THE TRANSPORT AND DEPOSITION OF RADIONUCLIDES DISCHARGED INTO CREEK WATERS FROM THE RANGER URANIUM MINE

A. Johnston, A.S. Murray, R. Marten, P. Martin.
Alligator Rivers Region Research Institute,
Office of the Supervising Scientist, Jabiru, NT, Australia

INTRODUCTION

The Ranger uranium mine in the Alligator Rivers Region of Australia's Northern Territory has been operational since 1981. Critical pathway analysis has shown that water transport of radionuclides from the mine site could be an important route for radiation exposure of members of the public; in the short-term such exposure could be as a result of the direct discharge of effluent waters into the nearby Magela Creek and in the long-term as a result of seepage of water from tailings repositories or the transport of erosion products from the rehabilitated site. In order to estimate the radiation exposure of the public from such processes it is necessary to model the transport of radionuclides in the creek and its associated flood plain.

Such a model has been developed for radionuclides in the particulate phase by studying the transport and deposition of naturally occurring radionuclides. The two major components of this program consisted of measurements of concentrations of all the long-lived nuclides of the uranium series in the waters of Magela Creek and in the sediments of the flood plain.

RADIOACTIVE DISEQUILIBRIUM IN SURFACE WATERS

The tropical monsoonal climate of the region is characterised by contrasting Wet and Dry seasons. The Magela Creek flows seasonally and during the Wet season flow can exceed $1000 m^3/s$ in periods of cyclonic depression. The significance of floods in the transport of suspended matter has been well documented for a number of rivers of the world and, in particular, for Magela Creek (Hart et al. 1982). The extent to which radioactive disequilibrium occurs in the particulate matter carried by the flood waters of Magela Creek has been used in this study as a means of identification of the source of sediments that have been deposited on the flood plain. Two floods were studied in detail; 19-21 February 1985 when a maximum instantaneous flow rate of 250 m^3/s was recorded, and 10 April 1986 when the maximum flow rate was 60 m^3/s. Water samples were collected every 2 hours throughout the floods and both filtered and unfiltered ($<0.45\mu m$) samples were analysed by alpha-particle spectroscopy (Martin and Hancock 1987).

The variation of total concentrations with time through the 1985 flood is shown in figure 1 for the isotopes ^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb, and ^{210}Po. A pronounced peak is observed in the concentrations of ^{226}Ra, ^{210}Pb and ^{210}Po about 10 hours after the start of the sampling program; this peak was in advance of the hydrograph which reached its maximum about 7 hours later. No such peak is observed for ^{238}U, and for ^{230}Th and ^{234}U (omitted for clarity) there was only a slight enhancement of concentrations. The concentrations of all nuclides in the filtrate remained essentially constant throughout the flood.

Hart et al. (1982) observed a similar peak of total concentrations in advance of the hydrograph for suspended solids and the metals Mn, Zn and Cu in their study of flood events in Magela Creek during the 1978-79 Wet season. In the present context the main significance of the current data, however, is the demonstration of a substantial disequilibrium in the uranium series radionuclides between ^{230}Th and ^{226}Ra in the suspended matter carried by Magela Creek.

The concentrations of ^{226}Ra in the particulate matter of samples collected during the flood of 10 April 1986 were obtained both with respect to water volume and with respect to the mass of suspended matter. The former data again show a peak in the radionuclide concentrations in advance of the hydrograph but the latter remain approximately constant throughout the flood; the mean value and standard deviation were 220 Bq/kg and 40 Bq/kg respectively. Thus the peak in radionuclide concentrations during floods is attributed solely to the increased concentrations of suspended solids and not to any significant variation in the concentration of radium in the suspended material. Analysis of similar material collected outside of flood periods shows similar constancy of radium concentrations at about 210 Bq/kg and concentrations of ^{230}Th of about 50 Bq/kg deduced from thorium systematics.

RADIONUCLIDE CONCENTRATIONS IN SEDIMENTS

Some 12 km downstream from Ranger the Magela Creek enters a floodplain system; in a typical Wet season the inundated area is about 200 km^2. Average values of radionuclide concentrations were obtained on 19 transects of the creek and floodplain by combining two measurement techniques. A rapid quantitative assessment of the distribution of natural radionuclides (primarily ^{226}Ra, ^{228}Ra, and ^{40}K) was provided by gamma-ray dose rate measurements. These dose rate data were then used to select a typical site on each transect from which sediment cores were obtained and subdivided into 3 cm sections. These sections were analysed by gamma-ray spectroscopy (Murray et al. 1987) to obtain concentrations of ^{238}U, ^{226}Ra, ^{210}Pb, ^{228}Ra, ^{228}Th and ^{40}K; the standard error in the dose rate data for each transect was then used as an estimate of the variability of individual concentrations. The reliability of this technique was confirmed by detailed study of one complete transect.

Concentrations of ^{238}U and ^{226}Ra in the top 3 cm of sediment are plotted as a function of distance downstream from the beginning of the floodplain in figure 2. In the sandy creek region ($x < 0$) concentrations are, as expected, low. The absolute concentrations and the extent of radioactive disequilibrium observed at the southern end of the floodplain ($0 < x < 5$ km) agree very well with observations on the suspended matter carried by the creek. However, disequilibrium is not observed on the northern part of the floodplain ($x > 20$ km). Therefore, since sedimentation rates are (from geomorphological evidence) approximately independent of location, sedimentation in the northern region (which accounts for about 80% of the floodplain area) must have arisen from inputs other than Magela Creek even though this creek provides about half the volume of water entering the floodplain.

INTERPRETATION

These data have been interpreted within the context of a two-compartment model of sedimentation; input of particulate matter from Magela Creek with a concentration of radium C_m, and input from the remainder of the catchment with concentration C_r. The average concentration of radium in surface sediments at distance x, C(x), is then given by

$$C(x) = (C_m - C_r)f(x) + C_r \qquad (1)$$

where f(x) is the fraction of sediment at x that arises from deposition of particulate matter from Magela Creek. The areal rate of deposition of radium, R(x), is related to both the concentration C(x) and to the rate of change of the radium load, L(x), in the water column; that is

$$R(x) = \rho r(x)\, C(x) \qquad (2)$$

and

$$R(x) = -\,(dL/dx)/w \qquad (3)$$

where ρ is the density of sediment, w is the floodplain width, and r(x) is the total sedimentation rate at x.

The form of f(x) and the values of the variables C_m and C_r have been determined from the radium data in figure 2; f(x) is given by $\exp(-x/\lambda)$ where the attenuation length λ is 8.5 km, C_m = 190 Bq/kg and C_r = 50 Bq/kg. Thus C_m is in good agreement with the observed value of radium concentrations in particulate matter of Magela Creek, namely about 220 Bq/kg. Assuming r(x) does not vary substantially over the region $0 < x < 3$ km, equations (2) and (3) can be solved to determine the current sedimentation rate, r, near the southern end of the floodplain. Thus $r = L_s/(w\lambda\rho)$ where L_s is the annual average load of suspended solids carried by Magela Creek. Using known values of w and L_s, 1 km and 5000 tonnes/y respectively, and the value of λ deduced above gives r = 0.4 mm/y. This value is in good agreement with independent estimates using thorium-radium dating of floodplain sediments from the same location.

CONCLUSION

The principal conclusion of this work is that particulate matter from Magela Creek appears to contribute to sedimentation on only a small fraction of the 200 km^2 flood plain. Using the value of λ determined above, about 90% is deposited in the first 18 km of floodplain with an area of about 30 km^2. Thus radionuclides released from Ranger in the particulate phase or which partition into this phase soon after discharge have a high probability of being retained within a small region of the floodplain system.

Hart, B.T., Davies, S.H.R., Thomas, P.A. (1982). Transport of iron, manganese, copper and zinc by Magela Creek, Northern Territory, Australia. Water Res. 16. 605-612.

Martin, P. and Hancock, G. (1987). Radionuclide analytical technique development. Alligator Rivers Region Research Institute, Annual Research Summary 1986-87. AGPS, Canberra.

Murray, A.S., Marten, R., Johnston, A., Martin, P. (1987). Analysis of naturally occurring radionuclides at environmental concentrations by gamma-ray spectroscopy. J. Radioanalytical Nucl. Chem., in press.

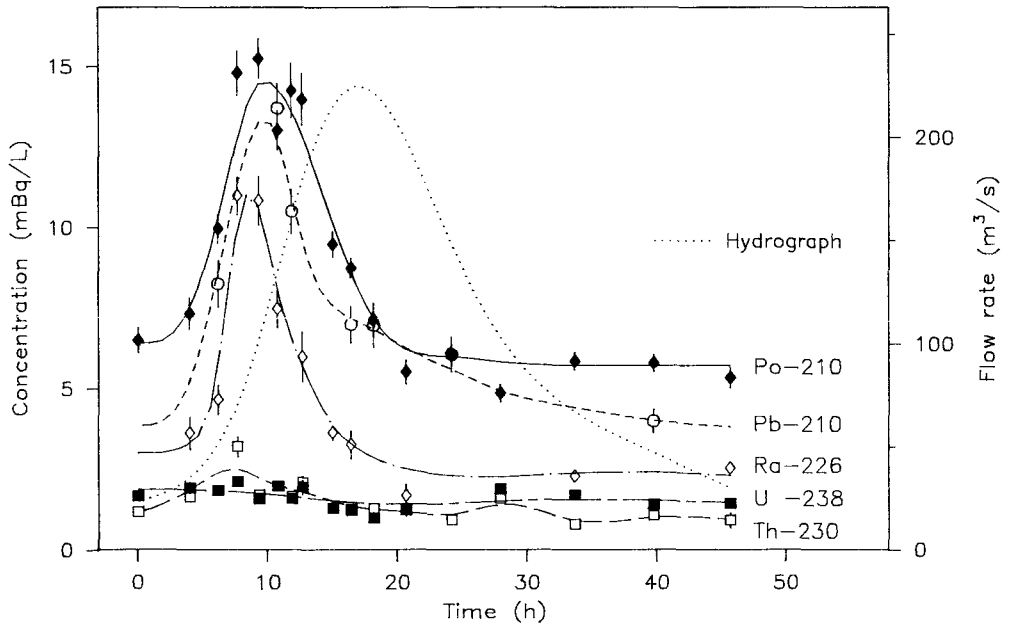

Figure 1 Variation of the concentrations of uranium series radionuclides in unfiltered water from Magela Creek during the flood of 19–21/2/85

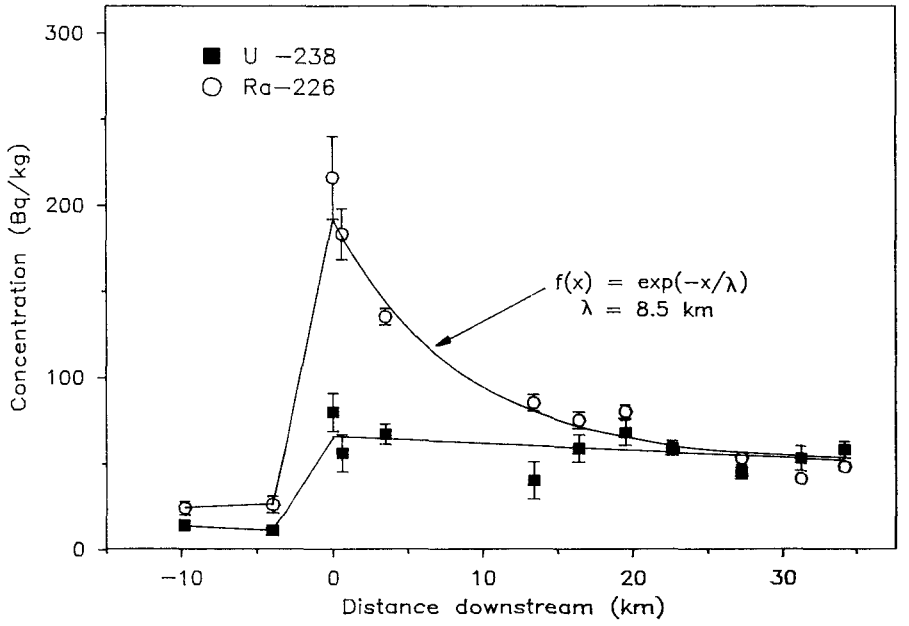

Figure 2 Radionuclide concentrations in the sediments of the Magela Creek and flood plain as a function of distance downstream from the beginning of the floodplain