REACTOR EXPERIENCES, WASTE MANAGEMENT AND ENVIRONMENTAL MONITORING

# MEASUREMENTS OF THE DISPERSION OF GASEOUS RADIOACTIVE EFFLUENTS FROM AN OPERATING BOILING WATER REACTOR*

William M. Carey†, Lewis Battist, Warren E. Keene †
American Environmental Control Systems, Inc.
Gaithersburg, Maryland

## Abstract

Measurements of off-site concentrations of the radioactive gaseous effluents from a BWR were correlated with measured meteorological parameters to define plume behaviour at a coastal site. Average ground concentrations were found to be in the $10^{-9}$μCi/cc range, while peak values were observed as high as $10^{-7}$μCi/cc. The data indicates that sea breeze fumigation and noctural fanning conditions significantly affect dispersion characteristics.

## Introduction

The waste gas from a boiling water reactor consists primarily of the noble gases and iodine isotopes which can be determined by spectroscopic analysis of samples obtained at the steam jet air ejector and gross activity measurements in the stack. The problem thus arises as to how the effluent disperses under the given meteorological conditions prevailing at the time of release, and how to determine the average and peak concentrations at any distance from the discharge point. These data are necessary to restrict the overall population radiation exposure.

The concentration of the gaseous effluents can be discussed in terms of the effective emission height, the transport and dispersion of the effluent. The effective height is variable as wind speed, ambient temperature and lapse rate affect the height to which the effluent rises. The transport of the gaseous effluent is determined by wind direction and speed. Surface characteristics that produce turbulence as well as diurnal effects are influential in producing complex wind patterns which are difficult to describe or predict. Finally, the dispersion of the effluent is dependent on the wind speed and the horizontal and vertical eddies produced by mechanical shear and temperature differences.

## Description of the Experiment

The objective of this endeavor was to provide measured values of the concentrations of radioactive gases at three locations near Millstone Point. (Ref. Table 1). The measured concentrations were correlated with meteorological data and stack emission data, to yield measured values of $\chi/Q$ (concentration/emission rate, (sec/m$^3$) on a half-hourly, daily and monthly basis.

The Environmental Monitoring System, ERMS, measured the changes in the near ground concentrations of radioactive gases above the natural background. Three groups of data were obtained by the ERMS. The flow through alpha detector electrically precipitates radon and thoron decay daughter products in the atmoshpere and measures subsequent alpha decays. The resulting countrate is indicative of the changing levels of radon and its daughter products in the atmosphere.

The cosmic ray monitor is located above the beta/gamma detector. As the cosmic ray flux at sea level is primarily composed of muons, this detector is in anti-coincidence with the shielded beta/gamma detector. If a cosmic ray muon traverses both detectors, the count observed in the beta/gamma detector is negated. This cosmic ray monitor shield is also sensitive to external gammas. The countrate from the cosmic ray monitor is indicative of the cosmic ray flux and external gamma radiation above 0.4 Mev.

The third detector is the beta/gramma detector. Sampled air is continuously blown through this detector and if beta and/or low energy gamma emitters are in this air, this countrate is indicative of their concentration. Radon, thoron and the daughters of these isotopes also contribute to this countrate. This system is calibrated and capable of detecting concentrations of Kr-85 as low as $10^{-9}\mu Ci/cc$.

Millstone Point Company personnel performed weekly analysis on primary coolant and steam jet air ejector samples to determine the composition of the gaseous effluent from the stack and provided "Q" value data.

Meteorological data was recorded at the 140 ft. tower near the stack by The Research Corporation of New England who provided all meteorological data. Wind speed and direction at the 140 ft. level were used to correlate with the measured values of near ground concentration at each site. Temperature measurements were recorded at 5', 70' and 140' in order that $\Delta T/\Delta h$ could be determined.

## Experimental Results

During the period of observation at the Millstone Point Boiling Water Reactor data similar to that shown in Figure 1 was collected. The alpha countrate which is proportional to the concentrations of the daughters of radon and thoron daughters in the atmosphere did not exhibit any drastic fluctuations as were observed in the beta/gamma chamber or the large enclosed anti-coincidence shield.

The observed peaks in the anti-coincidence shield were found to be due to the flux of external gamma radiation in the energy range of 0.4 Mev to 2.5 Mev and the character of these peaks strongly suggest that they are due to a plume traversing the detector. The flat region of the curve is the cosmic ray muon background.

The peaks in the beta/gamma countrate are due to the effect of this external gamma flux and the contribution of low energy photons and beta particles within the detector sample volume.

The data presented in summary form for the three sites, Figures 2 thru 4, were found to correlate with the direction of the wind as measured at the 140 foot level at the stack location and to exhibit a stong duirnal variation. The correlations are illustrated for the three sites in Figures 2 and 4.

The correlation with the "from" wind direction is more pronounced as the distance between the measurement point and the stack increases. The broadness of the histograms for Site I and Site II as well as the contributions when the wind was not in the direction of the measurement site, were found to correspond to stable meteorological conditions. This suggests, particularly for Site II data, that terrain effects are governing factors.

Table 1 summarizes the data for all sites. Peak and average concentrations at Site III were found to be lower than those at both Sites I and II. However, Site II exhibits higher peak and average concentrations than Site I. This may be explained by the occurrence of a sea breeze fumigation phenomena which will not occur frequently at the Site I distance. Average values for Sites I and II were found to be in the $10^{-9}$ to $10^{-7}\mu Ci/cc$ range, while for Site III in the $10^{-8}\mu Ci/cc$ range.

This study though primarily concerned with a determination of the $\chi/Q^*$ value, also measured the gamma flux dose, Table 1. The cosmic ray detector exhibits a flat response to gammas between 0.4 Mev to 2.5 Mev. The major contributors to this gamma flux are Cs-138 and Rb-88 with lesser contributions from Xe-138 and Kr-88. Considering that single scattered photons are also important, a good approximation to the dose rate is to select the mid-point of the energy range. The dose estimates shown in Table 1 could be refined to yield actual dose rates for each site.

## Conclustions

The results of this study indicate that while long-term average concentrations and doses from the effluent of a BWR are low, short-term values appear as perturbations on a slowly varying natural background. Thus the long-term average values can be obtained by averaging easily measured peak values. This type of measurement is considered desirable as the micrometeorological aspects of a coastal site are the predominant influence on near neutrally bouyant plumes. While current technology is being employed to achieve near zero release from BWR, this type of study provides a valuable data base for the prediction of doses and airborne concentrations in an accident situation.

For a costal site during the summer months, two phenomena seem to merit important consideration. Referencing Figure 4, one observes that when the vertical temperature gradient is super adiabatic $(\nabla T < \Gamma)$ ; one group of data is distinguished between mid morning and noon. Also, when the vertical temperature gradient is greater than the adiabatic lapse rate, another group of data is singularized as occurring mostly in the early morning hours.

These two groupings of the data are consistent with the existence of the sea breeze fumigation and a nocturnal fanning phenomena. That is to say that the changes in the solar radiation effect the near ground temperature profiles, which, if effected to a considerable height can effect the dispersion of the gaseous effluent.

In the early morning hours, the ground is cooler than the air above, consequently the temperature increases with height to some elevation at which a neutral temperature gradient is achieved. Under these stable conditions, the effluent plume will tend to seek a level at which it is neutrally bouyant. There it can remain for several miles, dispersion being accomplished by diffusion and the weak wind variability in the stable layer. Thus, the plume fans the perimeter of the reactor site serving as a localized source of external gamma's whose flux and concentration at near gound level is determined by the height of the plume above the ground.

At sunrise the solar radiation warms the ground faster than the air. The stable condition is gradually replaced by an unstable forced convection layer with a super adiabatic temperature gradient. $(\nabla T < \Gamma)$ This condition persists to some height at which a stable condition exists. This represents a capped inversion, the forced convection is due to the ground heating. A sea breeze fumigation condition exists when cool air from the sea moves inland over the heated ground. If the emission point is below this capped inversion, then the effluent is mixed downward and high ground concentrations can be observed as shown in the second group of data under discussion. The duration of this effect is strongly related to site topography. By late afternoon this situation is no longer present and a near neutral condition exists.

This data is consistent with this interpretation as that data representative of the fanning situation shows a slowly increasing external gamma flux with distance from the emission point. This is due to the fact that the plume is relatively constant in height and that the Cs-138 and Rb-88 actively increase with distance from the point of emission.

Table 1

| | Site I | Site II | Site III |
|---|---|---|---|
| Period of Measurement | Jun 22 to Jul 14, 1972 | Jul 14 to Aug 4, 1972 | Aug 4 to Aug 30, 1972 |
| Distance (meters) | 2570 | 5030 | 8210 |
| Direction (WRT to True North) | $059^{o}$ 013' | $054^{o}$ 021' | $059^{o}$ 057' |
| Elevation MSL (meters) | 36.2 | 16.7 | 30.4 |
| $\chi$ peak half-hour average ($10^{-9}\mu$Ci/cc) | 164 | 226 | 78.6 |
| $\chi$ peak daily average ($10^{-9}\mu$Ci/cc) | 24.6 | 36.0 | 13.5 |
| $\langle\chi\rangle$ period average ($10^{-9}\mu$Ci/cc) | 6.45 | 19.7 | 2.73 |
| $\chi/Q$ half-hour peak ($10^{-8}$sec/m$^3$) | 245 | 261 | 78.6 |
| $\chi/Q$ daily average peak ($10^{-8}$sec/m$^3$) | 33.8 | 42.2 | 15.1 |
| $\langle\chi/Q\rangle$ period average ($10^{-8}$sec/m$^3$) | 8.95 | 30.3 | 2.81 |
| Estimated average dose ($\mu$r/hr) | 2.83 | 8.64 | 1.197 |

* This study was conducted under the sponsorship of the Northeast Utilities Company.

† Ph.D. Candidates, Nuclear Science and Engineering Department, Catholic University of America.

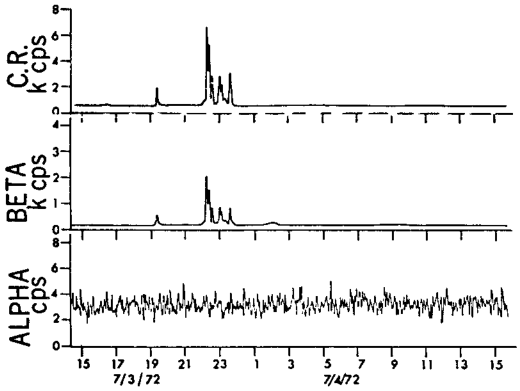


FIG.1, SITE 1

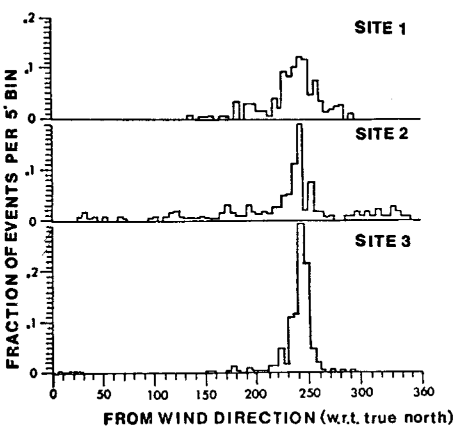


FIG.2, NORMALIZED HISTOGRAMS OF BETA/GAMMA EVENTS VERSUS WIND DIRECTION

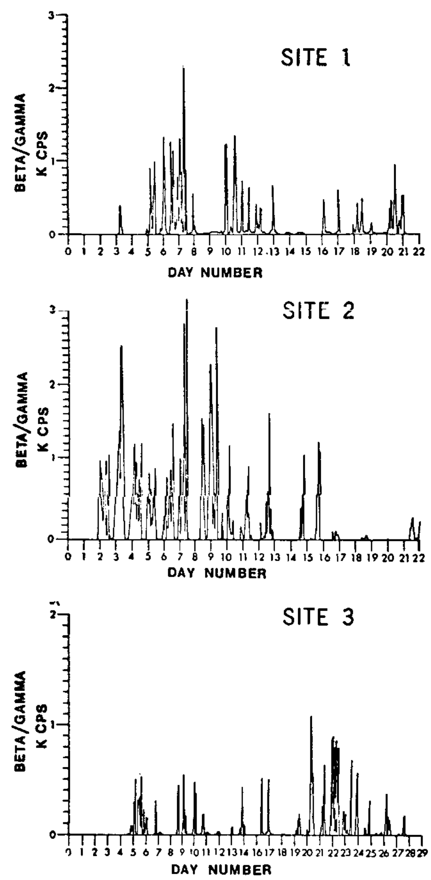


FIG. 3, SUMMARY OF BETA/GAMMA DATA

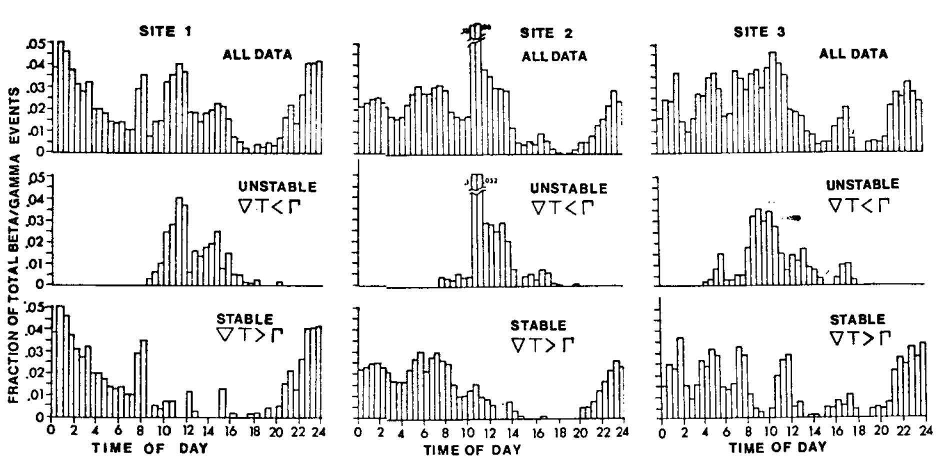


FIG. 4, NORMALIZED HISTOGAMS OF BETA/GAMMA EVENTS VERSUS TIME OF DAY.