EFFECTS OF ATMOSPHERIC STABILITY ON RADON DISPERSION IN THE LOWER BOUNDARY LAYER

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INTRODUCTION

Inhalation of the short-lived decay products of radon (Rn-222) is presently considered (UNSCEAR, 1985) to account for a significant fraction of the radiological risk from natural sources of radiation. Extensive monitoring programs carried out during mining operations in Australia have shown that, under normal atmospheric conditions, airborne radon and radon daughter concentrations are very low (Auty et al., 1984; Marshman, 1983). However, measurements at Nabarlek in the Northern Territory showed that radon and radon daughter concentrations increased markedly during periods of atmospheric stability (Leach et al., 1982a).

An instrumented 20 metre tower has been erected over an extended uranium ore deposit at Yeelirrie (lat. 27° 10' S, long. 127° 55' E) in Western Australia, as part of a long term study to improve our understanding of the processes associated with radon dispersion, particularly under temperature inversion conditions and to develop models for this dispersion.

DATA ACQUISITION AND ANALYSIS

Mean temperature, wind speed and radon concentration were measured at a site near the centre of the ore body in an area characterized by low, scattered scrub. The meteorological variables were measured using commercially available sensors, while the radon sensors were designed and built at ARL. The meteorological sensors were sampled every 20 seconds and a running mean and variance accumulated for each quantity. The radon sensors were polled every 10 minutes. A data acquisition cycle length of 20 minutes was chosen as being long enough to include low frequency micrometorological changes in wind and temperature, but not so long as to exclude the effects of the major high frequency fluctuations on the measured means and variances.

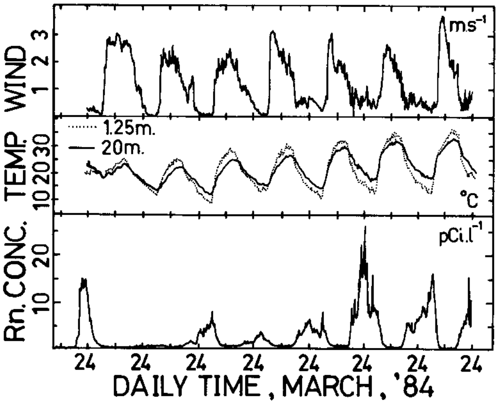
The raw meteorological data were combined with calibration results for each sensor to produce 20 minute average profiles of wind speed and temperature as a function of time. The raw radon data was analysed using the method of Stranden (1981), and converted to radon concentrations using the measured calibration factors.

RESULTS

At the tower site the radon emanation rate, averaged over 24 hours, as measured by the charcoal canister method (Countess 1977) was found to be 1.1±0.15 Bq/sq m/sec.

Figure 1 shows the radon concentration and horizontal wind speed at 1.25m and temperature at 1.25m and 20m as functions of time for a one week period in mid-autumn. During this period, temperature inversions accompanied by low horizontal wind speeds (near the ground) occurred every night. However, the nocturnal increase in radon concentration showed considerable variability from night to night.

FIGURE 1



The vertical radon flux was calculated using the formula

$$\text{flux} = -\left(D + \frac{k u_* z}{\phi_H(z/L)} \right) \frac{dC}{dz}$$

where z is height, L is the Monin-Obukhov length, which is a measure of the depth of the turbulent boundary layer; u_* is the friction velocity, which is related to the vertical turbulent momentum flux; C is the radon concentration at height z, D is the molecular diffusion constant for radon (1.2×10^{-5} sq m/sec), and $\phi_H(z/L)$ is a universal functional representation of the temperature gradient in the atmospheric boundary layer (Hanna et al., 1982). u_* and z/L were calculated by fitting the measured wind speed and temperature profiles to the universal functions for temperature gradient and vertical wind shear (Hanna et al., 1982) using a least squares method.

Figure 2 shows the variation of the calculated radon flux (normalized to the local radon emanation rate) as a function of atmospheric stability (characterized by the parameter z/L), for stable atmospheric conditions. A value of z/L = 0 corresponds to neutral stability. An increase in z/L corresponds to increasing stability of the atmosphere and suppression of vertical motion. The radon flux is close to the measured surface flux (emanation rate) at neutral

stability, and decreases systematically with increasing atmospheric stability. Also shown is the bulk Richardson number, defined by $B = (g.\Delta T.\Delta z)/(T.(\Delta U)^2)$, where g is the gravitational acceleration, T is the mean temperature in the height interval Δz, and ΔT and ΔU are the changes in temperature and wind speed across the height interval Δz. For stable conditions B and z/L are related by
$B = (z/L)/(1.0 - 5.0z/L)$.

FIGURE 2

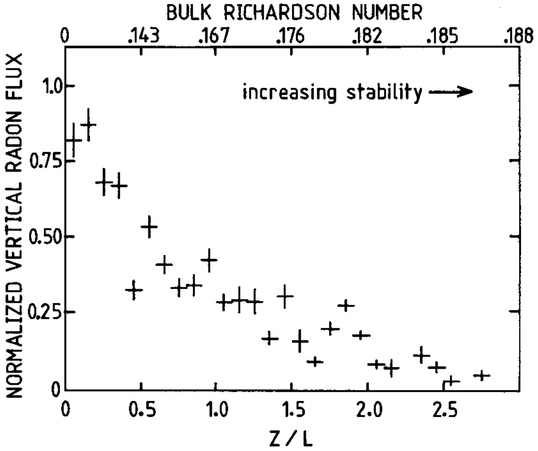


FIGURE 3

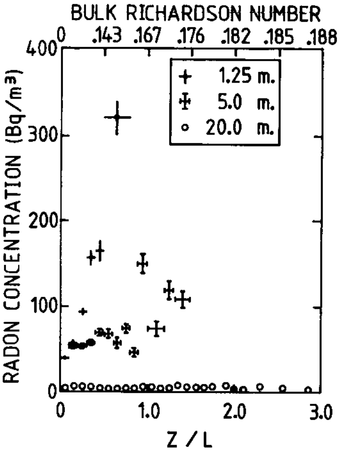


Figure 3 shows the variation of the radon concentrations at the three measurement heights as a function of z/L. The variation with stability decreases rapidly with height and is negligible at 20 metres.

DISCUSSION AND CONCLUSIONS

It is well established (Wallace et al, 1977) that, during the day when the vertical temperature gradient is negative (i.e. unstable conditions), the dominant mechanism for removing pollutants near the ground is eddy diffusion, while under temperature inversion (i.e. stable) conditions the vertical temperature gradient is positive and eddy diffusion is strongly suppressed. Consequently the wind speed near the ground should strongly influence pollutant concentration under inversion conditions. Binkowski (1983) has summarized the behaviour of the boundary layer during the day in terms of a turbulent mixed layer which is at least 0.5km deep, is capped by an inversion layer and maintained by convective heating from below. During the night this mixed layer collapses as the underlying heat source is removed, but there is still a shallow mixed layer present, even under conditions of extreme stability. This turbulent nocturnal layer is driven by wind shear from above. The transition from one state to the other seems to be very rapid. This is certainly consistent with the rapid build-up and decay of elevated radon levels observed during the current experiment.

The results presented here suggest that the variation of radon concentration with atmospheric stability is confined to the lowest 20 metres of the atmosphere. The radon concentration seems to vary rapidly across this layer, especially in stable conditions. This is consistent with the findings of other workers that the vertical diffusion of heat and momentum show their greatest variation near the ground. The results also show that the vertical radon flux in the lower boundary layer is equal to the measured emanation rate at the ground surface at the tower site for neutral atmospheric conditions and decreases with increasing atmospheric stability.

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