



DISCUSSION OF PAPERS

DISCUSSION OF "Radon Distribution in Domestic Water of Texas," by Irena Cech, Charles Kreitler, Howard Prichard, Alfonso Holguin, and Mengistu Lemma, September-October 1988 issue, v. 26, no. 5, pp. 561-569

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The purpose of this letter is to present an alternative explanation for the variations in the ^{222}Rn content of natural ground water observed by the authors of the Texas study. The authors suggest that the higher concentrations of ^{222}Rn (i.e., >3000 pCi/l) are related to "external sources" involving the interaction of shallow ground water with deeper, radium-rich waters associated with leaky faults and salt domes. By means of a closed-system aquifer model, we can show that the entire range of ^{222}Rn values reported for Texas (i.e., a one-order-of-magnitude range) may result from normal variations in aquifer porosities (5 to 35%) and radon emanation rates (10 to 30%). Spatial trends in these two aquifer parameters may have led the authors of the Texas study to spurious correlations among the ground-water ^{222}Rn concentrations and the proposed "external sources." Previous studies show that variations in porosity and radon emanation rates must be understood before interpreting spatial trends in the ^{222}Rn contents of ground water observed within any aquifer system (Hess *et al.*, 1985; Rama and Moore, 1984; King *et al.*, 1982). The authors of the Texas ground-water survey do not compare their results with other radon studies. Consequently, they arrive at a singular interpretation which is inconsistent with previous research.

Investigations of the ^{222}Rn distribution in ground water show that the range of values found in nature covers five orders of magnitude (Hess *et al.*, 1985). Furthermore, studies have shown that the ^{222}Rn concentrations in ground water may vary by over one order of magnitude among closely spaced samples within the same aquifer (Lively and Morey, 1982; King *et al.*, 1982). Ambiguous correlations often result from attempts to relate variations in the ^{222}Rn concentrations of ground water directly to the presence of uranium and ^{226}Ra in the aquifer (Lively and Morey, 1982; King *et al.*, 1982). Clearly, factors other than the uranium and radium content of the aquifer influence the concentrations of ^{222}Rn in the ground water (Hess *et al.*, 1985). Experimental studies show these factors are related to the physical characteristics of the aquifer materials, such as emanation rates of ^{222}Rn and porosities (Rama and Moore, 1984). It is possible to examine the effects of these two parameters on the ^{222}Rn content of ground water using a simple closed-system aquifer model.

To evaluate the results of the Texas study, we have employed a closed-system model of a homogeneous aquifer,

excluding all external sources and sinks for ^{222}Rn . The model is defined by:

$$\text{Rn}(t) = \text{Rn}_0 e^{-\lambda t} + [\text{ERa}_s \rho_s (\frac{1-\theta}{\theta}) + \text{Ra}_w] [1 - e^{-\lambda t}] \quad (1)$$

where t is time; Rn is the ground-water concentration of ^{222}Rn in pCi/l; Rn_0 is the initial concentration of ^{222}Rn in pCi/l; λ is the decay constant for ^{222}Rn ; E is the fraction of ^{222}Rn emanated from the aquifer solids to the ground water; Ra_s is the solid concentration of ^{226}Ra in pCi/kg; ρ_s is the density of the aquifer solids in kg/l; θ is the aquifer porosity; and Ra_w is the ground-water concentration of ^{226}Ra in pCi/l. In about five half-lives of ^{222}Rn (or 20 days), the system is in equilibrium and the model becomes:

$$\text{Rn} = \text{ERa}_s \rho_s (\frac{1-\theta}{\theta}) + \text{Ra}_w \quad (2)$$

If two assumptions are valid, the equilibrium form of the model may be used to study the qualitative effects of emanation rate and porosity on ground-water ^{222}Rn concentrations. The first assumption is that the rate of ^{222}Rn migration is slow and continuous enough to reach equilibrium with its sources in the aquifer. This assumption is reasonable considering the slow rates of change in ground-water flow and radon diffusion relative to the half-life of ^{222}Rn . The second assumption is that ^{222}Rn emanation rates and ^{226}Ra concentrations are constant long enough for the system to reach equilibrium. Experiments show that ^{222}Rn emanation rates do remain constant long enough and that the rate of ^{226}Ra migration in an aquifer is slow enough for the ^{222}Rn to reach secular equilibrium with its parent (Rama and Moore, 1984; Krishnaswami *et al.*, 1982). Both the first and second assumptions are supported by a field study of the temporal variations of ^{226}Ra and ^{222}Rn in ground water (King *et al.*, 1982). In this study, four wells were sampled repeatedly over a period of two years. Essentially no variations in the ^{222}Rn or ^{226}Ra ground-water concentrations were observed. These studies suggest that aquifers achieve and maintain equilibrium over a period of years between ^{222}Rn and ^{226}Ra .

Assuming that such equilibrium is reached, it is possible to use the closed-system aquifer model to estimate ground-water ^{222}Rn concentrations. Table 1 presents estimates of ^{222}Rn ground-water concentrations determined for various emanation rates and porosities. To illustrate the effects of porosity and emanation rates, the values for the ^{226}Ra concentrations are held constant at 500 pCi/kg for solid ^{226}Ra and 1 pCi/l for dissolved ^{226}Ra . These fixed

Table 1. ^{222}Rn Concentrations in Ground Water (pCi/l) for Various Rn Emanation Rates and Aquifer Porosities

Radon emanation rate	Aquifer porosity					
	5%	10%	15%	20%	25%	30% 35%
10%	2520	1190	750	530	400	310 250
15%	3780	1790	1130	800	600	470 370
20%	5040	2390	1500	1060	800	620 490
25%	6300	2980	1880	1330	1000	770 620
30%	7560	3580	2250	1590	1190	930 740

values are consistent with the observed ranges of ^{238}U contained in common rocks and minerals (Turekian and Wedepohl, 1961) and ^{226}Ra ground-water concentrations (Hess *et al.*, 1985). Likewise, the density of the aquifer matrix is held constant at 2.65 kg/l which is equivalent to the density of quartz. For this demonstration, the emanation rates are varied from 10 to 30% which is comparable to the range of values observed in experiments by Rama and Moore (1984) and Andrews and Wood (1972) on aquifer materials. The aquifer porosity ranges from 5 to 35%, falling within the normal range of porosities for consolidated and unconsolidated rock aquifers.

The estimates generated by the model range from 250 to 7560 pCi/l of ^{222}Rn within the ground water. The model shows that a large range of ^{222}Rn concentrations are possible without *any* variation in the concentrations of ^{226}Ra . Certainly, variations in the ^{226}Ra concentrations do occur in the aquifers sampled in the Texas study. However, as shown by the closed-system model, minor variations in the ^{222}Rn emanation rate and porosity may obscure any changes in the ^{226}Ra content of the aquifers.

Using the model as a guide, it is interesting to review some of the correlations cited in the Texas study among ^{222}Rn concentrations and the proposed "external sources." In Figure 6 of the paper, a correlation is drawn between well depth and ^{222}Rn ground-water concentrations. The authors suggest that the correlation may be due to a greater interaction of the ground water with deeper, more radium-rich formations. Although many interpretations are possible, one alternative is that the deeper wells are screened within more compacted and therefore less porous aquifers. The closed-system model shows that a reduction in porosity would lead to higher concentrations of ^{222}Rn in the pore waters. If this is the case, there is no need to call for "external sources" of ^{222}Rn to explain higher concentrations at depth within the aquifer.

In Figure 8 of the paper, the ^{222}Rn ground-water concentrations appear to decrease with increasing distance from two salt domes. Although the authors state that the correlation is statistically significant, the extreme scatter in the plot shows that very little of the variation in the ^{222}Rn content of the ground water collected from these wells is explained by their distance from the salt domes. Nevertheless, the authors use the evidence in Figure 8 to suggest that salt domes may provide an "external source" of ^{222}Rn . Many other interpretations are possible. For example, if the geologic dip is away from the salt dome—a normal consequence of salt diapirism (Halbouty, 1979)—older, more lithified rocks are brought closer to the surface near the salt dome. As a result, wells in the vicinity of a salt dome may sample less porous aquifers than wells of similar depth at greater distances from the salt dome. The model shows that this reduction in porosity would cause an increase in the ^{222}Rn concentration of the ground water. In either case, the extreme scatter in the plot presented in the Texas paper suggests that the salt domes have little relation to the ^{222}Rn concentrations.

These examples illustrate the difficulty of interpreting variations in ^{222}Rn concentrations within an aquifer. Without knowledge of aquifer composition, porosity, and radon emanation rates, it may be impossible to predict the effects of other factors on the ^{222}Rn content of ground water. More importantly, previous research has found extreme local variations in ground-water Rn concentrations within

the same aquifer. This variability is consistent with a closed-system model and demonstrates that an otherwise usable aquifer need not be abandoned due to excessive ^{222}Rn levels at one location. Conversely, due to the natural variability of aquifer porosity, low levels of ^{222}Rn at one location provide no assurance of low levels in nearby wells drilled within the same aquifer. To understand and predict the distribution of radionuclides in ground water, future surveys must include analyses of aquifer composition and texture. We strongly urge the authors of the Texas study to consider such factors with regard to occurrence of ^{222}Rn within public-water supplies.

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REPLY TO THE preceding Discussion by Philip T. King and John A. Connor of "Radon Distribution in Domestic Water of Texas"

by Irina Cech and Charles Kreitler

The argument presented by King and Connor is not new. The opinion exists that there is enough radium within a few meters of a well to supply all radium and radon found in the ground water. If this is a widely accepted viewpoint, then it is important to emphasize that this may be one of those phenomena which are believed to be random simply because the reasons for their variations have not been adequately studied. These considerations led us in 1984 to begin gathering data on radium (^{226}Ra) and its progeny radon (^{222}Rn) in domestic water in Texas to better