Technical Memorandum 45

Atmospheric concentrations of radon and radon daughters in Jabiru East

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Contents

Abstract

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The results of atmospheric concentration measurements of radon and PAEC (total and unattached) for a one year cycle in Jabiru East in the northern tropical region of Australia are reported. The average annual radon and PAEC total concentrations are 39 ± 5 Bqm^{-3} and 3.5 ± 0.5 mWL respectively. The high unattached radon daughter fraction, annual average of 0.21 ± 0.03, is attributed to the low concentration of condensation nuclei, about $(1.3 \pm 0.3) \times 103$ # cm^{-3}. Seasonal and diurnal variations are evident in these parameters. The unattached fraction is lower than average during the Dry season and also in the early morning when peaks occur in the radon and radon daughter concentrations. The condensation nuclei concentration and the equilibrium factor are higher than average during the dry months of the year.

This report will appear in a similar form in the *Proceedings of the Workshop on the Health Effects of Induced Radionuclides: Implications for Radiation Protection in Mining* (in press), Jabiru 25 September 1992.

Atmospheric concentrations of radon and radon daughters in Jabiru East

Introduction

In March 1989, an automatic monitoring station was installed in a caravan which enabled simultaneous measurements of atmospheric concentrations of radon, radon daughters (total and unattached) and condensation nuclei. Wind speed and direction were also measured at the same time. The primary objective of these measurements was to estimate the contribution of the ERA Uranium Mine at Ranger to atmospheric radon and radon daughter concentrations at selected locations within a few kilometres from the mine site. During the first year this station was mostly located at ARRRI in Jabiru East, about 2.5 km NW of the mine (fig 1). This paper presents some of the results from this station for an operational period of one year, March 1989 to February 1990, with the exception of the months of June and September 1989 when the station was used elsewhere.

Locality

Jabiru East and Ranger are located in the northern tropical region of the Northern Territory in Australia within the boundary of a uranium mine lease that is surrounded by Kakadu National Park. The climate is characterised by distinct Wet (November–March) and Dry (May–September) seasons. These seasonal boundaries are, however, not precise. For an average year in Jabiru East about 67% of the annual rainfall occurs between January and March, while <2% occurs between May and September. Bush fire management regimes are followed by the Kakadu National Park and Ranger Mine managements. Most of the bush fires occur during the period May to August. About 25% of the average rainfall occurs during the months of November and December, but the showers are localised and less frequent. According to the information provided by the Bureau of Meteorology (1993) the average annual rainfall is 1437 mm. For most years evaporation exceeds rainfall. The area, like other parts of northern Australia, is subject to cyclones.

During the Dry season, wind speed and direction are determined by the ESE to SE trade winds. In all seasons there is a late afternoon–early evening wind from the general NW direction that may be associated with the sea breeze. The monsoonal winds from the NW during the Wet season are not as persistent as the SE winds of the Dry season. Wind speeds are generally higher during the day time (9am–3pm) and during the early months of the Dry season (Clark et al 1993).

Jabiru East is no longer a residential town, but laboratories and offices are attended by about 100 people during the day time. The nearby Aboriginal camps at Gulungul Creek and Magela 009 are inhabited by about 15–20 people each, including children. The township of Jabiru (1500 people including adults and children) is the major population centre near Ranger. The

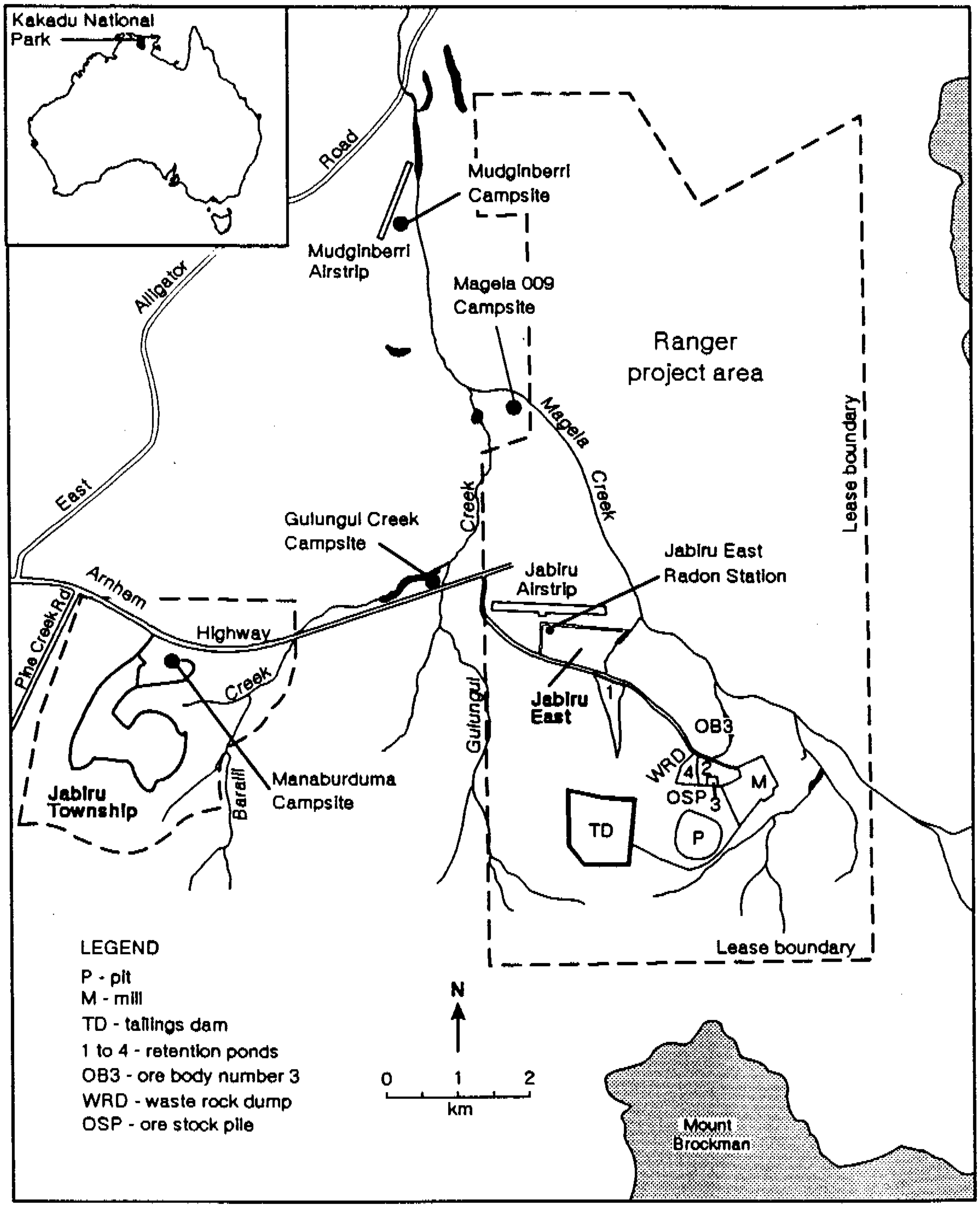

Figure 1 A locality map to show the population centres and the radon monitoring station in Jabiru East near ERA uranium mine at Ranger

permanent Aboriginal camp site at Manaburduma is occupied by twenty-five people (Wellings P, 1990 pers comm). Most visitors to Kakadu National Park come to Jabiru. The estimated number of Park visitors was about 220 000 in 1988. About 5% of the visitors came for a day trip only; the average stay for the remaining 95% was a little above four days (Preece 1989).

About 3000 tonnes of U_3O_8 was produced each year between 1981 and 1992 at Ranger but recently production has been reduced to about half this value. The average ore grade is about 0.3% U_3O_8 and the material less than 0.01% U_3O_8 is piled as waste rock. The ore stockpiles, waste rock dump, mining pit and tailings dam are the major radon sources. Their locations and the location of the sampling point for the measurements presented in this paper are identified in fig 1. According to an estimate reported by Akber et al (1992a), the mine-related sources contributed about 20% of the total 38 Bqm^{-3} annual average atmospheric radon concentration in Jabiru East for the period July 1990–June 1991. The background and mine-related radon concentrations in Jabiru and Manaburduma camp area were somewhat lower perhaps due to the lower local soil radioactivity and larger distance from the mine site. The background radon concentrations at the other two Aboriginal campsites are not known, but model-based estimates show that the mine-related atmospheric radon concentrations are comparable with those in Jabiru East (Akber et al 1993). The data sets for this paper are limited to a sampling point in Jabiru East only, but the findings may be broadly applied to other centres of demographic interest in the expectation that the trends of radon and radon daughter behaviour in the outdoor atmosphere are likely to be similar within a range of a few kilometres.

Instruments

The radon detection system used in the present study is similar to that described by Whittlestone (1985). It consists of a primary filter and a dehumidifier, a thoron delay chamber, a particle generator for radon daughters attachment in a 200 L mixing chamber and a ZnS detector. The air is sampled at a rate of 10 L per minute. The mixing and attachment step in the chamber introduces an approximately 60 minute delay between the collection and the detection step. The output data are corrected for this delay prior to data processing. Under optimum operational conditions, the detection limit of this system is lower than 1 Bqm^{-3}.

Radon daughters are detected by measuring the count rate of alpha particles on a filter paper through which air is drawn at a rate of 1 L per minute. A modified alpha Nuclear 400 system is used for counting. The unattached daughter detection system is similar to the total detection system but the filter is replaced by a wire screen with a mesh size of 400 per inch. Following the mathematical treatment of Ramamurthi and Hopke (1989), the wire screen parameters lead to a 50% collection efficiency cut-off point (d_p–50%) at ~ 7.1 nm. Front to total activity ratio (FT) of 0.7 is used for the calculations, which is in good agreement with the experimental findings of 0.67 ± 0.02 for d_p > 99.9% for an ultrafine (AMD 0–10 nm) activity size distribution mode (Solomon & Ren 1992). The detection efficiencies and the flow rates of radon and radon daughter detection systems are checked on a routine basis using standard thin alpha sources and flow rate meters. The calibrations are checked against the portable equipment calibrated at the Australian Radiation Laboratory.

The condensation nuclei concentration (CN) counter is a cloud chamber. The particle concentration is calculated from the difference in the optical transmission measured by a light emitting diode (LED) before and after the formation of a condensation cloud by the rapid expansion of the water saturated air sample. This instrument has been calibrated only once, at the time of installation in March 1989. The calibration can be traced back to a standard particle counter maintained by the CSIRO Division of Atmospheric Research.

Wind speed and direction are measured using standard meteorological equipment, calibrated in a wind tunnel at ANSTO. Meteorological measurements have been routinely carried out at the height of about 15 m above the ground, away from the interference of the arboreal canopy. Radon and radon daughter concentrations are also measured at the same height to improve the signal to noise ratio for estimates of the mine-related component of atmospheric radon and radon daughter concentrations using correlated wind direction measurements (Akber et al 1992a). Ambient aerosol densities are measured at a height of 2 m above the ground.

Further details of the instrumentation and operation have been described by Pfitzner and Whittlestone (1991).

Results and discussion

Continuous monitoring of radon and its daughters generates a time series of half-hourly concentrations in the atmosphere over prolonged periods of time. The average diurnal behaviour is illustrated here through a set of curves generated by averaging, on a half-hourly time basis, the total potential alpha energy concentration (PAEC total) data for the months of May, August and November 1989 and February 1990 (fig 2). The error bars correspond to the standard error in the mean values for each half-hour period. As the half life of radon daughters is comparable with the sampling time, an error is introduced due to their detection in the subsequent time intervals. The data are not corrected for this source of error but, as the response times of radon and radon daughter detection systems are similar, particularly during steady state conditions, this error is likely to cancel out in the calculation of the equilibrium factor. The inversion peaks in Jabiru East are generally broad, typically from 4 to 6 hours, shifting by up to a few hours on a day-to-day basis. Frequently more than one peak occurs. These characteristics of diurnal variations have lead to broad peaks in the monthly averages, typically from 2 am to 12 noon. The diurnal trends of radon and PAEC unattached are similar to those for the PAEC total plotted in fig 2.

Mean daily concentrations of radon and radon daughters for each month (monthly averages) are generated by using half-hourly averages similar to those shown in fig 2. The values in fig 3 are the monthly average radon concentrations for the reporting period. The average rainfall data for Jabiru East (also shown in fig 3) illustrate the distinct Dry and Wet seasons. As expected, radon concentrations were highest during the Dry season, indicating higher emission rates from the drier soils. Also, the radon concentrations for the earlier months of the Dry season (May–August) are higher than those for the later months (October–November). Similarly, the values appear to increase in December and January – at the onset of the Wet season. This behaviour of atmospheric radon concentrations is consistent with the expected changes in radon emanation with the soil moisture content as reported by other authors. For example, laboratory based experiments of Strong and Levins (1982) showed that for uranium tailing materials, the moist pores or capillaries emanated more radon than dry or water saturated pores and capillaries. They observed the maximum emanation occurring at about 6% of water content by weight. Thamer et al (1981) also reported consistently lower emanation from the dry uranium ores when compared with the 5–20% water saturated samples.

The seasonal variations in the PAEC total and PAEC unattached are broadly similar to those of radon. In detail, though, the ratio of PAEC total relative to radon concentration is higher during the dry months than during the wet months. This trend is reflected by an increase in the equilibrium factor F which varies between 0.45 and 0.60 for July–November and between 0.25 to 0.45 for March–May and December–February periods (fig 4b). The trend for the unattached radon daughter fraction f_p (fig 4a) is opposite to that of the equilibrium factor F. This fraction, defined here as the ratio of PAEC unattached to PAEC total, is between 0.2–0.4 for the wet months of the year. It drops to a value around 0.1 for the dry months.

The behaviour of f_p and F can vary with changes in the ambient aerosol density. A recent review (NRC 1991) summarises the work of many authors but most of these studies have been conducted in mine environments or indoors in houses under European conditions. Porstendorfer (1987) reported that (for indoor air) a higher particle concentration at the time of formation of ^{218}Po increases the equilibrium factor value because the attachment is then faster than the plate out. The experimental observations showed a decreasing trend in the unattached fraction f_p as a function of the condensation nuclei concentration (CN) 10^3–10^6 # cm^{-3} range in five different rooms. Reineking and Porstendorfer's (1990) limited study in the ambient atmosphere at Gottingen is associated with CN 2–4 × 10^4 # cm^{-3}, f_p 0.01–0.02 and F 0.53–0.67; no correlation is evident from their results. Perhaps the observations by Whittlestone (1990) at Cape Grim are

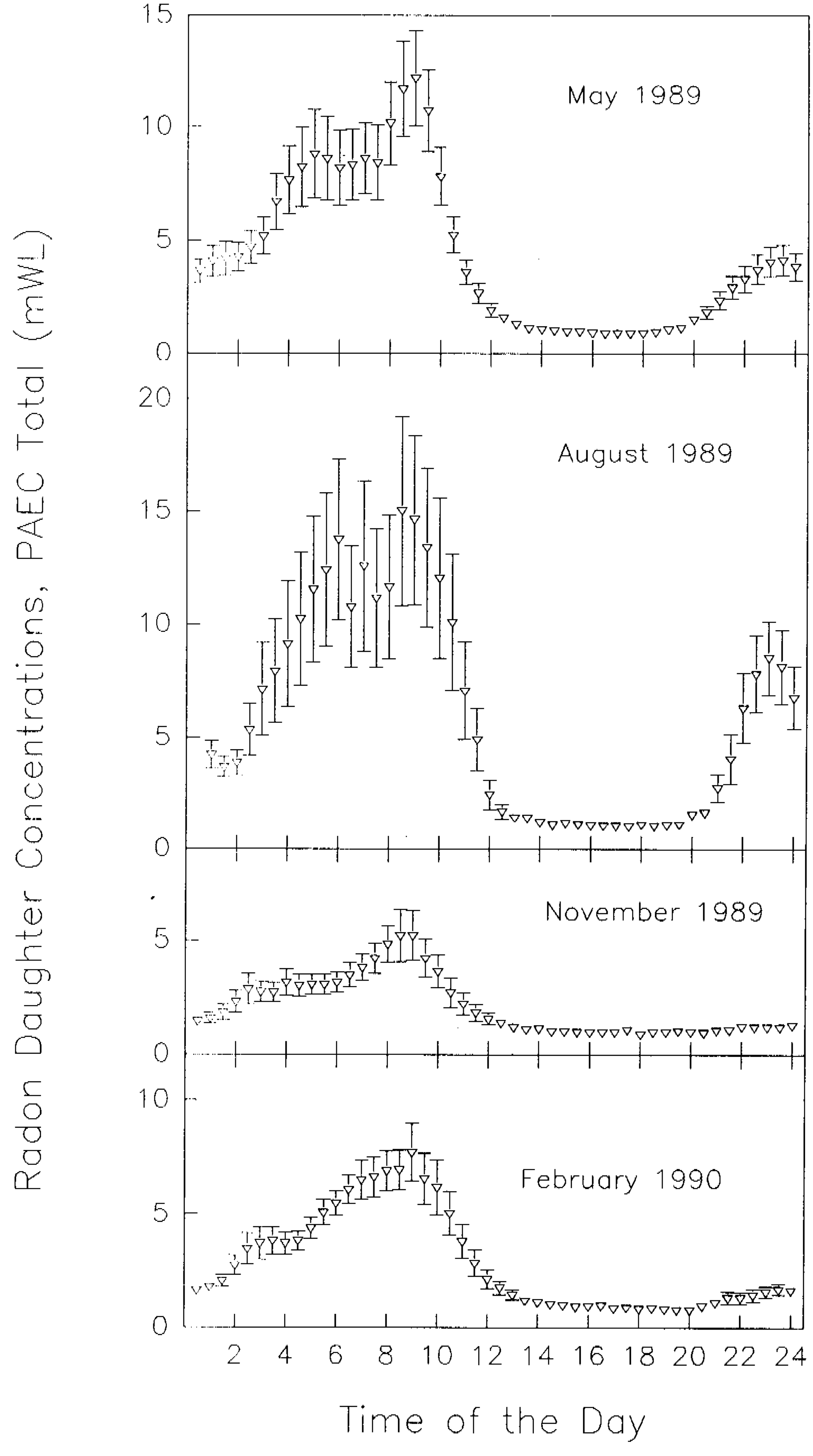

Figure 2 The average daily response curves of radon daughter concentrations for four different months in Jabiru East

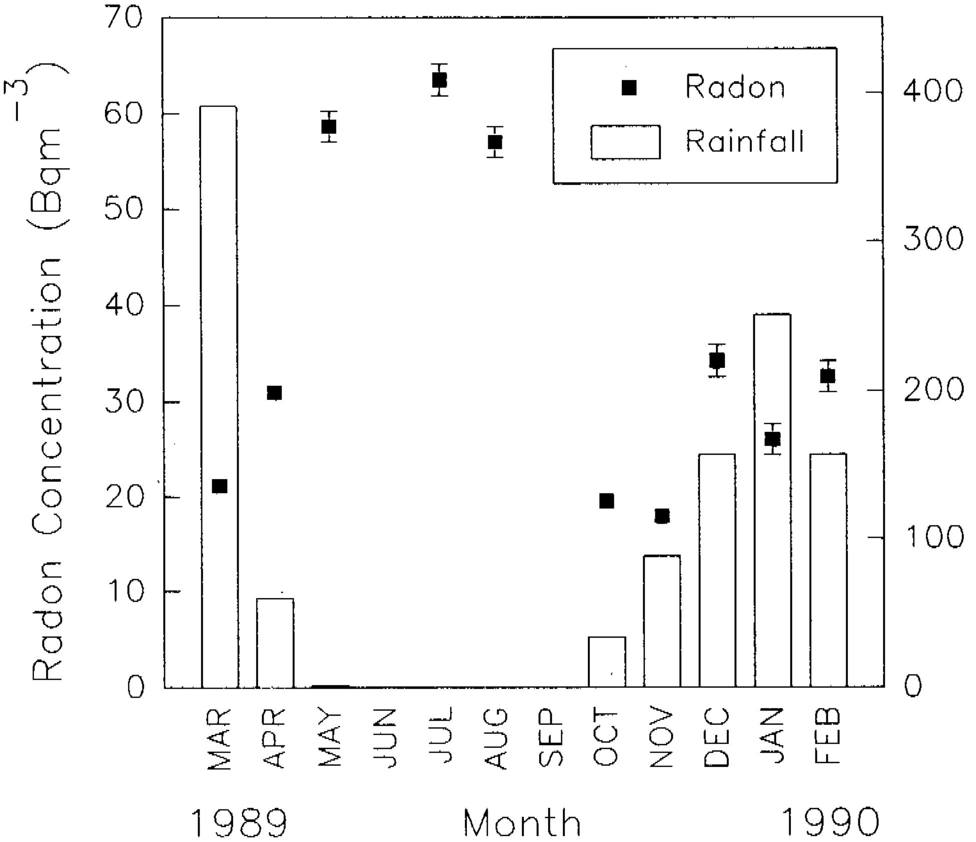

Figure 3 Monthly cumulative rainfall and average radon concentrations in Jabiru East during the period March 1989–February 1990

more relevant to this study as the data sets cover the particle concentration range of 30–3000 (# cm^{-3}), similar to those observed by us in Jabiru East. Whittlestone reports a decrease in F value from 0.86 to 0.1 as the particle concentration falls from 10^3 to 10^1 (# cm^{-3}). His data for unattached radon daughter concentrations are limited. One of the two data sets shows a downward trend in the f_p values from about 0.25 near 10^2 CN to about 0.05 near 2×10^3 CN. The other data set showed that f_p is not significantly different from zero in this particle density range. Earlier data of mine-related studies reviewed in NRC (1991) also show an inverse correlation between f_p and particle concentration values in the 10^3–10^6 region. The scatter in the data are large, typically up to an order of magnitude. Kojima and Abe (1988) observed diurnal variations in the aerosol density in a Japanese home. They noted that unattached radon daughter concentrations decreased when peaks occurred in the aerosol density.

Our observations of the condensation nuclei density (CN) are shown in fig 4c. Overall the CN values are low, averaging at 1.3×10^3 # cm^{-3}. The values are higher during the months of little to no rain (April–November) than those of significant rain (December–March). A sudden drop in the CN value for the month of July 1989 is hard to explain. Bushfires, which are frequent during these months of the year, are generally managed on an area-to-area basis. This can cause fluctuations in the CN values and may be responsible for a significant upward trend for the month of August. The bar graph in fig 4c represents the average monthly mass loading obtained from high volume sampler data for the period 1983–88 at several sites in the vicinity of Jabiru East (Akber 1992). The mass loading and condensation nuclei concentration trends are broadly similar.

A comparison of the CN, f_p and F (fig 4) trends shows broad agreement with the results of other observers; the equilibrium factor F increases and the unattached radon daughter fraction f_p

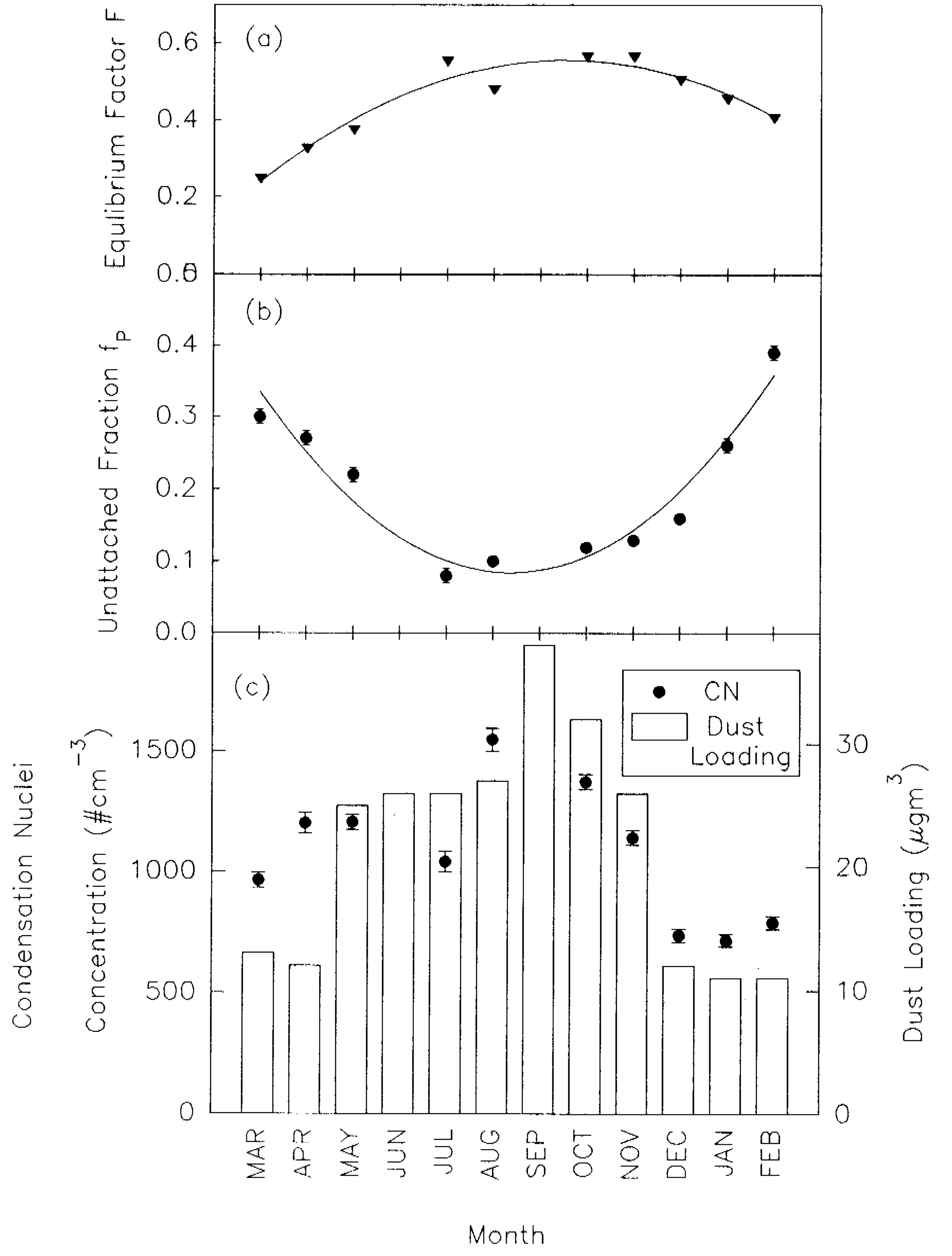

Figure 4 Monthly average values of (a) unattached fraction, (b) equilibrium factor and (c) condensation nuclei concentration and dust loading. With the exception of the dust loading values, the data are for Jabiru East during the period March 1989–February 1990. The dust loading data are the average values for the period 1983–1988 for several sites in the vicinity of Jabiru East

decreases with increases in the concentration of condensation nuclei. Our data set is, however, applicable to the outdoor non-urban conditions found in northern tropical Australia. The low CN values also explain the high unattached radon daughter concentrations compared with most other reported values which correspond to higher aerosol density environments.

Diurnal trends were observed in the unattached radon daughter fraction and the equilibrium factor. These trends show that, in addition to correlation with the concentration of condensation nuclei, the early morning calm conditions also appear to affect the attachment behaviour of radon daughters. This is illustrated in fig 5 (a–d) showing diurnal variations in f_p, F, CN and wind speed for an average day in the months of November 1989 and February 1990. The wind speed is generally low during the late night to early morning period. The CN values for this period are also low; they rise between 8–10 am and broadly follow the wind speed trend of the day. The downward trend of CN between 4–8 pm during the month of February is probably due to wash-out during the frequent afternoon rainfall.

Despite the lower CN values, both f_p and F show a downward trend during the early morning hours. This behaviour can probably be explained, at least qualitatively, through examining the production and fate of radon daughter atoms in the atmosphere. Lower F values occur when radon daughters have not achieved equilibrium with the parent radon in the atmosphere. This situation may be true for the early morning low wind speed periods of limited radon transport. The radon source under these conditions is expected to be local and the radon is detected before it reaches equilibrium with its daughters. During the daytime, radon is mixed more regionally and there is a longer period for daughter ingrowth and an increase in the F values.

A study by Woods (1989) shows diurnal variations in the equilibrium factor measured at the tailings repository of the Nabarlek uranium mine. Three sets of data were reported in that study covering periods of several days in October 1985, September 1987 and October 1988. The times of the equilibrium factor peaks vary in these data sets, with the September 1985 behaviour being similar to that observed in the present work for Jabiru East. Woods (1989) does not comment on the reported observations.

Early morning calm conditions also appear to favour the attachment of radon daughter atoms to the ambient aerosol, thereby leading to lower f_p values. Investigations of the exact cause of this behaviour are beyond the scope of this paper. The ambient aerosol characteristics, other than the density, such as the average particle size and the size distribution, can substantially alter the attachment rate of radon daughters (NCRP 1988, NRC 1991, Reineking & Postendorfer 1990). Little is presently known about the diurnal or seasonal variations in these parameters in Jabiru East. Hence the cause of low f_p values during the calm to low wind speed periods of the day should be further explored.

The average wind speed is low during the late months of the Dry season and may, in addition to the increase in the average CN values, be responsible for the low unattached radon daughter fractions during these months.

Table 1 summarises the annual average values of variables measured during this study. The estimates of PAEC (total) effective dose in Jabiru East (table 2) were obtained using a dose conversion factor of 8 mSv/WLM for adults and 10 mSv/WLM for juveniles. These conversion factors were based upon the value recommended by ICRP for the mine workers (ICRP 1985), corrected for different breathing rates for adults and juveniles (ICRP 1979) and the different organ size factor for juveniles (IAEA 1982). The ICRP dose conversion factor for inhalation of radon daughters by workers corresponds to values of the unattached radon daughter fraction in the approximate range 0–0.05 (ICRP 1981). The estimates of dose in Jabiru East need to be corrected upwards in the light of the information on the unattached radon daughter fraction reported in this paper. Using an average of the Jacobi–Eisfeld and James–Birchall models corresponding to 0.1 μm AMD (NEA 1983) a correction by a factor of 1.7 is proposed, corresponding to the annual average unattached fraction of 0.14 in Jabiru East. A more detailed

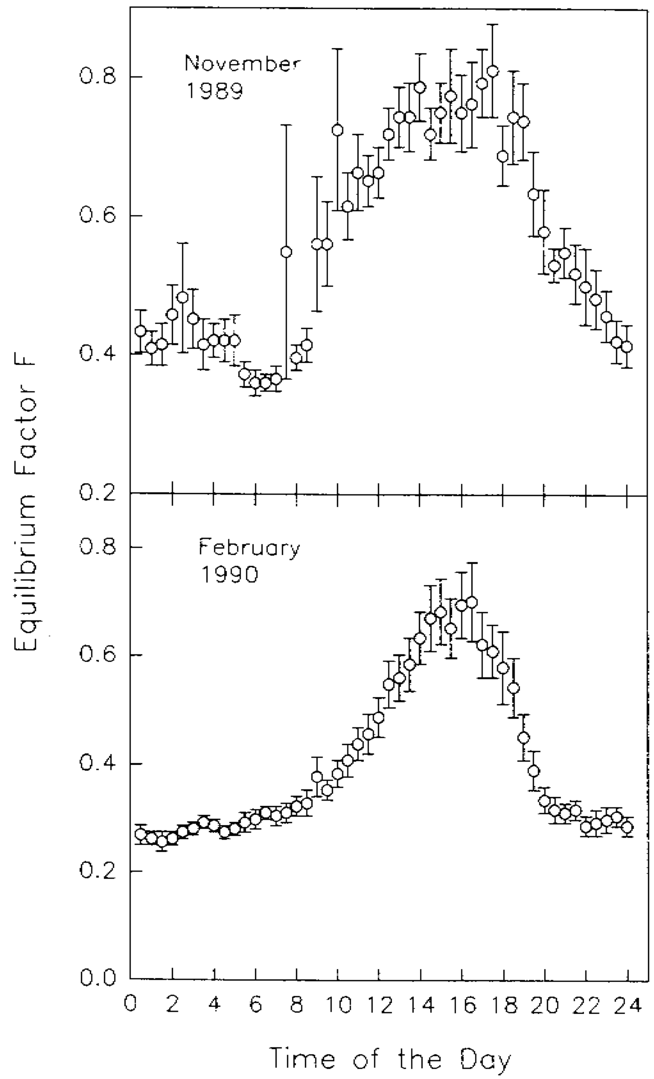

Figure 5a Average daily response curves of the equilibrium factor (F) for the months of November 1989 and February 1990 in Jabiru East

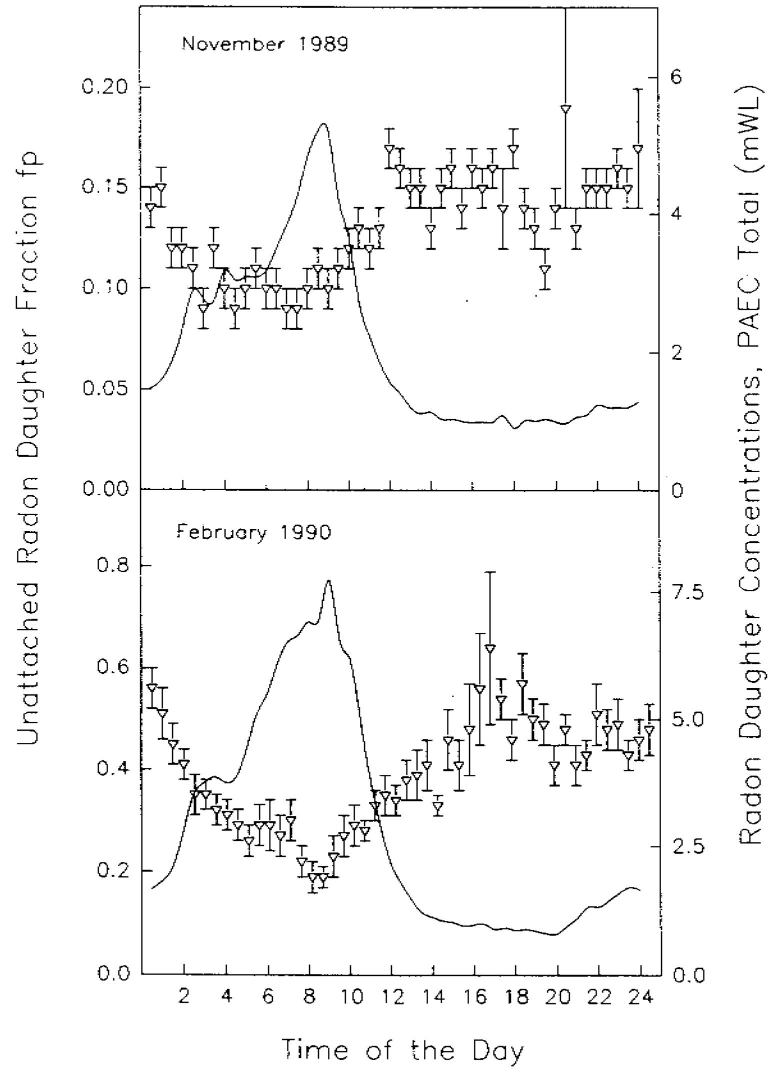

Figure 5b Average daily response curves of the unattached radon daughter fraction (f_p). The corresponding PAEC total values (line) are drawn to demonstrate the difference in diurnal trends of f_p and PAEC total

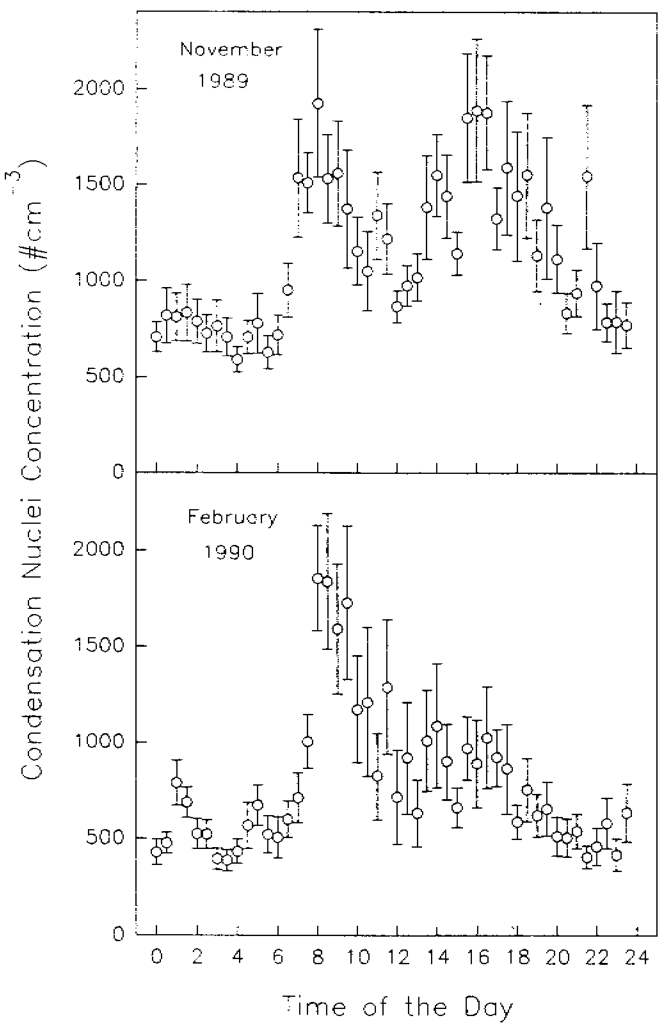

Figure 5c Average daily response curves of condensation nuclei concentrations

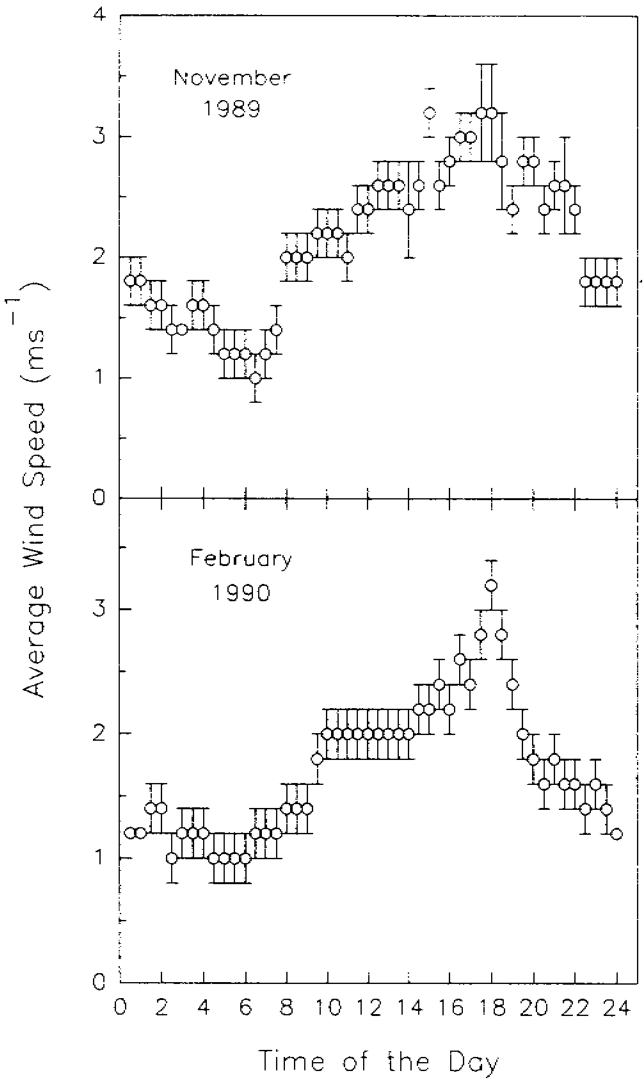

Figure 5d Half-hourly average wind speeds for the months of November 1989 and February 1990

Table 1 Average annual values of various parameters observed during this study in Jabiru East for March 1989–February 1990 period

Parameter	Value
Radon (Bqm^{-3})	39 ± 5
PAEC total (mWL)	3.3 ± 0.5
PAEC unattached (mWL)	0.46 ± 0.07
CN ($\#cm^{-3}$)	(1.3 ± 0.3) 10^3
F	0.45 ± 0.03
f_p	0.21 ± 0.03[a]
	0.14 ± 0.03[b]

a based on half-hourly PAEC (unattached) to PAEC (total) ratios

b based on the annual average PAEC (unattached) to PAEC (total) ratio

Table 2 Annual effective dose for Jabiru East

		Effective dose ($mSvy^{-1}$)			
		Total		Mine-related	
Source	Period	Juvenile	Adult	Juvenile	Adult
Akber et al (1992a)[a]	July 1989–June 1990	1.6	1.3	0.21	0.16
Akber et al (1992b)	July 1990–June 1991	1.5	1.2	0.22	0.17
Akber et al (1993)	March 1989–Feb 1990	–	–	0.30[b], 0.26[c]	0.24[b], 0.21[c]
This study	March 1989–Feb 1990	1.8	1.4		
Average		1.7	1.3	0.26	0.21

a Note an overlapping period of observations with other reported values. Data not included in average.

b Model

c Experimental

correction process could be followed but it will be complex because both the diurnal and the seasonal variations in radon daughter concentrations and values of the unattached fraction need to be taken into account in making an estimate of the annual effective dose. Any upward revision of the mine-related component of the effective dose is expected to be smaller than that for the background component because the radon transport from the Ranger Uranium Mine to centres of population is most significant during the dry months of the year and during the early hours of the morning when values of the unattached radon daughter fraction are lower than average. ICRP is currently in the process of revising the dose conversion factors for radon inhalation. Further adjustments in dose estimates may, therefore, be required when the outcome of this revision is known.

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Dr A Johnston's contribution at the early stage of this study is acknowledged.

References

Akber RA 1992. Suspension of dust in the vicinity of Ranger Uranium Mine: An estimate for the land application area. In *Proceedings of the Workshop on Land Application of Effluent Water from Uranium Mines in the Alligator Rivers Region.* Jabiru 11–13 September 1991, Supervising Scientist for the Alligator Rivers Region, AGPS Canberra, 258–277.

Akber RA, Johnston A & Pfitzner JL 1992a. Public radiation exposure due to radon transport from a uranium mine. *Radiation Protection Dosimetry* 45, 137–140.

Akber RA, Pfitzner J & Johnston A 1992b. Radon transport from Ranger Uranium Mine: A review of the public radiation dose estimates. *Radiation Protection in Australia* 10, 41–46.

Akber RA, Pfitzner J, Petersen MCE, Clark GH & Bartsch FKJ 1993. *Model based estimates of public radiation dose due to atmospheric transport of radon from Ranger Uranium Mine for one seasonal cycle.* Internal report 102, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Bureau of Meteorology 1993. Tabulation of climatic averages and extremes – Jabiru [leaflet] Commonwealth Government of Australia, Bureau of Meteorology.

Clark GH, Petersen MCE, Bartsch FKJ, Pfitzner J & Akber RA 1993. *The climatology and air pollution meteorology at Jabiru East, Northern Territory 1988 to 1990.* Open file record 87, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

IAEA 1982. Basic safety standards for radiation protection. Safety Series 9, International Atomic Energy Agency, Vienna.

ICRP 1979. *Reference Man: Anatomical, Physiological and Metabolic Characteristics.* Publication No. 23, Pergamon Press, Oxford.

ICRP 1981. *Limits for inhalation of radon daughter by workers.* Publication No. 32, Pergamon Press, Oxford.

ICRP 1985. *Radiation protection of workers in mines.* Publication No. 47, Pergamon Press, Oxford.

Kojima H & Abe S 1988. Measurement of the total and unattached radon daughters in a house. *Radiation Protection Dosimetry* 24, 241–244.

NCRP 1988. Measurement of radon and radon daughters in air. National Council on Radiation Protection and Measurements, Bethesda.

NEA 1983. *Dosimetry aspects of exposure to radon and thoron daughter products.* Report by a group of experts of the OECD Nuclear Energy Agency,

NRC 1991. *Comparative dosimetry of radon in mines and homes. Panel on dosimetric assumptions affecting the application of radon risk estimates.* Report by the Board on Radiation Effects Research, Commission on Life Sciences, National Research Council. National Academy Press, Washington DC.

Pfitzner J & Whittlestone S 1991. Automatic environmental radon station: Operators manual. Internal report 25, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Porstendorfer J 1987. Free-fractions, attachment rates, and plate-out rates of radon daughters in houses. In *Radon and its decay products: Occurrence, properties and health effects.* PK Hopke ed. Symposium Series 331, American Chemical Society, Washington DC, 285 – 300.

Preece M 1989. *Kakadu visitor survey 1982– 1988.* Summary Report. Australian National Parks and Wildlife Service, Canberra.

Ramamurthi M & Hopke PK 1989. On improving the validity of wire screen 'unattached' fraction Rn daughter measurements. *Health Physics* 56, 189–194.

Reineking A & Porstendorfer J 1990. 'Unattached' fraction of short-lived decay products in the indoor and outdoor environment: An improved single screen method and results. *Health Physics* 58, 717–727.

Solomon B & Ren T 1992. Counting efficiencies for alpha particles emitted from wire screens. *Aerosol Science & Technology* 17, 69–83.

Strong KP & Levins DM 1982. Effect of moisture content on radon emanation from uranium ore and tailings. *Health Physics* 42, 27–32

Thamer BJ, Nielson KK & Felthauser K 1981. *The effects of moisture on radon emanation.* Open file report 184-82 Bureau of Mines, US Department of Interior, Washington DC.

Whittlestone S 1985. A high-sensitivity Rn detector incorporating a particle generator. *Health Physics* 49, 847–852.

Whittlestone S 1990. Radon daughter disequilibria in the lower marine boundary layer. *Journal of Atmospheric Chemistry* 11, 27–42.

Woods DA 1989. *Concentration of radon and radon daughters during semi-dry tailings deposition by QML at Nabarlek (1985–88).* Technical memorandum 29, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Supervising Scientist for the Alligator Rivers Region

Research publications

Alligator Rivers Region Research Institute Research Report 1983
Alligator Rivers Region Research Institute Annual Research Summary 1984-85
Alligator Rivers Region Research Institute Annual Research Summary 1985-86
Alligator Rivers Region Research Institute Annual Research Summary 1986-87
Alligator Rivers Region Research Institute Annual Research Summary 1987-88
Alligator Rivers Region Research Institute Annual Research Summary 1988-89
Alligator Rivers Region Research Institute Annual Research Summary 1990-91
Alligator Rivers Region Research Institute Annual Research Summary 1991-92 (in press)

Research reports

RR1 Marchant R 1982. *The macroinvertebrates of Magela Creek, Northern Territory.* Research report 1, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (46pp)

RR2 Hart BT & McGregor RJ 1982. *Water quality characteristics of eight billabongs in the Magela Creek catchment.* Research report 2, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (60pp)

RR3 Thomas DP 1983. *A limnological survey of the Alligator Rivers Region. Volume I Diatoms (Bacillariophyceae) of the Region.* Research report 3 (i), Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (160pp)

Ling HU & Tyler PA 1983. *A limnological survey of the Alligator Rivers Region. Volume II Freshwater algae, exclusive of diatoms.* Research report 3 (ii), Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (176pp)

RR4 Bishop KA, Allen SA, Pollard DA & Cook MG 1986. *Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume I Outline of the study, summary, conclusions and recommendations.* Research report 4 (i), Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (63pp)

Bishop KA, Allen SA, Pollard DA & Cook MG 1990. *Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume II Synecology.* Research report 4 (ii), Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (155pp)

Bishop KA, Allen SA, Pollard DA & Cook MG (in press). *Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume III Autecology.* Research report 4 (iii), Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

RR5 Finlayson CM, Bailey BJ & Cowie ID 1989. *Macrophyte vegetation of the Magela Creek flood plain, Alligator Rivers Region, Northern Territory.* Research report 5, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (41pp)

RR6 Wasson RJ 1992. *Modern sedimentation and late quaternary evolution of the Magela Creek Plain.* Research report 6, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (349pp)

RR7 Martin P & Hancock G 1992. *Routine analysis of naturally occurring radionuclides in environmental samples by alpha-particle spectrometry.* Research report 7, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (119pp)

RR8 Murray AS, Johnston A, Martin P, Hancock G, Marten R & Pfitzner J (in press). *Transport of naturally occurring radionuclides in the surface waters of the Magela Creek and flood plain, northern Australia.* Research report 8, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

RR9 Woodland DJ & Ward PJ 1992. *Fish communities in sandy pools of Magela Creek, Alligator Rivers Region.* Research report 9, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (88pp)

RR10 Willett IR, Bond WJ, Akber RA, Lynch DJ & Campbell GD 1993. *The fate of water and solutes following irrigation with retention pond water at Ranger Uranium Mine.* Research report 10, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (132pp)

Technical memoranda

TM1 Hart BT, Davies SHR & Thomas PA 1981. *Transport of trace metals in the Magela Creek system, Northern Territory: I Concentrations and loads of iron, manganese, cadmium, copper, lead and zinc during flood periods in the 1978-1979 Wet season.* Technical memorandum 1, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (23pp)

TM2 Davies SHR & Hart BT 1981. *Transport of trace metals in the Magela Creek system, Northern Territory: II Trace metals in the Magela Creek billabongs at the end of the 1978 Dry season.* Technical memorandum 2, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (23pp)

TM3 Thomas PA, Davies SHR & Hart BT 1981. *Transport of trace metals in the Magela Creek system, Northern Territory: III Billabong sediments.* Technical memorandum 3, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (24pp)

TM4 Recher HR & Holmes RT 1982. *The foraging behaviour of herons and egrets on the Magela Creek flood plain, Northern Territory.* Technical memorandum 4, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (20pp)

TM5 Hart BT & McGregor RJ 1982. *Flocculation of retention pond water.* Technical memorandum 5, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (8pp)

TM6 James CD, Morton SR, Braithwaite RW & Wombey JC 1984. *Dietary pathways through lizards of the Alligator Rivers Region, Northern Territory.* Technical memorandum 6, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (15pp)

TM7 Hart BT & Davies SHR 1984. *Capacity of waters in the Magela Creek system, Northern Territory, to complex copper and cadmium.* Technical memorandum 7, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (42pp)

TM8 Baker L & Walden D 1984. *Acute toxicity of copper and zinc to three fish species from the Alligator Rivers Region.* Technical memorandum 8, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (31pp)

TM9 Thomas PA & Hart BT 1984. *Textural characteristics and heavy metal concentrations in billabong sediments from the Magela Creek system, northern Australia.* Technical memorandum 9, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (39pp)

TM10 Hart BT & Jones MJ 1984. *Oxidation of manganese (II) in Island Billabong water.* Technical memorandum 10, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (11pp)

TM11 Hart BT, Jones MJ & Breen P 1984. In situ *experiments to determine the uptake of copper by the aquatic macrophyte* Najas tenuifolia *R. Br.* Technical memorandum 11, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (13pp)

TM12 Hart BT, Jones MJ & Bek P 1985. *Use of plastic enclosures in determining the effects of heavy metals added to Gulungul Billabong.* Technical memorandum 12, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (25pp)

TM13 Hart BT, Jones MJ & Bek P 1985. *Fate of heavy metals in the Magela Creek system, northern Australia: I Experiments with plastic enclosures placed in Island Billabong during the 1980 Dry season – heavy metals.* Technical memorandum 13, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (46pp)

TM14 Hart BT, Jones MJ, Bek P & Kessell J 1985. *Fate of heavy metals in the Magela Creek system, northern Australia: II Experiments with plastic enclosures placed in Island Billabong during the 1980 Dry season – limnology and phytoplankton.* Technical memorandum 14, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (32pp)

TM15 Smith DI, Young PC & Goldberg RJ 1986. *Use of fluorometric dye tracing to simulate dispersion of discharge from a mine site: A study of the Magela Creek system, March 1978.* Technical memorandum 15, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (51pp)

TM16 Shine R 1986. *Diets and abundances of aquatic and semi-aquatic reptiles in Alligator Rivers Region.* Technical memorandum 16, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (57pp)

TM17 Cowie IE & Finlayson CM 1986. *Plants of the Alligator Rivers Region, Northern Territory.* Technical memorandum 17, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (54pp)

TM18 Julli ME 1986. *The taxonomy and seasonal population dynamics of some Magela Creek flood plain microcrustaceans (Cladocera and Copepoda).* Technical memorandum 18, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (80pp)

TM19 Tyler MJ & Crook GA 1987. *Frogs of the Magela Creek system.* Technical memorandum 19, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (46pp)

TM20 Johnston A 1987. *Radiation exposure of members of the public resulting from operations of the Ranger Uranium Mine.* Technical memorandum 20, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (22pp)

TM21 Anttonen T, Noller BN & Woods DA 1988. *Interlaboratory comparison of the measurement of uranium in urine.* Technical memorandum 21, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (24pp)

TM22 Ivantsoff W, Crowley LELM, Howe E & Semple G 1988. *Biology and early development of eight fish species from the Alligator Rivers Region.* Technical memorandum 22, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (68pp)

TM23 Cowie ID, Finlayson CM & Bailey BJ 1988. *Alien plants in the Alligator Rivers Region, Northern Territory, Australia.* Technical memorandum 23, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (34pp)

TM24 leGras CAA & Noller BN 1989. *The determination of zinc in Magela Creek water.* Technical memorandum 24, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (26pp)

TM25 Allison HE & Simpson RD 1989. *Element concentrations in the freshwater mussel,* Velesunio angasi, *in the Alligator Rivers Region.* Technical memorandum 25, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (262pp)

TM26 Vardavas IM & Cannon LM 1989. *A simple computer model for terrestrial and solar radiation transfer.* Technical memorandum 26, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (60pp)

TM27 Vardavas IM 1992. *Annual rainfall statistics for stations in the Top End of Australia: Normal and log-normal distribution analysis.* Technical memorandum 27, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (34pp)

TM28 Noller BN, McBride TP, Hunt CW & Hart BT 1989. *A study of the reproducibility of water conditions between small enclosures and a tropical waterbody.* Technical memorandum 28, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (20pp)

TM29 Woods DA 1989. *Concentration of radon and radon daughters during semi-dry tailings deposition by QML at Nabarlek (1985-88).* Technical memorandum 29, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (35pp)

TM30 Carter MW 1990. *The development of a regulatory mechanism for the control of water release from Ranger Uranium Mine.* Technical memorandum 30, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (31pp)

TM31 Riley SJ & East TJ 1990. *Investigation of the erosional stability of waste rock dumps under simulated rainfall: a proposal.* Technical memorandum 31, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (56pp)

TM32 Sadlier RA 1990. *The terrestrial and semiaquatic reptiles (Lacertilia, Serpentes) of the Magela Creek region, Northern Territory.* Technical memorandum 32, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (86pp)

TM33 Stockwell DR, Bentley KW & Kerr CB 1991. *In vitro dissolution of uranium mill products by the batch replacement method.* Technical memorandum 33, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (24pp)

TM34 Chartres CJ, Walker PH, Willett IR, East TJ, Cull RF, Talsma T & Bond WJ 1991. *Soils and hydrology of Ranger Uranium Mine sites in relation to application of retention pond water.* Technical memorandum 34, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (69pp)

TM35 leGras CAA & Noller BN 1991. *The determination of low concentrations of sodium, potassium, magnesium, calcium and strontium in natural waters by graphite furnace AAS.* Technical memorandum 35, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (18pp)

TM36 Brennan KG, Noller BN, leGras CAA, Morton SR & Dostine PL 1992. *Heavy metals in waterbirds from the Magela Creek flood plain, Alligator Rivers Region, Northern Territory, Australia.* Technical memorandum 36, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (59pp)

TM37 Padovan A 1992. *Isolation and culture of five species of freshwater algae from the Alligator Rivers Region, Northern Territory.* Technical memorandum 37, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (30pp)

TM38 Carter MW, Burns P, & Munslow-Davies L 1993. *Radiotoxicity hazard classification: the basis and development of a new list.* Technical memorandum 38, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (23pp)

TM39 Rippon GD, leGras CAA, Hyne RV & Cusbert PJ 1992. *Toxic effects of cyanide on aquatic animals of the Alligator Rivers Region.* Technical memorandum 39, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (17pp)

TM40 Devonport CC 1992. *A selected GIS bibliography.* Technical memorandum 40, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (91pp)

TM 41 Roberts RG, Uren CJ & Murray AS 1993. *Thermoluminescence dating techniques at the Alligator Rivers Region Research Institute.* Technical memorandum 41, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (63pp)

TM42 Rippon GD & Chapman JC 1993. *Laboratory procedures for assessing effects of chemicals on aquatic animals.* Technical memorandum 42, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (26pp)

TM43 Dostine PL, Humphrey CL & Faith DP 1993. *Requirements for effective biological monitoring of freshwater ecosystems.* Technical memorandum 43, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (26pp)

TM44 Devonport C & Waggitt PW 1994. *Geographic information systems and remote sensing in northern Australia: A compendium.* Technical memorandum 44, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (60pp)

TM45 Akber RA and Pfitzner JL (1994). *Atmospheric concentrations of radon and radon daughters in Jabiru East.* Technical memorandum 45, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (25pp)

Other publications

Supervising Scientist for the Alligator Rivers Region 1991. *Proceedings of the 29th Congress of the Australian Society of Limnology.* Jabiru 1990, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (135pp)

C Devonport, SJ Riley & SM Ringrose (eds) 1992. *Proceedings of the GIS and Environmental Rehabilitation Workshop. Darwin* 4–5 September 1992, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (161pp)

Supervising Scientist for the Alligator Rivers Region 1992. *Proceedings of the Workshop on Land Application of Effluent Water from Uranium Mines in the Alligator Rivers Region.* Jabiru 11–13 September 1990, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (366pp)

SJ Riley, C Devonport, PW Waggitt & B Fitzpatrick (eds) 1993. *NARGIS 93: Proceedings of the North Australian Remote Sensing and Geographic Information Systems Forum.* Darwin 9–11 August 1993, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (301pp)

Supervising Scientist for the Alligator Rivers Region (in press). *Proceedings of the Workshop on Biological Monitoring of Freshwater Ecosystems in Tropical Northern Australia.* 21–24 September 1993. AGPS, Canberra. (..... pp)

SJ Riley, PW Waggitt & C McQuade (eds) 1993. *Proceedings of the Symposium on the Management and Rehabilitation of Waste Rock Dumps.* Darwin 7–8 October 1993, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra. (182pp)

Office of the Supervising Scientist 1991. *Supervising Scientist for the Alligator Rivers Region Annual Report (1990-91).* AGPS, Canberra.

Office of the Supervising Scientist 1992. *Supervising Scientist for the Alligator Rivers Region Annual Report (1991-92).* AGPS, Canberra.