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^{222}RN AND ^{220}RN PROGENY RELATIONSHIP IN CANADIAN UNDERGROUND URANIUM MINES

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ABSTRACT

Radon and thoron progeny are found in some Canadian underground uranium mines. Because both contribute to dose exposure, their experimental determination is important. The relationship between radon progeny Working Level, WL(Rn), and thoron progeny Working Level, WL(Tn), has been investigated in uranium mines. Experimental measurements extended over the period 1981 to 1986, and consisted of about 700 measurements of each WL(Rn) and WL(Tn). The data were analyzed by standard linear and power function regression analysis. A power function relationship between WL(Rn) and WL(Tn) best seemed to fit the experimental data. The relationship obtained is of practical interest as it permits the calculation of WL(Tn) from experimental values of WL(Rn). The relationship is useful for dose exposure calculation purposes and in mine ventilation engineering calculations.

Keywords: Radon progeny, thoron progeny, uranium mines.

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LIENS DE FILIATION DU RN^{222} et du RN^{220} DANS LES MINES SOUTERRAINES D'URANIUM AU CANADA

par

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RÉSUMÉ

Des descendants du radon et du thoron sont présents dans certaines mines souterraines d'uranium au Canada. Comme ces deux minéraux augmentent les risques d'exposition au rayonnement, il est important de les déterminer expérimentalement. Dans les mines d'uranium, les rapports entre le niveau d'activité WL(Rn) des descendants du radon, et le niveau d'activité WL(Tn) des descendants du thoron, ont fait l'objet d'une étude. Pour réaliser le contrôle, environ 700 mesures du niveau d'activité des descendants du radon et des descendants du thoron ont été prises dans la période de 1981 à 1986. Ces données ont été soumises à une analyse ordinaire de régression linéaire et de puissance. Le rapport de puissance entre les descendants du radon et les descendants du thoron semble être celui qui s'apparente le plus aux données expérimentales. La relation obtenue est d'intérêt pratique car elle permet de calculer le niveau d'activité des descendants du thoron à partir des valeurs expérimentales obtenues pour les descendants du radon. La relation est également importante pour le calcul de l'exposition au rayonnement et pour le calcul technique de la ventilation dans les mines.

Mots-clé : Descendant du radon, descendant du thoron, mines d'uranium.

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INTRODUCTION

Radon gas and its short-lived progeny are found in relatively high concentrations in operating underground uranium mines throughout the world. Thoron gas and its short-lived decay products, a less common occurrence than radon gas and its progeny, are also found in some underground uranium mines in Canada and other countries.

It is a commonly accepted practice in Canada, as well as in other nations, to estimate radon progeny concentration alone for dose exposure calculation purposes. However, because thoron progeny, as well as radon progeny, are found in many uranium mines it is important to estimate both concentrations for personal radiation exposure purposes.

The accurate measurement of radon progeny and thoron progeny in radon/thoron mine atmospheres is not straightforward: it is a lengthy and time consuming task that severely limits the number of samples used for personal dosimetry and ventilation engineering purposes. Because of this it is important to determine whether there is a relationship between radon progeny and thoron progeny that can be used to derive one variable from the other with reasonable accuracy.

Because of the short half-life of the radon progeny compared with the relatively long half-life of the thoron progeny, the former is estimated first. Hence, the question is whether radon progeny measurements allow a reliable estimation of thoron progeny under average operating field conditions.

This paper presents data on the relationship between radon progeny and thoron progeny taken over an extended period of time at several locations of a Canadian underground uranium mine or uranium mines with similar mass gram ratio $^{238}U/^{232}Th$ and ventilation characteristics.

THEORETICAL BACKGROUND

Measurement of radon progeny and thoron progeny in radon/thoron underground uranium mine atmospheres vary widely in complexity according to the accuracy required and the radiation variable(s) of interest. Precise, simultaneous, activity concentration measurement of the short-lived decay products of radon (^{218}Po, ^{214}Pb and ^{214}Po) and the short-lived decay products of thoron (^{212}Pb and ^{212}Bi) can be carried out using 5-gross α-count techniques (Zh83). These techniques also enable the estimation of another useful quantity: the Working Level (WL), a quantity related to the total α-particle energy released by the radon or thoron progeny. The Working Level can be calculated from radon or thoron progeny activity concentrations.

If the progeny activity concentration is not necessary and only the Working Level is the variable of interest, simplified counting procedures are available. Routine measurement of radon progeny Working Level, WL(Rn), and thoron progeny Working Level, WL(Tn), can be conducted using two-gross α-count methods. The methods essentially consist of the following steps.

a) A sampling period. For moderate activity concentrations, the sampling period is in the range 3-10 min;

b) A waiting period of 40-90 min followed by an α-counting period of about 1-10 min; and

c) A waiting period of 5-11 h, after the end of sampling, followed by an α-counting period of 5-10 min.

The sampling and α-counting periods suggested above depend mainly on the radon progeny and thoron progeny activity concentrations. For low and very low activity concentrations, the sampling and counting periods could be substantially longer than those indicated above.

Steps (a) and (b) describe the Kusnetz method (Ku 56) for determining

WL(Rn). Steps (a) and (c) correspond to the Rock method (Ro70) for estimating WL(Tn). A more general and detailed method than can be used for both WL(Rn) and WL(Tn) has been developed by the author (Bi84).

The time-delay between steps (b) and (c) is necessary to allow complete decay of the radon progeny before counting the thoron progeny. However, it should be noted that because of the relatively long-life of the thoron progeny, radon progeny α-counting (see item (b)) requires correction to take into account the presence of thoron progeny.

Knowledge of WL(Tn) and WL(Rn) is not only of interest for radiation exposure calculation purposes, but the ratio WL(Tn)/WL(Rn) represents a good indicator of air flow conditions, i.e., ventilation characteristics, in underground uranium mines (Bi85).

The values of WL(Tn) and WL(Rn), and hence their ratio, in partially enclosed radioactive environments such as those corresponding to underground uranium mines depend on various factors such as:

a) the mass gram ratio $^{238}U/^{232}Th$;

b) air flow conditions at the location;

c) physical characteristics of the uranium and thorium-bearing ore;

d) environmental factors such as barometric pressure;

e) other factors, effects or phenomena such as plate-out on mine walls; and

f) mining operations.

Items (a), (b), (c) and (f) depend on the location in the mine. Because of this, the ratio WL(Tn)/WL(Rn) should be expected to vary from mine location to mine location. In general, however, reasonably representative average values for the mass gram ratio $^{238}U/^{232}Th$ and the physical characteristics of the ore can be assumed. Furthermore, if the ventilation characteristics of the mine are not drastically changed on a large scale or over the long-range, one might anticipate the ratio WL(Tn)/WL(Rn) to either remain roughly constant, and within the limits of experimental error or applicability for radiation exposure calculation purposes, or to vary in some predictable fashion.

Because different underground uranium mines may have significantly different ore grades, and hence different mass gram ratio $^{238}U/^{232}Th$, and ventilation characteristics, the relationship between WL(Rn) and WL(Tn) could vary substantially from mine to mine. For example, measurements in Ontario (Canada) uranium mines show a ratio WL(Tn)/WL(Rn) ~0.5-0.8, and higher, whereas mines in Saskatchewan (Canada) indicate WL(Tn)/WL(Rn) ~0. Hence, the conclusions derived from experimental data from one mine should not readily be applied to other mines.

A theoretical derivation of the relationship between WL(Rn) and WL(Tn) under field conditions is beyond the scope of this paper. The complexity of diffusion and transport mechanisms of radioactive gases through inhomogeneous and anisotropic media under varying air flow and barometric pressure conditions precludes the treatment of the problem here. Hence, only a useful empirical relationship is sought. However, for a relationship between two variables to be of practical interest and use, the relationship should be preferentially a simple one. Two kinds of relationships have been investigated here, namely a power function and a linear function.

The linear function can be represented as follows:

$$WL(Tn) = m\ WL(Rn) + b \qquad (1)$$

The power function is represented by Equation (2):

$$WL(Tn) = k\ WL(Rn)^{\alpha} \qquad (2)$$

The power function of Equation (2) can be transformed as follows:

$$\log WL(Tn) = \alpha \log WL(Rn) + \log k \qquad (3)$$

Equation (3) represents a linear function which in log-log paper will show as a straight line.

In this paper, experimental data on WL(Rn) and WL(Tn) have been collected and analyzed by regression analysis techniques to determine the best data fit according to Equations (1) and (2). Furthermore, a comparison has been made between the two relationships to ascertain the best theoretical fit to the experimental data.

EXPERIMENTAL PROCEDURE

Radon progeny and thoron progeny Working Level measurements were conducted in various working locations within a given underground uranium mine or mines with similar mass gram ratio $^{238}U/^{232}Th$ and ventilation characteristics.

Measurements extended mainly over the period 1981 to 1986. The discussion presented in this paper is based on approximately 700 independent measurements (samples) of each WL(Rn) and WL(Tn).

Although in general use was made of the Kusnetz (Ku56), Rock (Ro70), and Bigu (Bi84) methods to determine WL(Rn) and WL(Tn), other more elaborate methods were also concurrently employed such as the Thomas-Tsivoglou method (Th72), 5-gross α-count methods (Zh83), and α-spectroscopic techniques. These methods enabled determination of the radon progeny and/or thoron progeny activity concentration and hence their state of disequilibrium, a measure of the ventilation characteristics (e.g., age of mine air) of the locations where measurements were conducted.

After calculation of WL(Rn) and WL(Tn), frequency distribution graphs of WL(Rn) and WL(Tn) and of their ratio WL(Tn)/WL(Rn) were plotted, and correlation of WL(Tn) and WL(Rn) by regression analysis, using Equations 1 to 3 and well established statistical methods, was conducted as shown in the next section.

RESULTS AND DISCUSSION

Figures 1 and 2 show the frequency distributions corresponding to WL(Rn) and WL(Tn), respectively. Figure 3 shows the frequency distribution of the ratio WL(Tn)/WL(Rn).

The data of Figures 1 to 3 show that most values for WL(Rn) and WL(Tn) were below 0.3 and that the ratio WL(Tn)/WL(Rn) was relatively high, i.e., between 0.4 and 1.4.

Linear and power function regression analysis of WL(Tn) versus WL(Rn) experimental data gave the following relationships:

$$WL(Tn) = 0.47\ WL(Rn) + 0.074; \quad \sigma = 0.835 \qquad (4)$$

and

$$WL(Tn) = 0.557\ WL(Rn)^{0.727}; \quad \sigma = 0.936 \qquad (5)$$

where, σ stands for correlation coefficient.

The correlation coefficients corresponding to Equations 4 and 5 show that for the particular set of data presented here, the power function better describes the experimental data. It should be noted that the linear function predicts WL(Tn) = 0.074 for WL(Rn) ~ 0; this corresponds to a very large value of the ratio WL(Tn)/WL(Rn) which can only occur under either extremely high ventilation conditions, i.e., very 'young' mine air, or for very low mass gram ratio $^{238}U/^{232}Th$, or both, a rather unlikely practical situation. The power function, on the other hand, predicts WL(Tn) = 0 for WL(Rn) = 0, a seemingly more 'reasonable' result.

Data predicted by Equations 4 and 5 for a range of values of WL(Rn) have been tabulated for comparison purposes (Table 4). It can be seen that agreement of WL(Tn) calculated according to Equations 4 and 5 is within approximately 20% for WL(Rn) $\gtrsim 0.12$. For low values of WL(Rn), i.e., <0.07, the linear function predicts significantly higher values than the power function.

Because of the discrepancy noted above, the data were divided into two main groups, namely WL(Rn) <0.07 and WL(Rn) >0.07. Those two groups of data were analyzed independently using the statistical techniques discussed above. The results are as follows:

for WL(Rn) $\leq$0.07:

$$WL(Tn) = 1.921\ WL(Rn) - 0.004\ ,\ \sigma = 0.79 \qquad (6)$$

$$WL(Tn) = 0.65\ WL(Rn)^{0.767}\ ,\ \sigma = 0.82 \qquad (7)$$

for WL(Rn) >0.07:

$$WL(Tn) = 0.434\ WL(Rn) + 0.096\ ,\ \sigma = 0.83 \qquad (8)$$

$$WL(Tn) = 0.54\ WL(Rn)^{0.7}\ ,\ \sigma = 0.86 \qquad (9)$$

Comparison of Equations 7, 9 and 5 show that the power function for the three groups of data remains essentially the same and $0.82 < \sigma < 0.94$. However, the linear function for WL(Rn) $\leq$0.07 differs significantly from data for which WL(Rn) >0.07 and from data represented by Equation 4, i.e., the entire population.

Because the power function 'behaves' better than the linear function for any group of values of WL(Rn), and because Equations 5, 7 and 9 do not differ significantly, Equation 5 covering the range 0 $\leq$WL(Rn) $\geq$1 is assumed to best represent the experimental data.

Figure 4 shows the linear function and power function, i.e., Equations 4 and 5, respectively, corresponding to all experimental data. Figure 5 shows the power function (Equation 5) in log-log coordinates for all experimental data. It should be noted that because of the limited spatial resolution of the computer graphics, from which Figures 4 and 5 have directly been traced, only a fraction of the total data points appear in the graphs. However, the regression calculations and curves have been calculated using all the experimental data available, i.e., about 700 measurements.

CONCLUSION

It has been shown that experimental data of radon progeny and thoron progeny for particular underground uranium mine locations are best represented by a power function as shown by Equation 5. Hence, the thoron progeny Working Level can easily be derived from radon progeny Working Level experimental measurements with adequate accuracy for most practical purposes including approximate radiation and dose exposure calculations and for ventilation engineering purposes.

REFERENCES

Bi84 Bigu J. and Grenier, M.G., 1984. "Thoron daughter working level measurements by one and two gross alpha-count methods," Nuc. Inst. and Methods in Phys. Research 225, 385.

Bi85 Bigu J., 1985. "Theoretical models for determining ^{222}Rn and ^{220}Rn progeny levels in Canadian underground uranium mines - a comparison with experimental data," Health Phys. 48, 371.

Ku56 Kusnetz H.L., 1956. "Radon daughters in mine atmospheres." Am. Ind. Hyg. Assoc. J. 17, 1.

Ro70 Rock R.L., 1970. "Sampling mine atmospheres for potential α-energy due to presence of radon (thoron) daughters." U.S. Department of the Interior. Information Report IR 1015.

Th72 Thomas, J.W., 1972. "Measurements of radon daughters in air." Health Phys. 23, 783.

Zh83 Zhang Ch. and Luo D., 1983, "Measurement of mixed radon and thoron daughter concentration in air," Nuc. Inst. and Methods in Phys. Research 215, 481.

Table 1 - Theoretical data calculated with linear and power functions

WL(Rn)	$WL(Tn)_{LF}$* (Linear function)	$WL(Tn)_{PF}$** (Power function)	$\frac{WL(Tn)_{PF}}{WL(Tn)_{LF}}$
0	0.074	0.0	0.0
0.01	0.079	0.020	0.25
0.02	0.083	0.032	0.38
0.03	0.088	0.043	0.49
0.04	0.093	0.054	0.58
0.05	0.097	0.063	0.65
0.075	0.109	0.085	0.78
0.10	0.121	0.104	0.86
0.12	0.130	0.119	0.91
0.15	0.144	0.140	0.97
0.17	0.154	0.154	1.00
0.20	0.168	0.173	1.03
0.25	0.191	0.203	1.06
0.30	0.215	0.232	1.08
0.35	0.238	0.260	1.09
0.40	0.262	0.286	1.09
0.50	0.309	0.336	1.09
0.60	0.356	0.384	1.08
1.00	0.544	0.557	1.02

Note: The indices LF and PF indicate linear function and power function, respectively.

* Calculated according to Equation 4.

** Calculated according to Equation 5.

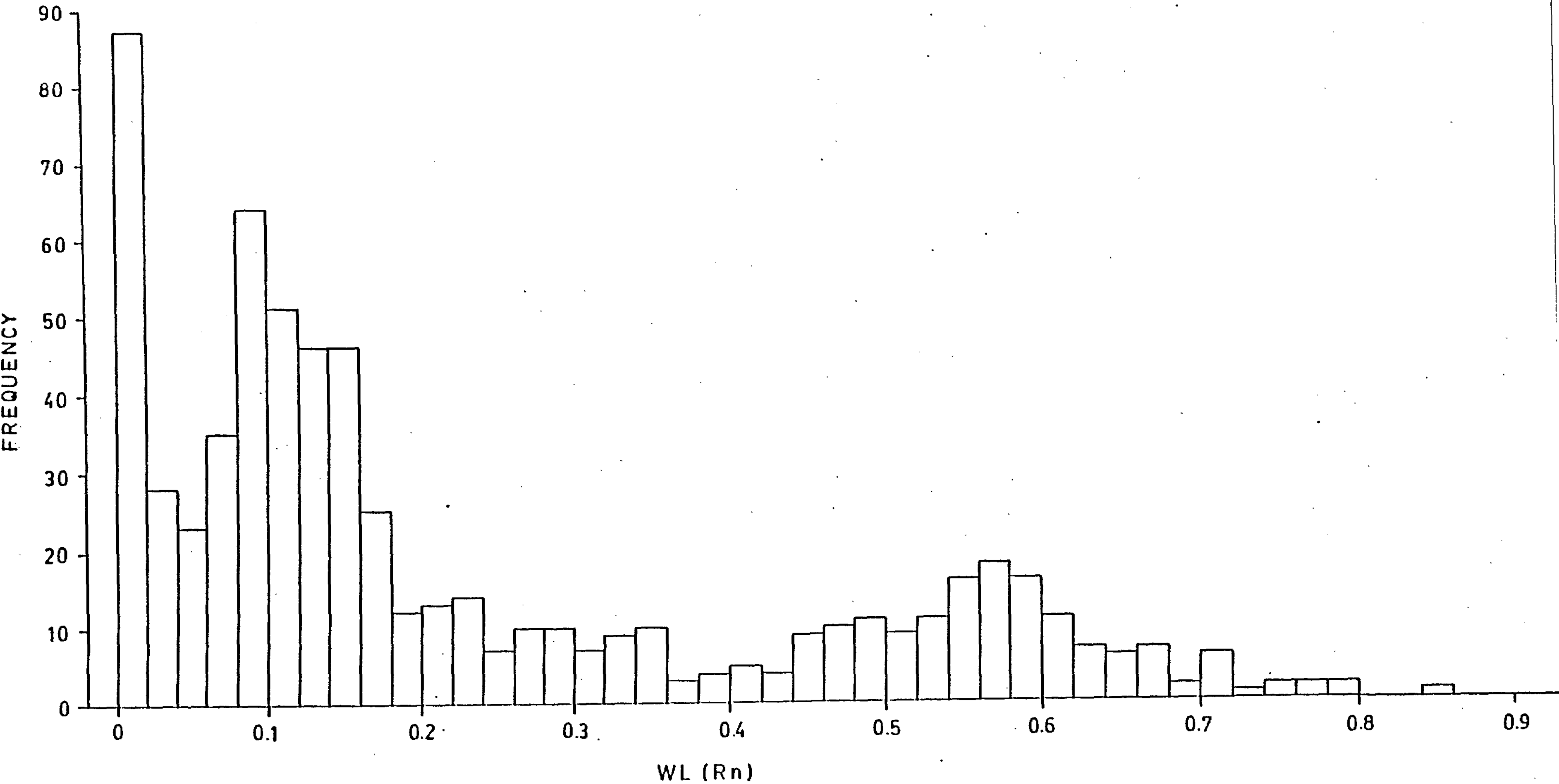

Fig. 1 - Radon progeny Working Level, WL(Rn), frequency distribution.

Figure 1

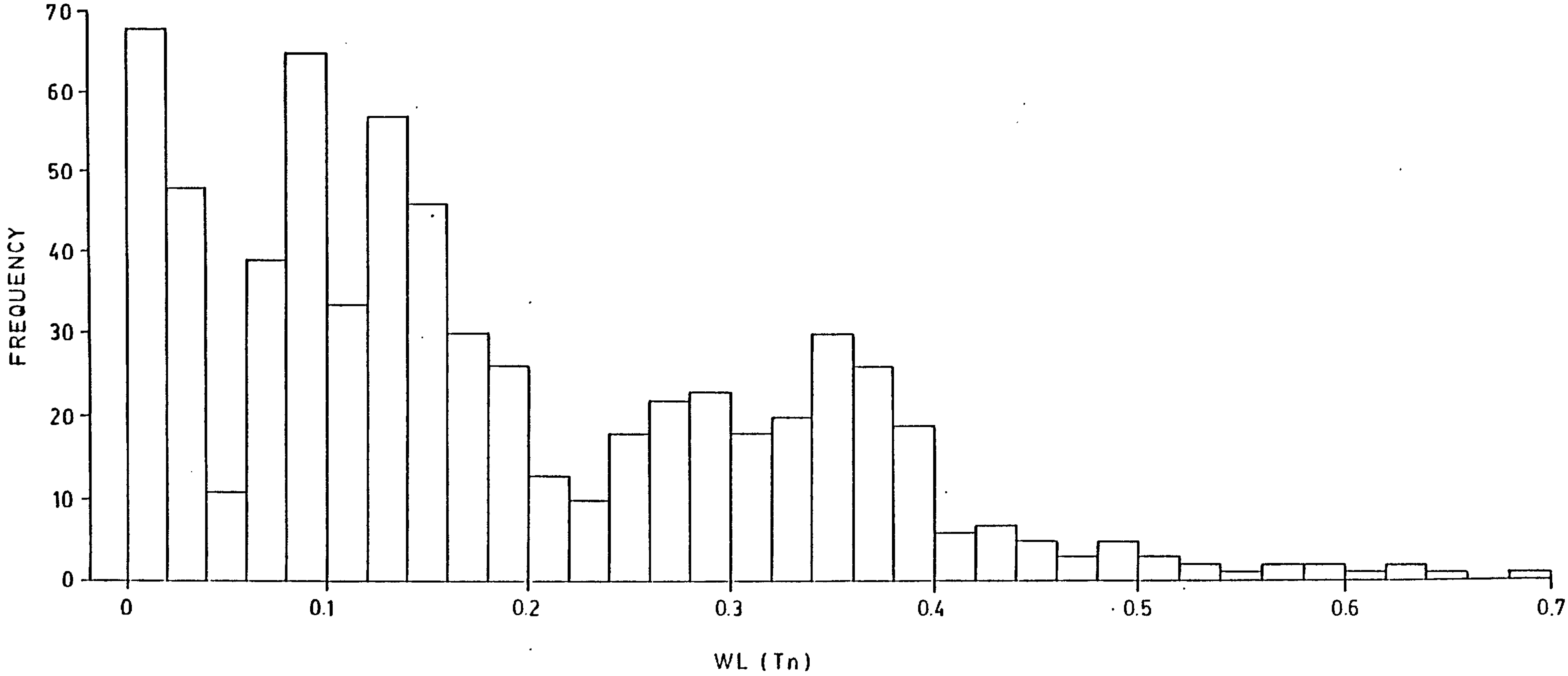

Fig. 2 - Thoron progeny Working Level, WL(Tn), frequency distribution.

Figure 2

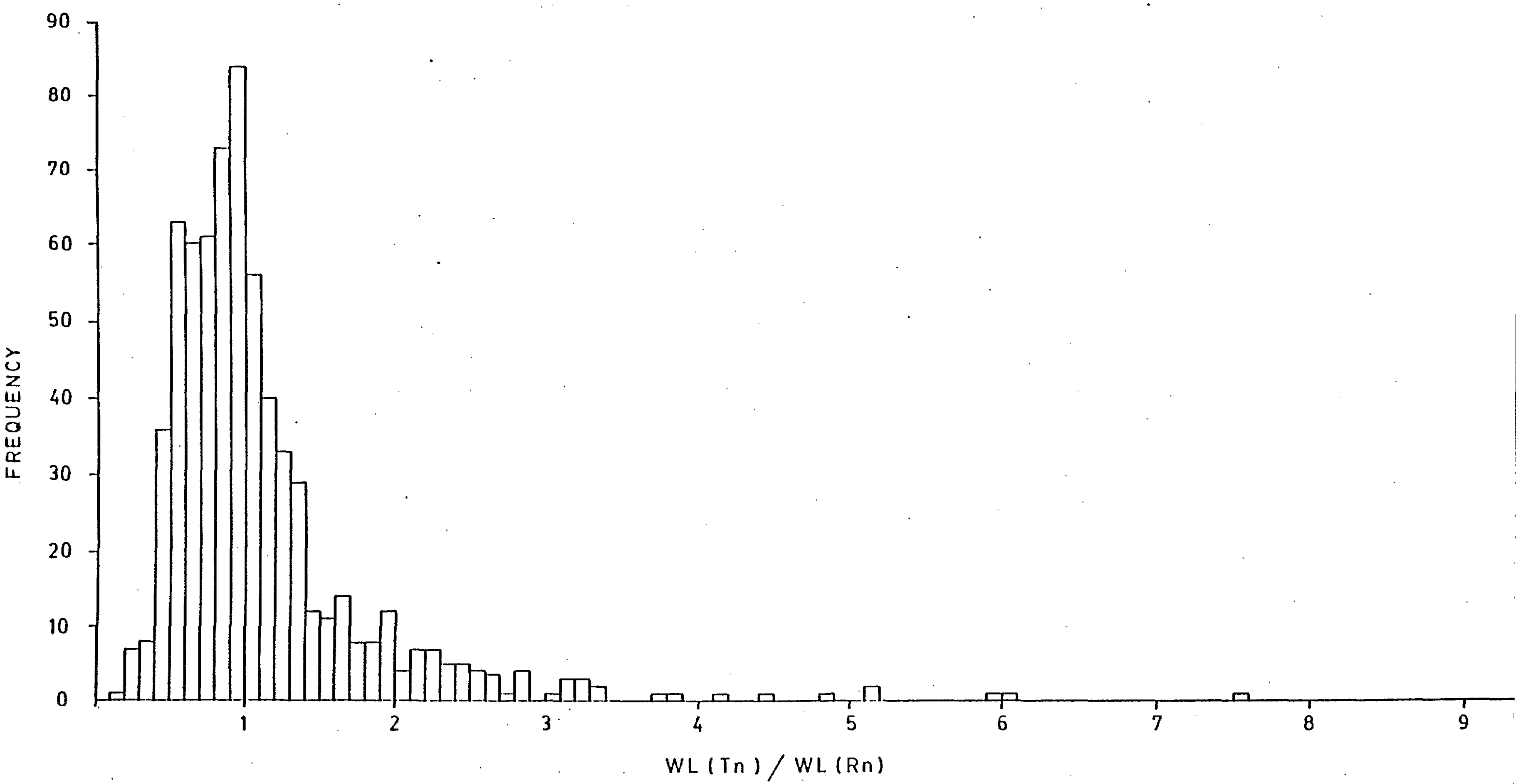

Fig. 3 - Thoron progeny Working Level to radon progeny Working Level ratio, WL(Tn)/WL(Rn), frequency distribution.

Figure 3

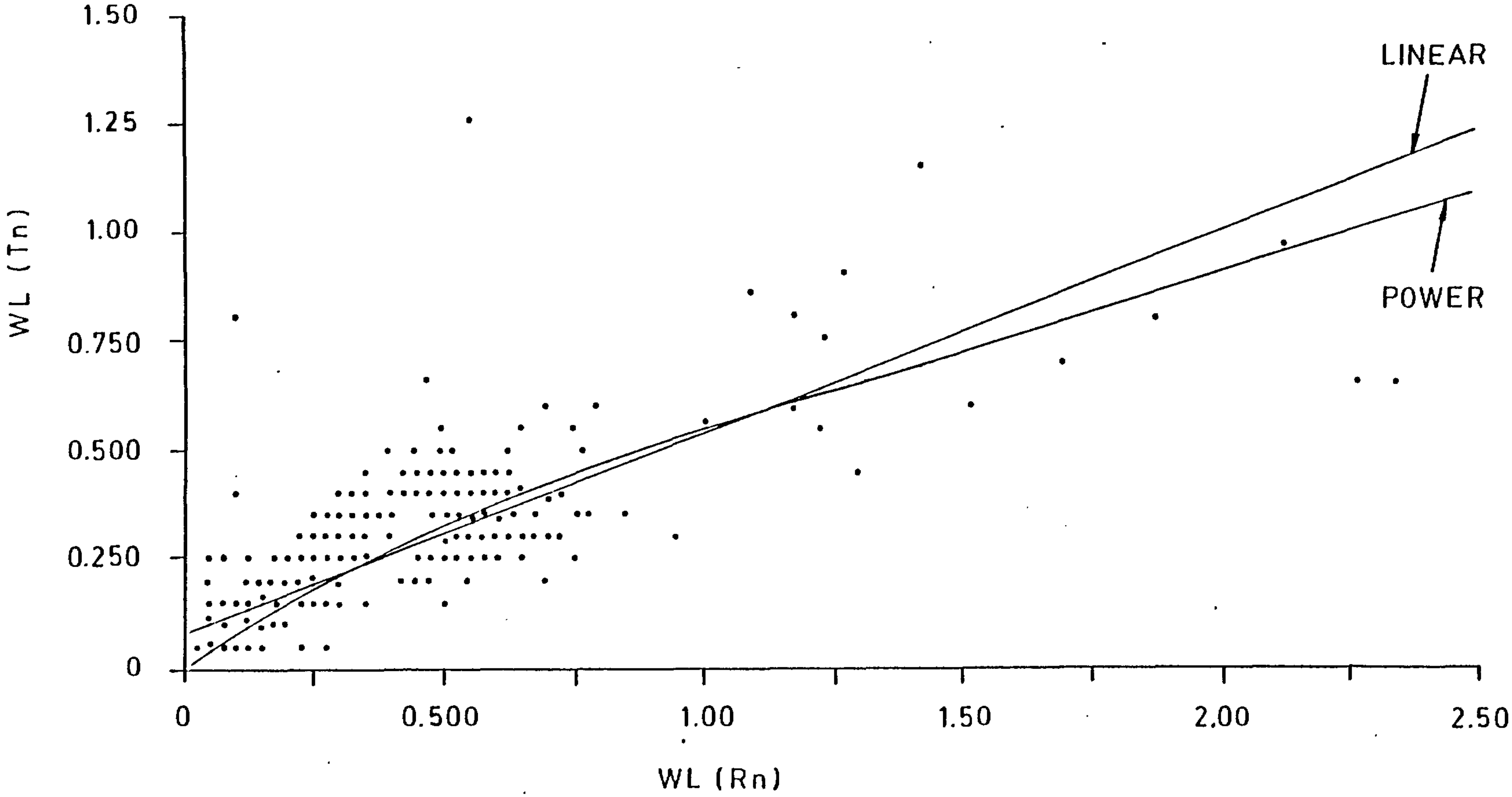

Fig. 4 - Thoron progeny Working Level, WL(Tn), versus radon progeny Working Level. WL(Rn). Dots represent experimental data. The curves represent best fitted linear and power functions by regression analysis.

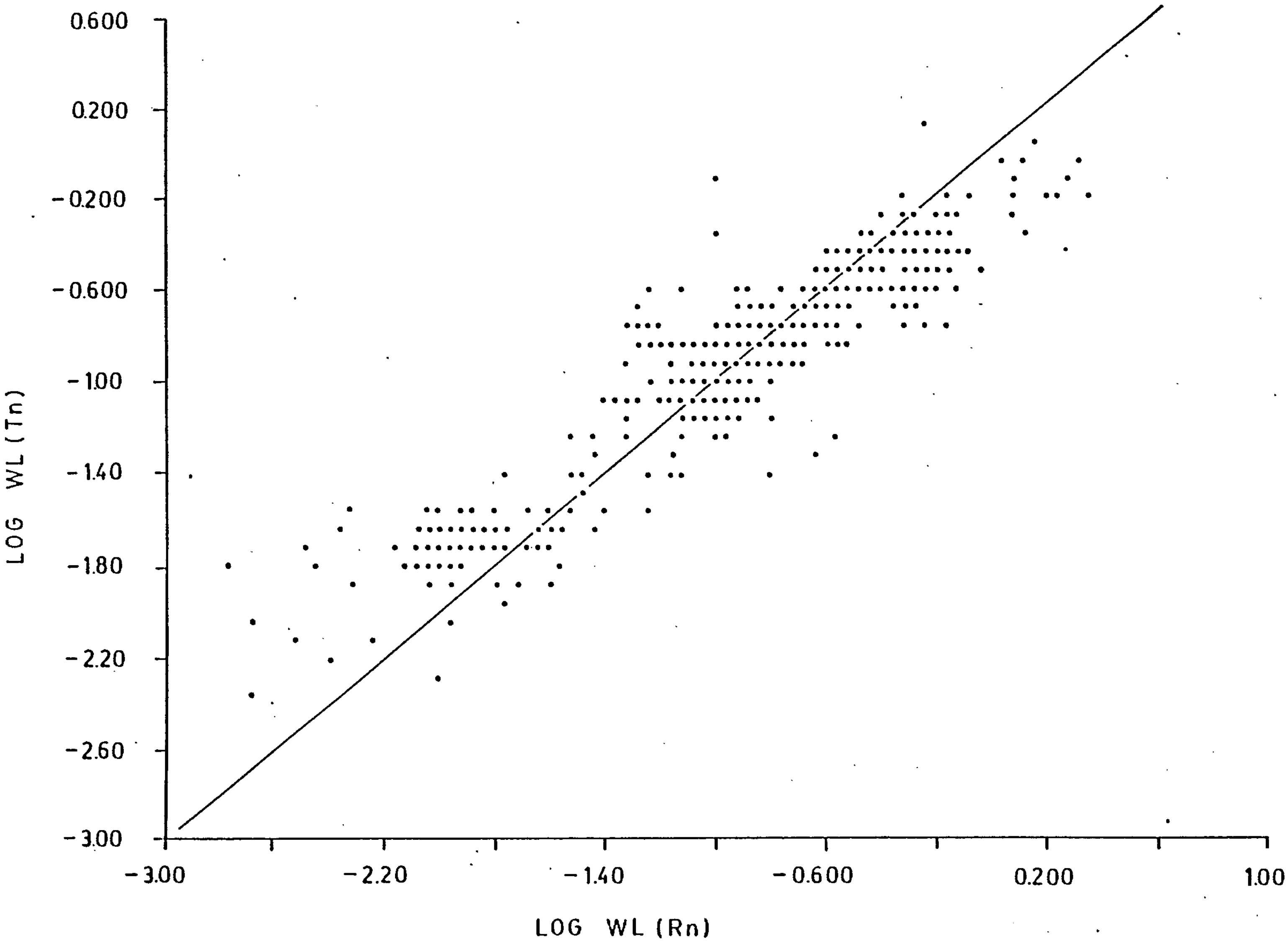

Fig. 5 - Thoron progeny Working Level, WL(Tn), versus radon progeny Working Level, WL(Rn). Dots represent experimental data. The straight line represents the best fitted power function by regression analysis.

Figure 5