RADON-222 MEASUREMENTS AT WAIRAKEI, BROADLANDS AND NGAWHA

N.E. Whitehead, Institute of Nuclear Sciences,
DSIR, Lower Hutt, New Zealand.

INTRODUCTION

The work reported here originally had its impetus in the paper of Axtman (1975) and comment aroused by it.

METHODS

The method used for estimation of radon is based on that of Kerr *et al.* (1962) as modified by Gregory (1976). It was designed for measuring radon in water, and is modified here to measure radon in steam.

At Wairakei, the bores selected were known to emit widely varying chemical compositions, and it was thought this might yield interesting information.

At Broadlands, as many bores as were open were sampled. In addition, analyses were performed on the water of the Waikato River.

The material emerging from the bores at Wairakei and Broadlands is a mixture of steam and water, and the water is separated from the steam in a cyclone separator. This water currently flows to waste, and might contain and release radon to the air. It was therefore analysed.

At Ngawha, samples were not collected from the bores which were very few in number, but from the hot springs only. Collection was done by G.L. Lyon of this Institute.

A final sample type was the stack gases at Wairakei. The separated gases from the condensed steam in the power station are mixed with air (about 1:2) and allowed to escape to the atmosphere through four stacks.

RESULTS

The results are shown in Tables 1-4. Figures are also calculated and tabulated from the data as reported by Robertson and Matthews (1978). The figures for carbon dioxide are from Lyon (personal communication).

The C-14 results are from Jansen (personal communication).

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DISCUSSION

Some attempt was made to judge the reproducibility of the method by the replicate sampling in the table. However, this assumes that the radon concentration in the bores does not vary. This may not be correct. Kruger and Umana (1975) quote sequential radon measurements on the bore of the Geysers field in California, and the Larderello field in Italy, as having a coefficient of variation of about ±10%. The same figure for the replicate samples here is 8.9%, which could mean that the reproducibility is limited by the fluctuations in the bores rather than the sampling method itself.

Most of the figures reported for the separated water samples, are not significantly greater than zero.

The results of analyses performed on variable dates show differences, but no clear trends emerge. Many more samples over many months would be required. This is different from the basis used by many authors. Direct comparison is hence difficult. However, D'Amore *et al.* (1977) quote figures in the range 7.8-161 nCi ℓ^{-1} and Belin (1959) for fumarole gases quotes 7-340 nCi ℓ^{-1}. Kruger and Umana (1975) give figures of a few nCi ℓ^{-1} for the Geysers field, and the figures for Larderello are 18-63 nCi ℓ^{-1}. Corresponding figures for New Zealand (not given in the table) would be 0.12-190 nCi ℓ^{-1} for Wairakei, and 1.3-11 nCi ℓ^{-1} for Broadlands. The main difference is some of the unusually low figures for low gas bores in the Wairakei field.

One immediate conclusion from the comparison of the separated waters at Broadlands with the bores is that the amount of radon remaining in the condensed water is usually negligible on comparison with the amount remaining in the gas phase.

Inspection of the figures for Wairakei shows that, in terms of the total discharge, the radon varies over four orders of magnitude, whereas Broadlands figures vary over one order of magnitude only. Why?

Semprini *et al.* (personal communication) sampled Wairakei for radon independently. Their results covered three orders of magnitude which suggests that the large variations amongst Wairakei bores may not be merely a function of sampling.

Normal and Spearman's rank correlation coefficients were calculated; the latterdo not depend on the form of the distribution. The results are given in Table 5.

Many correlations such as with mineral content were calculated for the Ngawha case, but the only significant ones were for the relationship with CO_2 and H_2S, which are tabulated.

It seems that there may be a negative correlation between C-14 and carbon dioxide. This suggests that they may have a different source. Carbon-14 would be expected to originate from the ground water reaching the system, but this means the carbon dioxide would come from much deeper. At least at Wairakei the implication is that the radon does also, because of its strong correlation with the carbon dioxide content. At both Wairakei and Broadlands the negative correlations between C-14 and radon again suggests that the radon does not chiefly originate from the ground water but from another source, again presumably the deeper levels. It is interesting to note that this conclusion was reached by D'Amore *et al.* (1975) who found a strong negative correlation between radiogenic argon (originating in ground water) and radon in the Larderello field.

Perhaps the most interesting conclusion from the correlations is seen in the correlations with carbon dioxide content of radon expressed as activity per litre of CO_2. The correlation is negative at Ngawha, negative (but possibly a zero correlation) at Broadlands and positive at Wairakei.

In the case of negative correlation, the interpretation must be that the radon does not originate from the same source as the carbon dioxide or hydrogen sulphide. This is quite a different situation from that at Wairakei. For the latter, CO_2 and radon are strongly linked in a positive way. It is possible that the radon at Ngawha originates from ground water or some other local source and is thereupon diluted with differing amounts of the carbon dioxide and hydrogen sulphide. Broadlands may be intermediate.

Another way of looking at this is to consider that at Ngawha the permeability may very likely be so poor that the radon decays before it reaches the surface, and so the local contribution dominates. Of course it should be remembered that the cases are rather different. At Ngawha surface gas was collected, but at Broadlands and Wairakei the gases came from deep bores.

Another interesting feature is the form of the data for Wairakei for the radioactivity per litre of CO_2 compared with the percentage CO_2 which shows a limit to the rate at which the radon and carbon dioxide can be generated at their formation site - perhaps basement greywackes.

The question of the origin of the radon in the geothermal field is of great interest. Material presented by Rich *et al.* (1977) is relevant here.

It has the consequence that uranium mobilisation is only in the last stages of activity in a geothermal area. This means that in an active geothermal field containing reducing substances (such as the hydrogen sulphide found at Wairakei and Broadlands), and at high temperatures, the uranium will not be mobilised, but will be retained in the host rocks.

Work of O'Connell and Kaufman (1976) shows that in geothermal waters U-238, U-234, Th-230, are generally in rough equilibrium. The major disequilibrium is between Th-230 and Ra-226, the latter being in excess. Mean concentrations in pCi ℓ^{-1} were: Rn-222 1170, Ra-226 24, U-238 3.6, Th-230 1.7, for more than 100 locations.

We conclude that the main source of Rn-222 is not Ra-226 in the water, but unmobilised radium.

The general lack of C-14 in the present samples suggests that the origin is mostly not local, but deeper.

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Table 1: Wairakei bores

Bore no.	Date	Rn-222 nCi kg^{-1} total H_2O	Ref. 11	nCi ℓ^{-1} CO_2	% CO_2 by weight	% modern C-14	Separated water nCi ℓ^{-1}
15	25/2/76	132.1±3.3	-	mean = 62±19	0.32	0.3	
15	1/10/76	70.6±0.5	-			"	
28	26/2/76	0.0175±0.0012	-	0.452±0.031	0.0076	0.8	
42	27/2/76	20.28±0.021	-	mean = 55.7 ± 2.6	0.068	0.7	
42	27/2/76	18.70±0.021	-			0.7	
42	28/7/78	18.79±0.10	-			0.7	
45	27/7/78	111.4±0.36	85.6	mean = 59±8	0.32	-	
45	27/7/78	83.15±0.34				-	
74	25/2/76	1.529±0.017	-	33.74±0.34	0.0089	0.75	
81	28/7/78	0.01729±0.00044	-	1.617±0.041	0.0021	3	
216	27/7/78	54.03±0.070	81.1	44.22±0.057	0.24		

Table 2: Broadlands bores

Bore no.	Date	Rn-222 nCi kg^{-1} total H_2O	Ref. 11	nCi ℓ^{-1} CO_2	% CO_2 by weight	% modern C-14	Separated water nCi ℓ^{-1}
8	29/9/76	1.09±0.034	-	0.446±0.015	0.56	0.3	
17	24/9/76	0.69±0.002	-	0.424±0.001	0.29	1.0	
18	24/9/76	1.341±0.067	-	0.1733±0.0087	1.53	0.4	
22	21/9/76						0.12±0.05
22	24/2/76	1.456±0.023	1.01	mean = 0.582±0.063			
22	28/9/76	0.617±0.053					0.0 ±0.07
22	28/9/76	1.492±0.064					0.04±0.08
22	26/9/76	2.568±0.91					
22	26/7/78	2.172±0.23					
23	24/9/76	0.739±0.075		0.246±0.025	0.63	0.7	0.0 ±0.02
25	30/9/76	0.390±0.049		0.113±0.014	1.31	1.0	0.07±0.09
27	22/9/76	1.97±0.05	1.76	0.1265±0.0032	3.1	0.5	0.04±0.04
28	22/9/76	1.97±0.08	-	0.387±0.015	1.29	0.6	0.41±0.05
28	30/9/76		-				0.14±0.09

Table 3: Sundry analyses

Bore no.	Date	nCi l^{-1}	Ref.11
Stack 1	26/ 2/76	13.4 ±0.3	
Stack 2	1/10/76	6.17 ±0.05	
Stack 3	"	4.18 ±0.06	
Stack 4	"	9.84 ±0.11	
Stack 1	27/ 7/78	7.56 ±0.06	8.3
Outlet	26/ 2/76	6.71 ±0.04	
Waikato	27/ 2/76	<0.28	
Outlet	24/ 9/76	0.02 ±0.02	
Outlet	24/ 9/76	0.008±0.05	
Outlet	27/ 9/76	0.298±0.086	
Outlet	29/ 9/76	0.07 ±0.07	
Outlet	29/ 9/76	0.254±0.06	
Stream	25/ 9/76	0.0 ±0.05	
Steam above stream	"	0.007±0.02	

Table 4: Ngawha Hot Springs

Site	Date	nCi $\ell^{-1} CO_2$	% CO_2
Favourite	30/6/77	0.76 ±0.10	55.3
Waitotara	29/6/77	2.02 ±0.25	71.0
Soda Spring sulphur lake	29/6/77	0.776±0.098	49.9
Tiger Bath	29/6/77	0.073±0.047	73.2
Velvet (spa)	30/6/77	14.3 ±1.1	87.4
Maori Well	29/6/77	2.48 ±0.15	48.8
Soda Spring L.Omapere	28/6/77	4.22 ±0.49	67.9
Jubilee	29/6/77	1.37 ±0.11	84.7
Velvet(domain)	27/6/77	3.46 ±0.22	44.5

Table 5.

Correlation between		Site	r	Probability of no correlation	Spearman correlation; sign and probability of no correlation	
CO_2/H_2O	C-14	Wairakei	-0.49	0.18	-	< 0.01
Rn/H_2O	CO_2	"	0.993	7.6×10^{-6}	+	0.05
Rn/H_2O	C-14	"	-0.54	0.18	-	0.05
Rn/CO_2	CO_2 %	"	-0.16	0.37	+	0.02
CO_2/H_2O	C-14	Broadlands	-0.30	0.24	-	> 0.05
Rn/H_2O	CO_2 %	"	0.35	0.20	+	> 0.05
Rn/H_2O	C-14	"	-0.71	0.046	-	0.05
Rn/CO_2	CO_2	"	-0.65	0.086	-	0.05-0.10
Rn/CO_2	CO_2	Ngawha	-0.173	0.35	-	< 0.05
Rn/CO_2	H_2S	"	-0.54	0.087	-	< 0.01