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Radon-222 Distribution in the
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RADON-222 DISTRIBUTION IN THE AQUIFERS OF THE SAGINAW LOWLAND

by

David W. Wills

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ABSTRACT

Three models are proposed to explain radon-222 distribution in groundwater aquifers of the Saginaw lowland. Random water samples obtained throughout the lowland indicate a high degree of variation and reveal no significant correlation with salinity, pH, groundwater temperature, depth of well, type of lithic source, or level of radium-226. Data does not support models for generation of radon-222 by radium-226 within the groundwater, or radon-222 derived from primary minerals as the source of radon-222 detected in the groundwater of the Saginaw lowland. The high degree of areal variation supports the model of radon-222 generated by adsorbed and coprecipitated radium-226.

ACKNOWLEDGEMENTS

I would like to acknowledge the support of my family, who tolerated my educational pursuit, the influence of my father, who taught me perseverance, and the patience and persistence of my friend and advisor, Dr. Grahame Larson.

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INTRODUCTION

I. Introduction

Exposure to radon-222 has been determined by the National Academy of Science (1988) and the U. S. Environmental Protection Agency (1988) to be a health hazard primarily because when its short-lived daughters are inhaled as solid particles, they become lodged in the airway and continue to decay. This decay results in the release of alpha particles which damage lung tissue, causing lung cancer (Cothern and Smith, 1987).

Groundwater is one of the primary pathways in which radon-222 enters residences and other structures, and can contribute significantly to the level of radon-222 in a structure (EPA, 1986). It is therefore important to determine the level and source of radon-222 in groundwater.

II. Objectives

The Saginaw lowland in southern Michigan (Figure 1.1) is an area of on-going research in hydrogeology and geochemistry due to the anomalous levels of chlorides, nitrates, and other undesirable compounds detected in the groundwater (Long et al, 1989: MDPH, 1986). To date, however, no significant survey has been conducted on levels of radon-222 in the groundwater.

The objectives of this research are: 1) to determine radon-222 levels in the groundwater within the shallow aquifers of

the Saginaw lowland, 2) to evaluate the health risks to the lowland's community, and 3) to determine the source of radon-222.

III. Theory

3.1 General

Radon-222 is a radioactive isotope in the U-238 decay series (Figure 3.1) and is the daughter product of radium-226. It has a half-life of 3.82 days and is highly soluble in water. Radon-222 decays to polonium-218 and a series of short-lived progeny through alpha and beta decay. The decay of radon-222 to polonium-218 involves the emission of an alpha particle containing two protons plus two neutrons from the radon-222 nucleus:

$$\text{Rn-222} \dashrightarrow \text{Po-218} + \text{He-4}$$

The alpha particle, which is actually a helium ion, is ejected at high speed (Friedlander et al, 1955). It is alpha decay, chiefly from the short-lived radon-222 progeny, which is thought to contribute to the development of carcinoma in lungs and associated tissues through damage to cellular DNA (National Academy of Science, 1988; Cothern and Smith, 1987).

3.2 Models for Radon-222 Occurrence in Groundwater

There are two possible sources for the origin of radon-222 in the groundwater within the shallow aquifers of the Saginaw lowland.

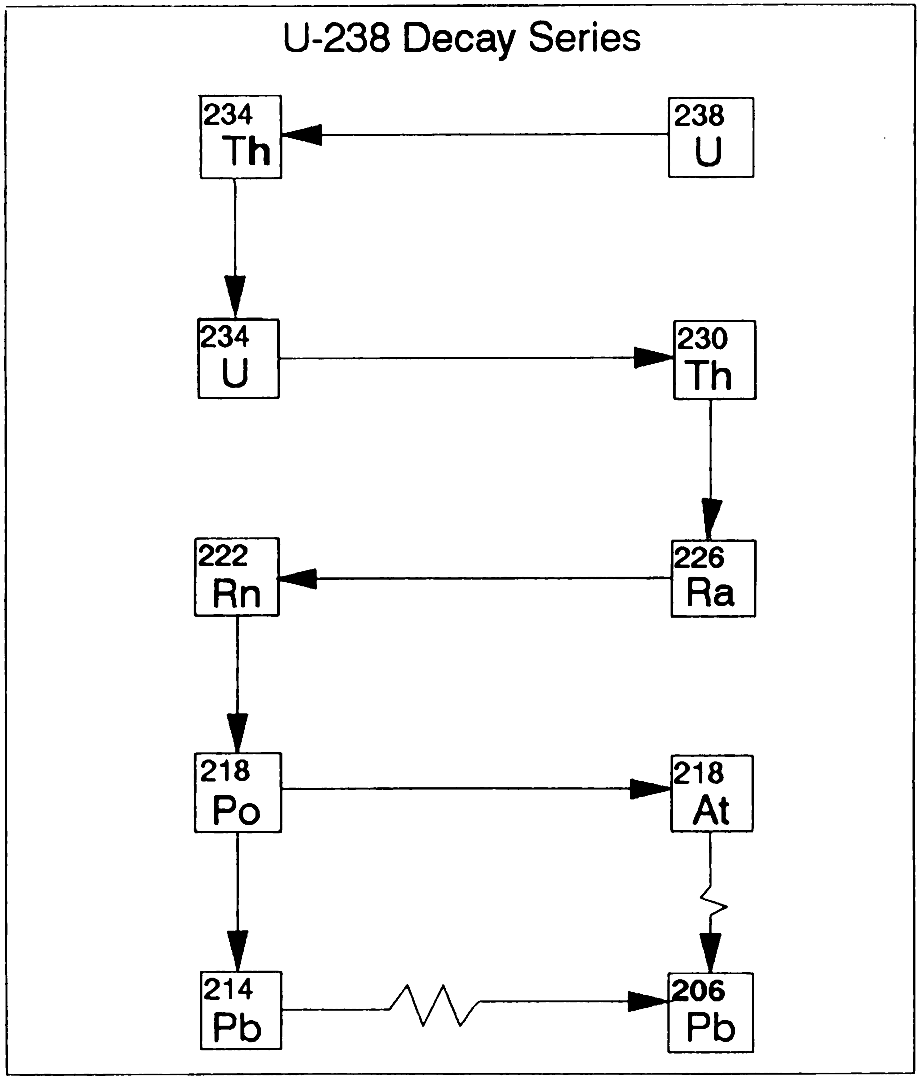

Figure 3.1 U-238 Decay Series

Radon-222 Derived from Radium-226 in Solution

Tanner (1964) describes conditions under which radium-226 can be leached from organic rich sediments high in uranium and thorium and in contact with brines, such as may exist in Michigan within the Antrim and Elsworth Shales (Long et al, 1989). He states that positive ions, such as sodium, magnesium, and potassium associated with elevated chloride levels of brines found at depth, combine with reducing conditions in the shale to provide a situation which favors the displacement of radium-226. The positive ions also prevent the radium-226 in solution from subsequently adsorbing onto mineral surfaces due to competition with chloride ions (Tanner, 1964). This radium-226, while still in solution, may eventually diffuse upwards together with chloride ions and could be the source of the radon-222 detected in shallow aquifers of the Saginaw lowland.

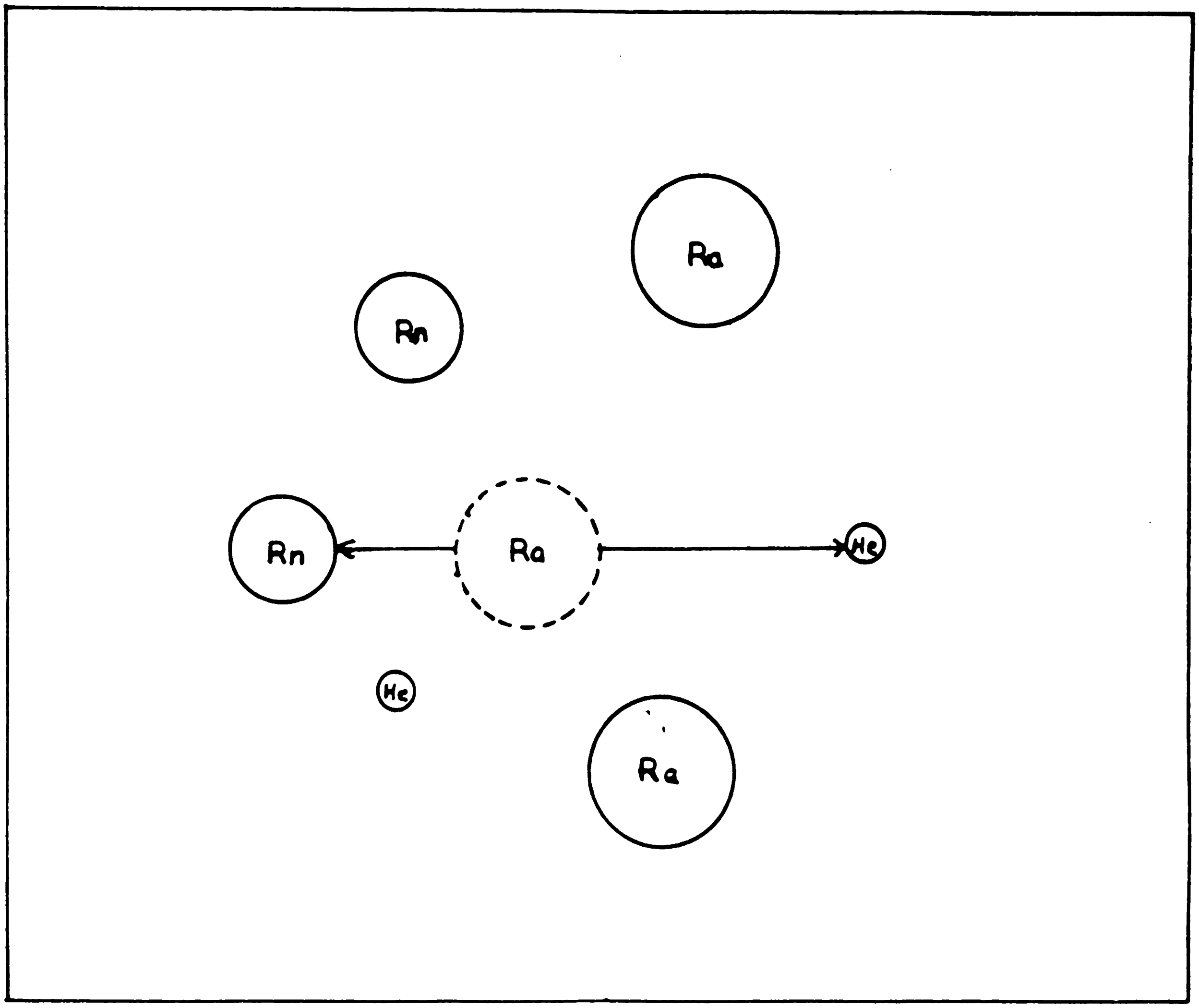

Figure 3.2 Radium-226 in solution decays to Radon-222

Radon-222 Derived from Radium-226 in Primary Minerals

As radium-226 decays and ejects an alpha particle, the resultant radon-222 atom can recoil in the opposite direction a distance of from 20 to 70 nm (Michel, 1987). If the original radium-226 atom is within a mineral and near a granular surface, then the radon-222 atom can be ejected into fluids within intergranular space (Figure 3.3). This process has been used to explain the occurrence of radon-222 in groundwater associated with granitic terraines, such as those found in Ontario or Utah (Lively and Morey, 1982; Tanner, 1964). It is also possible that radon-222 detected in the shallow aquifers of the Saginaw lowland originates from the same process.

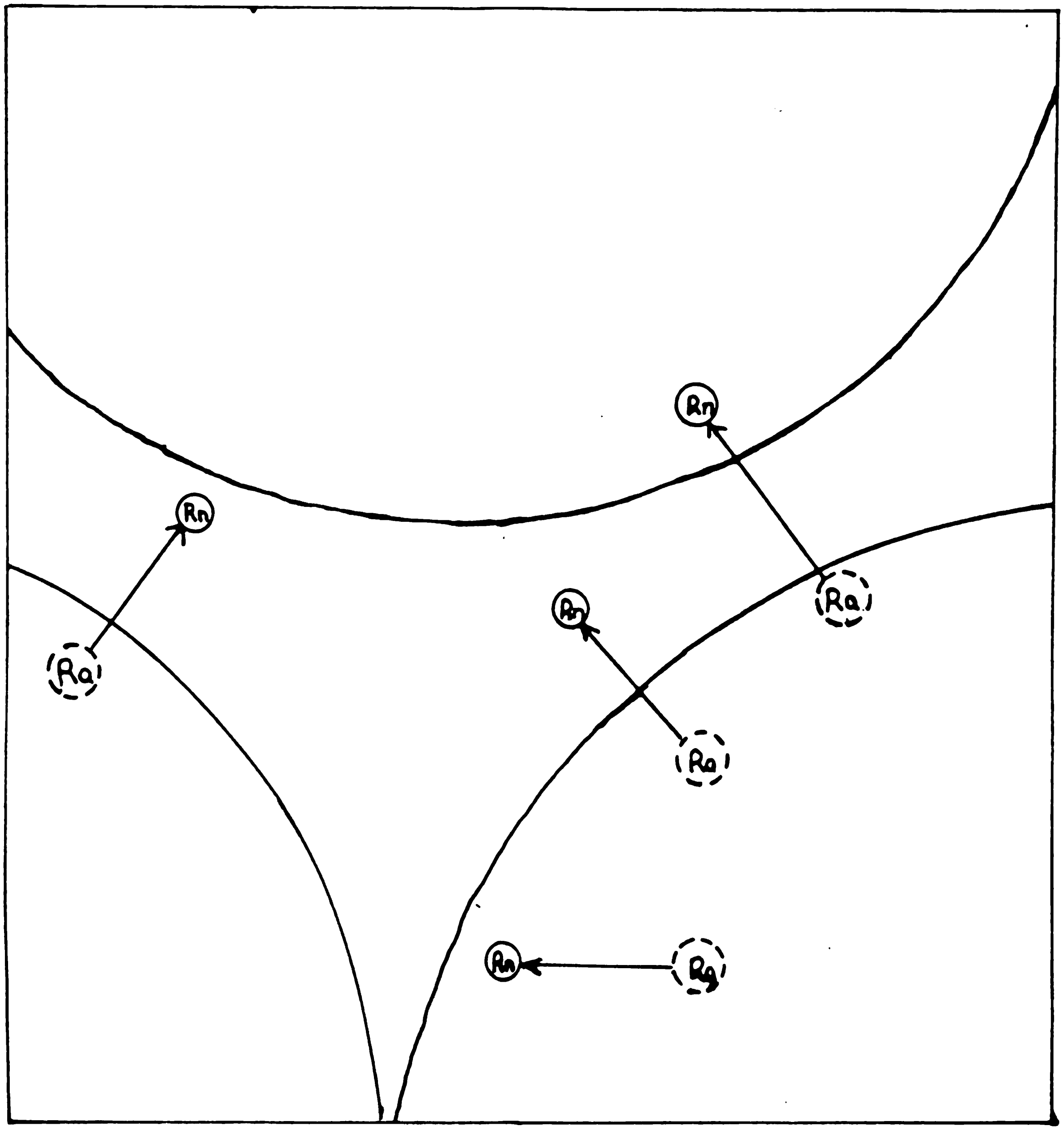

Figure 3.3 Radon-222 atoms ejected into intergranular space

Radon-222 Derived from Adsorbed and Coprecipitated Minerals

As previously mentioned, radium-226 can be leached from organic shales and can be associated with diffusing chloride ions. The solubility of both the radium-226 and chloride ions, however, would decrease upwards because of decreasing groundwater temperature towards the surface (Kirby and Salutsky, 1964) and may result in radium-226 adsorbing and coprecipitating onto primary and secondary mineral surfaces (Tanner, 1964).

As previously mentioned, Tanner (1964) states that the presence of positive ions associated with high chloride levels in groundwater restricts the ability of radium-226 to adsorb onto mineral surfaces. However, he further states that since groundwater near the surface is generally a mixture of meteoric and subsurface waters, this results in decreased chloride levels and consequently reduces the competition for adsorption sites and also permits radium-226 to adsorb and coprecipitate onto primary and secondary mineral surfaces.

The adsorbed and coprecipitated radium-226 resulting from a decrease in temperature and from lowered chloride levels subsequently decays, ejecting radon-222 into the groundwater within the intergranular space, similar to the process occurring within primary minerals.

An alternate process for radium-226 enrichment on surfaces of primary minerals exists in the glacial deposits overlying

the Saginaw lowland. Prior to being deposited in Michigan, these glacial deposits were derived in part from the weathering of granitic rocks in Canada. Michel (1987) describes a process whereby physical and chemical weathering in granitic rocks of uranium-rich feldspars form clays rich in uranium and progeny, including radium-226, which may intermix with primary rock formations or invade porous sediments or fractures and be deposited on rock surfaces. Eventually, these weathered sediments could be further eroded and transported by glaciers, and ultimately deposited in the Saginaw lowland.

The radium-226 located in enriched grain surfaces in both the Saginaw Formation and the glacial drift can contribute significantly to the emanating power of a sediment as the resultant radon-222 atoms are more likely to be propelled into the intergranular pore space (Figure 3.4).

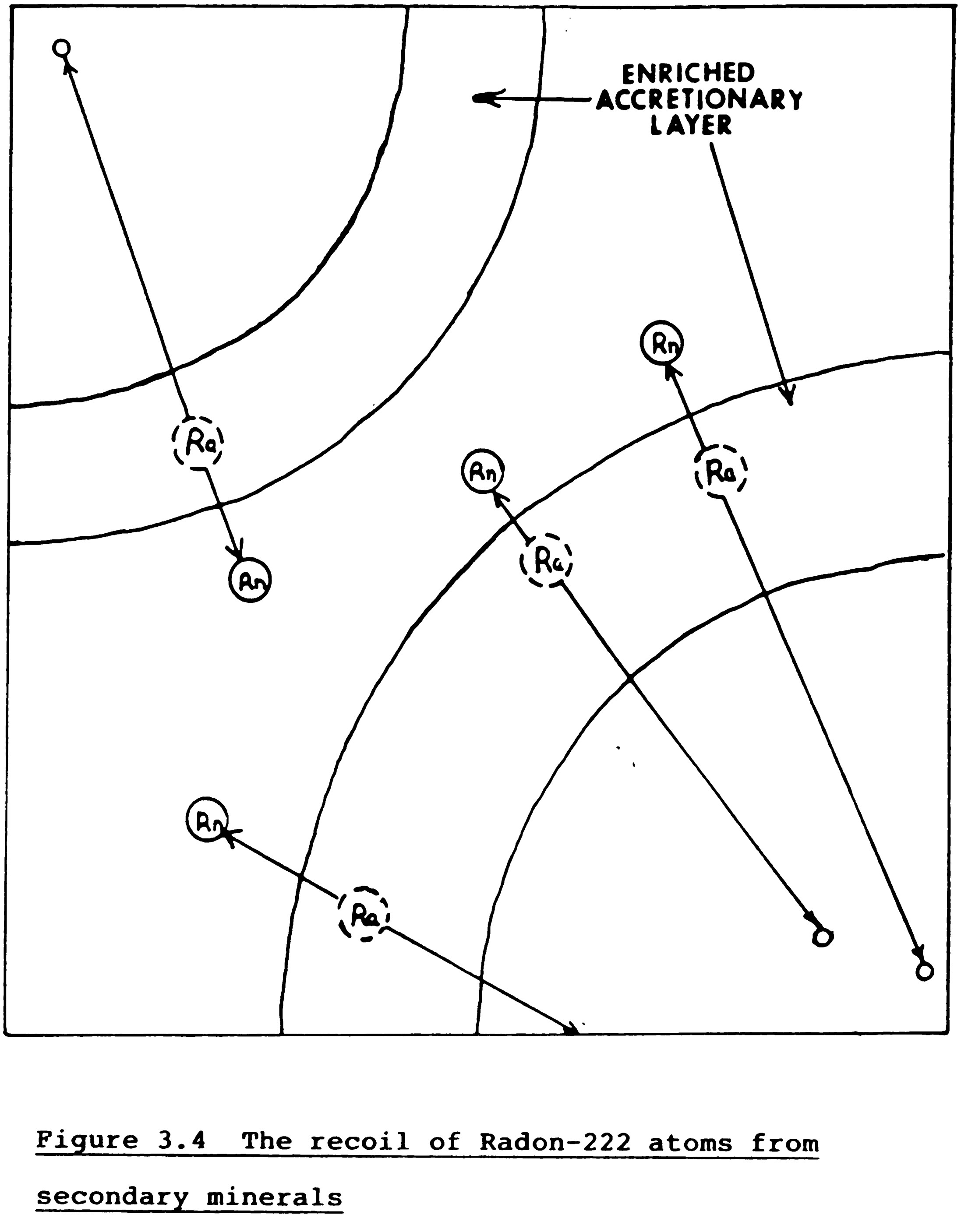

Figure 3.4 The recoil of Radon-222 atoms from secondary minerals

IV. Location and Physical Setting

4.1 General

The Saginaw lowland area of Michigan includes Bay, Saginaw, Midland, Gratiot, and portions of Gladwin, Tuscola, and Arenac counties (Figure 5.1), and is characterized by little relief. Surface elevations range from 176 meters along the shore of Saginaw Bay, to 282 meters in Gladwin County; the average elevation of the area is approximately 213 meters. The main rivers in the area are the Cass, Pine, Saginaw, and Tittibawassee. These drain generally eastward and discharge into Saginaw Bay.

As of 1980, the population in the lowland was approximately 550,000, with approximately half, or 228,000, concentrated in Saginaw County. The vast majority of the land area is rural, with numerous small towns and villages, and one major metropolitan area: the Bay City, Midland, Saqinaw tri-city area. The primary economic base is agriculture, although the cities of Midland and Saginaw are major industrial centers for the state.

4.2 Geology

The lowland lies in the east central portion of the Michigan Basin and is underlain by the Saginaw Formation, which is Pennsylvanian in age and consists primarily of coal and limestone (Vugrinovich, 1984). The formation ranges in

thickness from 0 meters in eastern portions of Arenac and Tuscola counties to approximately 163 meters in the western part of the lowland. In general, the formation decreases in thickness towards the east and dips slightly towards the west.

Overlying the Saginaw Formation is up to 30 meters of glacial drift (Rieck, 1980). The drift consists mainly of lacustrine clay and silt, till, and minor amounts of sand and gravel (Martin, 1955). Collectively, these sediments form a broad plain associated with glacial lakes Saginaw, Algonquin, and Stanley (Leverett and Taylor, 1915).

Several morainic systems associated with the retreating Saginaw Ice Lobe cut northwest to southeast across the lowland area. These include the Port Huron, Fort Worth, and Defiance moraines and are generally recognized by their gently rolling topography (Leverett and Taylor, 1915). They consist mainly of clay-rich till and minor amounts of sand and silt. Also occurring along the shoreline of Saginaw Bay and in scattered pockets inland from the Bay are ridges and dunes of well-sorted, fine-to-medium sand.

4.3 Hydrology

The primary source of fresh water in the lowland is from bedrock aquifers, drift aquifers, and surface waters - chiefly Saginaw Bay waters. Most rock wells draw water mainly from sandstone units of the Saginaw Formation, although a few wells in the extreme northeastern and southeastern parts of the sandstone units of the Saginaw Formation, although a few wells in the extreme northeastern and southeastern parts of the lowland draw from the Bayport Limestone or the Michigan Formation. In general the number of bedrock wells increases towards the west, where some are as much as 152 meters deep.

Water from the Saginaw Formation does not exceed maximum contaminant levels (MCL's) for nitrate or fluoride, but some samples exceed secondary MCL's for chloride, iron, sulfate, total dissolved solids, and specific conductance (Long, et al., 1985).

Since clay-rich lake bed deposits are the dominant drift material in the lowland, wells are generally set to tap isolated deposits of sand and gravel beneath the surface. These deposits are usually thin and discontinuous, and recharge capacity is very limited. Approximately 42 percent of the region has greater than 10 percent bedrock wells as opposed to drift wells. This is primarily in the eastern portion of the lowland where the drift material is less than 30 meters thick. The percentage of bedrock wells decreases towards the west as the drift thickens; few bedrock wells occur in the western third of the lowland, which is underlain by 60 meters to 180 meters of drift.

Water from drift aquifers is generally similar to that from the Saginaw Aquifer; nitrate and fluoride is below the primary MCL, but some wells contain water exceeding the secondary MCL

V. Sampling Strategy and Methodology

5.1 Sampling Strategy and Methodology

A total of 56 wells were sampled for radon-222 within the Saginaw lowland (Figure 5.1). About half of these wells were from Bay County, the rest were from the remaining six counties.

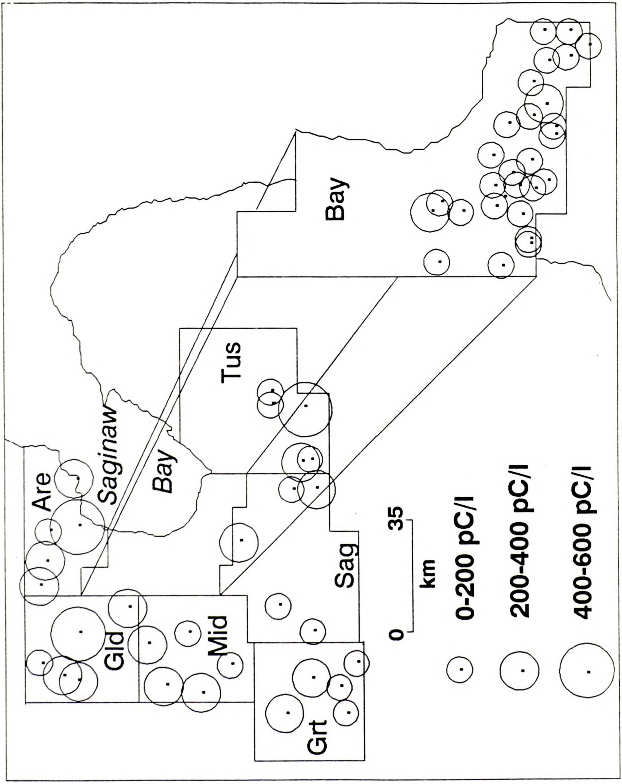

Figure 5.1 Wells sampled with the Saginaw lowland

The following procedure (EPA, 1978) was used for collection of radon-222 samples:

1. A hose was attached to a household faucet after insuring that the water did not go through a softener system. The faucet was turned on full and allowed to run approximately 20 minutes to obtain a fresh sample from the well. The stabilization of temperature was used as an indication the sample was directly from the well shaft.

2. The flow of water was reduced to minimize turbulence during sample collection.

3. The end of the hose was placed in a funnel which filled with water, immersing the hose end.

4. The tip of a hypodermic needle was placed approximately 3 cm below the surface of the water, and 15 ml of water was slowly drawn into the syringe. This water was then ejected. This procedure was repeated twice to rinse the syringe.

5. Approximately 15 ml of water was again slowly drawn into the syringe. The syringe was inverted and any air bubbles and extra water was slowly ejected to leave exactly 10 ml.

6. The cap was removed from a scintillation vial containing a premeasured amount (10 ml) of N E N Products mineral oil-based high-efficiency scintillation solution. The

tip of the needle was placed near the bottom of the scintillation solution, and the water was slowly ejected into the solution.

7. The needle was slowly withdrawn and the cap of the vial was tightly replaced.

8. Each vial was identified by marking it with the time and date of collection, sample number, and field identification (site ID) number. Additional records were kept of the site location, well type and depth, water temperature, and conductivity.

9. Steps 4 through 7 were repeated to obtain an additional separate sample from the same source.

5.2 Instrumentation and Counting Procedure

The radon-222 activity, as determined by disintegrations per minute, was measured with a Beckman 8100 series Liquid Scintillation Detector. The following procedure (Gray, 1980) was used to determine the radon-222 activity:

1. Due to the short half-life of radon-222, all samples were measured for radon activity within 72 hours of the time of collection. Most of the samples were measured within 24 hours of collection.

2. The samples were allowed to equilibrate to room temperature for a minimum of three hours prior to counting.

3. The sample vials were shaken to insure equilibration, wiped with a clean damp cloth to insure the glass sides were clean, and placed in the Liquid Scintillation Detector in the

following order: background vials, standards, and samples.

4. The activity in each vial was measured for a period of twenty minutes. This step was repeated once.

5. At the end of the counting procedure, the time from the beginning of the count until each individual vial had been measured was added to the overall time since collection. The results of the two counts for each vial were averaged to give the overall activity, and the ratios for the two channels were compared to insure they were similar to the ratios determined by the standards. The efficiency of the above procedure, as determined from the known radon-222 standards, is 97% (Appendix C).

5.3 Standards

The following radon-222 standards, obtained from the Eastern Region U. S. Environmental Protection Agency Laboratory in Montgomery, Alabama, were used to calibrate the Liquid Scintillation Detector to establish efficiency and to determine the CPM/pCi conversion factor:

1650 pCi/l
2100 pCi/l
2400 pCi/l
4800 pCi/l
7500 pCi/l

The 4800 pCi/l standard was also used to generate an energy spectrum for radon-222 decay by initially counting the standard with a "wide open" window (0-1000) on the detector.

The window was then progressively closed from the top limit of 1000 in intervals of 50 to generate the decay spectrum illustrated in Appendix B.

Standards for C-14 and tritium were also used to generate decay spectrums in the same manner for their respective isotopes (Appendix B). During sample counting, one channel was devoted to measuring the activity above the C-14 and tritium decay spectrum limits, which includes the majority of the radon-222 decay spectrum. The activity of this channel was then compared to the wide-open channel to insure the resultant ratio was consistent with the ratio obtained for the same ranges for the radon-222 standards. This insured the activity being measured was radon-222 activity.

5.4 Determination of Radon Content

CPM/pCi Conversion Factor

Formula 5.1 (EPA, 1978) was used to convert CPM's to pCi/l.

$$B=Sb-Rb/A \qquad 5.1$$

Where B= CPM/pCi conversion factor

A= Activity of Standard (pCi)

Sb= Count Rate of Standard (CPM)

Rb= Background Count Rate (CPM)

Calculation of Minimum Detectable Activity

The minimum detectable activity, as determined for each water sample, is defined as the lowest ascertainable activity level for radon-222 (Gray, 1985):

$$A_I = (1/B\ X\ K1\ R_b\ /T)\ X\ 100 \qquad 5.2$$

Where AI = Minimum Detectable Activity in pCi/l

B = Mean CPM/pCi conversion factor derived from five standards

K_1 = 1.65

Rb = Background count rate (CPM)

T = Count time in hours

A_I is the ability of the detector, within the limits of its efficiency and counting time, to reliably measure an activity above background.

Calculation of Radon-222 Activity

Formula 5.3 (EPA, 1978) was used to determine the radon-222 activity.

$$\text{pCi/l} = (\text{net CPM}/B/\text{decay})\ X\ 1000\text{ml/liter}/10\text{ ml} \qquad 5.3$$

Where net CPM = gross CPM - background CPM

B = CPM/pCi conversation factor

decay = $\exp(-7.56\ E^{3T})$

T = time lapse from collection to counting in hours

The two sigma counting error as given in percent is (EPA, 1978):

$$\frac{\frac{S_b}{T} + \frac{R_b}{T}}{\text{net CPM}}$$

Where S_b = Gross CPM

Rb = Background CPM

T = Count time in hours

5.5 Sources of error

To determine if there was a variation in radon-222 concentration in groundwater over time, five sites were selected at random, then sampled and analyzed three times from May, 1987 to August, 1987. The mean variation of the radon-222 activity was 11.4%. A precaution for the possibility of errors in the sampling process included the repeated sampling described above, and the obtaining of two separate samples for each site. Errors due to machine counting were minimized by counting each sample twice, and by repeated counting of the standards to determine the amount of variation.

Additional measurements included temperature and salinity, which were tested with a conductivity/temperature meter. Radium-226 levels were also determined by MDPH for 26 wells in Bay County by measuring gross alpha radiation using an alpha track detector. Other parameters recorded included well type, drift or bedrock, and well depth which were obtained from well logs. The depth of the wells sampled ranged from 17 meters below ground level, to 171 meters. The mean depth was 57 meters, and the standard deviation was 35 meters. Of the wells sampled, 21 were drift wells, and 35 were bedrock wells.

VI. Results

6.1 Radon-222 Content of the Groundwater

The radon-222 concentration in the samples of groundwater obtained from the study area ranged from a low of 4.6 pCi/l, which is below the significance level for the analytical

method used (Gray, 1980), to a high of 562.3 pCi/l. The mean was 174.2 pCi/l, and the standard deviation was + or - 121.6. See appendix A for a complete list of values.

6.2 Salinity

The salinity, or total dissolved salts, of the groundwater ranged from a low of 250 umhos to a high of .03 mhos. The mean was 3215 umhos with a standard deviation of + or - 4490 umhos.

6.3 Temperature of the groundwater

The temperature of the groundwater samples obtained at the time of sampling was measured with an electronic thermometer previously calibrated with a laboratory thermometer. The resultant values ranged from 9.1 degrees to 15.7 degrees Centigrade. The mean temperature was 12.5 with a standard deviation of + or - 1.97 degrees.

6.4 Radium-226 Content

Samples were obtained from Bay County approximately three to six weeks prior to radon-222 sampling. Samples were drawn directly from taps with unsoftened water, and poured into clean sample bottles. These samples were analyzed for combined levels of both radium-226 and radium-228, with radium-226 results ranging from 0.3 pCi/l to 108.7 pCi/l. The mean was 12.96 with a standard deviation of + or - 4.10 pCi/l.

6.5 Alkalinity and pH

The alkalinity of the groundwater samples ranged from 64 to 1250, with a mean of 373 and a standard deviation of 257.5.

The pH of the samples ranged from 6.8 to 8.5, with a mean of 7.6 and a standard deviation of .31.

VII Discussion

7.1 General

The levels of radon-222 measured in the groundwater samples from the Saginaw lowland were within anticipated values for groundwater from formations consisting of sandstones, gray shales, and carbonates that normally contain relatively low levels of uranium (Cothern and Smith, 1987), and are well below the 10,000 pCi/l proposed by the EPA as constituting a high-danger level. There was no discernable pattern to the areal distribution of the radon-222 in the groundwater (Figure 5.1). In fact, some of the lowest values recorded were from wells located within 4 or 6 km of those wells yielding relatively high values. The low levels measured should preclude the groundwater as a source for concern over radon hazards in normally constructed residences and other structures.

With respect to the vertical distribution of radon-222, a plot of radon-222 vs. depth (Figure 7.1) shows little relationship. In fact, the correlation coefficient between the two parameters is 0.215. In addition, the data show that the highest and lowest concentration of radon-222 both occur at relatively shallow depth (<70m).

Comparison of the radon-222 concentration recorded from wells open to the drift vs. those open to the Saginaw

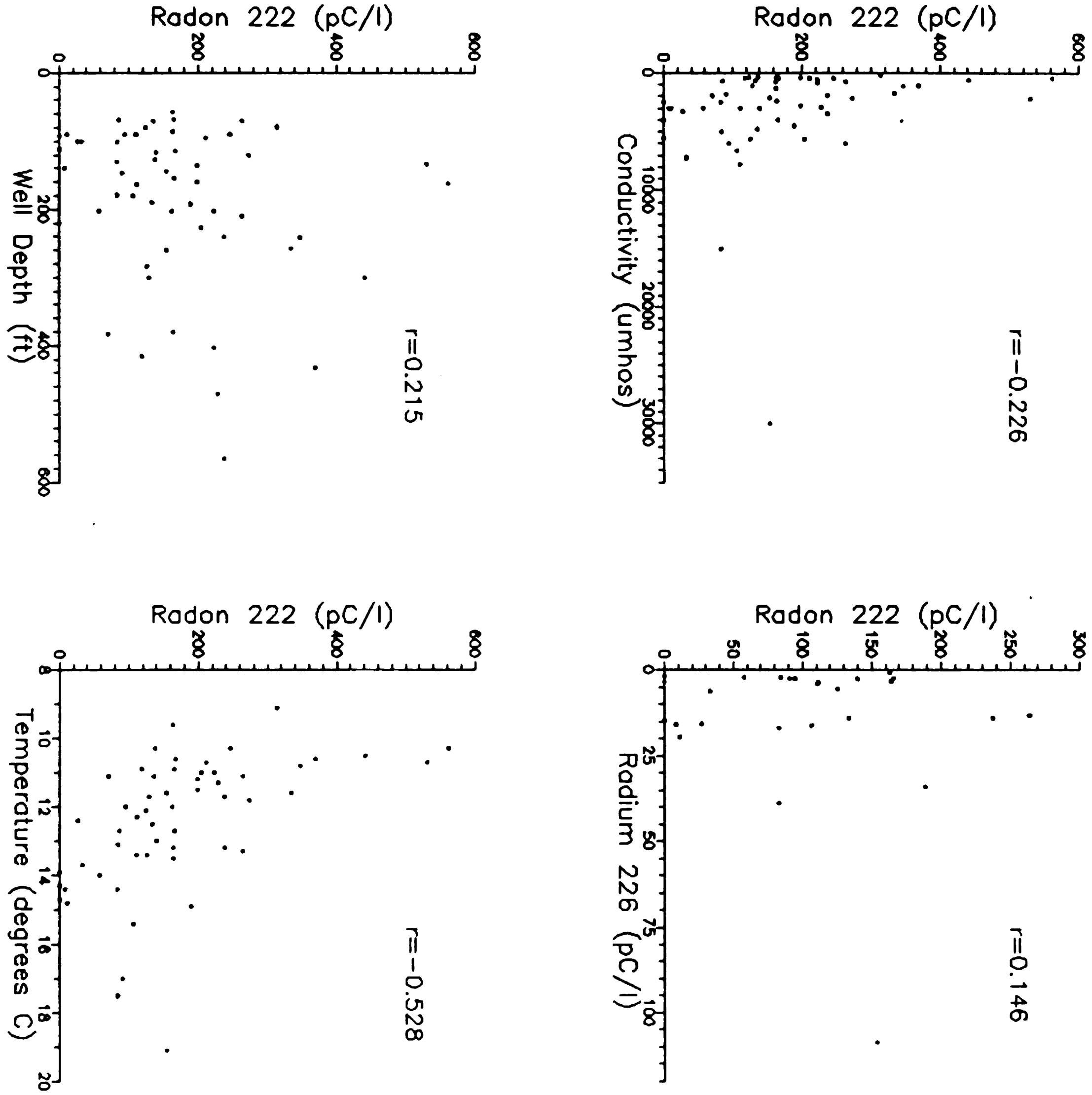

Figure 7.1 Plot of Radon-222 vs. other parameters

Formation also show no discernable relationship.

7.2 Radon-222 Derived from Radium-226 in Solution

Generation of radon-222 by radium-226 within the groundwater should result in a high correlation between measured radon-222 and radium-226 values. A plot of the radon-222 and radium-226 for wells in Bay County (Figure 7.1) however, yield a correlation coefficient of only 0.146. In fact, many of the lowest values for radon-222 obtained from Bay County also yield some of the highest values so far obtained for radium-226. These observations would suggest that radium-226 in solution is not a major source for the radon-222. This would be consistent with the findings of Lively and Morey (1982) for radon-222 in groundwater from east-central Minnesota and with the findings of Dyck (1980) from northeast Ontario.

Furthermore, Michel (1987) and Tanner (1964) explain that radium-226 is primarily immobile and occurs in solution in only low concentration in the shallow (<50m) groundwater environment, and that the most likely source of radon-222 is radium-226 precipitated in the vicinity of the well, rather than radium-226 present in the groundwater. This process of radium-226 precipitation and immobility may also operate in the aquifers of the Saginaw lowland, and may explain the lack of correlation between radon-222 and radium-226.

7.3 Radon-222 Derived from Radium-226 in Primary Minerals and from Adsorption and Coprecipitated Minerals

The results demonstrate that the radon-222 detected in the groundwater of the aquifers of the Saginaw lowland is not derived from radium-226 in solution, therefore it must be originating from either the primary minerals within the Saginaw Formation and/or glacial drift, the secondary minerals, or both.

The composition of the Saginaw Formation and glacial drift is known and includes the following primary minerals: quartz, calcite, dolomite, feldspars, "coal", clay minerals, hornblende, tremolite-actinolite, orthopyroxenes, clinopyroxenes, garnet, epidote, rutile, sphene, zircon, and tourmaline, as well as the secondary minerals Fe and Mn oxides, carbonates, hydroxides, and silicates (Vugrinovich, 1984, Dworkin, 1984). Of the above minerals; feldspars, "coal", zircon, clay minerals, Fe and Mn oxides, and silicates can contain significant quantities of uranium-238 and progeny, including radium-226 (Dyck, 1978, Tanner, 1964, Asikainen, 1981, Lively and Morey, 1982).

Whether the primary or secondary minerals containing radium-226 are the source of the radon-222 in the groundwater can only be determined by direct measurement of the amount of radium-226 within the minerals. Such measurements are analytically very difficult and are beyond the scope of this research project.

However, based on the extreme vertical and horizontal variability of the radon-222 measurements of the groundwater, it would appear that the probable source of radon-222 is from

secondary minerals. This is based on the likelyhood that, unlike primary minerals, secondary minerals are distributed within the Saginaw Formation and glacial drift non-uniformly, and would give rise to non-uniform values of radon-222 within the groundwater. The non-uniform distribution of secondary minerals is attributable to the high hydrologic variation within the Saginaw Formation and glacial drift; differences in permeability and flow rates leads to diversity in the availability of ions for adsorption and coprecipitation sites. Clay minerals, as compared to other minerals, also provide an effective adsorbent of radium-226 and other secondary minerals.

VIII. Summary and Conclusion

The data shows that radon-222 levels in the groundwater aquifers vary considerably, even over short distances, and that high and low values often occur in wells of close proximity and at equivalent depths. There is also a marked lack of correlation with any of the other parameters tested, i.e. well depth, conductivity, alkalinity, pH, and temperature. In particular, there is no correlation between radon-222 and radium-226 in solution which contradicts expectations if the model for radon-222 derived from radium-226 in solution is used. Due to the general uniformity of distribution of primary minerals, as contrasted to the extreme variation of radon-222 values in the groundwater, there is no discernable support for primary minerals as a major source of the radon-222 detected in the groundwater.

The variation in permeability and flow rates within the Saginaw Formation and glacial drift leads to an expectation of variation in adsorbed and coprecipitated secondary minerals, including radium-226. This provides a plausible explanation of the variation in radon-222 levels within the groundwater, and identifies secondary minerals as the likely source of radon-222 in the groundwater.

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APPENDICES

APPENDIX A

ID	TYPE	DEPTH	COND	TEMP	RADON	RADIUM
Bay1	1	100	7200	13.7	33.0	6.2
Bay2	2	260	30000	19.1	153.8	108.7
Bay3	2	92	4000	14.3	0	3.5
Bay4	2	116	3000	13.0	139.7	2.7
Bay5	1	90	7800	13.4	110.6	4.1
Bay6	2	154	4000	12.7	165.6	2.4
Bay7	1	90	3000	14.8	11.4	19.6
Bay8	2	210	6000	13.3	263.7	13.2
Bay9	2	140	3000	14.4	8.4	15.8
Bay10	2	192	4500	14.9	188.8	34.2
Bay11	1	111	2500	14.7	0	1.8
Bay12	2	179	15000	14.4	83.0	38.9
Bay13	1	180	6600	15.4	106.3	16.1
Bay14	1	190	650	12.5	133.3	14.0
Bay15	2	220	5500	13.9	0	15.8
Bay16	2	202	3000	14.0	57.9	2.2
Bay17	2	240	3500	13.2	237.1	14.0
Bay18	2	283	5600	13.4	125.5	5.5
Bay19	1	147	1800	17.0	90.5	2.6
Bay20	2	380	2400	13.5	164.1	3.2
Bay21	1	163	3000	12.3	111.5	3.6
Bay24	2	130	2500	17.5	83.0	17.0
Bay25	1	85	1300	13.2	163.1	0.8
Bay26	2	100	3300	12.4	27.1	15.7
Bay27	1	101	5000	13.1	84.3	2.1
Bay29	1	90	6000	12.0	94.5	2.5
Grt1	2	403	516	11.0	223.0	-
Grt2	2	203	783	12.0	162.4	-
Grt3	2	383	1911	11.1	71.0	-
Grt4	1	114	463	10.6	167.2	-
Grt5	2	565	1917	11.7	237.6	-
Tus1	2	127	312	10.3	138.1	-
Tus2	2	162	426	10.3	562.3	-
Tus3	2	160	393	11.5	198.6	-
Tus4	2	416	418	10.9	118.1	-
Tus5	1	68	275	10.9	165.4	-
Gld1	1	79	250	9.1	314.0	-
Gld2	1	57	373	9.6	163.1	-
Gld3	1	95	433	10.7	211.1	-
Gld4	2	300	598	10.5	440.9	-
Gld5	2	202	820	11.0	223.2	-
Are1	2	257	1713	11.6	333.5	-
Are2	2	133	2224	10.7	531.0	-
Are2	2	300	1080	11.7	129.1	-
Are4	2	432	1100	10.6	368.8	-
Are5	1	90	493	10.3	245.9	-
Mid1	1	80	383	12.1	124.3	-
Mid2	2	470	2946	11.3	228.5	-
Mid3	2	241	1128	10.8	346.6	-
Mid4	1	70	4793	11.1	136.2	-
Mid5	1	120	2160	11.8	273.3	-
Sag1	2	144	2124	11.6	153.8	-
Sag2	1	69	713	12.7	86.2	-
Sag3	2	135	2795	11.2	198.3	-
Sag4	2	70	740	11.1	264.1	-
Sag5	2	226	5630	11.0	204.4	-

APPENDIX A

Type: 1 = Drift well
2 = Bedrock well

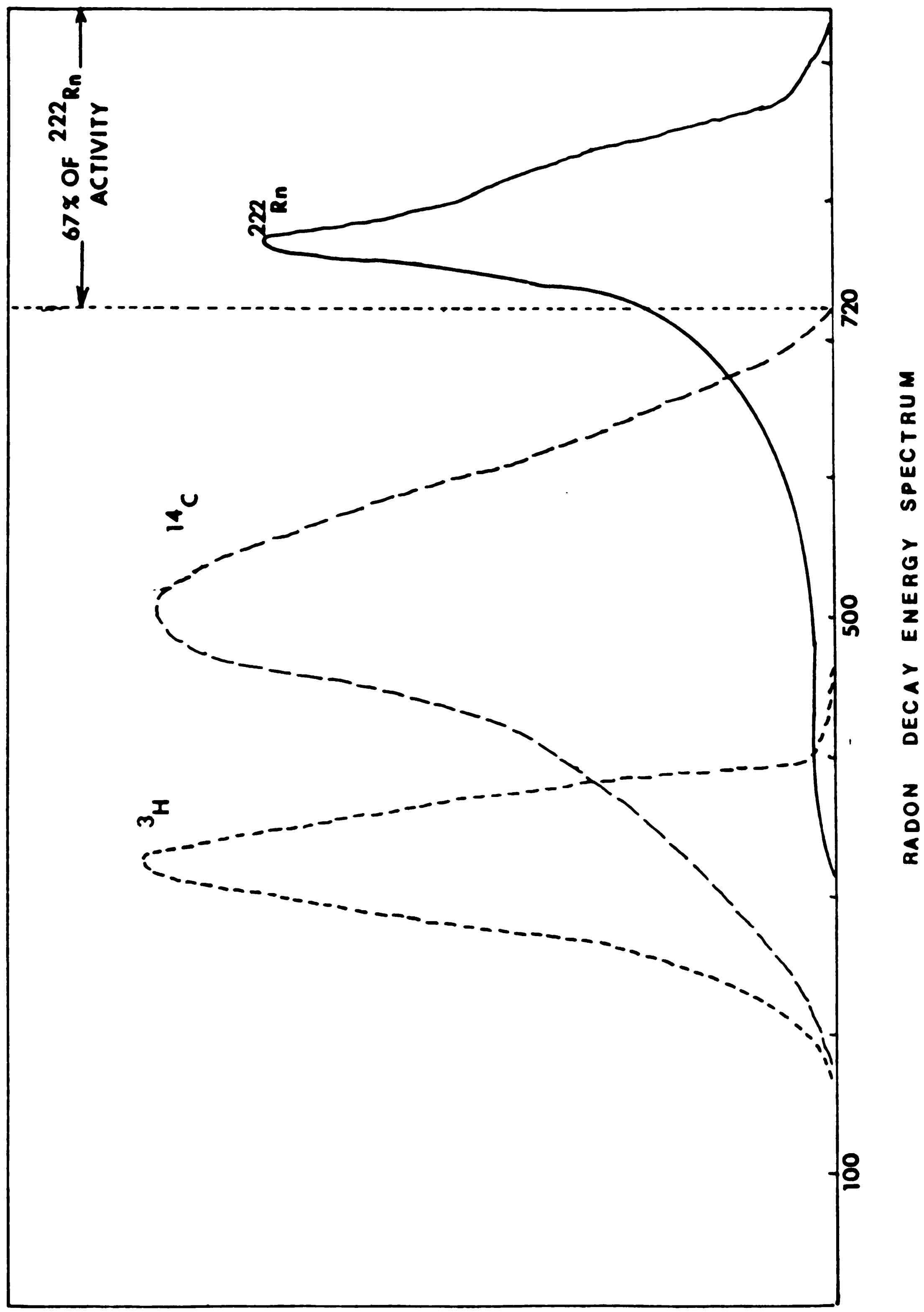
Depth: Measured in feet below surface

Conductivity: Measured in micromhos

Temperature: Measured in degrees Centigrade

Radon: Measured in pC/l

Radium: Measured in pC/l - Total Radium (Ra-226 + Ra-228)



APPENDIX B

RADON DECAY ENERGY SPECTRUM

APPENDIX C

EFFICIENCY TEST - BECKMAN 8100 SERIES LIQUID SCINTILLATION DETECTOR

DATE:12-24-86

STANDARDS

#1 - 16.5 pCi/10ml or 1650 pCi/l
#2 - 20.0 pCi/10ml or 2000 pCi/l
#3 - 24.0 pCi/10ml or 2400 pCi/l
#4 - 30.0 pCi/10ml or 3000 pCi/l
#5 - Background

COUNTS

Each sample counted twice for 20 minutes, limits 0 to 1000 (wide open).

BACKGROUND

Count #1 = 43.35
Count #2 = 42.70
Average Background (Rb) = 43.025

STANDARD COUNT RATE (Sb)

#1
Count #1 = 213.55
Count #2 = 205.00
Average = 209.28

#2
Count #1 = 260.55
Count #2 = 251.25
Average = 255.9

#3
Count #1 = 276.70
Count #2 = 264.55
Average = 270.63

#4
Count #1 = 356.70
Count #2 = 339.60
Average = 348.15

CALCULATION OF CPM/pCi CONVERSION FACTOR (B)

$$B = (Sb - Rb)/A$$

B = CPM/pCi
A = Standard Activity (pCi)
Sb = Standard Count Rate (CPM)
Rb = Background Count Rate (CPM)

#1
(209.28 - 43.025)/16.5 = 10.076

#2
(255.9 - 43.025)/20.0 = 10.644

#3
(270.63 - 43.025)/24.0 = 9.484

#4
(348.15 - 43.025)/30.0 = 10.171

B = 10.09 CPM/pCi

CALCULATION OF RADON ACTIVITY

#1
(209.28 - 43.025)/10.09 X 100 = 1647 pCi/l

#2
(255.9 - 43.025)/10.09 X 100 = 2109 pCi/l

#3
(270.63 - 43.025)/10.09 X 100 = 2255 pCi/l

#4
(348.15 - 43.025)/10.09 X 100 = 3023 pCi/l

CALCULATION OF EFFICIENCY

#1
1647/1650 = .998

#2
2000/2109 = .948

#3
2255/2400 = .940

#4
3000/3023 = .992

AVERAGE EFFICIENCY = .97

EFFICIENCY TEST

DATE: 01-19-87

STANDARDS

#1 - 16.5 pCi/10ml or 1650 pCi/l
#2 - 24.0 pCi/10ml or 2400 pCi/l
#3 - 48.0 pCi/10ml or 4800 pCi/l

COUNTS

Each standard counted twice for 20 minutes per channel

Limits: Channel 1 = 0 - 1000
Channel 2 = 720 - 1000
(Note: 720 is the upper limit for C-14 decay energy)

BACKGROUND (Rb)

Count #1
Channel 1 = 43.50
Channel 2 = 13.65
Count #2
Channel 1 = 44.25
Channel 2 = 13.90

Rb = 43.875
(Channel 2 = 13.775 = 31.4% of channel 1)

STANDARD COUNT RATES (Sb)

		Channel 1	Channel 2
#1			
	Count 1	205.85	130.60
	Count 2	207.85	135.95
	Average	206.85	133.28
			64.4% of channel 1
#2			
	Count 1	299.05	205.80
	Count 2	293.50	197.50
	Average	296.28	201.65
			68.1% of channel 1
#3			
	Count 1	530.45	373.30
	Count 2	546.30	388.20
	Average	538.38	380.75

70.7% of channel 1

CPM/pCi CONVERSION FACTOR (B)

B = (Sb - Rb)/A

#1
(206.85 - 43.875)/16.5 = 9.877
#2
(296.28 - 43.875)/24.0 = 10.517
#3
(538.38 - 43.875)/48.0 = 10.302

B = 10.23 CPM/pCi

CALCULATION OF ACTIVITY

#1
(206.85 - 43.875)/10.23 x 100 = 1593 pCi/l
#2
(296.28 - 43.875)/10.23 X 100 = 2467 pCi/l
#3
(538.38 - 43.875)/10.23 X 100 = 4833 pCi/l

EFFICIENCY

#1
1593/1650 = .965
#2
2400/2467 = .973
#3
4800/4833 = .993

AVERAGE = .98