of phase with the true wind direction at unpredictable times. In an attempt to minimize errors caused by this anomalous behavior, the wind directions recorded at the site were compared on an hourly basis with those obtained from the National Weather Service at St. Cloud, Minnesota, and the site data were thereby validated. During periods in which the site data were found to be in error, the recorded site direction was rotated 180° to obtain the true wind direction. Due to the data cross-checking procedure employed, this anamoly did not result in appreciable error. However, the situation does indicate the importance of a facility-maintained quality assurance program for meteorological data.

During the latter portion of this study, NSP was installing a new meteorological system. This system consisted of a 100 m tower and automatic data reduction equipment. Data from the new tower were not available during this study. The availability of summary meteorological data in future studies would significantly reduce the manual efforts required.

The gaseous release rates used in this study were obtained from the plant operating reports (10) for the period of the study. Preliminary sample calculations indicated that the majority of the gamma exposure rate at ground level was due to six nuclides emitted from the stack, therefore, all subsequent calculations of exposure rate were based on releases of these nuclides. These six gaseous nuclides which were released in measurable quantities, together with their fractional abundances and the approximate fraction of ground level exposure rate at 2 km from the stack, are given in table 2. This information indicates that at 2 km, approximately 90 percent of the exposure rate was due to the three nuclides krypton-87, krypton-88, and xenon-135. The fractional exposures were estimated assuming D stability and 4 m/s wind speed.

Table 2

Calculated

relative noble gas releases

Nuclide	Fractional abundance based on total activity	Calculated fraction of ground level exposure rate at 2 km
^{85m}Kr	.079	.02
^{87}Kr	.200	.27
^{88}Kr	.210	.56
^{133}Xe	.147	.01
^{135}Xe	.289	.10
^{138}Xe	.075	.04

D. Model Description

A brief description of the four calculational models considered in this study is given in table 3 and discussed below:

1. AIREM (11) is the atmospheric dispersion model developed by the Office of Radiation Programs for long-term exposure predictions. This program uses an "exposure integral" data file obtained from execution of the program EGAD (12) to evaluate the exposure rates from the external gamma emitters. The EGAD calculation involves numerical integration over the cloud geometry for each respective point of interest on the ground.

2. The calculation using AIREM.SI uses the same structure as the model above but the exposure rate estimate is made using the traditional sector-averaged Gaussian calculation (13) of ground-level concentration at receptor points and conversion to exposure rate by an exposure conversion factor (14) using average gamma energies from Lederer, et al (15).

Table 3

Differences among exposure models

	AIREM	AIREM.SI	RRR	ACRA
Plume Dispersion	Sector Averaged	Sector Averaged	Sector Averaged	Single Plume
Output summed over:				
Nuclide	Yes	Yes	No	Yes
Stability Class	Yes	Yes	Yes	No
Multiple Wind Field Input	Yes	Yes	Yes	No
Variable lid height with stability class	No	No	Yes	Yes
σ_z evaluation	Internal	Internal	Input Data	Input Data
Core Requirements	182K	182K	140K	314K
Relative cost to run	$2	$1	$5	$16

3. The RRR Model was written by Reeves, et al (16) and has been used by the U. S. Atomic Energy Commission in the preparation of environmental impact statements (17,18) for nuclear power plants. The calculational procedure employed is the sector-averaged Gaussian estimation of ground-level concentration similar to that employed in AIREM.SI. Values for vertical standard deviations are entered as data rather than calculated internally as in AIREM.SI. In addition, output is left in concentrations by each nuclide without direct conversion to exposure rate. Such minor differences in input data requirements and output format variations should lead to inconsequential differences in the results or applicability of the two models.

4. The ACRA model was written by Stallmann and Kam (19) for reactor accident analysis. The differences between calculational procedures employed in this model and those previously mentioned are quite significant. Three dimensional Gaussian diffusion is assumed and exposures are determined by numerical integration over all points in the cloud which contribute significantly to the respective receptor points. Single runs consist of data for a given release function, a single stability category, wind speed, and wind direction. Consequently, the results are intended for analysis of relatively short-term releases when dispersion characteristics are relatively constant.

V. Results

A. Field Measurements

The results of the field measurements are presented in tables 4 and 5. The PIC results were first tabulated on 2-hour intervals and subsequently summed for the intervals shown. The time periods shown in these tables correspond to the TLD readout intervals. The data collection was incomplete during some of the time periods due to power failures and instrument malfunctions.

Table 4

Total exposure
(mR)

Time Period	Site A PIC	Site A TLD[1]	Site B PIC	Site B TLD[1]
08/29-10/02/73	10.45	9.90	8.02	7.95
10/02-11/06/73	14.54	14.03	NC	9.71
11/06/73-01/07/74	26.52	24.55	16.70	15.92
01/07-01/27/74	12.10	11.66	6.45	6.54
01/27-03/18/74	17.60	15.95	12.16	12.25
03/18-05/13/74*	11.27	11.64	10.89	10.59

Time Period	Site C PIC	Site C TLD[1]	Site D PIC	Site D TLD[1]
08/29-10/02/73	7.57	7.45	NC	7.97
10/02-11/06/73	8.32	8.64	8.40	8.91
11/06/73-01/07/74	15.07	13.96	NC	14.47
01/07-01/27/74	NC	4.97	5.51	5.13
01/27-03/18/74	NC	10.90	11.54	11.21
03/18-05/13/74*	NC	11.40	NC	11.20

NC Data collection not complete.
* Reactor shut-down for refueling.

[1] These values represent the mean of three dosimeters at each site. All standard errors of the mean were less than 2%.

Table 5

Net exposure
(mR)

Time Period	Site A TLD[1]	Site A PIC	Site B TLD[1]	Site B PIC
08/29-10/02/73	2.61	3.15	1.32	0.91
10/02-11/06/73	6.66	6.39	3.01	NC
11/06/73-01/07/74	11.43	12.99	4.01	NC
01/07-01/27/74	7.47	8.02	2.73	2.75
01/27-03/18/74	5.29	8.51	2.55	3.20

Time Period	Site C TLD[1]	Site C PIC	Site D TLD[1]	Site D PIC
08/29-10/02/73	0.32	0.81	1.13	NC
10/02-11/06/73	1.44	1.33	1.69	1.33
11/06/73-01/07/74	1.13	3.20	1.90	NC
01/07-01/27/74	0.84	NC	1.09	1.66
01/27-03/18/74	0.47	NC	0.94	NC

NC Data collection not complete for this site.

[1] These values represent the mean of three dosimeters at each site. All standard errors of the mean were less than 2%.

Table 4 gives the total exposure, natural background plus facility contribution, as measured by both the PIC's and the TLD's. A statistical comparison of these values is given in figure 4: a linear regression analysis using the form y = bx+a was performed with the PIC measurement as the y values and the TLD measurements as the x values. The results of this analysis yielded a regression equation of y = 1.16 (x) - 0.93 with a correlation coefficient of 0.996.

The natural background measurements were subtracted from the total exposure measurements to yield the net exposures shown in table 5.

Shown in figure 5 is the comparison of net TLD to net PIC measurements for the period of the study. Regression analysis of these data resulted in a regression equation of y = 1.089 x +0.48 with a correlation coefficient of 0.962.

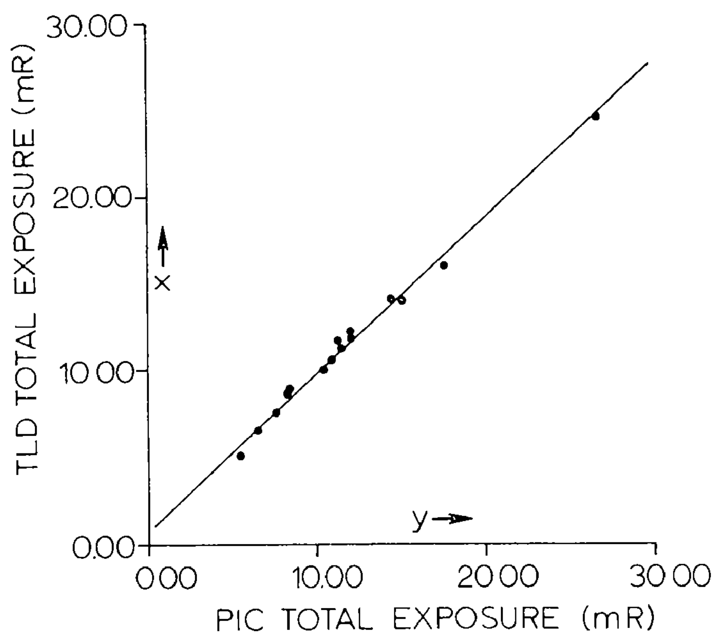

Figure 4. Comparison of TLD & PIC (total exposure)

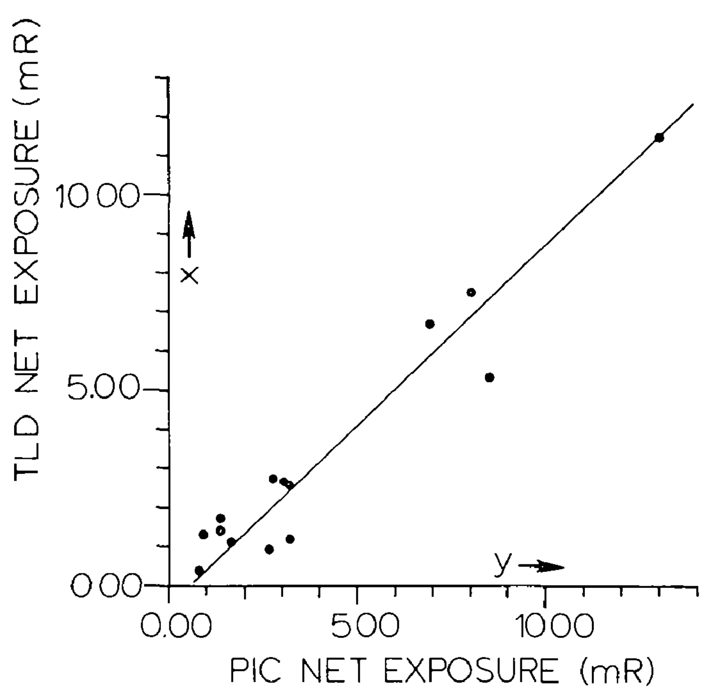

Figure 5. Comparison of TLD & PIC (net exposure)

B. Model Validation

Each of the four computer models was used to obtain predictions of monthly gamma exposures which were compared to their respective observed exposure as measured by the PIC's.

The model validation and comparison portion of the study applied the data from the 4 months September - December 1973. This portion of the study was not extended beyond 4 months due to the manpower and computer time required to set up data files and execute each of the four calculational model studies. The adequacy of this length of time for estimating plume exposure has been shown in a previous report (20), which indicated the predicted/observed ratios for 1 month of data are not significantly different from those for 2- and 4-month periods.

The observed net exposures at each of the four sites for the 4 months, September - December 1973, are shown in table 6 to range from 5.88 mR at Site A in November to 0.32 mR observed at Site D in September. Corresponding values of monthly predicted exposure for each of the four computer codes are also shown.

Table 7 gives the ratios of monthly predicted exposure to the corresponding observed exposure for each of the four models. The mean value of predicted/observed ratios range from a low of 1.25 (σ = 0.518) for the AIREM model to a high of 2.402 (σ = 1.18) for the ACRA model. To formalize the comparison of the performance of each of the models, several statistical tests were run on the predicted/measured ratios obtained. These tests were divided assuming the predicted/measured ratios to be a random variable. The tests were divided into two groups; the first set of tests assumed that the variable was distributed normally and the second set assumed that the variable was distributed log-normally. Results of both sets of tests are given below.

Normal Distribution Treatment: To test the assumption of homogeneity of the four within-group variances, a Bartlett Test (21) was performed. The null hypothesis of equal variances was rejected at the 99 percent level and, therefore, the one-way analysis of variance could not be used as an exact test of the results from the four models. Consequently a pooled-variance range test (22) was applied to the results. This test showed that the results from AIREM, AIREM.SI and RRR were not significantly different at the 99 percent level, but the results from ACRA were significantly different. This result is not at all surprising after a cursory examination of the results in table 7 and one recalls that the single plume calculation inherently gives higher predictions for elevated releases than does the sector-averaged calculation.

Table 6

Predicted and Measured Exposure Values (mR)*

	Site A					Site B				
	Mea-		Predicted			Mea-		Predicted		
Mo/Yr	sured	AIREM	AR-SI	RRR	ACRA	sured	AIREM	AR-SI	RRR	ACRA
9/73	2.49	2.04	0.74	0.92	3.71	0.78	0.90	0.80	0.95	2.44
10/73	3.02	3.08	3.30	3.32	4.68	1.02	1.08	1.25	1.25	2.77
11/73	5.87	5.24	3.43	3.80	7.02	2.48	2.15	2.44	2.30	3.94
12/73	5.70	4.62	5.48	6.95	5.12	1.66	1.61	1.94	2.39	2.81
Total	17.08					5.94				

	Site C					Site D				
	Mea-		Predicted			Mea-		Predicted		
Mo/Yr	sured	AIREM	AR-SI	RRR	ACRA	sured	AIREM	AR-SI	RRR	ACRA
9/73	0.75	0.58	0.58	0.52	1.15	0.32	0.60	0.55	0.53	1.53
10/73	0.52	0.74	0.89	0.81	1.65	1.13	0.81	0.76	0.88	1.86
11/73	1.52	3.42	4.11	3.28	6.43	0.80	1.69	1.78	1.78	2.88
12/73	2.20	2.99	3.36	3.04	4.87	1.53	2.54	2.45	2.40	4.08
Total	4.89					3.78				

*Values given are above background at the respective sites.

Table 7

Predicted/measured exposure ratios for four models

Mo/Yr	Site	AIREM	AIREM.SI	RRR	ACRA
9/73	A	0.82	0.30	0.37	1.49
	B	1.16	1.03	1.22	3.14
	C	0.77	0.77	0.69	1.53
	D	1.88	1.72	1.66	4.78
10/73	A	1.02	1.09	1.10	1.55
	B	1.06	1.23	1.22	2.72
	C	1.42	1.71	1.56	3.17
	D	0.72	0.67	0.60	1.65
11/73	A	0.89	0.58	0.65	1.20
	B	0.87	0.98	0.93	1.59
	C	2.40	2.89	2.30	4.53
	D	2.12	2.29	2.24	3.62
12/73	A	0.81	0.96	1.22	0.90
	B	0.97	1.17	1.44	1.69
	C	1.36	1.53	1.38	2.21
	D	1.66	1.60	1.57	2.67
Mean		1.25	1.28	1.26	2.40
Range		0.72-2.40	0.30-2.89	0.37-2.30	0.90-4.78
Standard deviation		0.52	0.66	0.55	1.18
Standard error of the mean		.13	.16	.14	.30

Perhaps the most important outcome of these tests is that the three other models AIREM, AIREM.SI. and RRR produced results which were not significantly different as measured at these four measurement sites.

Log Normal Distribution Treatment: The ratios in table 7 were transformed with the expression $z = \ln(r)$. Analysis of variance was then performed using the model

$$z_{ijk} = \mu_o + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad \text{where}$$

α, β, and γ correspond to method, site, and month effects respectively. The only interaction considered was $(\alpha, \beta)_{ij}$ which represents the interaction between method and site - a possibility where AIREM and ACRA consider the expected plume distribution above the receptor while the other models assume a uniform concentration equal to the ground level concentration.

A 0.05 level of significance was chosen to define the critical region for the test statistics. The interaction (α,β) has $F = .232(9,45)$ so rejection of the null hypothesis is not supported by the data. Similarly $F = 1.568(3,45)$ for the monthly effect and so it too is deemed insignificant. The method and site effects α and β provide test statistics of $F = 9.15(3,45)$, $p < .0002$ and $F\ 9.19(3,45)$, $p < .0002$ respectively and so both effects are considered significant. At this point the analysis of variance was repeated removing the interaction from the model. The tests for α, β, γ were $F = 10.49(3,54)$ ($p < .0001$), $F = 10.54(3,54)$ ($p < .0001$), and $F = 1.80(3,54)$ ($p < .15$). Once again the method and site effects are significant but the monthly effect is not statistically significant by this three factor test.

The underlying assumptions of homogeneity of variance and additivity were investigated for a two-way classification of the data, the monthly observation providing four replications for each call. Bartlett's test (23) was used to evaluate the homogeneity of variance. The test statistic indicated that the hypothesis of homogeneity should be accepted. Tukey's test (24) for additivity was then performed. The resulting $F = .075(1,53)$ indicates that the effects can be considered additive under the log transformation. Arranging the means in order:

Method	AIREM.SI	RRR	AIREM	ACRA
$\bar{Z}$	.1164	.274	.1477	.7665

The difference between models can be studied. Using a Q test (24), the critical difference between mean D is given by:

$$D = Q_{.05}\, S/\sqrt{M} = 3.76 \cdot 3939/\sqrt{16} = .369$$

$(a = 4,\ f = 54)$

where a is the number of methods (4) and f is the degrees of freedom for s (54), and n is the number of observations for the mean (16).

It is apparent that the differences between the means of the first three methods are insignificant but that the fourth model ACRA has a mean significantly greater than any of the other methods.

In summary:

(a) The log transformation is consistent with the need for additivity and homogeneity.

(b) Any interaction between site and method is not supported by the study.

(c) The monthly effect is negligible.

(d) Site effects are not negligible. The site variance is comparable to the residual variance.

(e) The mean for ACRA is significantly greater than for the other methods which do not differ significantly.

C. Measured and Predicted Gaseous Concentrations

In addition to the direct exposure measurements, two field measurements of gaseous ^{133}Xe concentrations have been examined with regard to relating these to predicted values. These samples were collected by evacuating a 34-liter tank and subsequently filling to atmospheric pressure after locating the plume centerline using mobile PIC field measurements.

After collection, the samples were returned to the laboratory for analysis using a noble gas separation apparatus and counting the concentrated samples in a liquid scintillation counter. The hemispherical immersion approximation was used to predict exposure rates from the measured concentrations. The procedure involved converting the measured concentration of noble gas nuclides using the noble gas ratio nuclide mix as stated in the July - December 1973 operating report (10). Next the total exposure rate was calculated using the exposure rate conversion factors for each of the noble gas nuclides. For the two plume centerline concentrations of 0.032 and 0.036 $\mu Ci/m^3$ the exposure rates of 96.4 and 108.4 μR/hr respectively were obtained. The 95% confidence limits obtained from those values is 102 ± 108 μR/hr. This value compares reasonably well with the measured exposure rate of 150 μR/hr at plume centerline using a PIC during the interval in which the air samples were taken (see table 8).

The field measurements show that ground-level concentrations and predictions are reasonably consistent considering that only two measurements were made. This indicated that both the dispersion calculation and the conversion from concentration to exposure rate by the computer models appear to agree within a factor of two. A larger number of field gas concentrations in subsequent studies could place a better confidence interval on agreement of measured and predicted values.

Table 8

Measured and predicted values based on field gaseous xenon concentration (January 28, 1974)

Measured total noble gas release rate	AIREM calculated Ground-level concentration	AIREM calculated Exposure rates
115,500 μCi/sec[a]	0.069 μCi/m^3	212 μR/hr[b]

Measured ground-level concentration of ^{133}Xe	Exposure rate calculated from ground-level concentration	95% confidence on exposure rate calculated from measured ^{133}Xe concentration
0.032 μCi/m^3	96.4 μR/hr	102 ± 108 μR/hr
0.036 μCi/m^3	108.4 μR/hr	

Exposure rate measured with PIC during the air sampling: 150 μR/hr

Stability class (calculated from variance of crosswind direction): B

Estimated fraction due to ^{133}Xe: 0.133

Distance from point of collection to stack: 2.5 km

Effective stack height: 100 m

Wind speed: 1.8 m/s

[a] Estimated total noble gas mixture.
[b] Calculated from July - December 1973 noble gas mixture.

VI. Discussion

The three sector-averaged computer models were quite close in predicting the exposures observed over the 4-month interval at each of our measuring sites.

For the case where the data were treated as normally distributed, the AIREM model has the lowest mean predicted/measured exposure ratio of 1.25. When the data were treated as coming from a log-normal distribution the calculated mean for the AIREM.SI was closest to unity. For both of the above cases the only model producing results significantly different was ACRA. This single plume accident model was found to be overly conservative for both cases when estimating monthly exposures.

These results are consistent with those obtained by Martin (25) in his application of AIREM to 1 year of field data and by Gogolak (1) in his study of several atmospheric codes applied to 2 months of data.

Since the range of measurement sites used in this study varied from 1.4 to 3.3 km, care should be exercised in extrapolation of the results of the inter-code comparison to a different range of distances.

Based on the observed correspondence between predicted and measured exposures, the use of variance of horizontal wind direction for estimating stability classes over the period of this study appears quite satisfactory.

The excellent agreement between the gross TLD and PIC measurements shown in table 4 and figure 4 demonstrates the ability of this type TLD to accurately measure low total environmental radiation exposure levels. However, the comparison of the net exposures (table 5) as recorded by the PIC's and TLD's shows significant differences. By examining the background subtraction methods for both PIC's and TLD's, the net exposure differences were determined to be a result of an inability to accurately measure and "subtract out" the natural background component from the total or gross exposure in the TLD's. The background was measured by the PIC on a continuous basis and the plant contribution was determined by integrating only the peak or additional exposures. However, the TLD background was determined with the TLD's during only one period of plant shut-down, 3/18-5/13. Therefore, any seasonal or daily variations in the natural background due to rainfall, snow, etc. were not accounted for in the determinations of net exposures. Although variations in background with time were shown not to be significant in a three factor experiment using model, site, and time, there is evidence from comparison of the total and net results to suggest that the fixed background subtraction adds error into the net TLD estimates.

The manual reduction of PIC strip chart data in this study has apparently led to no serious errors in evaluation of the net exposure observed from the gaseous plume. However, a machine-oriented data reduction process as discussed by Gogolak and Miller (26) to account for variations in natural background is under study and may be useful in subsequent studies.

VII. Summary and Conclusions

The results of the intercomparison study of four widely used models have demonstrated the usefulness of each model for predicting ground-level exposure rates.

For three models AIREM, AIREM.SI, and RRR, the mean predicted/measured exposure ratios for external exposure were 1.25, 1.29, and 1.26, respectively, and standard errors of the means were less than 0.3. The use of the short-term accident code ACRA did result in markedly increased error. In summary, based on the assumption of normally distributed data, the model AIREM demonstrated the predicted/measured exposure ratio closest to unity. Use of this or other similar models for predicting external exposures has been shown to be quite acceptable for most applications. Further studies in this area should emphasize extending the analysis to a wider range of distances from the release point. Furthermore, analysis of particulates from a source having a higher release rate should be included.

The usefulness of PIC's for making low-level exposure measurements was demonstrated by this study. The ability of this instrument to accurately measure exposure rates of a few μR/hr above natural background was clearly evident.

The results of this study exhibit the ability of this type TLD to accurately measure total environmental exposures in the range of a few mR per month. However, the ability to accurately measure an increase of 5 mR per year above natural background is questionable. This is due to difficulty in determining the natural background portion of the total exposure. The method used to account for natural background in this study is not as desirable or accurate as an extended (1 to 2 years) pre-operational survey. Unless seasonal and other variations in natural background can be accurately determined, it will be impossible to measure facility contributions in the range of 5-10 mR/year with this type TLD. Due to the low cost involved the TLD's might serve as an integral portion of an external radiation monitoring system including both TLD's and PIC's.

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