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The Correlation between Radon Emission Concentration and Subsurface Geological Condition

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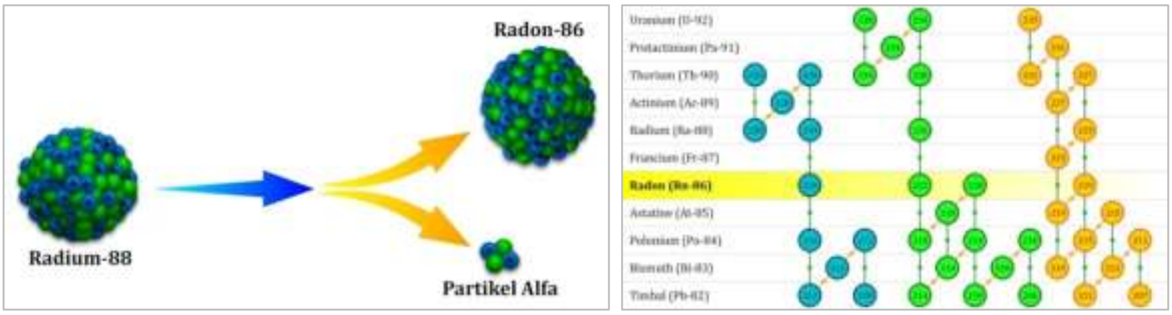
Abstract. Exploration activities with standard methods have already encountered many obstacles in the field. Geological survey is often difficult to find outcrop because they are covered by vegetation, alluvial layer or as a result of urban development and housing. Seismic method requires a large expense and licensing in the use of dynamite is complicated. Method of gravity requires the operator to go back (looping) to the starting point. Given some of these constraints, therefore it needs a solution in the form of new method that can work more efficiently with less cost. Several studies in various countries have shown a correlation between the presence of hydrocarbons and Radon gas concentration in the earth surface. By utilizing the properties of Radon that can migrate to the surface, the value of Radon concentration in the surface is suggested to provide information about the subsurface structure condition. Radon is the only radioactive substance that gas-phased at atmospheric temperature. It is very abundant in the earth mantle. The vast differences of temperatures and pressures between the mantle and the earth crust cause the convection flow toward earth surface. Radon in gas phase will be carried by convection flow to the surface. The quantity of convection currents depend on the porosity and permeability of rocks where Radon travels within, so that Radon concentration in the earth surface delineates the porosity and permeability of subsurface rock layers. Some measurements were carried out at several locations with various subsurface geological conditions, including proven oil fields, proven geothermal field, and frontier area as a comparison. These measurements show that the average and the background concentration threshold in the proven oil field (11,200 Bq/m^3) and proven geothermal field (7,820 Bq/m^3) is much higher than the quantity in frontier area (329 and 1,620 Bq/m^3). Radon concentration in the earth surface is correlated with the presence of geological faults. Peak concentrations of Radon takes place along the fault.

1. Passive Soil Radon Method

Radon is the only radioactive substance that gas-phased at atmospheric temperature. Radon has the atomic number 86 and is the result of the decay of Radium. Radium emits alpha rays along with the release of energy thus two protons and two neutrons will be lost. These events generate Radon particles and cause the change of phase from solid into gas.



(a) (b)

Figure 1. (a) Radium decays into Radon. (b) Radioactive decay chain

In the chain of decays, Radon can be formed by three main rows (series) of radioactive decay, namely Uranium series producing Radon-222 and Radon-218, Thorium series that produces Radon-220 (called Thoron) and Actinium series which produces Radon-219 (called Actinon). The concentration of the radioactive substance, in this case Radon, expressed in radioactivity per unit volume in units of Becquerel per meter cubic (Bq/m^3). Unit of Becquerel states the number of decays per unit time (count of decay per second). Thus the unit of Bq/m^3 has meaning the number of Radon gas atoms decay every second in a meter cubic of air volume. Other standard unit which is often used is Currie per liter (Ci/l). 1 Ci radioactivity is comparable to 37 Mega Bq.

Radon with mass number of 222 is the most stable isotope of Radon in nature. This isotope has a half-life of 3.8 days. In addition to Radon-222, there are at least 17 isotopes of radon gas found, which altogether have a very short half-life. Of the overall Radon isotope, Radon-222 is considered the most appropriate for the research with Passive Soil Radon method. On the periodic table of elements, Radon is classified in the category of noble gas, namely a gas which has a stable number of valence electrons (8 electrons in the outermost orbit) thus not combined with other particles, even with fellow Radon atoms.

1.1. Radon in Nature

Radioactive is the biggest contributor of earth heat. 50% of heat in the core of the earth comes from the energy produced in the decay of a radioactive substance activity. The existences of radioactive materials are abundant in the Earth mantle. In addition to surface through volcanic activity, Radon gas from the Earth mantle also moves through rock pores. Some Radon atoms are stuck together with oil and gas in the hydrocarbon trap, so it is believed that hydrocarbon reservoirs have high radioactive content.

Radon is the heaviest gas atom on the periodic table of elements, thus to move against the direction of gravitational force it needs external force. The main factor that helped Radon moves toward earth surface is the difference of Radon gas concentrations causing the radon gas transports (diffusion) and pressure from the center of the earth due to the high temperatures and pressures in the direction of the earth surface (convection flow). Radon migration process caused by convection flow is more dominant than the diffusion process.

Radon movement to the surface is strongly influenced by the media went through. Radon will be concentrated higher on media easily passed, namely a media with high porosity and permeability, and will be concentrated lower in media with low porosity and permeability. Through the mechanism of diffusion, Radon gasses in the rocks have a low transport speed, a maximum of only 155cm.

Table 1. Average distance of Radon and Thoron diffusion (Tanner, 1964).

Media	Average distance (Radon)	Average distance (Thoron)	Diffusion Coeff. (cm^2/s)
Air	220	2,8	10-1
Porous soil	155	2	5 x 10-2
Water	2	0,03	10-5
Saturated porous soil	1,55	0,02	5 x 10-6
Dry sand	160	2	5 x 10-2
Dry porous soil	155	2	5 x 10-2

Some carrier gas in the process of convection are CO_2, NO_X and SO_X. With the high temperature and pressure below the surface, CO_2 gas of combustion in the Earth mantle is pumped to the surface of the earth. Migration of CO_2 gas will be the convection currents for Radon atom to get to the surface.

2. Results Of The Previous Study

2.1. Application of Radon Detection Method
Radon gas detection method has been widely applied. Some of them are:

- Characterizing SGD (Submarine Groundwater Discharge).
- Preliminary exploration for Uranium prospecting.
- Exploration of geothermal.
- Early detection of earthquakes (Japan).

In the case of early detection of earthquakes, anomalous Radon concentration occurs a few days before an earthquake. This proves that changes in subsurface structure affect the value of Radon concentrations in the surface.

2.2. Phenomena of NORM in Oil and Gas
An interesting fact from the discovery of NORM (Naturally Occurring Radioactive Materials) in oil and gas has been found by researchers. The emergence of the value of radioactive concentration (Radon) in the oil well higher than the background concentration was first reported by Himstedt and Burton. In 1920 to 1930, the presence of NORM in the oil and gas also appeared in a number of scientific papers in Russia and Germany.

J.E Tilsley and P. R. J. Nichols (1991) stated that the tests of the 13 samples from field in South Wellcheburg, Ontario (3 gas fields and 10 oil fields) shows a strong correlation between the accumulation of radioactive gases with hydrocarbon deposit. The study was conducted by calculating the decay of Radium of soil samples taken.

A year later, the mapping of the concentration of Radon-222 gas conducted by Lu Zuhui using passive method in the area of Webei Hollow and Saihantal Hollow, Sangdong shows that there is the presence of suitability between Radon gas anomaly and hydrocarbon deposits. In 2001, a study from Al-Tamimi and Abu Murad succeeded in proving that the Radon concentrations near fault is much higher than background concentration.

The activities above lead to temporary conclusion that oil and gas field has a higher background concentration than frontier area. This is in line with the conclusions of the study conducted by Liu Zhi et. al. (1993) and David (2005). Based on the assessment of the theory, hypothesis developed later is: Radon concentration on the surface characterizing the structure and characteristics of the material underneath.

3. Methodology

The main instrument in the research entitled Implementation of Passive Soil Radon Method is the detectors of Radon, RAD7. RAD7 is a digital radioactive counter instrument based on “Geiger Muller counter”. RAD7 instrument detects radon gas by capturing the entire alpha particles sucked out of the ground. Alpha particle is then detected by a Geiger Muller counter and sorted based on the energy carried by the alpha particles. At the time of Radon-222 atom decays to Polonium-218, it will be accompanied by the release of alpha particles that carry energy of 5.59 MeV. While on detecting Thoron, Radon-220 decays become Polonium-216 along with the release of alpha particles with an energy of about 6.4 MeV.

4. Data and Discussion

This activity is comprised of several data collection stages undertaken in different place under different geological conditions.

4.1. Frontier Area 1 (Kalimantan) and 2 (Sumatera)

The frontier area 1 has not been widely explored. There are limited data on both geological and geophysical subsurface. Radon measurement was conducted with a route along provincial highways from the west to the east and several tracks of smaller roads in the north and south of the main route. There is a total of 181 measurement points, in which the interval between the points varies between 1 and 4 km. The value and position of those measurement points if plotted will constitute a contour map as shown in figure 2(a). The average concentration of the entire observation points above is 3,320 Bq/m^3 and the highest concentration is 53,000 Bq/m^3.

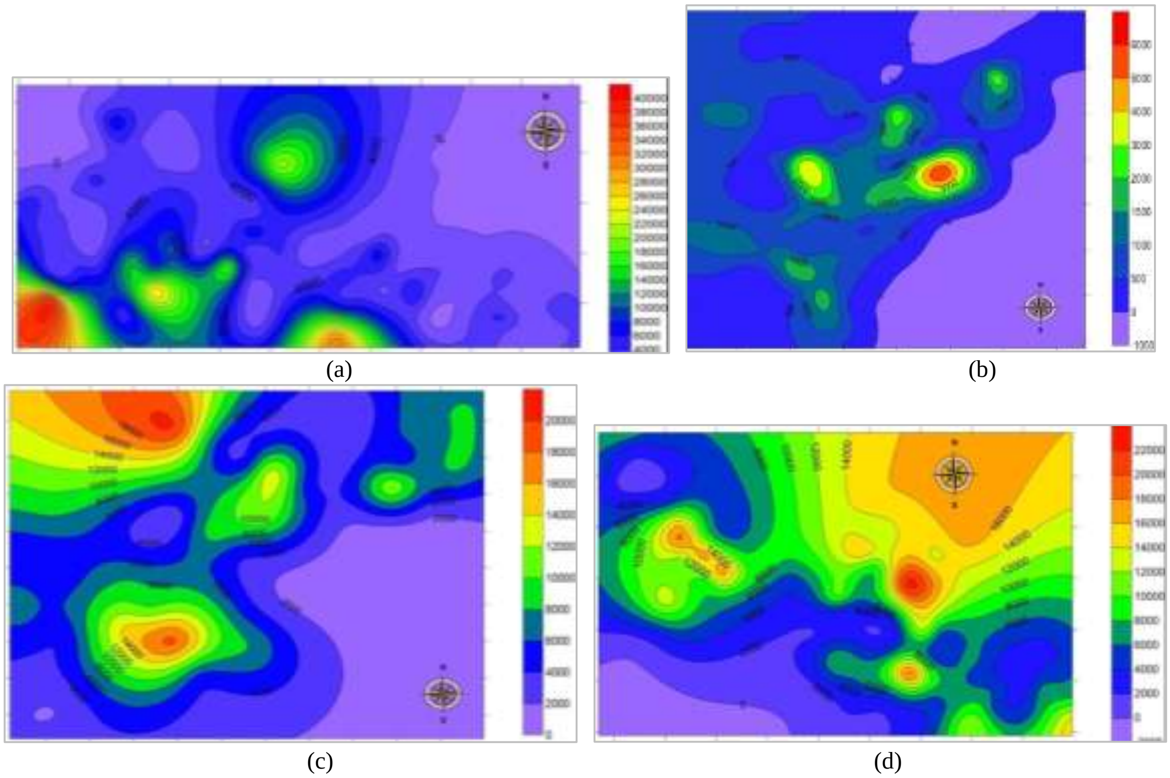


Figure 2. The contour map illustrating Radon concentration in (a, b) frontier area, (c) geothermal and (d) oil field.

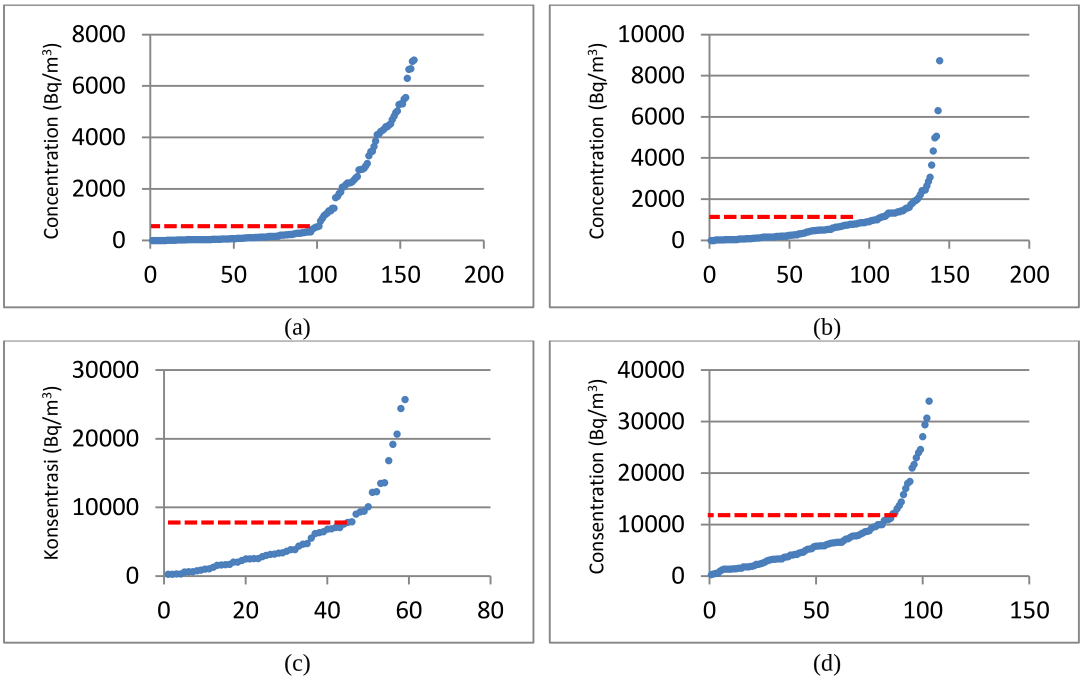


Figure 3. Normal probability plot of (a, b) frontier area, (c) geothermal manifestation and (d) oil field.

This frontier area 1 is swampland covered with soils several decades ago. Both geological and geophysical data for the area remain unavailable. Soils at a depth of more than 50 cm have very high water content. Thus, measurement can be performed only at a maximum depth of 30 cm. It was done in 144 points. It took a grid form with a 2-km interval between the points. A contour map from plotting the Radon data of the area is presented in figure 2(b). Result of the field measurement on Radon concentration indicates that the highest value is 8,740 Bq/m^3 while the average value is 900 Bq/m^3.

4.2. Geothermal Manifestation Area, Sumatera

The province is rich in geothermal potential. Radon measurement carried out here aims to examine the existence of grabens. The Radon measurement in this area was undertaken in 59 points. Such measurement generates a contour map as presented in figure 2(c). Result of Radon measurement in this area generates data with a quite high average value by 5,880 Bq/m^3 and the highest value by 25,700 Bq/m^3.

4.3. Geothermal Well

The chosen area is a geothermal field that has been producing. The Radon measurement was conducted around the operating geothermal production and injection wells. The purpose of selecting the location is to confirm and to test the hypothesis that the geothermal reservoir has a great energy to produce the convection flow that bring the Radon to the surface. In order to test the hypothesis, the measurement was conducted in 6 location points, they were 2 production wells, 2 injection wells, and 2 abandoned geothermal wells. The results of Radon Measurement on the location obtained the highest value of 89.000 Bq/m^3 in production well 2. Those 6 location points generated the data as shown in figure 4.

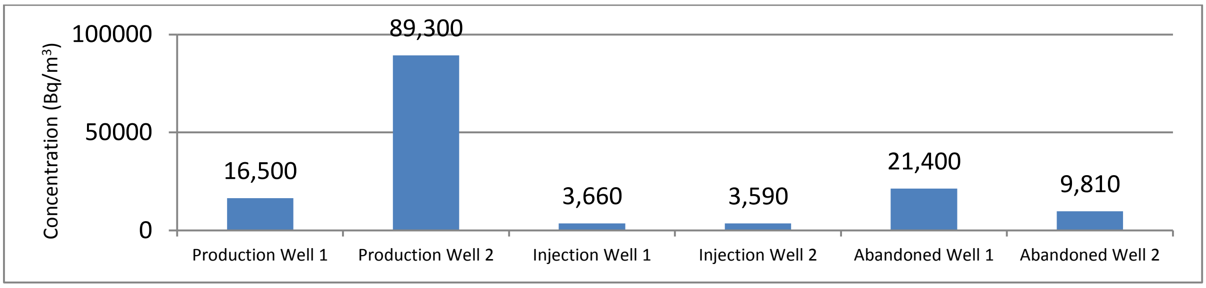
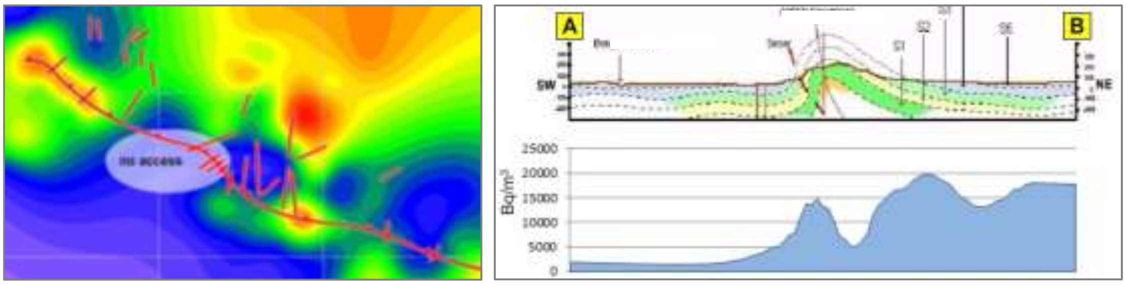


Figure 4. Radon concentration on geothermal wells



(a) (b)

Figure 5. (a) Radon and the distribution of fault based on IKONOS. The red line shows the fault. (b) Comparison of the geological cross-section and Radon one

Based on the map above, the fault is distributed from the southeast to the northwest coincide with of Radon concentration in some locations. Continuity of Radon concentration is cut in areas that are not accessible so it can not be measured. We can make a conclusion that the radon concentrations is correlating positively to the fault structure. From figure 5 it can be seen that the Radon concentration rises drastically in the fault zone. High Radon concentration around point B is the background concentration which is influenced by the content factor (subsurface materials). The cross section also provides a positive correlation between the Radon concentration towards the river. The value measured near point A (river) is very low because Radon cannot be measured in soil with high humidity.

Statistical test with a normal probability plot method is also applied to the data of Radon to separate the anomaly and background concentration. Threshold zone on normal probability plot is shown in the area with the data to form a linear trendline. Data that is away from the linear trend line has entered an anomalous zone. The boundary between the two zones is named threshold. Normal probability plot of oil field data is shown in the graph in figure 3(d). Based on the graph, the value of threshold in the oil field is 11,200 Bq/m^3.

4.4. Producing Oil Field

This is the only field with the subsurface information that has been known before this activity. The field has been producing oil for a long time. There are thousand wells that has been drilled and still produce oil until now. The measurement was conducted with the intervals between the measurement points are 500m. The data of Radon measurement results generated the contour map as shown in figure 2(d). The data has an average value of 7.663 Bq/m^3 with the highest value of 34.000 Bq/m^3.

Based on the comparison chart of threshold concentration above, it can be concluded that the background concentration on the oil field is the highest. It also make an evidence that the field with geothermal manifestations have a high background concentrations. Thus, Radon method has the potential to be used as an initial exploration of geothermal.

5. Conclusion

Radon measurement results showed a strong correlation between Radon concentrations in the surface and the faults. In the oil field, the value of background concentration (threshold) of Radon is higher than the frontier one and the results of measurements in geothermal field shows a very strong correlation between Radon concentrations and geothermal reservoir. In its application for oil and gas exploration, the role that Passive Soil Radon Method plays is just supporting data.

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