CROSS SECTION OF RADON CONCENTRATION AT WAIRAKEI

Roland N. Home, University of Auckland, and
Paul Kruger, Stanford University

The radioactive gas radon ^{222}Rn is produced naturally within the earth's crust by the decay of radium 226. ^{226}Ra is itself a daughter product of uranium, but constitutes the major source of radioactivity in the lithosphere (Cadigan and Felmlee 1977). In a static hydrothermal situation the ^{222}Rn would be in radioactive equilibrium with ita parent ^{226}Ra; however experiments in active geothermal areas and hot springs have shown concentrations of radon greatly in excess of radium equilibrium (Grigg and Rogers 1929). Clearly radon is mobilised by recoil and diffusion into the fluid within the rock (Andrews and Wood 1972) and may be collected throughout a volume of reservoir by fluid movement. The moving fluid will gain radon from the rock it passes but will also lose it again due to radioactive decay. The 3.83 day half life of ^{222}Rn makes it a useful indicator of fluid movements, and Warren and Kruger (1978) have suggested the measurement of radon on cross-sections of geothermal fields to observe the distribution of steam "age".

The collection of radon samples in geothermal regions is not new, and measurements have been made in many places in the world (see for example, Belin (1959), Stoker and Kruger (1975), D'Amore, Sabroux and Zettwoog (1978)), including Wairakei (Whitehead 1979). The samples taken in the present study were collected and analysed using a method based on that of Stoker and Kruger (1975). Steam samples were tapped from the downstream side of the separator and collected in evacuated 4.7 litre steel bottles. The bottles were then shipped to the laboratory at Stanford University where the non-condensible gases were stripped from the bottle and the radon separated on to activated charcoal at -80°C. The radon was subsequently liberated at a temperature 350 C and its alpha activity counted using a ZnS alpha scintillation detector flask and photomultipliea. It was determined during the time between the two sets of samples that the standard deviation of a single measurement (calibrated against a NBS radium standard) could be reduced from 7% to 1% if a larger sample were taken. Consequently for the second set of samples a condensing system was used for collection (see figure 1) which resulted in a much greater quantity of gas being taken into the bottles. In each of the two series, samples were taken as quickly as possible to avoid the effecrs of time variation in radon concentration.

In order to obtain a sensible cross-section, the wells along the Waiora fault were selected as representing an identifiable geological structure along which radon concentrations might be expected to vary in a predictable manner. The radon concentration will vary due to a number of influences, but the most Important of these are (1) fluid properties (2) fluid movement and (3) decay. The rate of accumulation P(nCi/kg/hr) of radon depends on fluid density (D'Amore et Sabroux. 1976)

$$P = \frac{\rho_r E}{\rho_f \phi} \qquad (1)$$

where E is the emanating power of the rock (nCi/kg/hr), ρ_r and ρ_f are the densities of the rock and the fluid and ϕ is the porosity. As a consequence, steam or gas will have a higher concentration of radon than water. Considering the fluid movement and decay of radon, the radon concentration as a function of distance may be derived, assuming "pipe" flow

$$C = C_o e^{-\frac{\lambda x}{u}} + \frac{P}{\lambda}\left(1-e^{-\frac{\lambda x}{u}}\right) \quad (2)$$

where λ is the decay constant, u is the speed of flow and x is the distance moved. From this equation it may be seen that the concentration will be C_o for small x (or large u), and P/λ for large x (or small u). Thus the concentration may either increase or decrease with distance, depending on the relative magnitudes of C_o and P/λ. With typical values of E 5×10^{-4} nCi/kg/hr and ρ_r 2×10^3 kg/m^3 one obtains for steam ($\rho_s = 0.01\times10^3$ kg/m^3 at saturated conditions at 220°C) P/X = 132 nCi/kg and for water ($\rho_w = 0.84\times10^3$ kg/m^3) P/X = 1.57 nCi/kg. These values may vary somewhat as the emanating power of the rock is a variable parameter (λ however is fixed at 7.553×10^{-3}/hr). However under the same conditions the equilibrium concentration in steam. should be about 84 times that in water. The concentration may be less than that for water if there is dilution due to the mixing in of fresh ground water (which contains no radon); however it cannot rise above the steam equilibrium concentration unless there is some additional enrichment such as might be caused by the preferential association with CO_2. So, for example, at Wairakei a high enthalpy well such as WK15 has a radon concentration of about 100 nCi/kg of condensate (Whitehead 1979) whereas lower enthalpy wells such as WK71 have a much lower concentration around 1 nCi/kg of condensate. The lower figure becomes still lower when expressed per kg of reservoir fluid. There may be effects of CO_2 enrichment - for example Whitehead's figures for well 45 which showed a concentration 111 nCi/kg when the CO_2 content was 0.32% and 83 NCi/kg when it was 0.0089% (on the same day). This effect may be overemphasised as the effect of CO_2 would be to increase the steam fraction in the reservoir fluid. A8 a counter example Broadlands shows much lower (and more uniform) radon concentrations of order 5 nCi/kg (Whitehead 1979) despite high concentrations of CO_2 (0.5 - 3%).

The results of the current sampling series may be summarised in two cross-sections, those along the Waiora fault (Table 1) and those perpendicular (Table 2). A map of the field is shown in figure 2.

Table 1. Samples along Waiora fault (SW to NE)

Well	Date	Rn(nCi/kg)	Enthalpy	% CO_2(molar)
86	7.3.79	3.4	1209kJ/kg	0.024
46	4.5.79	4.2	1026	0.003
a3	4.5.79	2.5	1009	0.005
72	4.5.79	69	1519	0.03
30	4.5.79	0.85	982	0.0007
71	4.5.79	0.95	956	0.001
70	30.8.79		1098	0.006
68	30.8.79		1033	0.002
67	31.8.79		979	0.001
27	31.8.79		1037	0.002
81	31.8.79		984	0.001
55	31.8.79		1003	0.001

Table 2 Samples across Waiora fault (Northwards)

Well	Date	Rn(nCi/kg)	Enthalpy	% CO_2(molar)
70	30.8.79		1098kJ/kg	0.006
108	31.8.79		1023	0.013
76	31.8.79		989	0.002
80	7.3.79	139	1426	0.056
80	31.8.79		1426	0.056

In the main the Waiora fault shows low concentrations of radon while wellr outside show higher values. There is a decreasing trend from well 86 at one end of the fault towards 71 in the middle. Well 72 ha6 a high radon concentration compaoed to this trend; however this is attributable to its high enthalpy and CO_2 content. Considering the relatively high CO_2 content of well 86 it can be seen that in fact its radon concentration is rather lower than that of neighbourlng 46. Well 28 is further SW along the Waiora fault from 86 and was sampled for radon by Whitehead, showing a concentration of **only 0.149lnCi/kg.** Indications are then that wells 28, 71 and 30 produce from liquid coaditions (downhole pressure > 26 bars) while wells 86, 46, 83 and 72 have two-phase conditionr in the formation. A quick calculation of the parameter group x/u provides an estimate of the ratio V/Q – the volume of rteam in the reservoir over the volume flow rate (of steam) from the well. This ratio is a measure of the length of time it would take a particle of fluid to travel from the boiling front to the well. Values for wells 83, 46 and 86 are 1.5, 3.3 and 24 hours respectively, while for well 72 the value is 6.1 hourr. It is not so simple to determine the actual volumes involved without evaluating the in place steam quality. However as an upper bound (using well head quality) the tuo-phase zone would have a radius of about 30 meters from the well if the flow were rpherical.

In conclusion, the measurement of radon concentration can provide a useful diagnostic for the purpose of reservoir monitoring. Although the enthalpy of the produced fluid is an indicator of two-phase conditions in the reservoir, it is not always directly correlated with the volume over which the two-phare conditions exist. The measurement of radon concentration provider an estimate of the distance travelled mince vaporisation and can therefore provide a rough estimate of reservoir permeability - a low enthalpy well with unusually high radon concentration can be interpreted as drawing vapour from some distance and therefore having higher than average permeability or a small but long and highly conductive path for flow. The radon concentration can isolate the difference between two wells of the same effective permeability one of which ha8 matrix permeability and one of which har fracture permeability.

In the long term the monitoring of radon concentrations is an indicator of the extension of two phase conditionr in the reservoir, regardless of whether or not the enthalpy alao changer. It is therefore recommended that systematic measurements be made from the early production testing stages of development in future field. There is an ideal opportunity to do this along with the firrt discharges at Ngawha,

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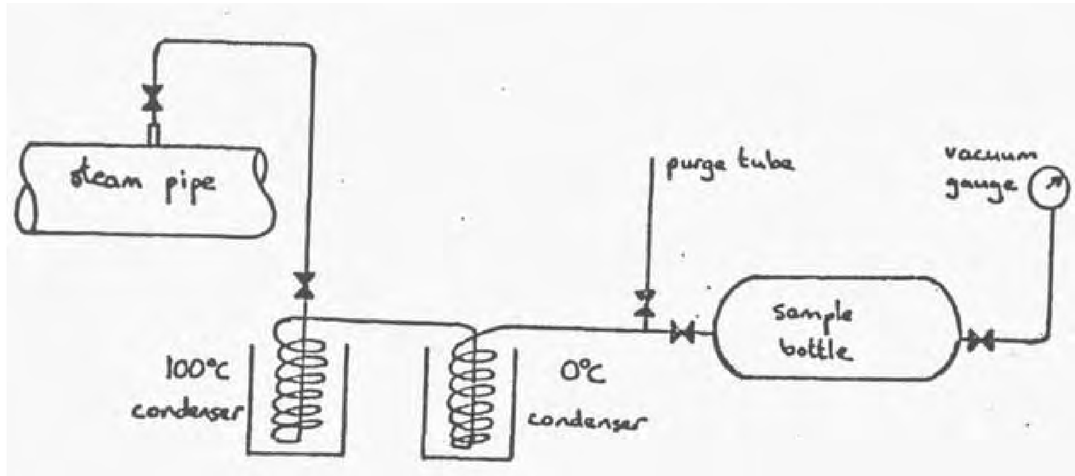

Figure 1: Schematic of collection system

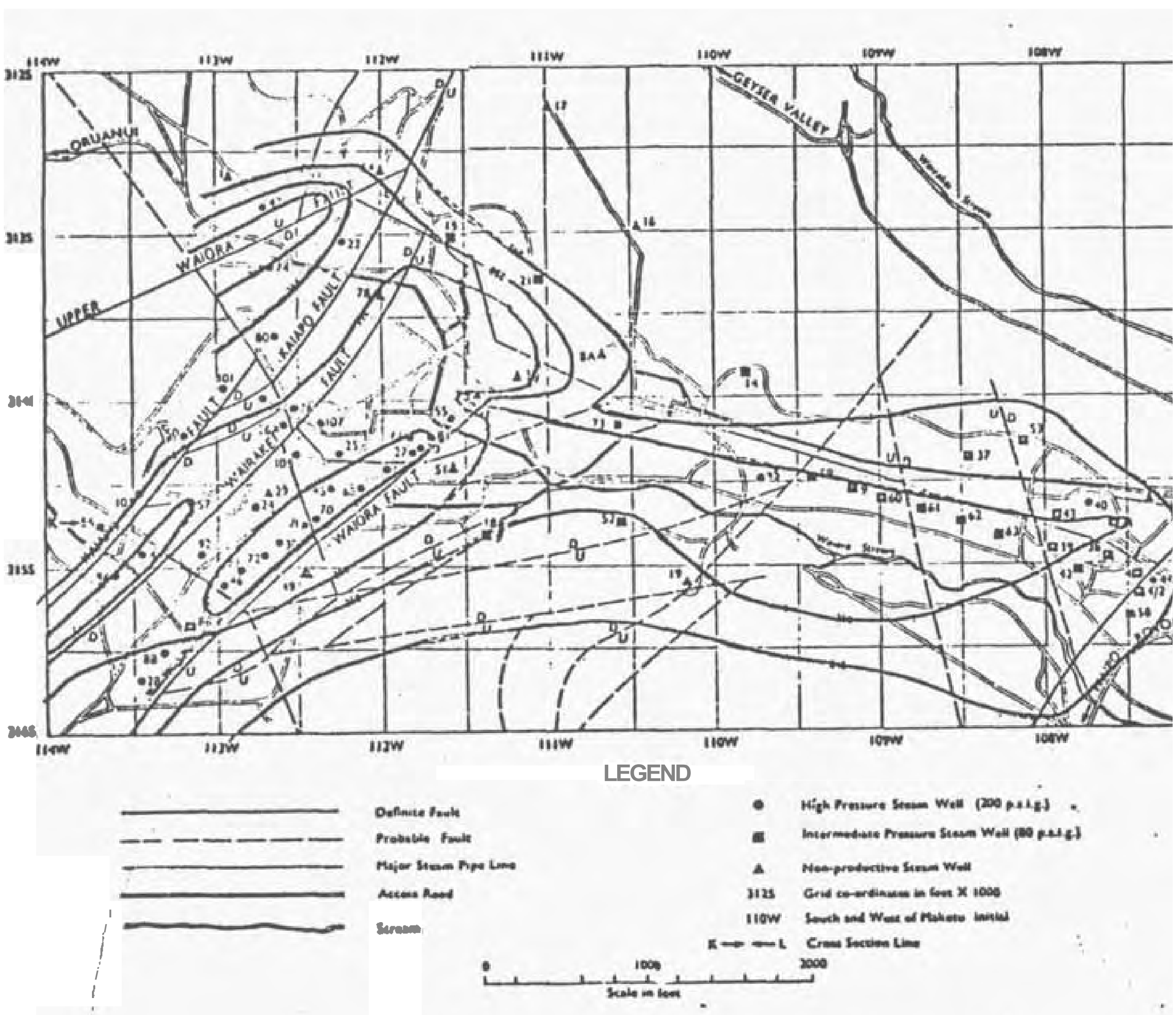

Figure 2: Map of Wairakei