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# A COMPARISON OF THE RESPONSE OF A NAI SCINTILLATION CRYSTAL WITH A PRESSURIZED IONIZATION CHAMBER AS A FUNCTION OF ALTITUDE, RADIATION LEVEL, AND RA-226 CONCENTRATION

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# A COMPARISON OF THE RESPONSE OF A NAI SCINTILLATION CRYSTAL WITH A PRESSURIZED IONIZATION CHAMBER AS A FUNCTION OF ALTITUDE, RADIATION LEVEL, AND RA-226 CONCENTRATION

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ABSTRACT

The Grand Junction Uranium Mill Tailings Remedial Action-Radiological Survey Activities Group (UMTRA-RASA) program employs a screening method in which external exposure rates are used to determine if a property contaminated with uranium mill tailings is eligible for remedial action. Portable NaI detectors are used by survey technicians to locate contaminated areas and determine exposure rates. The exposure rate is calculated using a regression equation derived from paired measurements made with a pressurized ionization chamber (PIC) and a NaI detector. During July of 1985 extensive measurements were taken using a PIC and a NaI scintillator with both analogue and digital readout for a wide range of exposure rates and at a variety of elevations. The surface soil was sampled at most of these locations and analyzed for $^{226}$Ra. The response of the NaI detectors was shown to be highly correlated to radiation level but not to $^{226}$Ra concentration or elevation.

## INTRODUCTION

The Uranium Mill Tailings Remedial Action Program (UMTRAP) is responsible for decontamination of inactive uranium mill sites and associated "vicinity properties". Vicinity properties include residences, schools, parks, motels and other public and commercial structures (1). These properties were contaminated with waste uranium mill tailings primarily through the use of tailings as a substitute for sand in construction projects.

The Department of Energy (DOE) was charged with the performance of the UMTRA Program. It identified over 8200 candidate properties (designated properties) of which about 7000 are located in Grand Junction, CO (1).

One of the steps in the remedial action process is a radiological survey of each designated property to determine eligibility for decontamination by UMTRA. These surveys are conducted by Oak Ridge National Laboratory (ORNL) which is designated as the Inclusion Survey Contractor (ISC).

The Pressurized Ionization Chamber (PIC) is considered to be the standard instrument for environmental exposure rate measurements. However, because of its size, weight and cost it is not practical as a portable survey meter. Therefore, the gamma surveys are performed primarily with portable instruments consisting of a NaI scintillator with an analogue ratemeter (scintillometers). The scintillometers are relatively inexpensive, portable, and have a high sensitivity with a rapid response. However, they measure ionizing events in the crystal, not exposure.

Readings made with the scintillometer, in kilo Counts Per Minute (kCPM), are transformed to exposure rates (μR/h) using an equation developed through a regression analysis of paired pressurized ionization chamber and NaI scintillometer measurements (2).

It is imperative to understand the response of the portable scintillators as a function of exposure rate. Since both detectors are subjected to the combination of terrestrial and atmospheric radiation, this study was designed to observe the response of each as a function of elevation and concentration of $^{226}Ra$ in soil.

## METHODS

Exposure rates were measured using a Reuter Stokes RSS-111 pressurized ionization chamber modified with an integrated display in units of μR/h (3, 2). The calibration of the PIC was verified at the beginning of the project using two sources of $^{226}Ra$ in a procedure recommended by the manufacturer, and field checked daily using a $^{60}Co$ source.

A NaI scintillator (3.2 cm dia.; 3.8 cm ℓ) with an analogue rate meter was tested. This system was identical to the configuration used by the ISC survey teams. Estimates of count rate were made by averaging the meter reading over a timing interval of approximately 10 s.

A second NaI scintillator (2.5 cm dia; 2.5 cm ℓ) with a digital scaler was also compared to the response of the PIC. The count rate was determined by integrating over a 60 s time interval.

Each of the NaI scintillometers was field checked daily using a depleted uranium source. All measurements were taken at ground level since the screening criteria for vicinity properties are written for ground level measurements (2).

Data collection was performed in several steps. In order to determine the response of the NaI crystals under background conditions, the city and surrounding areas of Grand Junction were divided into a 2.56 $km^2$ grid. One hundred and twenty-five locations were measured on this grid. In order to obtain the response at higher levels of radiation, twenty-five measurements were made in the vicinity of the uranium mill tailings pile. A series of measurements were taken from 1500 m to 3300 m along Grand Mesa to determine the response of each detector as a function of elevation.

At each site the top 15 cm of soil was removed using a post hole digger. Approximately 350 g of each sample was dried and analyzed for $^{226}Ra$ concentration. This analysis was performed using a NaI spectrometer and a computer algorithm developed by ORNL (2). Response as a function of $^{226}Ra$ concentration was then determined.

## RESULTS

Figure 1 shows the paired readings of the PIC (μR/h) and the NaI scintillometer (kCPM). The data was plotted on a log-log scale because of the dynamic range of the readings. The solid curve illustrates the result of a regression analysis. The data were separated into two sections in order to simplify the equations.

From 0-50 kCPM the response of the NaI system was a linear function of exposure rate. At higher readings a power function was required. The equations obtained from the regression analysis are:

$$\text{Exposure Rate } (\mu R/h) = (kCPM) + 8.3 \qquad kCPM \leq 50 \tag{1}$$

$$\text{Exposure Rate } (\mu R/h) = 0.53\ (kCPM)^{1.2} \qquad kCPM > 50 \tag{2}$$

The $R^2$ for equation (1) was 95 and that for equation (2) was 99. This combination provided a satisfactory fit to the data but as can be seen from Figure 1, there is a tendency for the equation to overestimate the true values at low count rates. Generally, this distribution of residuals is unacceptable. However, for screening purposes the equations seem to be adequate. The dashed lines in Figure 1 show an interval of ± 20% about the regression lines. It is clear that over 95% of the true readings fall within this interval.

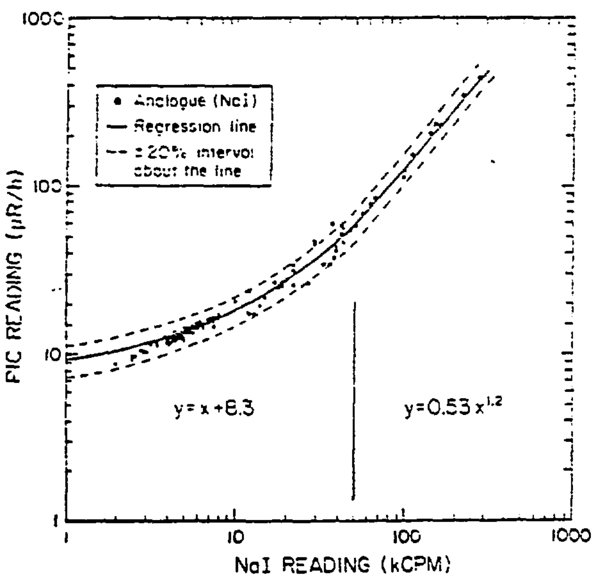


Figure 1. Plot of paired readings for the pressurized ionization chamber and the NaI scintillometer with analogue display showing the two regression equations that intersect at 50 kCPM.

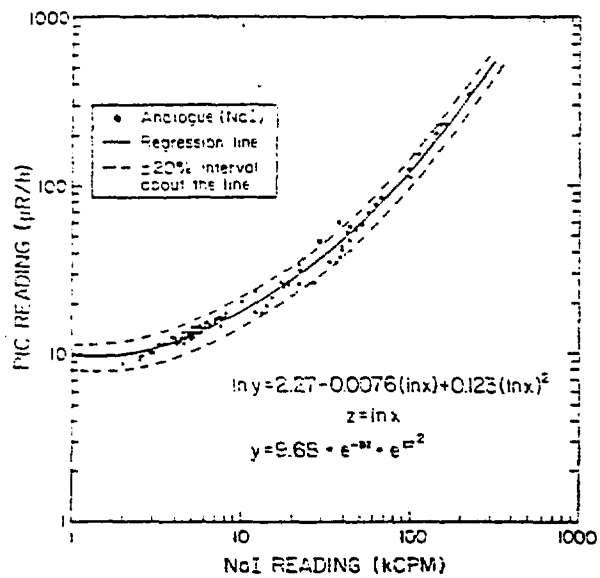


Figure 2. Plot of paired readings for the pressurized ionization chamber and the NaI scintillometer with analogue display with a quadratic function over all exposure rates measured.

Another regression analysis of the data was made using a quadratic function on the log-log scale. This model yields the desired normal distribution of residuals. This curve is shown in Figure 2. The equation describing this curve is:

$$\ln(y) = 2.27 - 0.0076(\ln x) + 0.123(\ln x)^2 \tag{3}$$

Thus,

$$\text{Exposure Rate } (\mu R/h) = 9.7\ (kCPM)^{-0.0076} \{(kCPM)^{0.123}\}^{\ln(kCPM)} \tag{4}$$

Although this function is statistically superior based on the distribution of residuals, it is quite cumbersome to use and does not vastly improve the confidence interval based on ± 20% variation as shown in Figure 2.

Figure 3 shows the response of the NaI detector for low values of exposure rate. There is an apparent threshold which indicates that the NaI scintillator does not respond until the exposure rate is greater than 8 μR/h.

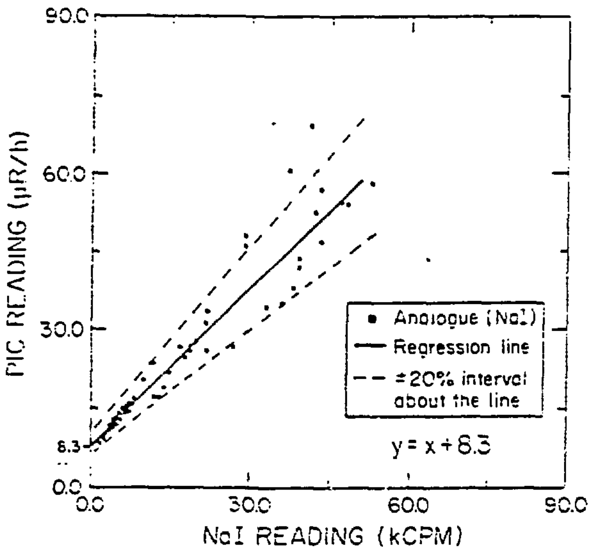


Figure 3. Plot of paired readings for the pressurized ionization chamber and NaI scintillometer with analogue display at low exposure rates which shows a threshold at 8.3 μR/h.

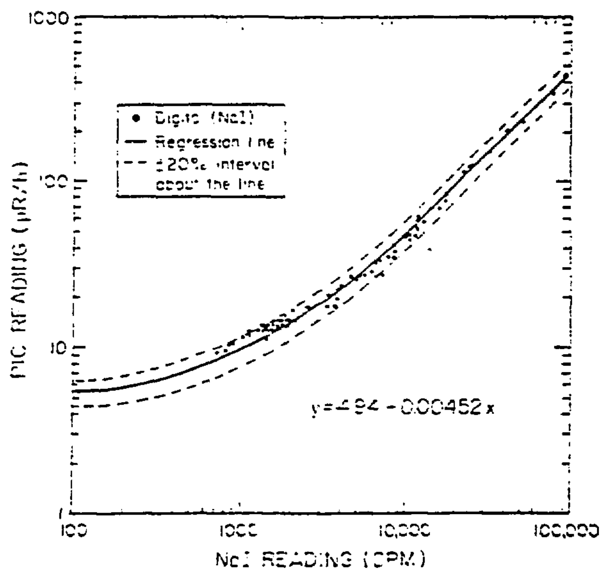


Figure 4. Plot of paired readings for the pressurized ionization chamber and the NaI scintillometer with digital display showing a linear fit over all exposure rates measured.

Figure 4 shows the response of the NaI detector with a digital scaler. In this situation a single linear expression was sufficient to fit the data:

$$\text{Exposure Rate } (\mu R/h) = 5 + 0.0045 \text{ (CPM)} \quad (5)$$

$$\text{Exposure Rate } (\mu R/h) = 5 + 0.45 \text{ (kCPM)} \quad (6)$$

Notice that there is a threshold exposure rate of 5 μR/h for the scintillometer with a digital scaler.

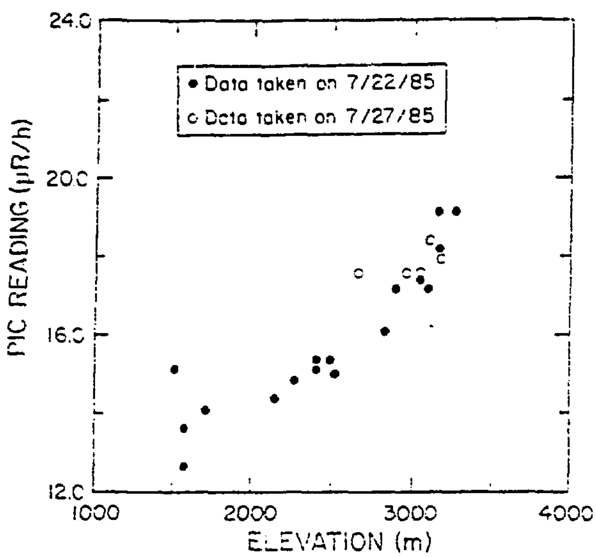


Figure 5. The response of the pressurized ionization chamber vs. elevation between 1500 m and 3400 m along Grand Mesa, CO.

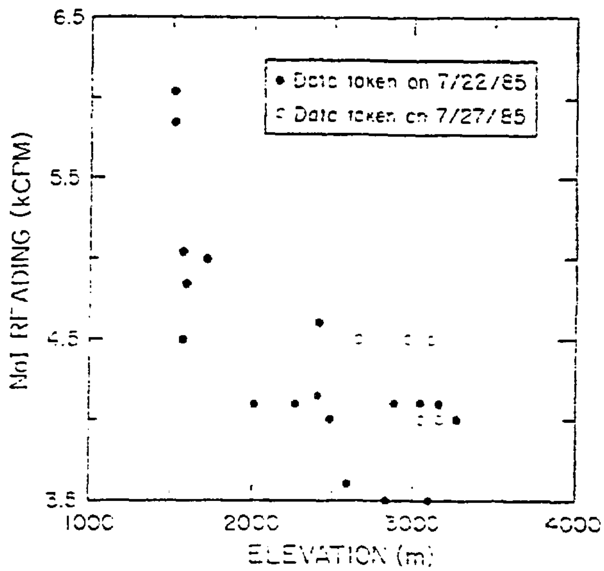


Figure 6. The response of the NaI scintillometer vs. elevation between 1500 m and 3400 m along Grand Mesa, CO.

Figure 5 shows the response of the PIC as a function of elevation. There is a clear correlation between exposure rate and elevation. Figure 6 shows the response of the NaI detector as a function of elevation. There does not appear to be any correlation between the count rate and elevation. Figure 7 shows the paired readings of the PIC and NaI detector for the data previously shown in Figures 5 and 6. Notice that for the data taken at higher elevations the NaI scintillator underresponds when compared to the regression equation obtained at lower elevations.

Figure 8 is a plot of the concentration of $^{226}$Ra in surface soil as a function of exposure rate measured by the PIC. Figure 9 is a plot of $^{226}$Ra concentration as a function of the NaI reading. Neither of these show any apparent correlation. Notice that $^{226}$Ra concentrations at or below the minimum detectable concentration are observed over the entire range of exposure rates and NaI readings.

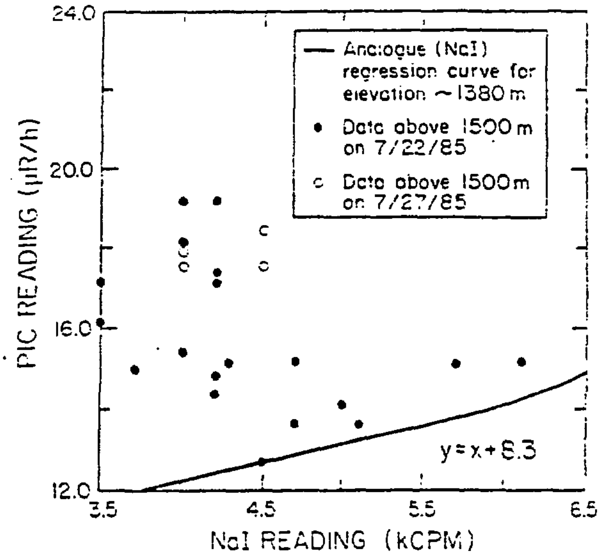


Figure 7. Plot of paired readings taken above 1500 m elevation for the pressurized ionization chamber and the NaI scintillometer. The solid line is the equation obtained from the regression analysis shown in Figure 1.

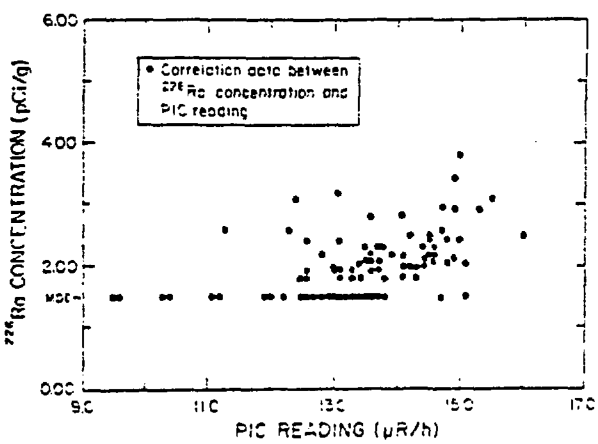


Figure 8. Plot of $^{226}$Ra concentration in soil as a function of pressurized ionization chamber reading. The minimum detectable concentration was 1.5 pCi/g.

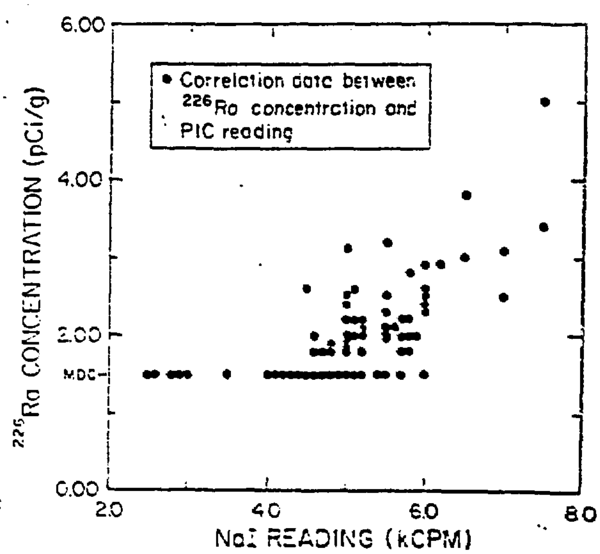


Figure 9. Plot of $^{226}$Ra concentration in soil as a function of NaI scintillometer reading. The minimum detectable concentration was 1.5 pCi/g.

## CONCLUSIONS

At elevations below 1500 m the count rate of portable NaI survey meters was correlated to the external exposure rate measured with a pressurized ionization chamber (PIC). The response was linear for low count rates, but a power function was required at higher count rates when measured with an analogue meter. Both digital and analogue scintillometers displayed thresholds in the sense that they did not respond to exposure rates measured with the PIC below 5 µR/h and 8 µR/hr, respectively. It is suggested that this corresponds to missing pulses generated by atmospheric radiation which are not registered by the rate meters.

The response of the PIC increased with elevation. However, there was no correlation between the NaI detectors and elevation. The response of the NaI scintillometers was probably due to random changes in the terrestrial component. The correlation between the PIC and elevation was preserved even when the output of the NaI was subtracted from the PIC. This is further evidence that the NaI detectors did not respond to atmospheric radiation.

Attempts to correlate the response of the PIC and NaI detectors with the concentration of $^{226}$Ra in soil directly below the point of measurement were entirely unsuccessful.

The insensitivity of the portable NaI scintillometers to atmospheric radiation might be explained by considering the stopping power of high energy muons and the path length distribution through the crystal. The stopping power for minimum ionizing particles in NaI is 4.8 MeV/cm (5). Using Cauchy's theorem, the mean path length through the 2.5 cm * 2.5 cm cylinder is 2/3 of the diameter which is 1.7 cm. This corresponds to an energy deposition greater than 8 MeV. It is not clear how the amplifier and discriminators process such large signals. For this cylindrical geometry only about 2% of the events would be less than 2 MeV which is in the range of those produced by terrestrial gamma rays (6).

In summary, NaI scintillometers can be used for rapid screening of external exposure rates. Caution must be exercised when large variations in elevation are anticipated. The measured exposure rates were not correlated to the concentration of $^{226}$Ra in soil taken directly below the point of measurement.

## ACKNOWLEDGMENT

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