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INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

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SYMBOLS

HELIUM	A1	⊙
	A2	◬
	FLASK	⬡
RADON		⊡

INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

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ABSTRACT

Monitoring of radon and helium concentrations and measurements of geochemical parameters (He^3/He^4 ratios, N_2 and Ar concentrations, Ra^{226} and Pb^{210} activities, D/H and O^{18}/O^{16} ratios in water, conductivity) at primary network sites on the Elsinore, San Jacinto, and San Andreas faults has continued at monthly intervals during 1977. During the past six months the major effort in this study has been devoted to completing helium measurements on all samples collected since the inception of monitoring in August, 1974, using the portable field mass spectrometer ("helium sniffer"). With the incorporation of a laboratory vacuum system for removing all gases but helium and neon, and the use of calibrated helium standards, the field mass spectrometer routinely operates with a precision of 1%. Nitrogen and argon, extracted with helium from the water samples, are collected on charcoal for gas chromatographic analysis, and helium aliquots for measurement of the He^3/He^4 ratio are also saved.

This report presents the first complete set of graphs of radon and helium measurements vs. time for all network samples during the three year monitoring period 1974-1977, together with a tabulation of all the data. With the exception of several geothermal wells in which severe two-phase separation problems, irregular usage, and sampling difficulties, have resulted in relatively poor helium records, the data provide reasonably good, and in many cases excellent, baseline levels for both helium and radon. Several patterns of variation are observed, including quite constant concentrations, seasonal or periodic maxima and minima in both gases, and irregular fluctuations (at Eden, Soboba, and Warner Hot Springs) which are probably correlated with variations in usage patterns. In many cases the helium and radon variations are positively correlated, with fractional concentration fluctuations which are approximately of the same magnitude rather than being proportional to two-phase partition coefficients as had been expected. In other cases (Eden Hot Springs, Agua Caliente), helium and radon variations are uncorrelated, perhaps due to different source functions.

Measurements of nitrogen and argon on network samples has just begun, but significant applications of these measurements to the understanding of the helium and radon variations have already emerged. It is found that the He-Ar and N_2-Ar data constitute linear arrays which can be described by a two-component mixing model. The high-concentration end-member ("input component") is water approximately saturated with atmospheric N_2 and Ar at

~15°C, 1 atmosphere, enriched in helium by underground addition, and either slightly enriched in Ar by partial loss of gas or slightly enriched in N_2 (or air) by a yet undetermined process. The low-concentration component is a surface layer of hot spring water in solubility equilibrium with the atmosphere at the spring temperature and thus containing essentially no helium. Up to 75% of the initial helium in the water feeding the hot spring has been lost by gas separation and dilution with the atmospheric component; the latter effect is the major process which lowers the helium concentration. These results are obviously highly significant for the interpretation of possible precursory variations in helium and radon concentrations and detailed studies on the associated gases are continuing.

Measurements of gas phase radon in the soil at eight network sites and three test sites in La Jolla, carried out by D. Macdougall, has continued; graphs and tabulated results of the complete data are presented. At three sites on the Imperial fault, the sampling period which ended in September of this year, about one month before two earthquakes of M=4.9 and 4.2, produced the highest values yet measured at these sites. The counting rates then dropped abruptly during the last sampling interval (one-month) which included the actual earthquakes. There is considerable variability in the soil radon records and they are strongly affected by condensation of water droplets at some sites in some seasons, which reduces the effective surface area exposed to radon (but does not otherwise affect the detection characteristics of the cellulose nitrate film). There is no obvious correlation between soil radon activity and radon concentration in the liquid phase at sites where both have been measured.

1. INTRODUCTION

Radon monitoring on the Southern California network continued during the past six months. During this grant period a major effort was made to analyze the entire inventory of samples stored for helium analysis, using the small helium mass spectrometer with calibrated standards. All the samples have been analyzed, and we now report the complete set of both radon and helium data on the entire network (Appendix 1). Samples collected each month are now being analyzed for helium as well as radon on a continuing basis, with other analyses (dissolved N_2 and Ar, stable isotope ratios D/H and O^{18}/O^{16} in water, and Ra^{226} and Pb^{210} activities) made on selected samples at regular intervals.

2. SAMPLING NETWORK

The "Southern Network", from San Bernardino to the Imperial Valley, is shown in Figure 1. Sites designated as the primary network, for monthly sampling, are listed in Table 1. A "secondary network" of sites, sampled at occasional intervals for comparison studies, is listed in Table 2. Minor changes in the plumbing and pumping equipment at several of these wells continue to cause difficulties in obtaining a good continuous record, but no major changes in the network have occurred since the last report.

A new sampling site, the E. Robison well, has been located on the southern portion of the San Jacinto fault at Ocotillo Wells, an area in which there is a conspicuous gap in the sampling network.

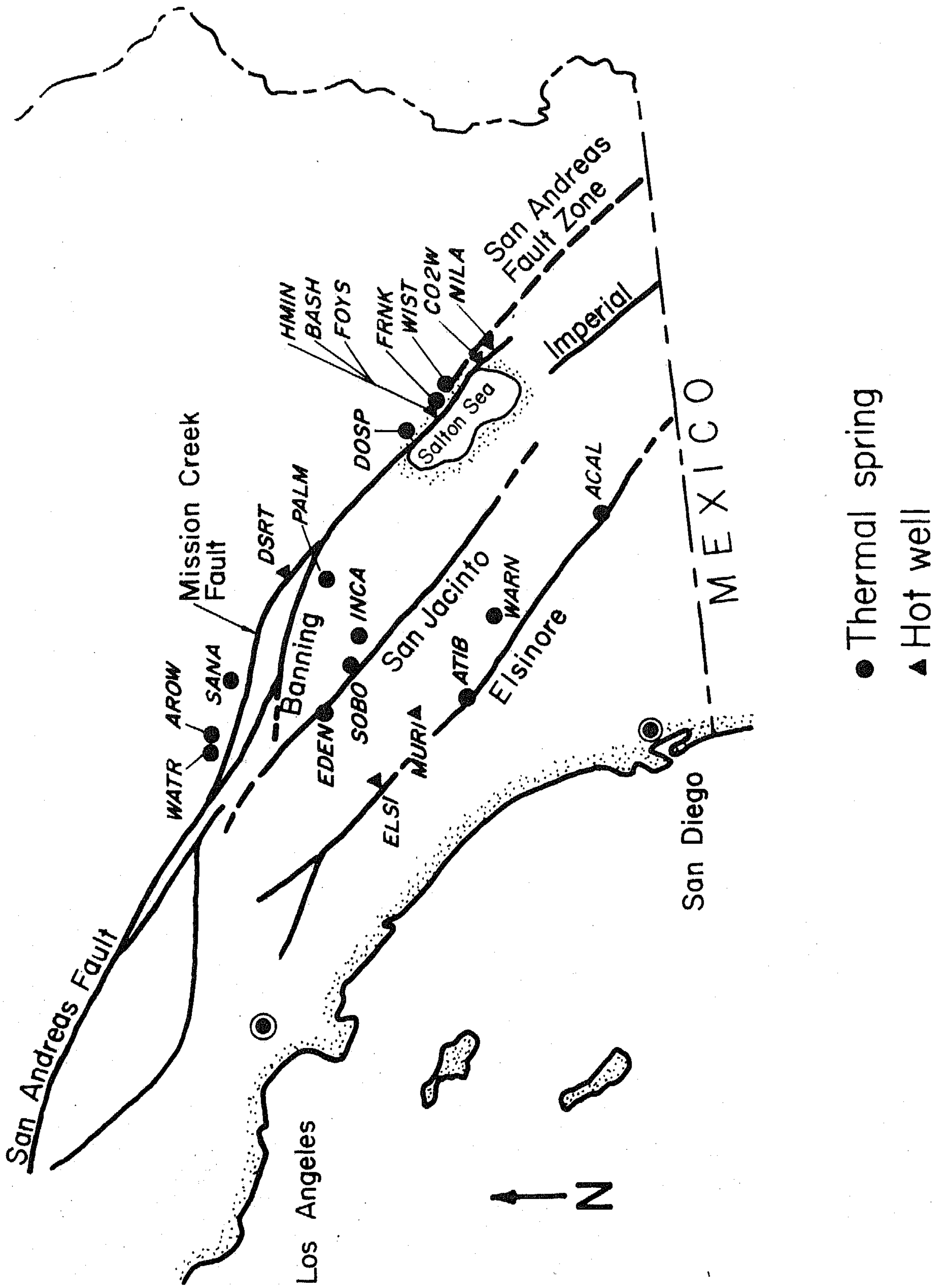

San Andreas Fault Zone
HMIN
BASH
FOYS
FRNK
WIST
CO2W
NILA
Imperial
Salton Sea
DOSP
Mission Creek Fault
DSRT
PALM
INCA
Banning
San Jacinto
WARN
ACAL
MEXICO
AROW
SANA
WATR
EDEN
SOBO
ATIB
MURI
Elsinore
ELSI
San Diego
San Andreas Fault
Los Angeles
N
Thermal spring
Hot well

Figure 1

TABLE 1: PRIMARY SAMPLING NETWORK

SITE CODE	LOCATION	TYPE	T°C	WARING NUMBER
	Elsinore Fault			
ELSI-1W	Elsinore Hot Spring	Well	40	169
MURI-1W	Murrieta Hot Springs	Well	54	170
ATIB-1W	Agua Tibia Springs	Well	38	178
WARN-1P	Warner Hot Springs	Pool	56	179
ACAL-1S	Agua Caliente, Borrego Park	Spring	38	180
	San Jacinto Fault			
EDEN-1P	Eden Hot Springs, Beaumont	Pool	38	172
SOBO-1P	Soboba Springs, San Jacinto	Pool	36	174
INCA-1P	Indian Canyon Springs, San Jacinto	Pool	36	
	San Andreas Fault (San Bernardino Area)			
AROW-1P	Arrowhead Hot Springs	Pool	80	162
SANA-1P	Santa Ana Canyon	Pool	41	163
	Mission Creek - Banning Faults			
DSRT-1W	Desert Hot Springs	Well	41	174-A
PALM-1P	Palm Springs	Pool	40	175
	San Andreas Fault (Imperial Valley)			
HMIN-1W	Hot Mineral Well, Salton Sea	Well	75	176-A
BASH-1W	Bashford's Baths, Salton Sea	Well	63	
FRNK-1P	Frink Spring, Salton Sea	Spring	31	
CO2W-1W	CO_2 Wells, Salton Sea	Well	40	

TABLE 2: SECONDARY SAMPLING NETWORK

SITE CODE	LOCATION	TYPE	T°C	WARING NUMBER
	Elsinore Fault			
MURI-1P	Murrieta Hot Springs	Pool	49	170
WARN-2P	Warner Hot Springs	Pool	53	179
WARN-3P	Warner Hot Springs	Pool	56	179
ACAL-2S	Agua Caliente, Borrego Park	Spring	37	180
ACAL-1P	Agua Caliente, Borrego Park	Pool	30	180
ACAL-2P	Agua Caliente, Borrego Park	Pool	31	180
	San Jacinto Fault			
EDEN-2P	Eden Hot Springs, Beaumont	Pool	32	172
	San Andreas Fault (San Bernardino Area)			
AROW-1W	Arrowhead Hot Springs	Well	80	162
	San Andreas Fault (Imperial Valley)			
DOSP-1P	Dos Palmos Springs, Salton Sea	Spring	28	176
FOYS-1W	Fountain of Youth, Salton Sea	Well	57	
WIST-1P	Wister Mud Pots, Salton Sea	Pool	16	
WIST-6P	Wister Mud Pots, Salton Sea	Pool	15	
NILA-2W	Niland Slabs, Imperial Valley	Well	42	

The well is close to the surface expression of the 1968 Borrego Mtn. earthquake, and samples groundwater at depths of 80 to 185 feet. Some plumbing modifications are required for sampling, which we hope to begin this year.

Sampling at Hot Mineral Well in the Imperial Valley (HMIN-1W) was discontinued after July, 1977, because of large irregular two-phase fluctuations caused by a plumbing modification. The large increases in helium and radon in July (Fig. 11) are due to unavoidable trapping of gas during water collection. We are continuing to inspect the well at monthly intervals in order to resume sampling if possible.

3. DISSOLVED HELIUM AND RADON MEASUREMENTS

The complete set of data on helium and radon in the liquid phase for each primary network site through September, 1977, is presented in Figures 2 through 13. As in the data tabulations, the sites are arranged from west to east by faults and from north to south along each fault (Figure 1). All radon measurements have been made on one-liter water samples collected in evacuated bottles, using alpha scintillation counters to count the radon stripped from the water samples in the laboratory.

Samples for helium analyses are collected in two types of containers, both designed to insure the integrity of the sample relative to helium leakage. Most samples are collected in duplicate in soft copper tubing in which 20-gram samples of water are sealed by pinching off the tubing with refrigeration clamps. The water sample is admitted to a vacuum line by rerounding one of the pinch-seals after connecting the tubing to the line and pumping out the air. The other type of sampler used is a 50 cc. evacuated flask made of Corning 1720 glass, a special glass of very low helium permeability, sealed with a two-way glass stopcock through which the inlet tubing can be flushed before admitting the sample to the flask. The evacuated flasks are used when sampling conditions are such that the hydrostatic or pressure head of a spring or well cannot be used to flush water through the copper tubes. Water from the flasks is admitted directly to the vacuum line through the inlet stopcock.

The helium analyses are made on the small portable mass spectrometer (the "sniffer") by measuring the peak height of He^4 after removing N_2, O_2, Ar, and other gases except neon on charcoal at liquid nitrogen temperature. The He-Ne mixture is pumped to a titanium getter and the spectrometer inlet by a small diffusion pump which is then closed off from the inlet prior to expanding the gases into the machine from a fixed volume. The spectrometer inlet is a Granville-Phillips variable leak which is kept at a fixed setting; pressure in the spectrometer is adjusted by the pump-out valve to the oil diffusion pump, which is adjusted to give reasonable peak intensities for a set of samples and standards. The standards are a set of three calibrated He-N_2 mixtures which span the helium concentration range from atmospheric to the highest values encountered in the networks. The samples are run alternately with appropriate sized standards, so that each sample is bracketed by two standards run with the same pump-out valve setting. The helium blank of this system is less than 0.05 x 10^{-6} ccSTP of helium, which corresponds to the helium contained in one gram of air-saturated water and is completely negligible for all samples except "CO_2 Wells" in the Imperial Valley, for which it amounts to about 3% of the sample at most. The overall precision of measurement with the laboratory inlet system is about 1 percent on replicates of standards.

In the following graphs of the helium measurements, the copper tubing samples, which are collected in tandem, are distinguished as "A1" (symbol = a circle) for the first tubing sample (closest to the source), and "A2" for the second sample (symbol = a triangle) in the pair. The samples collected in evacuated glass flasks are denoted by a hexagon symbol. The distinction between the A1 and A2 samples in the copper tubing collections is necessitated by the difficulties in sampling several of the hot wells by this method, namely ELSI-1W, MURI-1W, and ATIB-1W, on the Elsinore fault, BASH-1W in the Imperial Valley, and recently, with the installation of a modified pumping system, HMIN-1W in the same area. In these wells, the high pressure at the sampling point has necessitated the use of copper tubing samplers, even though errors in the helium sampling are caused by this procedure.

The sampling effect for helium is seen in Figures 2 and 3 for the three Elsinore Fault wells (ELSI, MURI, and ATIB), and in Figures 11 and 12 for the two Imperial Valley hot wells (HMIN and BASH). The A1 sample, first in line, is often (though not always) higher in helium content than the A2 sample collected second in line. In all these wells, the emerging fluid is in two phases, and the first copper tube tends to trap gas bubbles which, because of the extreme insolubility of helium, gives an erroneously high helium content. Recent experiments on some of these wells, in which we were able to collect samples in flasks as well as in copper tubes by modifying the sampling system have shown that the A2 samples agree much better with the larger flask samples, indicating an addition of He to the A1 sample, rather than loss from the A2 sample. (Some of these results can be seen in last helium collections at ATIB-1W, shown in Figure 3. Duplicate experiments, not plotted in the figure, show that the flasks give much more reproducible, and generally lower, helium concentrations than the tubes, and always agree better with the second tube when the two tubes give different results). It appears that accurate sampling of two-phase hot wells requires collection in evacuated containers in which the correct proportion of the phases can be obtained, and we are currently in the process of modifying the sampling systems so that this procedure can be routinely carried out in a safe way.

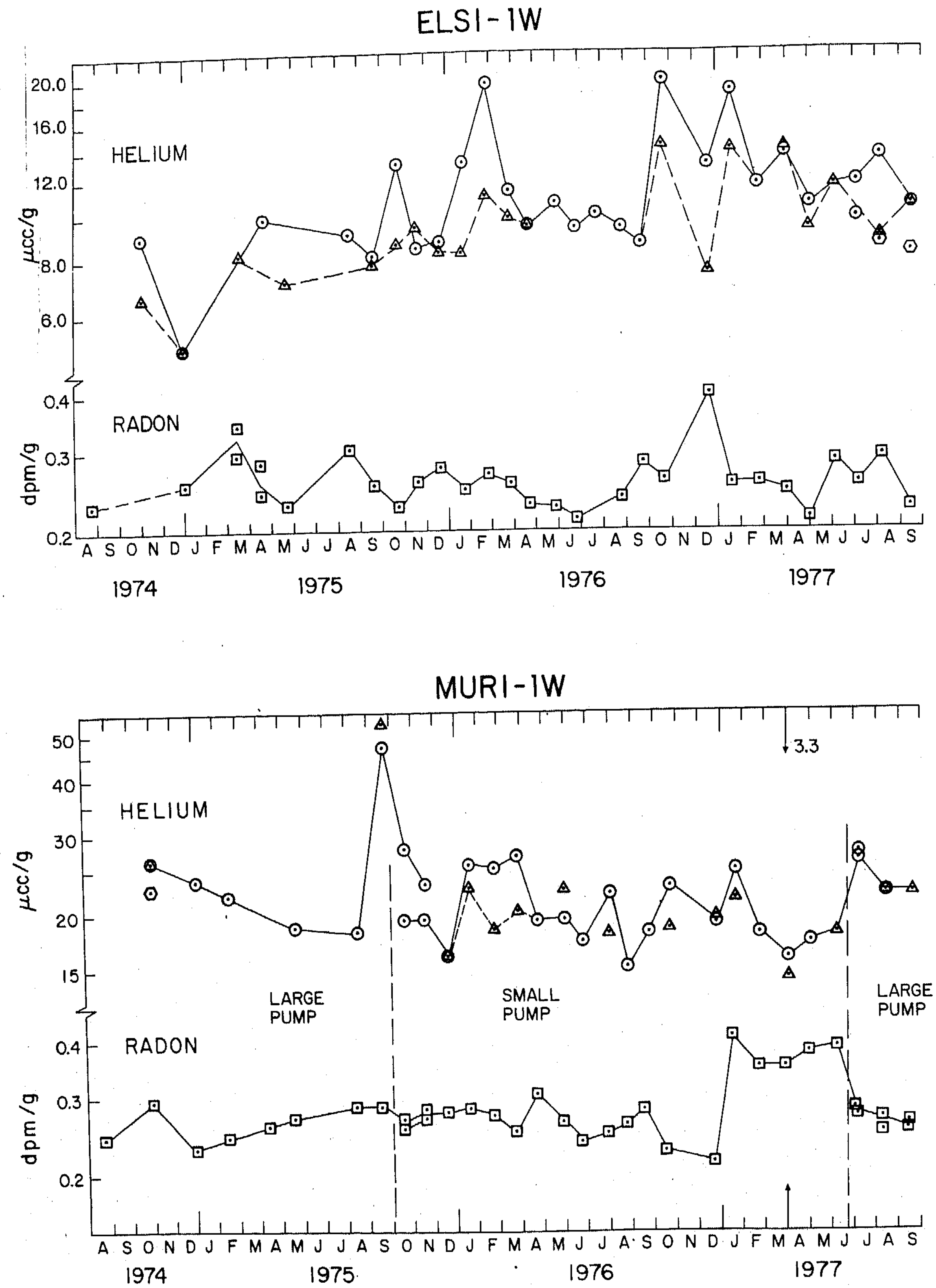


Figure 2 (Elsinore Fault)

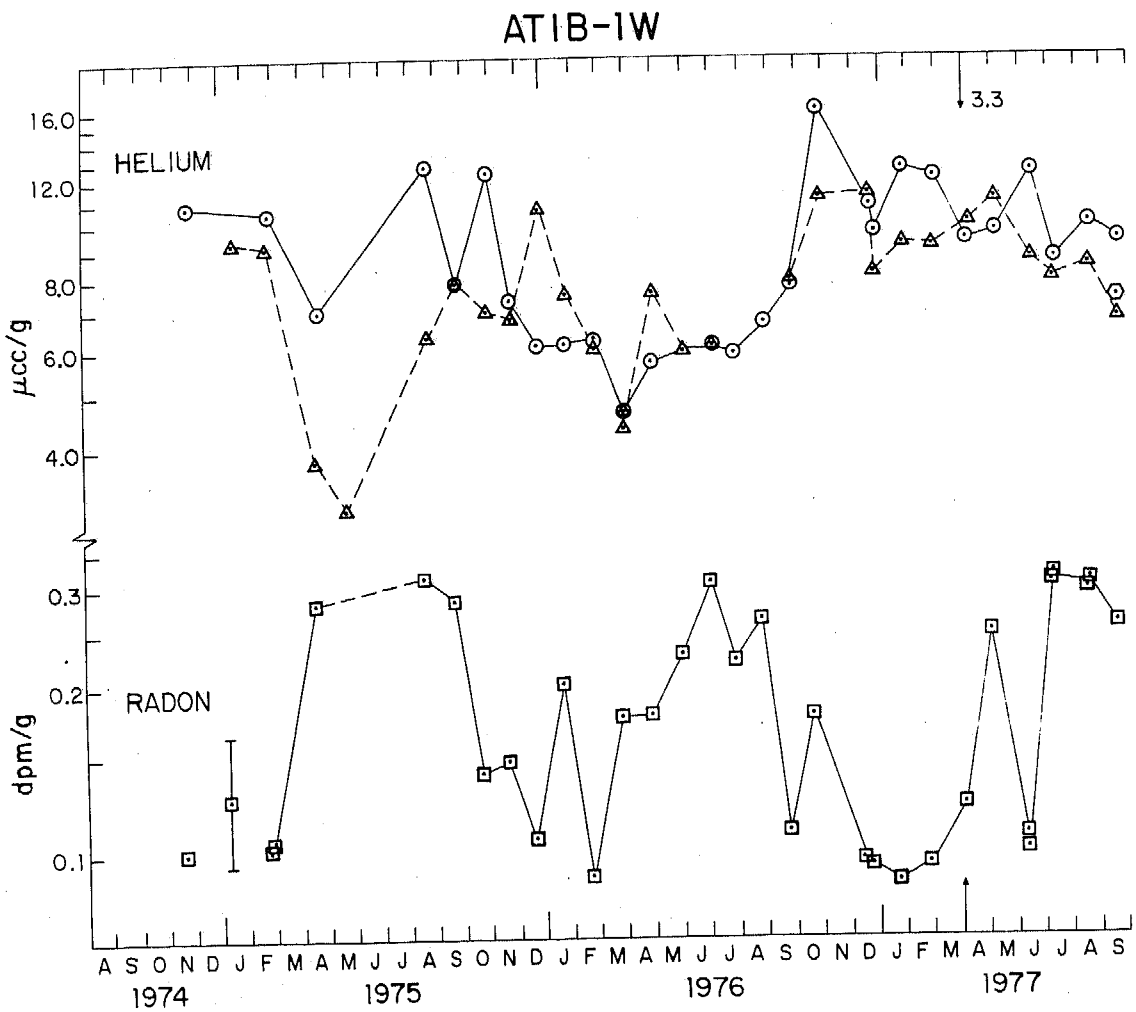


Figure 3 (Elsinore Fault)

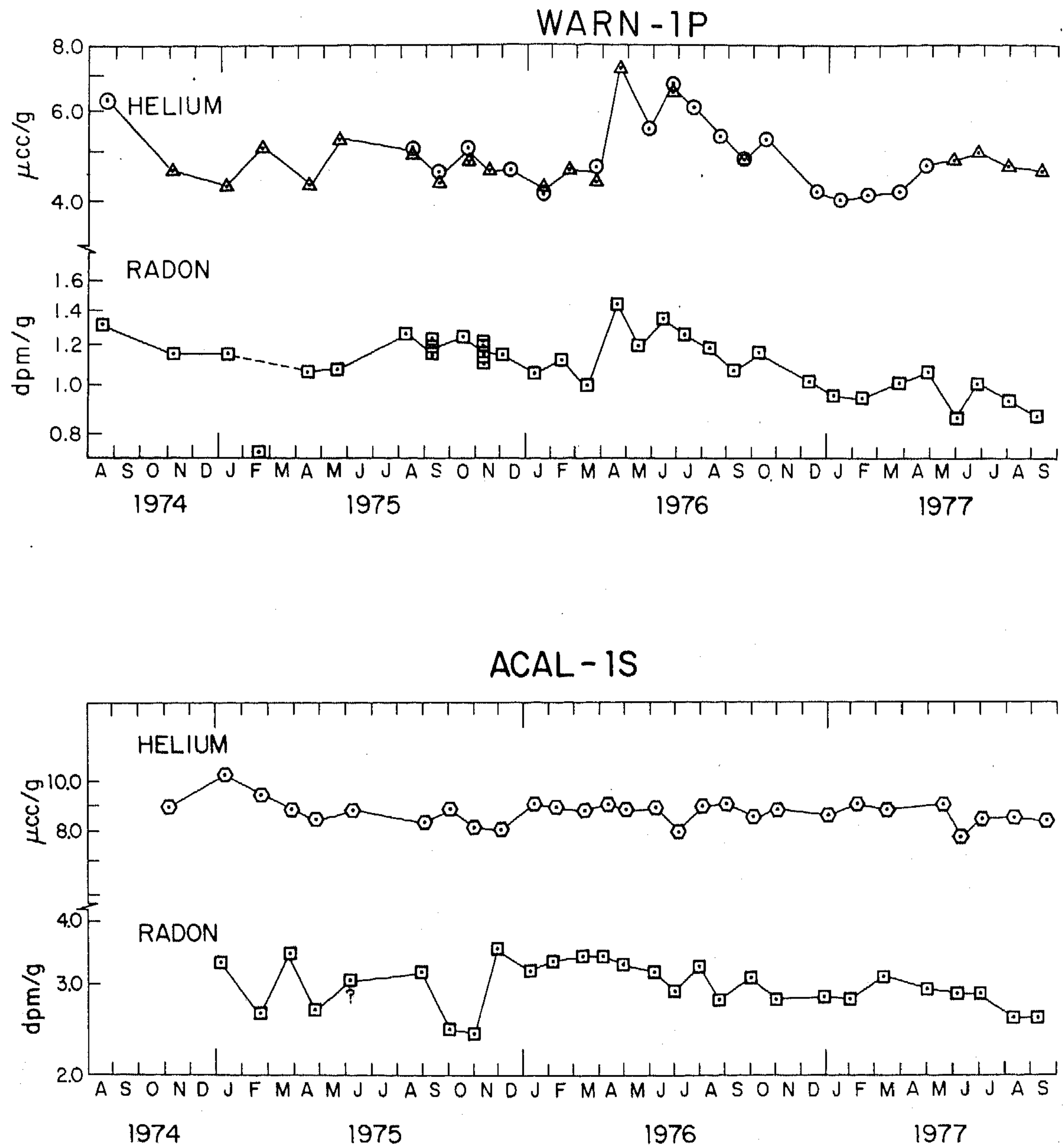


Figure 4 (Elsinore Fault)

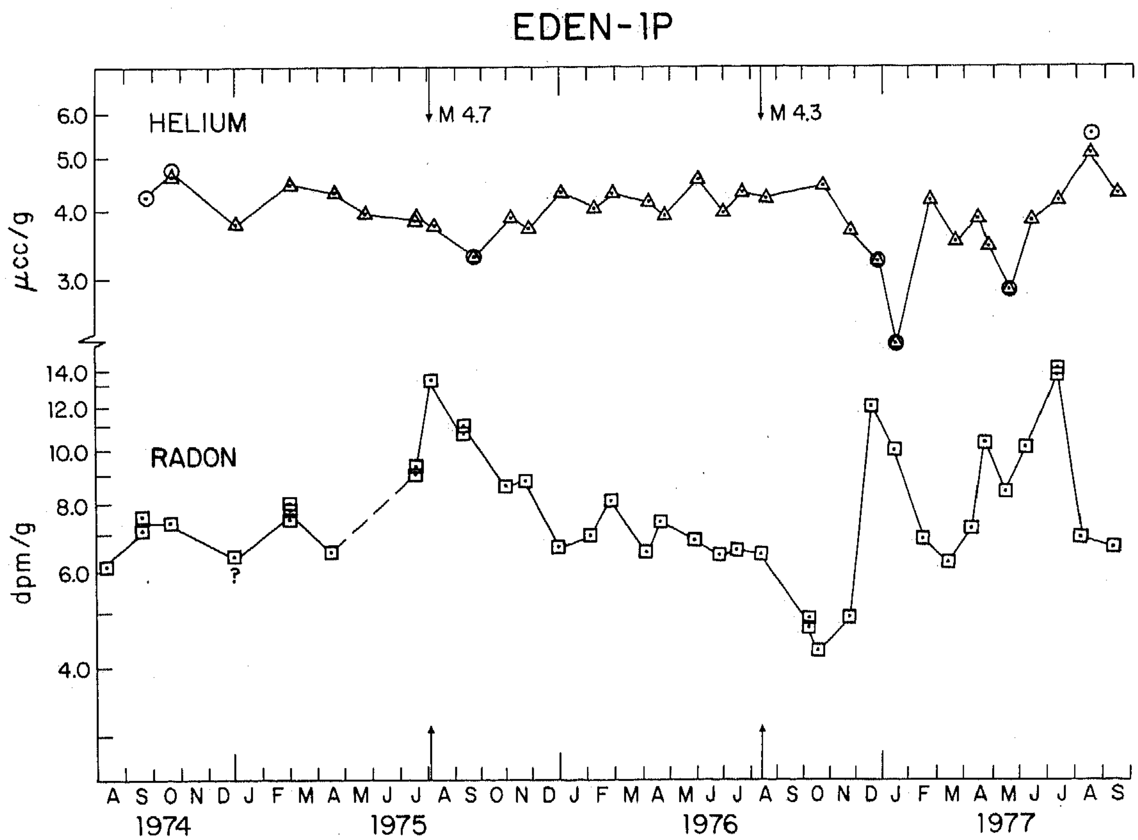


Figure 5 (San Jacinto)

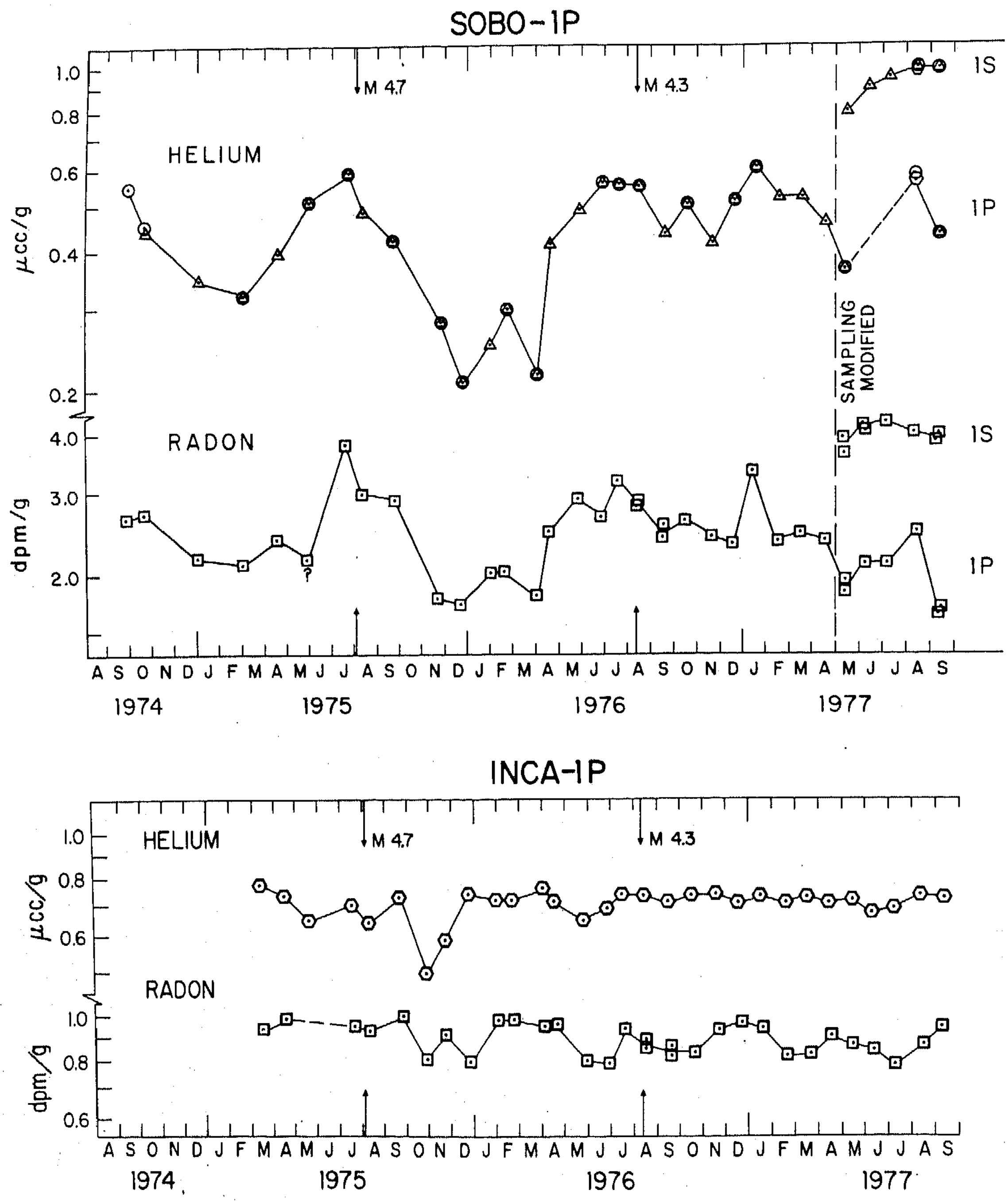
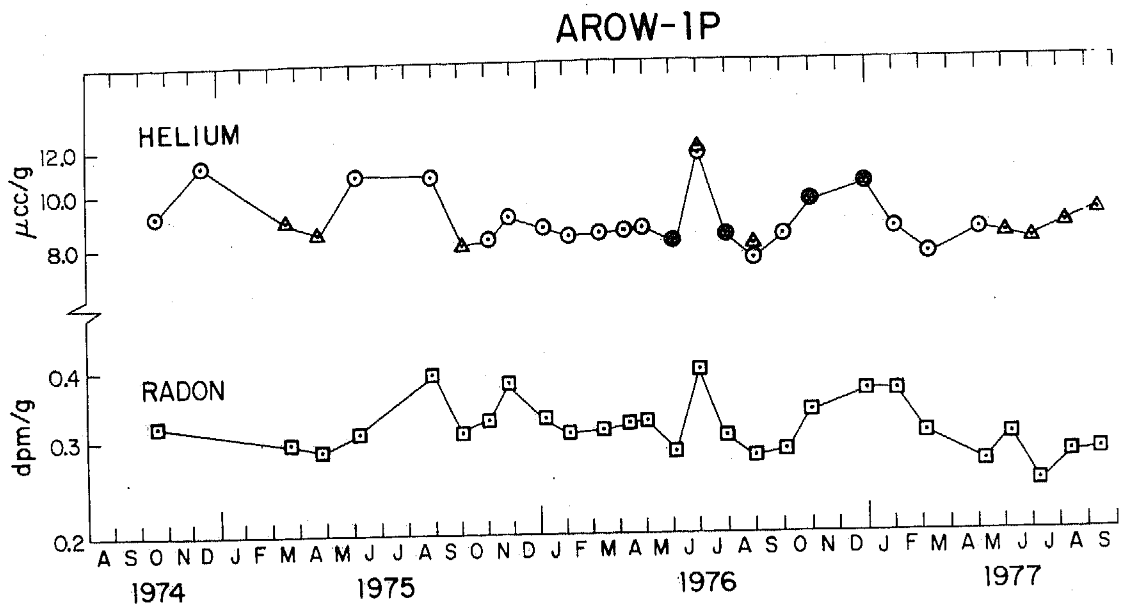


Figure 6 (San Jacinto)



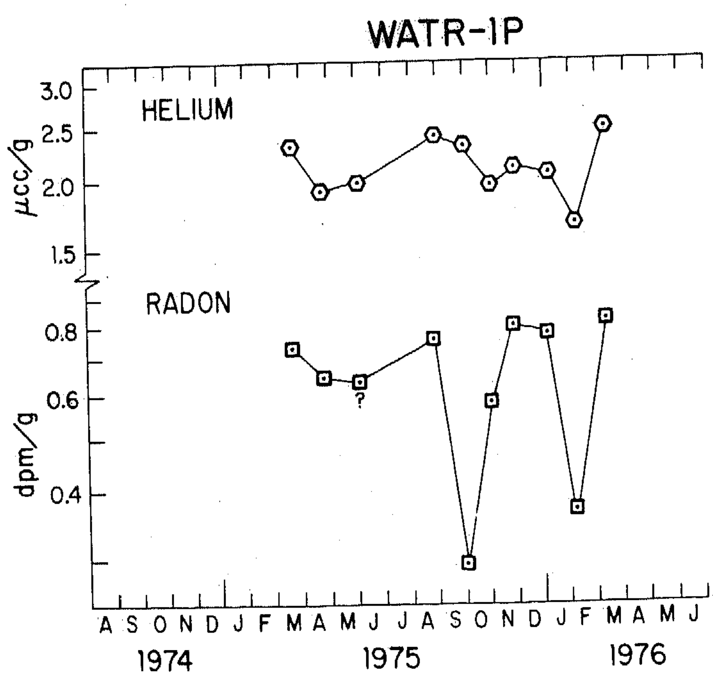


Figure 7 (San Andreas, San Bernardino area)

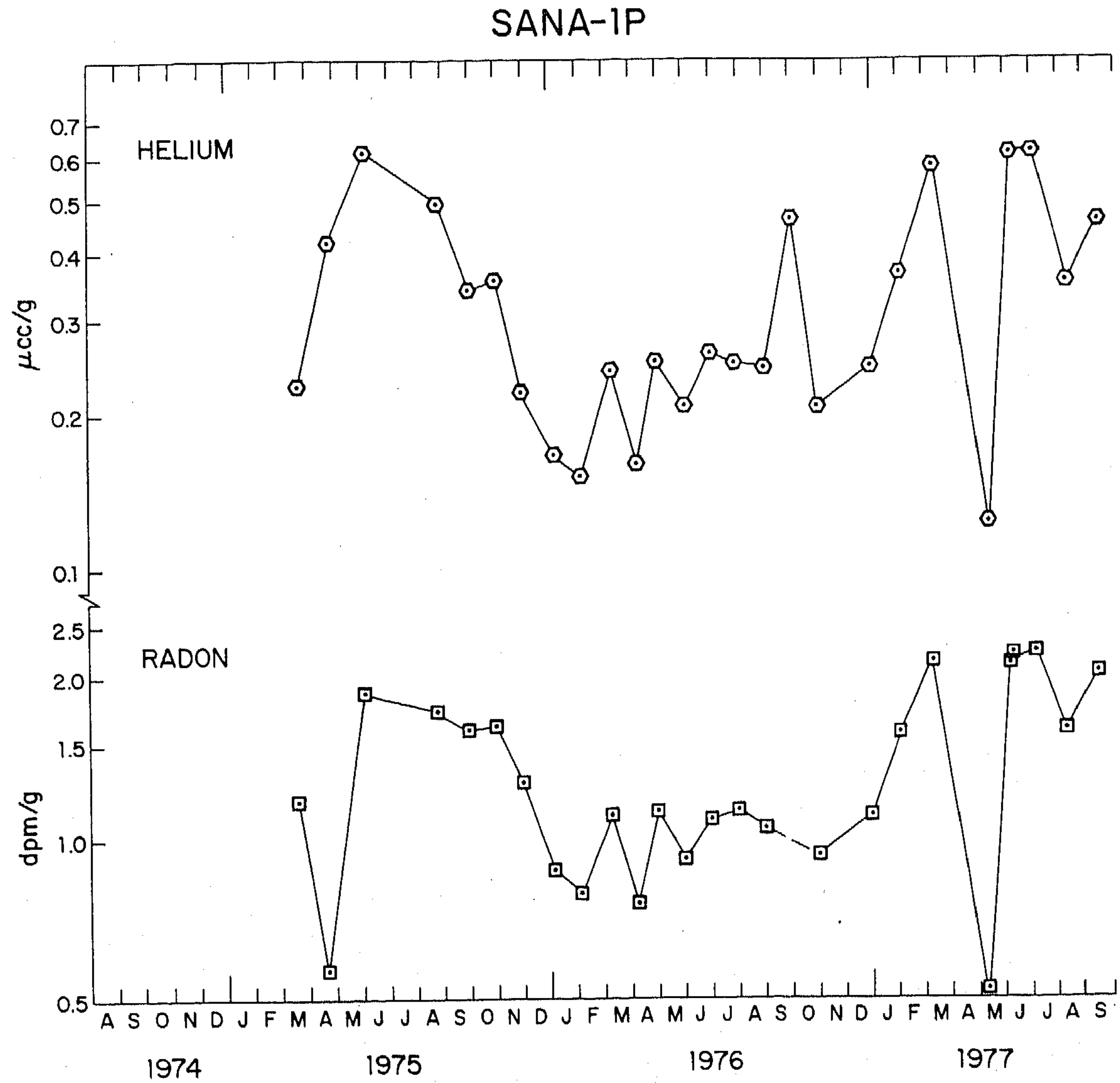
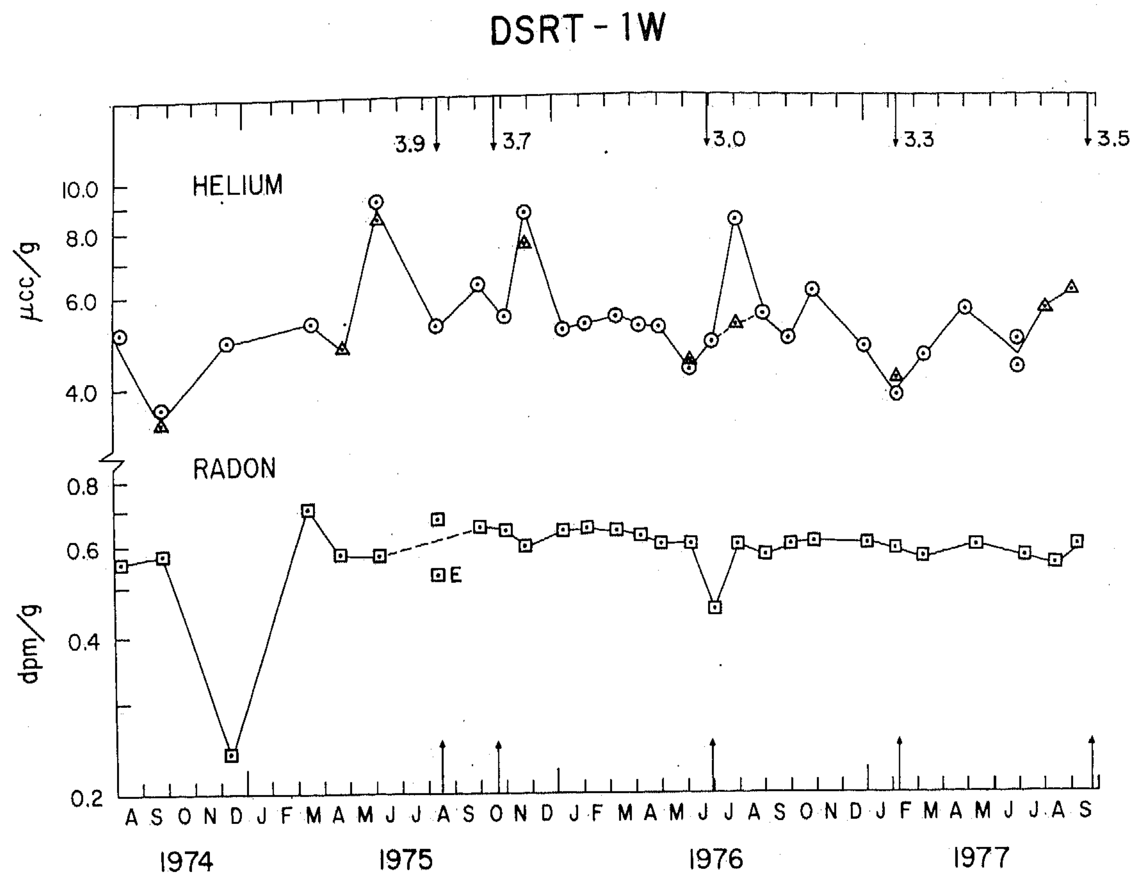


Figure 8 (San Andreas)



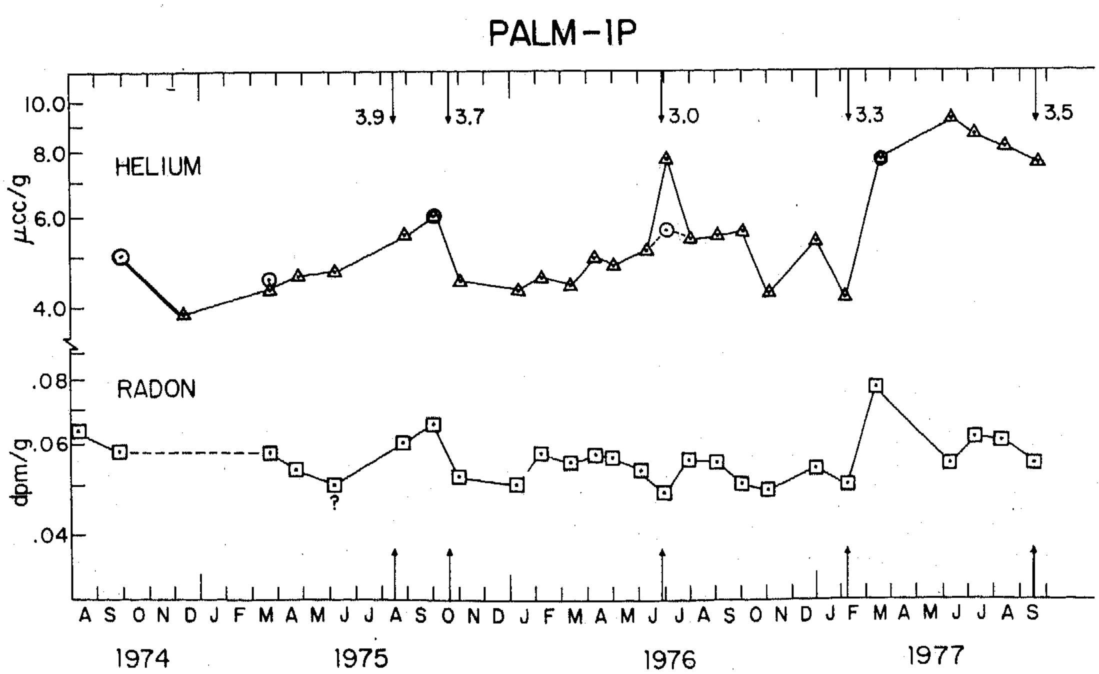


Figure 9 (Mission Creek - Banning Faults)

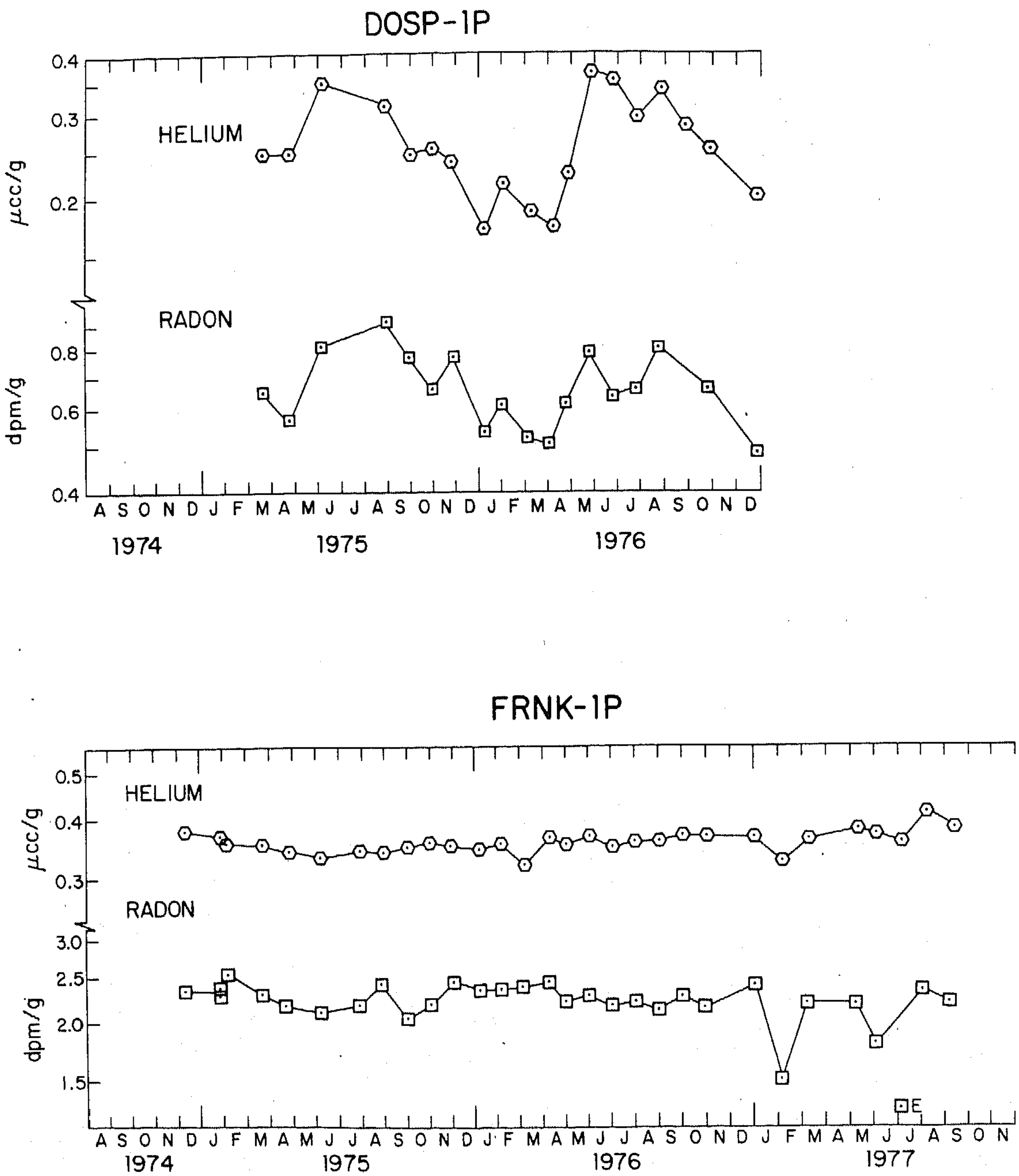


Figure 10 (San Andreas - Imperial Vallev)

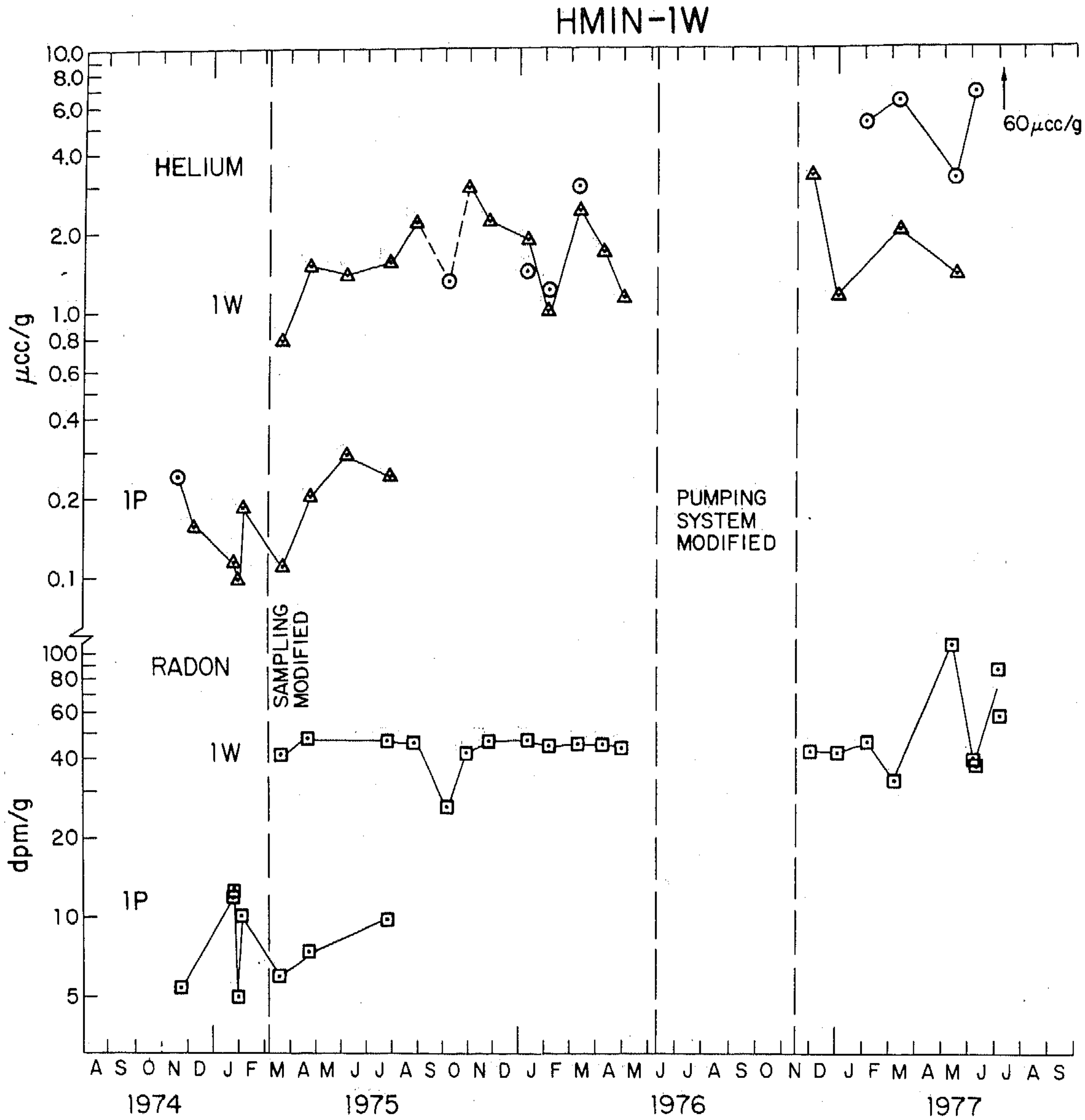


Figure 11 (Imperial Valley)

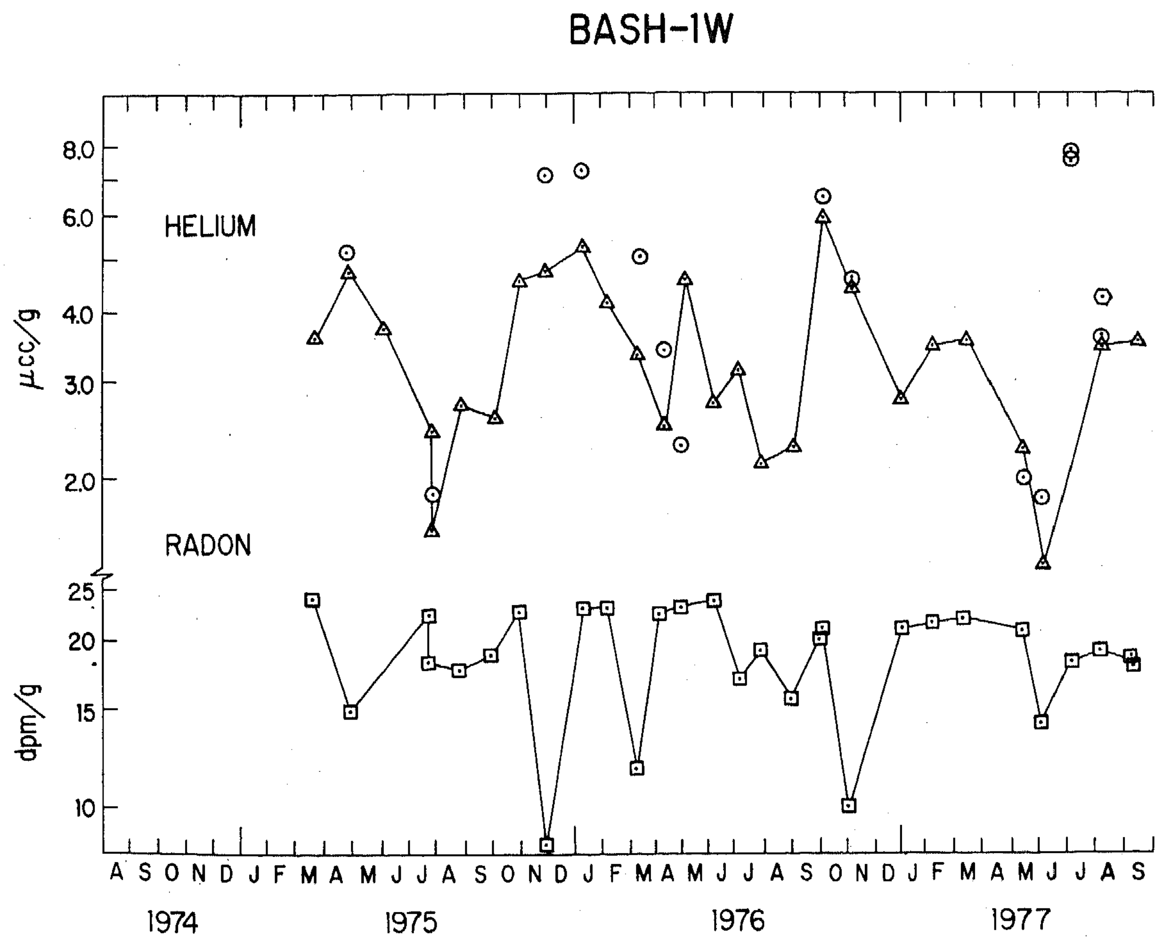


Figure 12 (Imperial Valley)

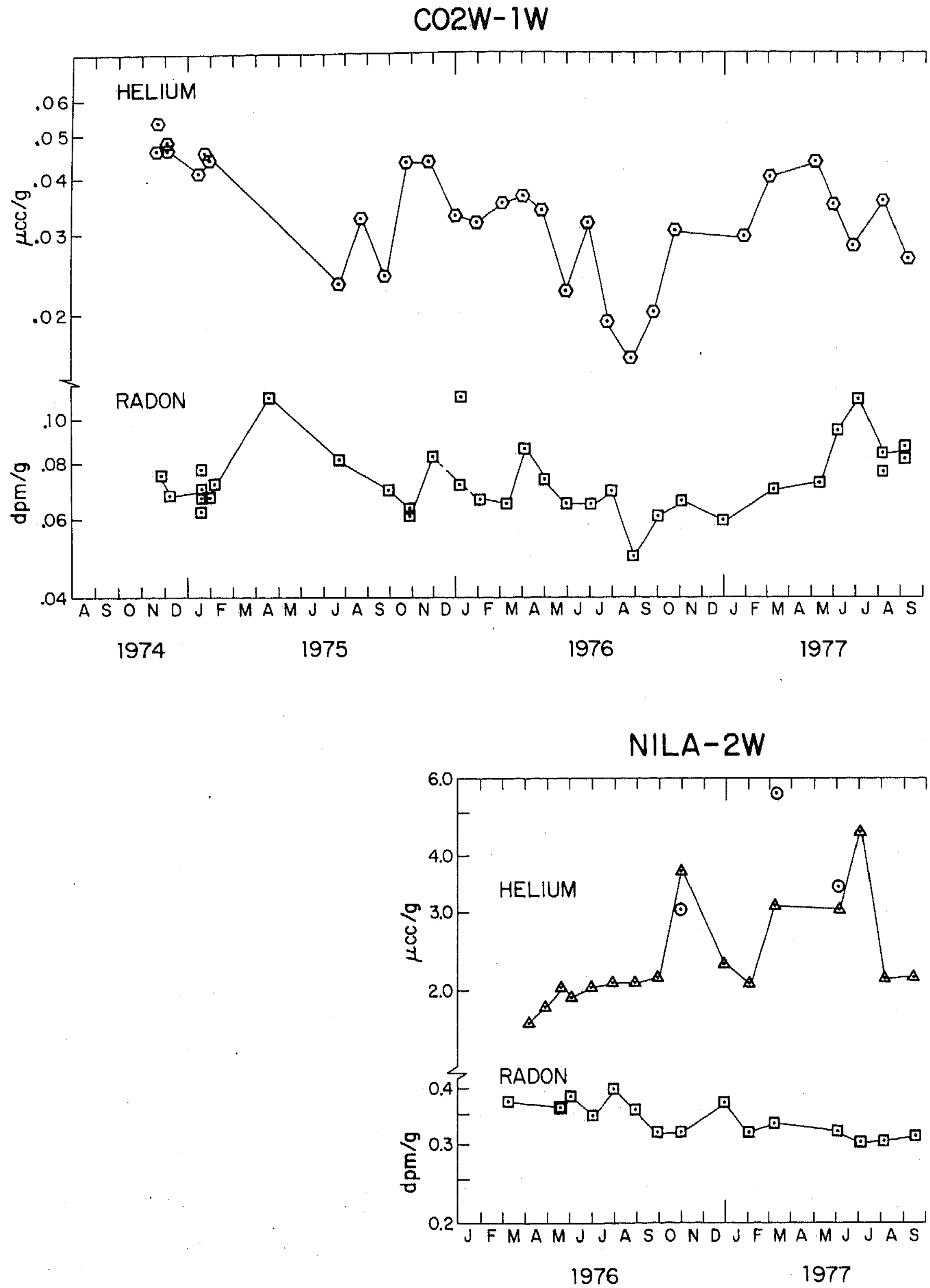


Figure 13 (Imperial Valley)

4. HELIUM AND RADON IN WELL SAMPLES

All of the wells in the Southern Network are geothermal wells, with temperatures ranging from about 40°C (Agua Tibia and CO_2 Wells) to approximately 70°C at Hot Mineral Well and Bashford in the Imperial Valley. All of these wells are two-phase systems and almost all of them are affected by variations in usage and occasional changes in pumping or plumbing systems, so that the establishment of a general baseline concentration is particularly difficult for helium. The best records have been obtained from Desert Hot Springs (DSRT-1W, Figure 9), and Murrieta Hot Springs (MURI-1W, Figure 2). The radon record from DSRT is remarkably uniform and does not correlate with the occasional helium concentration spikes which are probably two-phase effects. The one low radon value in December, 1974, is probably a sampling effect due to a collection method which was discontinued after that time because loss of gas phase was noticed in that sample. Several earthquakes of magnitude 3 to 4 have occurred near Desert Hot Springs; these events are marked in Figure 9 - they show no apparent correlation with radon or helium variations. The radon record at Murrieta Hot Springs is also uniform, except for an increased activity in the period January-June, 1977, which included a small earthquake of M=3.3 (Figure 2). Unfortunately this increased activity followed a one-month period between the December and January collections during which this resort was closed down and the well was not used. Well temperatures during February to June were about 4°C lower than normal, indicating that the well was not completely flushed to normal conditions until July of this year. The helium record at Murrieta is reasonably good as a baseline; the one high value late in 1975 is not understood, but may be correlated with a change in the pumping system (Figure 2).

The radon record at Agua Tibia shows a strong seasonal variation with a summer maximum occurring with great regularity (Figure 3). This well is almost completely unused from October to April when the streams are flowing (although it is flushed for our sampling). The main usage starts in May or June when the streams dry up, and this clearly results in the observed maximum due to the increased flow rate and shorter decay time. The lack of helium correlation may be due to variations in the gas loss, which occurs upstream in the flow system at a point where the well cannot be sampled.

The radon records at ELSI (Figure 2), and CO2W-1W and NILA-2W (Figure 13), are also reasonably good, but the helium records in these wells are more severely affected by sampling problems. NILA-2W is a new well, drilled in March of 1976; it has shown a steady decline in radon activity and irregular helium fluctuations which appear to be real. CO2W, also in the Imperial Valley, is an usused well with a broken casing through which both gas and water emerge. There are observable variations in the gas flow which are associated with some of the variability in the radon and helium records; for example, increased gas loss was noted in September of 1976, and the radon decrease with a corresponding much greater effect for helium (due to its greater partitioning into the gas phase) is clearly correlated with this fluctuation.

The most difficult wells to monitor systematically are the two high-temperature wells in the Imperial Valley: HMIN-1W (Figure 11) and BASH-1W (Figure 12). Hot Mineral Well (HMIN-1W) has been severely affected by pumping system modifications; there are large cavitation effects resulting in uncontrollable gas slugs at the sampling orifice. Sampling of this well was discontinued this year when the helium content suddenly increased by an order of magnitude and the two samplers began to give different results (Figure 11). However, we continue to examine the well monthly and it is hoped that conditions in the well may stabilize with the continued usage of the new pumping system.

5. HELIUM AND RADON IN SPRING SAMPLES

Ten springs have been monitored continuously on the Southern Network; an eleventh - Waterman Hot Springs - was sealed off early in 1976 after a one-year record had been obtained. All of these are "hot springs" in the sense of exhibiting temperatures greater than ambient air temperatures; the temperatures range from 31°C (at Frink Spring) to 80°C at Arrowhead Hot Springs. In general these springs give much better records than the hot wells because the two-phase separation effects - when present - tend to take place more smoothly and consistently, and the usage effects are less important.

Spring monitoring sites are distinguished by an "S" in the label if the emerging source water is sampled directly (ACAL-1S), or a "P" (INCA-1P) if sampling is done from a pool fed by an underground source. The helium and radon records are plotted on a logarithmic scale in Figures 2 to 13 so that the fractional variations are directly comparable. For gas-loss effects, the fractional helium loss is expected to be an order of magnitude greater than the radon loss, because of the much greater insolubility of helium and consequent greater partitioning into the gas phase. One of the most significant findings of the present results is that, in general, the variations in these two gases have approximately the same percentage fluctuation, indicating a more-complicated effect. This effect is being studied by means of measuring the associated nitrogen and argon fluctuations, and the first results of this work are described in the following section.

Five of these springs show reasonably constant baseline levels for one or both components. ACAL-1S (Figure 4) shows a remarkably steady helium concentration over three years; the radon record is irregular during 1975 (some bubbling was noted in this normally single-phase spring from August to November of that year), and shows a steady monotonic decrease of radon activity since November, 1976. INCA-1P (Figure 6) also shows a very steady helium record with minor radon excursions about a constant baseline. (This is a two-phase spring in which gas loss occurs; it is also affected by usage. The single low helium value in late 1975 is associated with an exceptionally low water level). AROW-1P (Figure 7), another two-phase spring shows minor fluctuations in which the radon and helium variations are well-correlated and represent approximately the same fractional variations despite the order of magnitude difference in gas-phase partitioning (this effect is discussed in the following section). PALM-1P (Figure 9) shows a fairly steady radon activity but an irregular helium record with "sawtooth" autumn maxima in 1975 and 76, and an increased helium level thereafter. Several earthquakes of magnitude 3 to 4 have occurred north of Palm Springs on the Mission Creek fault (these are shown in Figure 9) and the helium records may be affected by these events, but the irregular record during the present year precludes any definite conclusion. Finally FRNK-1P in the Imperial Valley gives an excellent steady baseline for both helium and radon (Figure 10); the one low radon measurement (February, 1977) is associated with a sampling effect in which bubbles were lost in a sampling valve while drawing the radon sample.

Two of these springs show remarkable periodic or seasonal variations; in both cases the radon and helium variations are well-correlated and show the same fractional excursion. SANA-1P (Figure 8) shows a remarkable two-year periodicity with correlated radon and helium maxima in the summers of 1975 and 1977, but broad minima during 1976. DOSP-1P in the Imperial Valley (Figure 10) shows a very pronounced summer maximum in both helium and radon during 1975 and 1976, obviously related to recharge and flow rates. This low-temperature and low-He^3 spring is no longer being monitored continuously, but occasional spot checks for variations relative to this pattern will be made.

The remaining three springs show irregular variations which are probably related to irregular usage patterns. Warner Hot

Springs (WARN-1P, Figure 4) showed a rapid increase in both components in April, 1976, at a time when the water level dropped to the lowest level ever observed by us. Since then there has been a steady decrease in radon to activities less than those observed prior to this event, associated with a helium decrease to the previous baseline concentration. EDEN-1P (Figure 5) and SOBO-1P (Figure 6), on the San Jacinto fault, have shown radon variations which, as described in previous reports, have been associated with one or both of two earthquakes of magnitude 4.7 and 4.3 about 20 miles south of these springs on the fault in August of 1975 and 1976. At EDEN-1P (Figure 5), a radon peak was associated only with the 1975 event. The helium record shows no correlation with either earthquake, but does indicate a decrease in January, 1977, which may be associated with a nearby earthquake of M=3.0 during that month. The record in this spring, however, is highly irregular due to variable usage. The inhabitants moved away in September, 1976, and since then the level has fluctuated very irregularly due to occasional usage by neighbors. We are continuing to monitor the spring because of the exceptionally high radon activity at this site, but unless regular usage of the water is resumed the record will probably not be very reliable.

At nearby SOBO-1P on the San Jacinto (Figure 6), the record prior to 1977 indicates a seasonal summer maximum in both helium and radon, similar to the regular oscillation observed at DOSP-1P. However, the levels did not decrease in late 1976, and the 1977 record has been complicated by installation of a new sampling system upstream of the pool, and by a shut-down of the institution during which the pool has been completely drained, in September 1977. (The upstream sampling point, designated SOBO-1S in Figure 6, shows significantly higher radon and helium concentrations). In January of this year, a period of low water usage prior to the September closing began, and the irregular usage may have affected the record since the summer of 1976. We have gone to considerable effort to install an integrating flowmeter at this site, so it is hoped that regular usage and normal conditions will be re-established in the near future.

In general, these springs are providing reasonably good baseline records for helium and radon. Only two earthquakes of magnitude greater than 4 have occurred anywhere near these sites (the two San Jacinto events 20 miles south of the three sites on this fault), and no clear associations with any earthquakes have yet been seen. In the meantime, however, the baseline values have been established, and considerable progress in understanding the nature of the radon and helium variations which have been observed is being made, as described in the following section.

6. HELIUM-ARGON-NITROGEN CORRELATIONS

In order to study the processes responsible for the observed helium and radon fluctuations it is necessary to look at variations in associated "conservative" gases which are generally not strongly influenced by addition to groundwater from rocks. Ar^{40} is of course a radiogenic daughter of K^{40}, so that one may expect a slight addition of argon associated with helium to the initial argon content of the water, and nitrogen may be produced by bacterial activity, but these effects should be small because of the high atmospheric concentrations of these two gases. (Measurements of the Ar^{40}/Ar^{36} and N^{15}/N^{14} ratios in these gases are planned in order to elucidate these effects). During the extraction process for helium on the portable mass spectrometer vacuum line, N_2 and Ar in the water samples are quantitatively trapped on charcoal at liquid nitrogen temperature. These gases are then transferred to a glass breakseal tube containing charcoal, and analyzed separately on a gas chromatographic system constructed for this purpose during the past year. Although time does not permit N_2 and Ar analysis of all samples collected, we are currently analyzing from half to one-third of the samples in the complete collection, concentrating on those which are associated with major helium variations. At present we have a detailed N_2-Ar record for Arrowhead Hot Springs (AROW-1P) and partially complete data on seven other springs. (The accumulated data will be included in the "geochemical parameter" list beginning with the next report). We here discuss primarily the AROW-1P data which have yielded considerable insight into the nature of the radon and helium fluctuations, which are well-correlated in this spring (Figure 7).

In Figure 14 the dissolved helium and nitrogen concentrations at AROW-1P are plotted against the dissolved argon concentration. The N_2-Ar data form a linear array (r=0.95) which lies below the atmospheric N_2-Ar solubility curve (dashed line), on the "Ar-rich" side of the curve. These samples thus appear to represent a two-component mixture, in which the high-gas concentration, or "input component" does not, however, lie on the original surface water solubility curve. This may be due to an approximately 10% enrichment of Ar^{40} by radiogenic Ar addition underground, or it may represent an input component which has suffered some loss of a gas phase by bubble separation. The trajectory for a solution phase losing gas at 80°C from an initial point on the atmospheric solubility equilibrium curve at 15°C, 0.92 atm (total pressure at the spring elevation) is shown by the "gas loss" curve in the upper right part of the diagram; the solution is enriched in argon by this process because nitrogen, being less soluble, is preferentially lost. An Ar^{40}/Ar^{36} analysis will ultimately decide between these mechanisms, but since gas loss by bubbles is actually observed in the spring, we have chosen to represent the "input component" as water which has been partially stripped of gas by two-phase separation.

(Assuming the initial saturation to have occurred at 15°C, 0.92 atm pressure, and single-stage gas stripping at 80°C, the spring input temperature, the parameter "psi", which is the ratio of gas flux to liquid flux out of the spring can be calculated; the value defined by the intersection of the loss curve with the observed

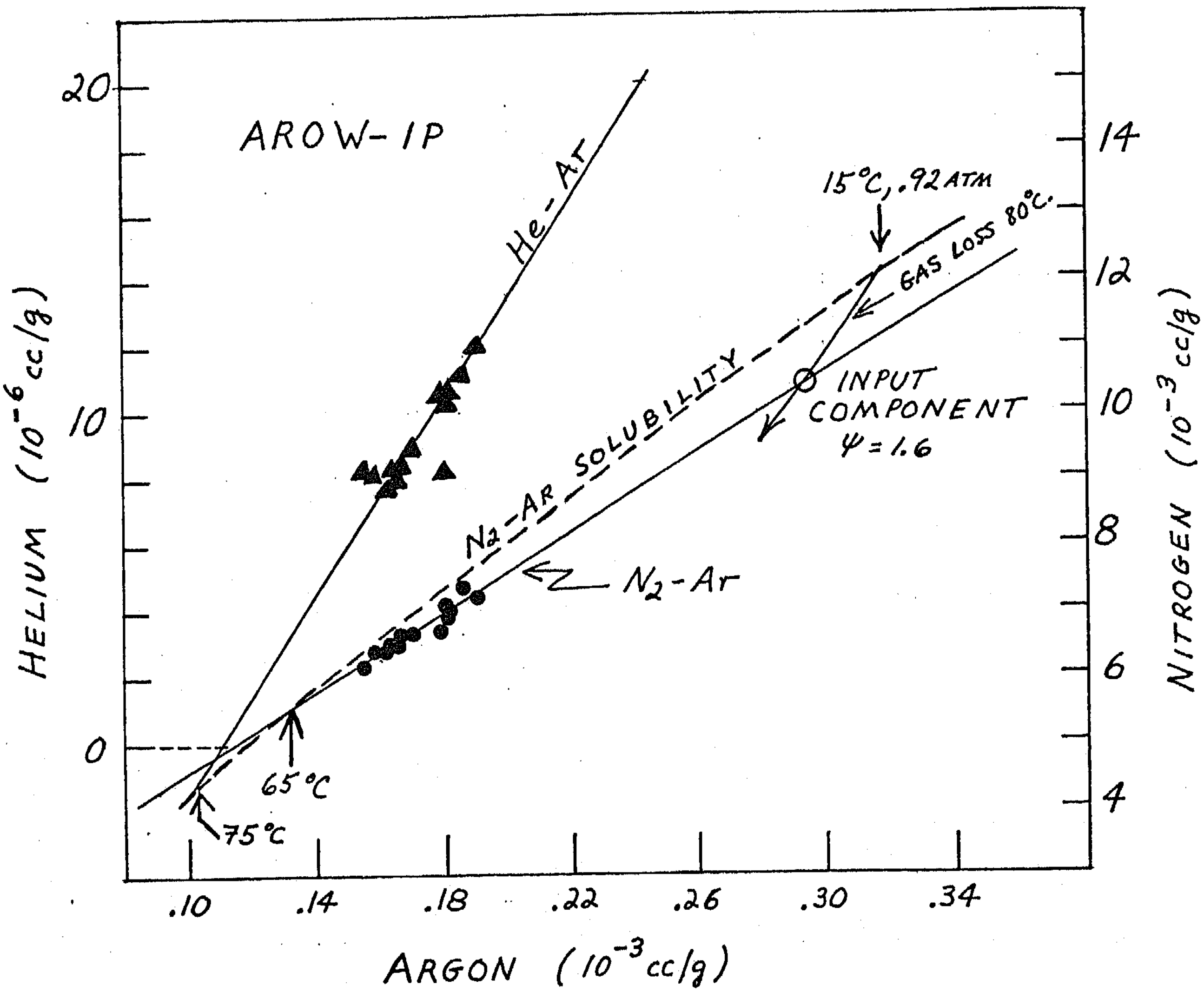


Figure 14. Helium and Nitrogen vs. Argon at AROW-1P.

N_2-Ar array is 1.6 ccSTP of total gas/liter of water. A crude measurement of these fluxes, made by Horowitz, gave 25 ccSTP/minute of gas flow vs. approximately 19 liters/minute of water flow, which corresponds to a value of 1.3 ccSTP/liter of water, in good agreement with the required value. Thus the fixing of the input component by the gas-loss process is entirely consistent with the data).

The most significant aspect of the N_2-Ar array, however, is the intersection with the atmospheric solubility curve at the approximate temperature of the surface water in the hot spring. There is a temperature gradient in this spring, with high temperature (80°C) at the bottom of the artificial pool fed by the upwelling spring, and lower temperatures at the surface. The gradient has been measured only once, during very high winds which caused considerable stirring; the observed near-surface temperature was 77°C. The actual intersection point in Figure 14 is only 65°C, but the difference is within the precision with which the solubility curve is known at these temperatures and the precision with which the slope of the N_2-Ar array is defined. Thus the second "component" defined by the array is water which is saturated with N_2 and Ar at approximately the surface temperature of the spring itself. The N_2-Ar variations therefore reflect varying degrees of mixing between the "input component", i.e. the heated groundwater originally saturated with gas under atmospheric conditions and partially stripped of gas by bubble separation during flow into the spring enclosure, and a "high-temperature equilibrium" component produced by re-equilibration with the atmosphere in surface water of the spring.

The He-Ar array for these samples is strikingly in accord with this model. As shown in Figure 14, the array is linear, and the helium concentration goes to zero (or the atmospheric equilibrium value of about 0.03×10^{-6} ccSTP/gram) at almost exactly the Ar concentration at which the N_2-Ar mixing line intersects the solubility curve. The helium loss by dilution with the "high-temperature equilibrium" component is of course much greater than the loss of N_2 and Ar because of the very low atmospheric concentration of helium (5 ppm). The same effect also applies to radon because of the low atmospheric radon concentration relative to the radon concentration in the spring.

This model thus accounts completely for the fact that radon and helium in the spring samples are well-correlated, with the same fractional variations in concentration (cf. Figure 7), due to the fact that the equilibrium component has essentially zero concentration of both gases. In this particular spring, we are observing only 25% of the original helium concentration in the input fluid before gas separation occurs. From the solubilities and the observed data, we find that there is an initial loss of 15% of the original helium due to the gas-phase separation, and a further 60% loss by dilution with the water which has exchanged with the atmosphere. The original helium content of the water is thus found to be about 32×10^{-6} ccSTP/gram, about 4 times the observed "baseline" value of 8×10^{-6}.

Nitrogen-argon measurements on other springs have not yet been completed, but the partial data for the following spring sites: ACAL-1S, EDEN-1P, INCA-1P, SANA-1P, PALM-1P, and DOSP-1P, all show the same effect of dilution with a high-temperature solubility equilibrium component, indicated by the intersection of the N_2-Ar array with the atmospheric solubility curve at the observed spring temperature, with a similar effect for the helium vs. argon dilution line. The two-component model thus appears to have general validity for a wide range of spring types, and to account for the frequent observation of similar fractional helium and radon variations in these springs.

It is apparent that these gas-loss and two-component dilution effects serve to reduce considerably the amplitude of possible precursory effects related to seismic activity. This is especially true in springs such as DOSP-1P (Figure 10) and SANA-1P (Figure 8) which exhibit periodic oscillations. The N_2-Ar data for these two springs are very well correlated with each other and with helium and radon; the "high-temperature" (28°C and 38°C) equilibrium component is at a maximum in winter at DOSP, and during 1976 at SANA, and the periodic fluctuations in helium and radon are entirely due to alternations between extreme values of the two components. At Dos Palmos, the "input component" is not depleted of N_2 and Ar, but instead is enriched in N_2 relative to original low-temperature atmospheric solubility. This is also true of ACAL, INCA, EDEN, and PALM, all of which are "N_2-rich" waters relative to the solubility curve, in contrast to AROW, SANA, and WARN, which are "Ar-rich". We expect that further studies involving isotopic measurements on argon and nitrogen will enable us to determine the reasons for these differences in input components, which in turn will help us understand the intrinsic relationship between radon and helium in these springs. For example, the excellent correlation between radon and helium at the WARN, AROW, SANA, and DOSP network sites, all of which obey the two-component model, probably indicates that radon and helium at these sites are derived from single sources. On the other hand, there is a complete lack of correlation between helium at Eden Hot Springs and Agua Caliente where the He-N_2-Ar relationships also obey the model (He goes to zero concentration at the N_2-Ar intersection with the solubility curve at 35°C). In this case the radon is probably derived from a different source than the helium, and its concentration does not depend on fluctuations in the proportions of the two components.

7. SOIL RADON (By D. Macdougall)

There has been evidence for long-distance radon movement within the earth for many years (see Tanner 1958, 1964). Short term fluctuations related to meteorological factors are well-known; long term patterns have been related to uranium bearing ore bodies (Weidenbaum et al., 1970; Gingrich, 1975; Mogro-Campero and Fleischer, 1977) and to the stresses associated with seismic activity (Sadovsky et al., 1972; King, 1976). Because of the short half life of radon 222 (3.8 days), these latter observations imply relatively rapid (convective?) transport of radon gas through permeable soil and rock matrices.

We report here measurements of gas phase radon monitored at the eight sites shown in Figure 15. An additional three test sites in La Jolla, away from active fault traces, have been monitored for seasonal variations. Details of the experimental procedure, and discussions of earlier results were included in previous reports (Technical Reports Nos. 5 and 6). Kodak alpha sensitive cellulose nitrate (CA80-15) was used as the detector for all measurements. Only alpha particles with energy $\lesssim$ 4 MeV are recorded as tracks. Thus daughter products adsorbed on the surface of the plastic, as well as uranium-bearing dust particles, will not produce extraneous tracks. Based on calibration experiments with a ^{208}Po source, reproducibility of count rate in this material is excellent. Moisture does not affect the detection characteristics, except for the case of actual water droplets condensed on the film, which reduce the surface area

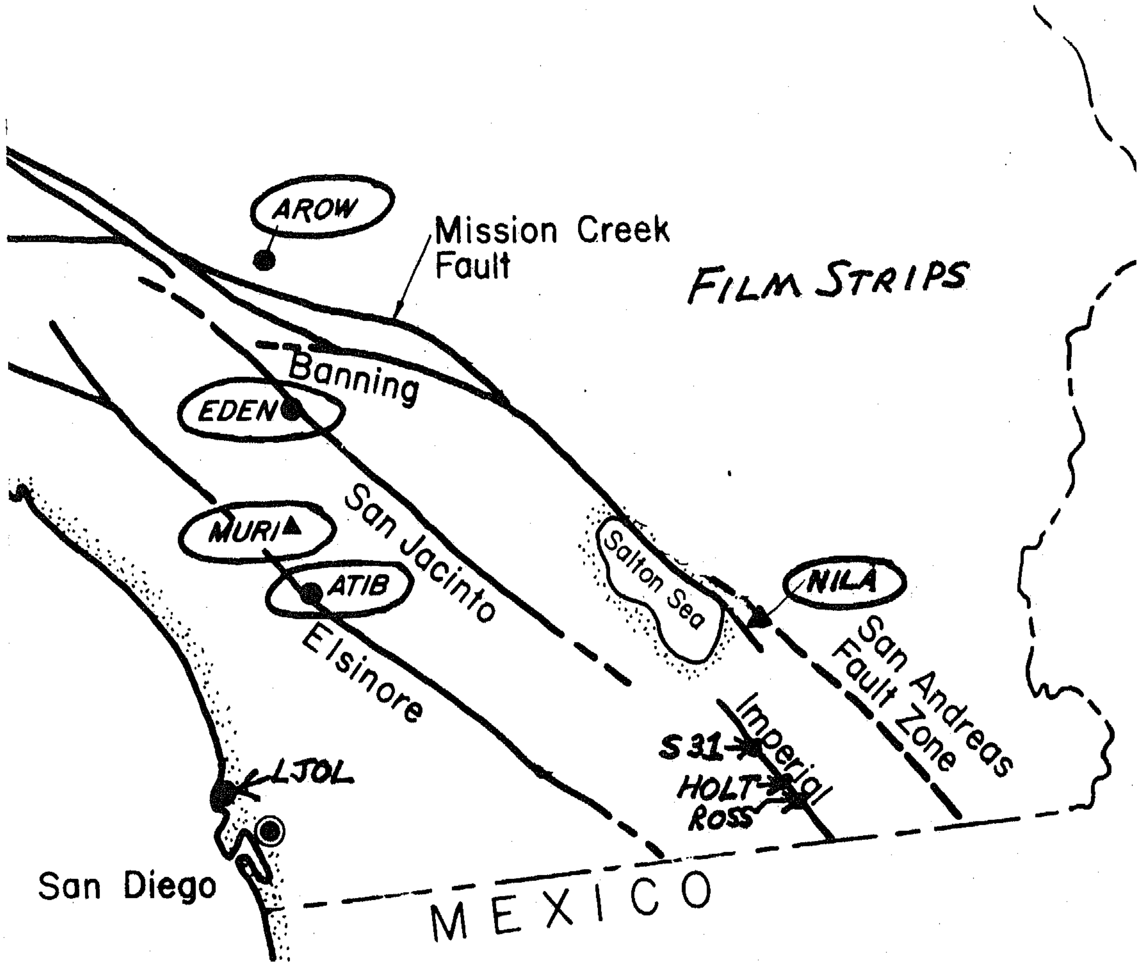

AROW
Mission Creek
Fault
FILM STRIPS
Banning
EDEN
San Jacinto
MURI
ATIB
Elsinore
Salton Sea
NILA
San Andreas
Fault Zone
Imperial
S 31
HOLT
ROSS
LJOL
San Diego
MEXICO

Figure 15

exposed to air. This is a general problem for alpha track radon measurement, and is discussed in Technical Report No. 6; we have not yet devised a simple and effective solution to this problem. All cases where water droplets were observed on the detector when it was collected are marked with a "W" in Figures 16 through 21. In these cases, care was taken not to count areas of the plastic with obviously very low track density. However, many of these results may still be spuriously low.

At one site (NILA, Figure 19) it was necessary to move the sampling hole. This was done on July 3, 1977, and is indicated on Figure 20. Results before and after this change may not be strictly comparable.

Figure 16 through 21 show the results of measurements accumulated over approximately the past fifteen months. Data for the network sites are also tabulated in Appendix 3. With the exception of the La Jolla sites (SRD-F, SRD-B and HC YARD), each data point represents an integrated count over a time period of approximately one month. The sampling interval at the La Jolla sites has varied considerably and is currently one week. Data are plotted at the mid-point of the sampling intervals.

Because large variations in absolute activity are recorded from site to site, counts in Figures 16 through 21 are plotted logarithmically so that fractional changes may be compared easily, regardless of the total counting rate. As discussed in the previous report (Technical Report No. 6), there is no obvious correlation between the soil gas phase and the liquid phase radon at sites where both have been measured. This becomes quite evident when

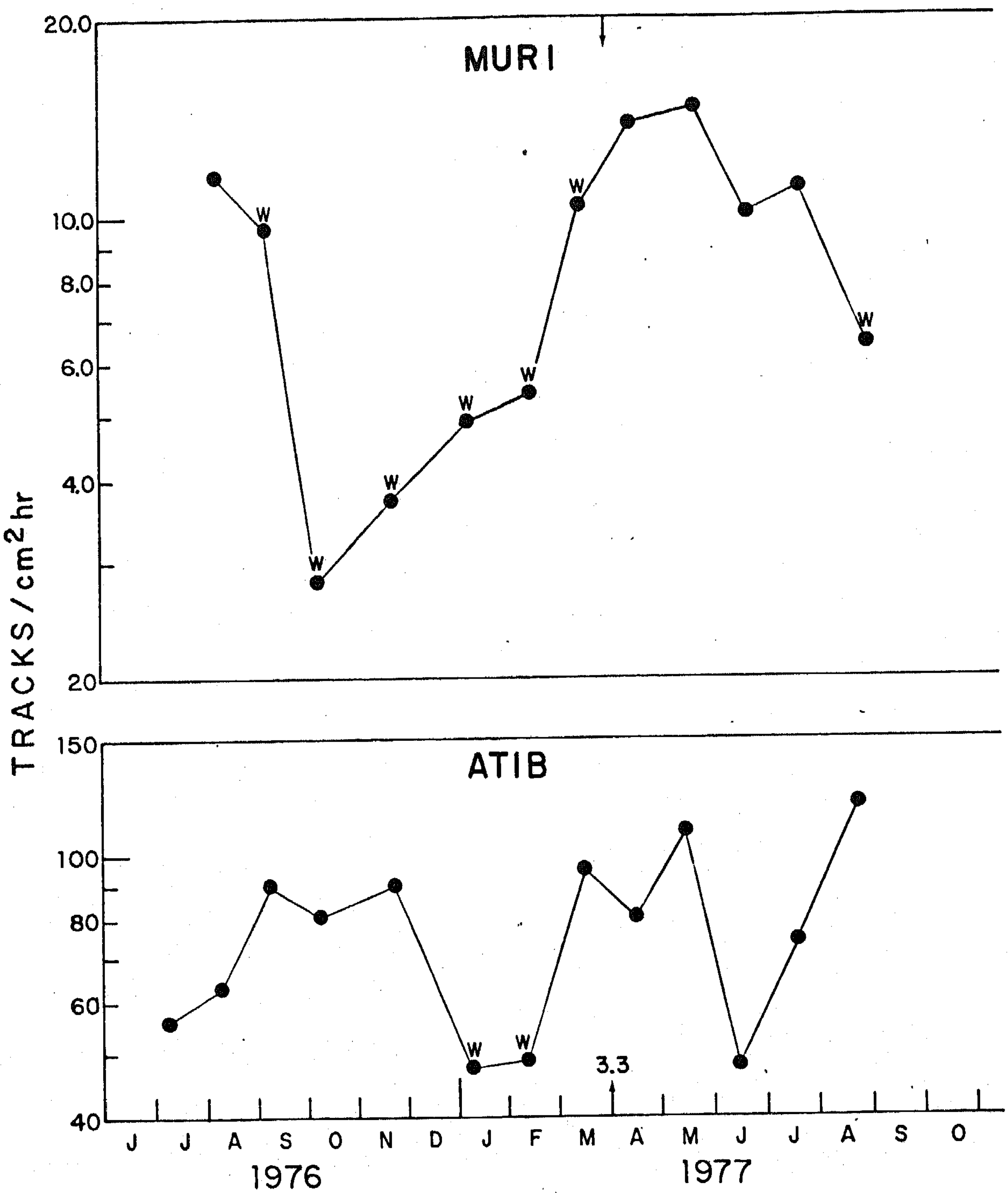

MURI
ATIB
TRACKS/cm^{2}hr
20.0
10.0
8.0
6.0
4.0
20
150
100
80
60
40
W
3.3
J J A S O N D J F M A M J J A S O
1976
1977

Figure 16

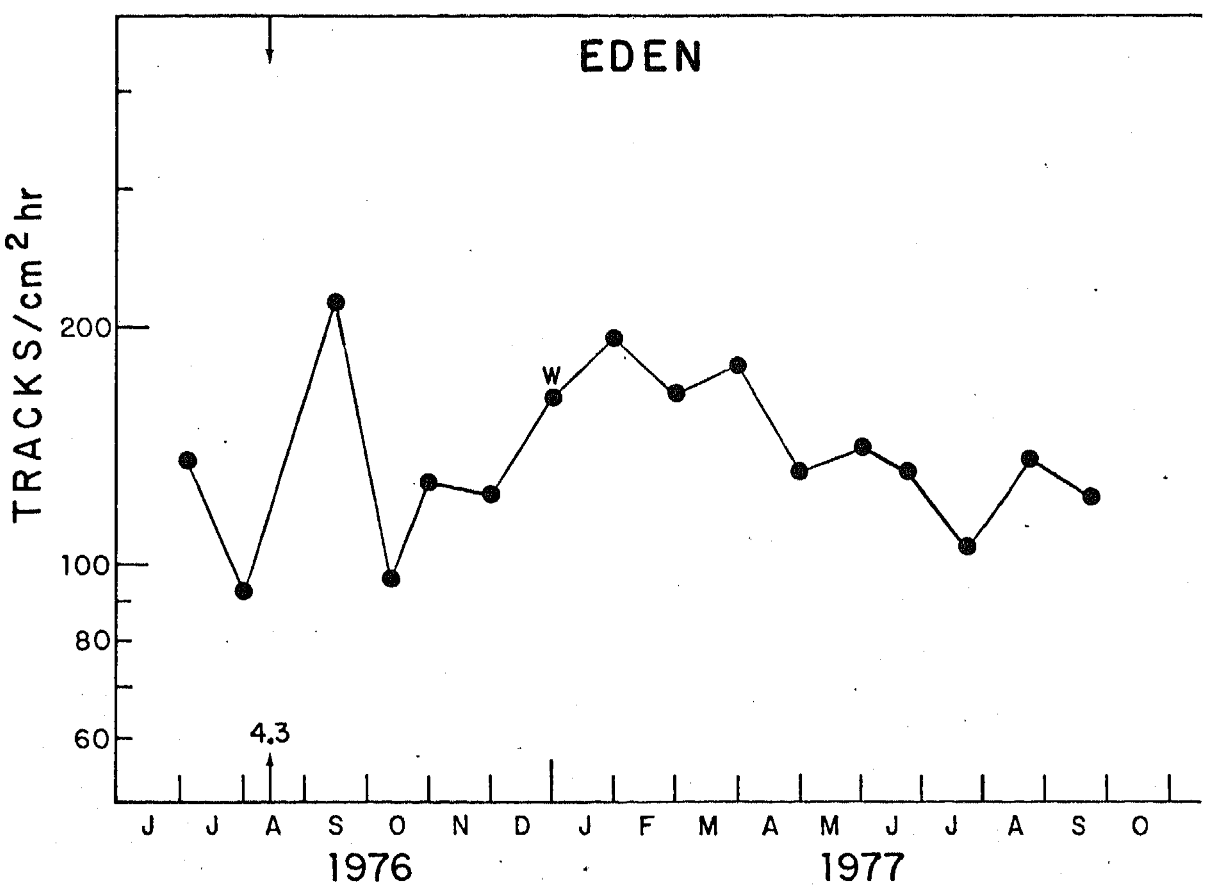

EDEN
TRACKS/cm²hr
200
100
80
60
4.3
W
J J A S O N D J F M A M J J A S O
1976
1977

Figure 17

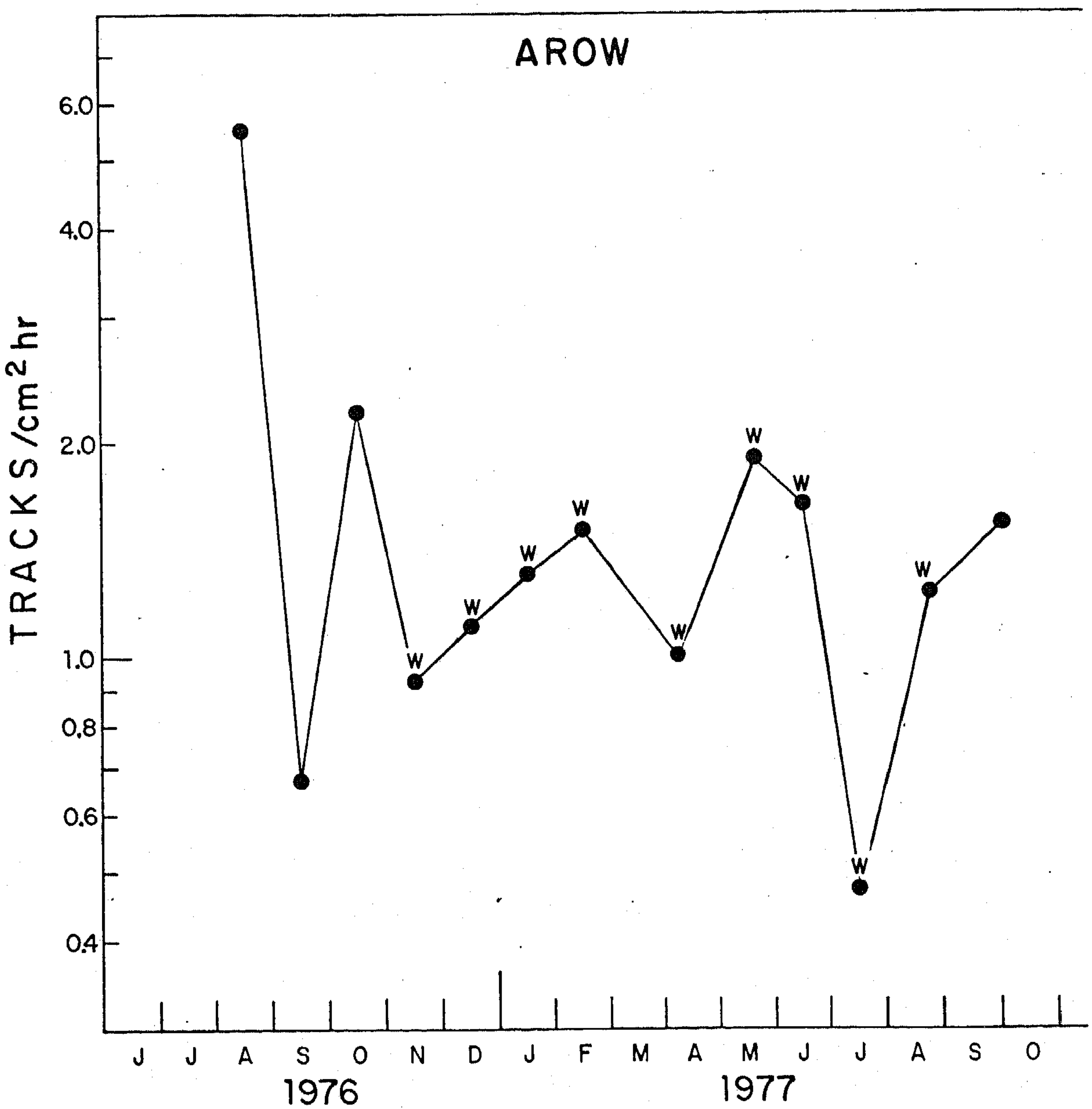

AROW
TRACKS/cm² hr
6.0
4.0
2.0
1.0
0.8
0.6
0.4
W
J J A S O N D J F M A M J J A S O
1976
1977

Figure 18

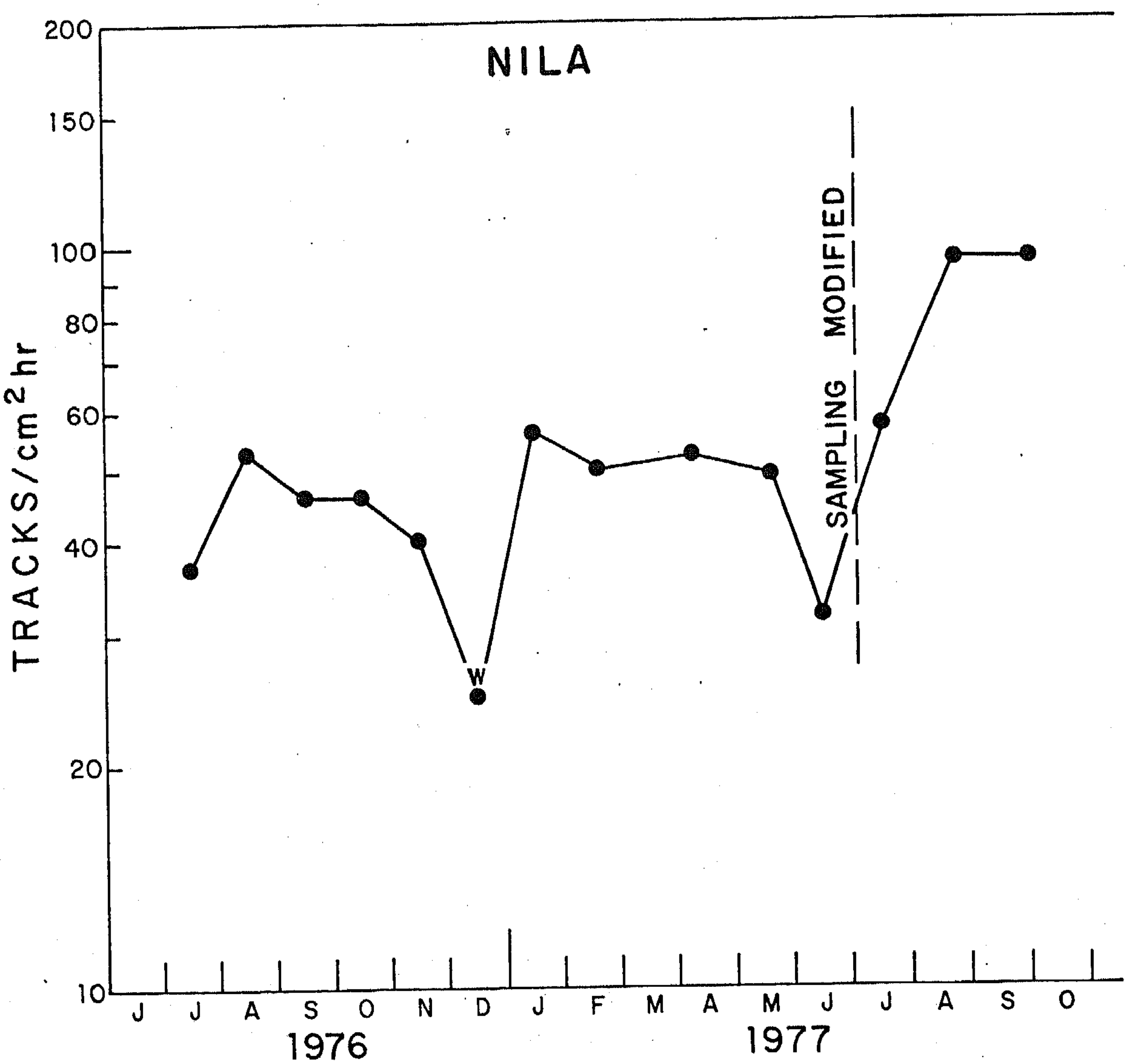

NILA
TRACKS/cm2 hr
200
150
100
80
60
40
20
10
SAMPLING MODIFIED
W
J J A S O N D J F M A M J J A S O
1976
1977

Figure 19

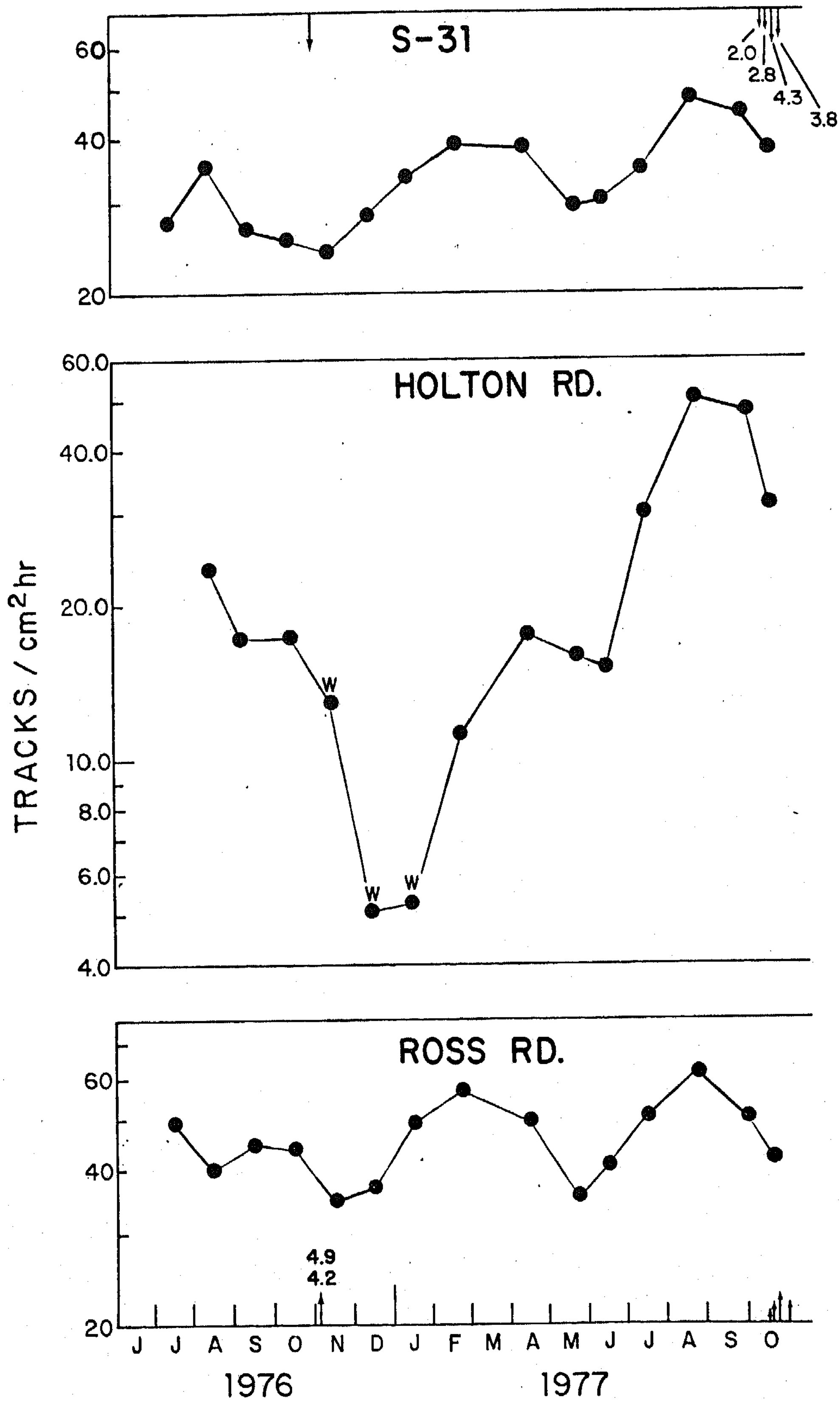

S-31
60
40
20
2.0
2.8
4.3
3.8
HOLTON RD.
60.0
40.0
20.0
10.0
8.0
6.0
4.0
W
W
W
TRACKS / cm²hr
ROSS RD.
60
40
20
4.9
4.2
J J A S O N D J F M A M J J A S O
1976
1977

Figure 20

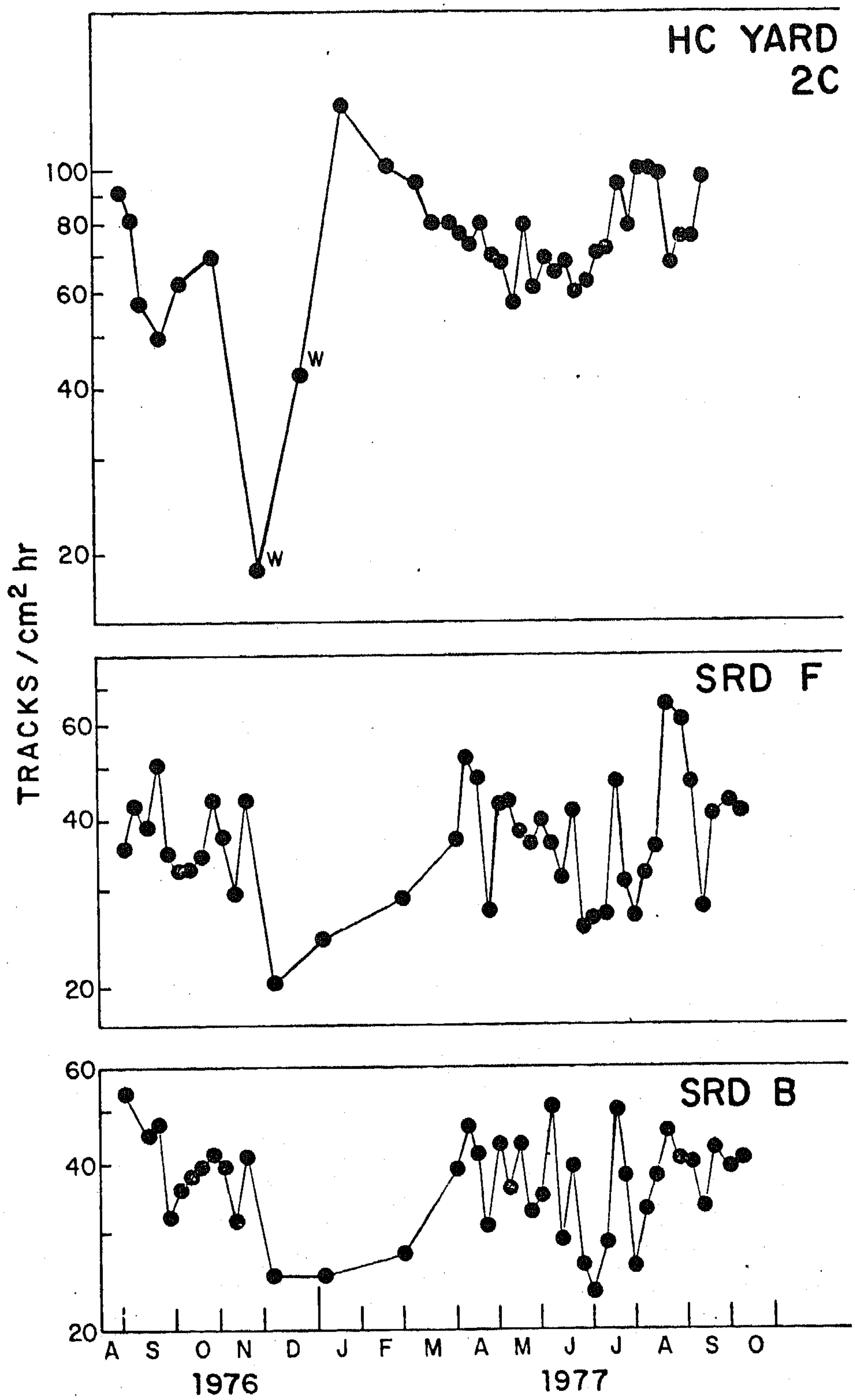

HC YARD
2C
100
80
60
40
20
W
W
TRACKS / cm2 hr
SRD F
60
40
20
SRD B
60
40
20
A S O N D J F M A M J J A S O
1976
1977

Figure 21

Figures 2, 3, 5, 13 and 16 - 19 are compared.

Figure 20 shows results of the measurements made at the three Imperial Fault sites. With continuous data now available for more than a year's time, it is obvious that there is a close similarity among these three records. For an unknown reason, the amplitude of variations seems to be considerably greater at the HOLTON RD. site than at the two others. Two earthquakes, of magnitude 4.9 and 4.2, occurred along the Imperial Fault in early November, 1976. In our previous report (Technical Report No. 6) we noted that there was no obvious feature of the soil radon data that could be identified with these events. However, the recent (October 1977) earthquake swarm within a few miles of these three sites was preceded by a distinct peak in soil radon activity. The sampling period ending September 13, about a month before the onset of the earthquake activity, produced the highest values we have yet measured at each of the three sites. Counting rates dropped sharply for the last sampling interval, which spanned the period of earthquake activity. Re-analysis of the earlier part of the record also shows a more subdued peak in counting rate preceding the November 1976 earthquake activity by about the same amount of time. Especially at the ROSS RD. site, the recording period spanning the earthquake activity also showed a distinct drop in count rate. This drop also coincided with a large storm (rainfall $\sim$0.7 inches), but even greater precipitation during storms at the end of December 1976 and in January 1977 did not have a similar effect on the count rates. The observed winter high values seem to be typical of most sites, except perhaps those in La Jolla.

Measurements at the La Jolla sites show that there is considerable week-to-week variation. The monthly records apparently smooth out these changes, and show longer term variations, such as the winter bulge of high values observed at other sites.

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8. ACKNOWLEDGEMENTS

Mr. R. Poreda made most of the helium measurements listed in this report; his interest in the work and many contributions to the analytical procedure are gratefully acknowledged. A. Birket contributed significantly to both the field and laboratory work before his retirement to a life of ease in northern California. We also wish to acknowledge with gratitude the helpful cooperation of Mr. E. Robison of Ocotillo Wells in adding his well to the monitoring network. The continued assistance of all those whose sites are being monitored is also greatly appreciated.

LIST OF TECHNICAL REPORTS PREVIOUSLY SUBMITTED

Investigation of Radon and Helium as Possible Fluid-Phase Precursors to Earthquakes, H. Craig, J.E. Lupton, Y. Chung, and R.M. Horowitz

No. 1	SIO Reference Number 75-15	Mar. 1975
No. 2	SIO Reference Number 75-23	Aug. 1975
No. 3	SIO Reference Number 75-35	Dec. 1975
No. 4	SIO Reference Number 76-9	May 1976
No. 5	SIO Reference Number 76-15	Oct. 1976
No. 6	SIO Reference Number 77-6	Apr. 1977

APPENDIX 1

RADON AND HELIUM TABULATIONS: LIQUID PHASE

The accumulated measurements of helium concentrations and radon activities in the liquid phase are listed in the following table, together with the collection dates and temperature and conductivity data. Sampling locations are listed by fault from west to east (Elsinore, San Jacinto, San Andreas), and from north to south along the individual faults. The primary network locations are marked with asterisks before the names.

The laboratory precision for helium measurements with the He^4 mass spectrometer is about 1%; however uncertainties due to sampling effects may be considerably greater because of the low solubility and high diffusivity of helium. The helium concentrations are tabulated in units of 10^{-6}ccSTP/gram of water.

Radon activities are tabulated in units of dpm/gram of water. Sample data with an "X" in the "Radon Note" column after the first entry for a site are "excess radon" values, corrected for the Ra^{226} activities listed in Appendix 2 (tabulated in units which differ by a factor of 1000 from the radon units). The other data are total radon activities; in these cases the radium correction is always insignificant. The long-term precision in radon measurements is better than 5%.

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
ELSINORE FAULT							
* ELSI -1W	8/22/74	40.0	835	0.222			
1W	11/ 8/74	40.0	710	0.186		6.570	A1 G
						4.400	A2 G
						20.700	A3 G
1W	1/ 3/75	35.0		0.270		5.040	A1
						5.070	A2
1W	3/17/75	40.4	855	0.349	A	8.170	A2
				0.290	B		
1W	4/17/75	39.4	820	0.239	A	9.840	A1
				0.274	B		
1W	5/20/75	39.4	705	0.237		7.180	A2
1W	8/14/75	42.0	670	0.305		9.080	A1
1W	9/18/75	41.0	685	0.251		8.140	A1
						7.820	A2
1W	10/22/75	40.0	680	0.229		13.010	A1
						8.630	A2
1W	11/18/75	39.7	725	0.257		8.440	A1
						9.500	A2
1W	12/19/75	40.0	710	0.275		8.730	A1
						8.290	A2
1W	1/23/76	40.1	670	0.246		12.990	A1
						8.280	A2
1W	2/24/76	39.9	720	0.274		19.540	A1
						11.070	A2
1W	3/26/76	40.8	700	0.254		11.310	A1
						9.840	A2
1W	4/23/76	39.4	740	0.245		9.430	A1
						9.570	A2
1W	5/28/76	40.1	700	0.226		10.660	A1
1W	6/25/76	40.6	700	0.212		9.350	A1
1W	7/22/76	41.1	720		L	10.020	A1
1W	8/25/76	42.2	715	0.234		9.330	A1
1W	9/22/76	40.0	820	0.279		8.660	A1
1W	10/20/76	40.0	760	0.256		19.850	A1
						14.140	A2
1W	12/21/76	38.9	690	0.401		12.920	A1
						7.440	A2
1W	1/21/77	40.0	780	0.254		18.740	A1
						13.910	A2
1W	2/25/77	40.0	790	0.254		11.570	A1
1W	4/ 1/77	40.3	880	0.242		13.450	A1
						14.450	A2
1W	5/ 3/77	40.8	890	0.210		10.370	A1

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* ELSI -1W	5/ 3/77					9.190	A2
1W	6/ 9/77	40.6	960	0.283		11.540	A2
1W	7/ 6/77	40.8	970	0.252		11.620	A1
						9.660	A2
1W	8/12/77	40.5	1300	0.290		13.340	A1
						8.860	A2
						8.570	F
1W	9/16/77	40.0	1000	0.222		10.290	A1
						10.320	A2
						8.100	F
MURI -1P	8/22/74	49.0		0.493			
* MURI -1W	8/22/74	53.0	1280	0.241			
1W	11/ 6/74	54.0	1270	0.294		25.900	A1 G
						26.500	A2 G
						22.800	F G
1W	1/ 3/75	54.0	1270	0.231		23.400	A1
1W	2/20/75	54.2	1270	0.244		21.850	A1
1W	4/16/75	53.3	1260	0.258			
1W	5/20/75	52.2	1260	0.268		18.500	A2
1W	8/14/75	54.0	1260	0.285		18.050	A1
1W	9/16/75	54.0	1260	0.286		46.530	A1
						53.760	A2
1W	10/21/75	53.0	1265	0.256	A	27.870	A1
		52.0		0.269	B	19.100	B1
1W	11/18/75	53.6	1270	0.283	A	23.220	A1
		50.8		0.268	B	19.250	B1
1W	12/19/75	50.6	1270	0.281		15.960	A1
						16.210	A2
1W	1/23/76	53.3	1260	0.282		25.250	A1
						22.670	A2
1W	2/24/76	53.7	1270	0.270		25.170	A1
						18.160	A2
1W	3/26/76	53.3	1270	0.250		26.540	A1
						20.080	A2
1W	4/23/76	52.8	1275	0.308		19.100	A1
1W	5/28/76	53.0	1270	0.266		19.180	A1
						22.550	A2
1W	6/25/76	54.4	1240	0.241		17.170	A1
1W	7/22/76	53.4	1210	0.249		22.200	A1
						17.990	A2
1W	8/24/76	52.8	1295	0.262		15.000	A1
1W	9/22/76	53.3	1320	0.282		17.900	A1
1W	10/20/76	52.5	1300	0.233		23.030	A1
						18.390	A2

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* MURI -1W	12/21/76	50.6	1330	0.216		18.630	A1
						19.370	A2
1W	1/21/77	50.0	1340	0.414		24.940	A1
						21.600	A2
1W	2/25/77	48.9	1380	0.359		18.050	A1
1W	4/ 1/77	48.3	1380	0.350		15.670	A1
						14.260	A2
1W	5/ 3/77	48.3	1410	0.383		17.200	A1
1W	6/ 9/77	47.8	1405	0.387		17.880	A2
1W	7/ 6/77	51.4	1300	0.281	A1	26.230	A1
				0.266	A2	25.650	A2
1W	8/11/77	52.2	1300	0.270	A1	22.310	A1
				0.250	A2	21.620	A2
1W	9/16/77	52.1	1300	0.254	A1	22.110	A2
				0.260	A2		
* ATIB -1W	11/21/74	38.0	495	0.099		10.780	F G
1W	1/ 8/75			0.146	A ,?		
		38.4	525	0.105	B ,?	9.410	B2
1W	2/20/75	38.0	560	0.099	A1	10.570	A3
				0.107	A2	9.230	A2
1W	4/16/75	36.2	730	0.277		7.050	A1
						3.810	A2
1W	5/20/75	35.8	720			3.150	A2
1W	8/14/75	38.0	510	0.313		12.760	A1
						6.450	A2
1W	9/17/75	38.0	520	0.285		7.820	A1
						8.180	A2
1W	10/22/75	38.0	500	0.140		12.610	A1
						7.140	A2
1W	11/18/75	38.2	500	0.148		7.480	A1
						6.900	A2
1W	12/19/75	38.6	500	0.106		6.120	A1
						10.930	A2
1W	1/23/76	38.3	510	0.201		6.260	A1
						7.700	A2
1W	2/24/76	38.6	500	0.090		6.410	A1
						6.150	A2
1W	3/26/76	36.9	1010	0.177		4.760	A1
						4.420	A2
1W	4/23/76	37.7		0.176		5.800	A1
						7.760	A2
1W	5/28/76	37.7	580	0.228		6.150	A2
1W	6/26/76	38.0	530	0.306		6.260	A1
						6.200	A2
1W	7/22/76	38.0	520	0.222		6.080	A1

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND μMHO	RADON DPM/G	NOTE	HELIUM μCC/G	NOTE
* ATIB -1W	7/22/76					6.010	A2
1W	8/24/76	38.0	560	0.263		6.970	A1
						6.860	A2
1W	9/22/76	38.4	530	0.108		7.870	A1
						8.410	A2
1W	10/22/76	38.3	540	0.177		16.570	A1
						11.500	A2
1W	12/14/76	38.5	530	0.096		11.110	A1
						11.870	A2
1W	12/21/76	38.6	520	0.094		9.900	A1
						8.520	A2
1W	1/21/77	38.6	530	0.089		12.980	A1
						9.520	A2
1W	2/25/77	38.4	550	0.095		11.620	A1
						9.540	A2
1W	4/ 1/77	37.8	790	0.121		9.710	A1
						10.470	A2
1W	5/ 3/77	36.8	520	0.252	A1	10.100	A1
				0.242	A2	11.490	A2
1W	6/ 8/77		690	0.114	A1	11.870	A1
				0.101	A2	8.840	A2
1W	7/ 6/77	37.8	520	0.324	A1	9.010	A1
				0.302	A2	8.260	A2
1W	8/12/77	37.8	530	0.297	A1	10.470	A1
				0.279	A2	8.690	A2
				0.287	A3	5.800	F1
				0.289	A4	5.520	F2
1W	9/16/77	38.0	530	0.242	A1	9.690	A1
				0.234	A2	7.040	A2
						7.610	F1
						6.300	F3
WARN -2P	8/16/74		483	0.942		3.990	G
2P	11/ 6/74	53.0			NC		
WARN -3P	11/ 6/74	56.0			NC		
* WARN -1P	8/16/74	53.0	486	1.320		6.720	A1 G
1P	11/ 6/74	57.0	484	1.160		4.600	A2
						5.100	A1 G
						5.510	F G
1P	1/ 8/75	56.0	485	1.150		4.240	A2
1P	2/20/75	56.2	482	0.563		5.080	A2
1P	4/16/75	55.9	490	1.070		4.300	A2
1P	5/20/75	56.0	485	1.080		5.240	A2
1P	8/15/75	57.0	487	1.270		4.950	A1

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* WARN -1P	8/15/75					5.040	A2
1P	9/17/75	56.8	482	1.190	A1	4.300	A1
				1.220	A2	4.540	A2
				1.200	A3		
				0.850	A4		
				1.140	A5		
1P	10/21/75	56.8	481	1.260		5.060	A1
						4.810	A2
1P	11/18/75	58.9	482	1.210		2.290	A1 E
						4.550	A2
1P	12/12/75	57.2	483	1.100	A1	4.600	A1
				0.865	A2	4.100	A2 E
				1.150	A3		
				1.190	A4		
				1.200	A5		
				1.160	A6		
1P	1/23/76	58.9	480	1.070		4.020	A1
						4.230	A2
1P	2/24/76	57.8	487	1.140		3.910	A1E
						4.580	A2
1P	3/26/76	57.2	480	1.020		4.600	A1
						4.300	A2
1P	4/23/76	58.7	480	1.470		6.360	A1E
						7.180	A2
1P	5/28/76	57.7	462	1.230		5.520	A1
1P	6/25/76	58.8	459	1.380		6.700	A1
						6.510	A2
1P	7/22/76	56.4	443	1.280		6.010	A1
1P	8/24/76	58.4	477	1.220		5.310	A1
1P	9/22/76	57.9	500	1.100		4.800	A1
		57.9				4.780	A2
1P	10/20/76	56.9	550	1.200		5.230	A1
1P	12/21/76	56.9	550	1.060		4.140	A1
1P	1/21/77	58.8	540	1.010		4.000	A1
1P	2/25/77	56.4	490	0.992		4.060	A1
1P	4/ 1/77	57.8	485	1.090		4.150	A1
1P	5/ 3/77	56.0	487	1.110		4.670	A1
1P	6/ 3/77	58.2	482	0.908		4.770	A2
1P	7/ 1/77	57.5	480	1.070		4.930	A2
1P	8/ 6/77	56.0	480	1.000		4.620	A2
1P	9/13/77	57.4	488	0.908		4.540	A2
ACAL -1P	8/16/74	30.0	525	0.566			
1P	11/ 6/74	30.0		1.090			
ACAL -2P	8/16/74	31.0	530	0.629		3.670	A G

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
ACAL -2S	8/16/74	37.0	520	1.610			
2S	11/ 6/74	37.0	510		NC		
* ACAL -1S	11/ 6/74	39.0		3.310		8.990	F G
1S	1/ 8/75	38.0	510	2.630		10.490	F G
1S	2/20/75	38.0	510	1.500		9.390	F
1S	3/20/75	38.0	510	3.460		8.770	F
1S	4/25/75	37.9	510	2.700		8.420	F
1S	6/ 5/75	38.0	510	3.050	?	8.770	F
1S	8/28/75	38.4	510	3.180		8.320	F
1S	10/ 3/75	38.3	500	2.440		8.810	F
1S	11/ 2/75	38.3	510	2.390		8.110	F
1S	11/27/75	38.0	545	3.530		8.000	F
1S	1/ 9/76	37.9	510	3.200		9.060	F
1S	2/ 6/76	37.7	520	3.340		8.930	F
1S	3/11/76	37.5	510	3.420		8.840	F
1S	4/ 8/76	37.9	510	3.380		9.050	F
1S	4/30/76	37.9	510	3.280		8.850	F
1S	6/ 4/76	38.3	510	3.160		8.920	F
1S	7/ 3/76	38.2	500	2.900		7.940	F
1S	7/30/76	38.3	510	3.260		8.980	F
1S	9/ 1/76	38.2	505	2.750		9.060	F
1S	10/ 2/76	38.2	520	3.110		8.570	F
1S	10/30/76	38.2	510	2.820		8.300	F
1S	12/31/76	38.0	500	2.860		8.600	F
1S	2/ 4/77	37.8	510	2.820		9.020	F
1S	3/11/77	38.0	510	3.120		8.840	F
1S	5/13/77	37.5	510	2.950		9.030	F
1S	6/ 3/77	37.9	510	2.890		7.780	F
1S	7/ 1/77	37.8	510	2.890		8.550	F
1S	8/ 6/77	37.8	520	2.590		8.550	F
1S	9/13/77	38.0	530	2.660		8.480	F

SAN JACINTO FAULT

SAMPLE	DATE	TEMP	COND	RADON	NOTE	HELIUM	NOTE
EDEN -2P	8/ 7/74	32.0	456	6.450	X		
2P	9/26/74	32.0	448	5.620		3.330	A1 G
						3.250	A2 G
2P	10/19/74	30.0	455	4.480			
2P	1/ 3/75	25.0	451	2.200	?		
2P	9/18/75	29.0	446	3.370		2.770	A2

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE	
* EDEN -1P	8/ 7/74	38.0	433	6.130	X			
1P	9/26/74	38.0	427	7.140	A1	4.300	A1	G
				7.660	A2	4.220	A2	G
1P	10/19/74	37.0	436	7.460		4.780	A1	G
						4.700	A2	
1P	1/ 3/75	35.0	431	6.410	?	3.790	A2	
1P	2/28/75	35.8	430	7.540	A1	4.500	A2	
				7.840	A2			
				7.340	A3,?			
1P	4/17/75	35.2	436	6.420		4.370	A2	
1P	5/22/75	36.0	431			4.030	A2	
1P	7/18/75	37.8	433	9.460	A1	4.140	A2	E
				8.940	A2	3.930	A4	
1P	8/ 7/75	38.8	430	13.200		3.780	A2	
1P	9/18/75	38.3	428	10.900	A1	3.330	A1	
				10.600	A2	3.360	A2	
1P	10/29/75	37.7	425	8.480		3.940	A2	
1P	11/20/75	37.0	425	8.760		3.700	A2	
1P	12/23/75	35.5	422	6.640		4.420	A2	
1P	1/30/76	36.0	425	6.970		4.100	A2	
1P	2/20/76	35.2	426	6.080		4.410	A2	
1P	4/ 1/76	36.0	416	6.480		4.280	A2	
1P	4/16/76	35.8	414	7.400		4.000	A2	
1P	5/26/76	36.8	414	6.860		4.690	A2	
1P	6/24/76	37.7	420	5.950		4.040	A2	
1P	7/14/76	37.6	421	6.070		4.440	A2	
1P	9/12/76	37.5	429	5.790	A1	4.300	A2	
				6.240	A2			
1P	10/ 9/76	36.4	450	4.940	A1			
				4.670	A2			
1P	10/15/76	36.4	440	4.280		4.600	A2	
1P	11/17/76	35.4	445	4.920		3.790	A2	
1P	12/14/76	37.6	440	12.000		3.350	A1	
						3.360	A2	
1P	1/12/77	37.2	426	10.100		2.360	A1	
						2.380	A2	
1P	2/16/77	36.0	430	6.890		4.310	A2	
1P	3/16/77	35.0	455	6.170		3.660	A2	
1P	4/12/77	35.5	415	7.150		4.050	A2	
1P	4/21/77	37.0	418	10.300		3.590	A2	
1P	5/11/77	36.9	420	8.380		2.990	A1	
						2.960	A2	
1P	6/ 8/77	37.5	420	10.100		4.020	A2	
1P	7/ 6/77	38.2	428	13.800	A1	4.330	A2	
				13.300	A2			
1P	8/10/77	38.5	418	7.140	A1	5.910	A1	

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* EDEN -1P	8/10/77			6.490	A2	5.070	A2
1P	9/11/77	38.0	418	6.490		4.490	A2
SOBO -1S	5/11/77	40.5	320	3.940	A1	0.822	A1
				3.630	A2	0.827	A2
1S	6/ 8/77	40.0	315	4.150	A1	0.936	A2
				3.980	A2		
1S	7/ 6/77	41.1	315	4.210		0.997	A2
1S	8/12/77	41.4	320	4.000		0.990	A1
						1.006	A2
						0.956	F
1S	9/11/77	41.1	320	3.770	A1	1.008	A1
				3.870	A2	0.999	A2
* SOBO -1P	9/26/74	37.5	316	2.640		0.549	A2 G
1P	10/20/74	37.8	313	2.710		0.434	A1 G
						0.454	A2 G
1P	1/ 3/75	34.8	315	2.170		0.351	A2
1P	2/28/75	35.8	313	2.110		0.324	A1
						0.325	A2
1P	4/17/75	35.5	318	2.370		0.404	A2
1P	5/22/75	35.8	315	2.160	?	0.524	A1
						0.526	A2
1P	7/18/75	39.0	309	3.790		0.597	A1
						0.602	A2
1P	8/ 7/75	40.2	318	2.990		0.518	A2
1P	9/18/75	40.7	319	2.890		0.426	A1
						0.433	A2
1P	11/20/75	38.2	321	1.780		0.285	A1
						0.288	A2
1P	12/23/75	38.7	323	1.720		0.210	A1
						0.217	A2
1P	1/30/76	36.6	326	2.020		0.258	A2
1P	2/20/76	33.6	327	2.040		0.299	A1
						0.308	A2
1P	4/ 1/76	35.8	326	1.790		0.220	A1
						0.225	A2
1P	4/16/76	35.2	326	2.470		0.427	A2
1P	5/26/76	37.2	335	2.910		0.504	A2
1P	6/24/76	37.6	340	2.650		0.578	A1
						0.576	A2
1P	7/14/76	38.3	341	3.160		0.579	A1
						0.577	A2
1P	8/12/76	37.3	342	2.870	A1	0.568	A2
				2.840	A2		

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND μMHO	RADON DPM/G	NOTE	HELIUM μCC/G	NOTE
* SOBO -1P	9/15/76	36.7	340	2.510	A1	0.452	A2
				2.370	A2		
1P	10/15/76	36.4	355	2.590		0.525	A1
						0.521	A2
1P	11/17/76	35.2	347	2.400		0.437	A2
1P	12/14/76	37.9	339	2.320		0.527	A1
						0.531	A2
1P	1/12/77	38.9	335	3.300		0.618	A1
						0.623	A2
1P	2/16/77	38.0	312	2.340		0.543	A2
1P	3/16/77	36.9	350	2.450		0.545	A2
1P	4/12/77	34.5	320	2.360		0.482	A2
1P	5/10/77	36.9	315	1.800	A1	0.381	A1
				1.920	A2	0.379	A2
1P	6/ 8/77	34.5		2.110			
1P	7/ 6/77	33.2		2.120			
1P	8/11/77					0.591	A1
						0.591	A2
1P	8/12/77	35.0		2.480		0.605	A1
						0.583	A2
						0.574	F
1P	9/11/77	33.0	338	1.690	A1	0.434	A1
				1.640	A2	0.446	A2
* INCA -1P	3/14/75	35.2	233	0.934		0.769	F
1P	4/17/75	35.9	227	0.981		0.729	F
1P	5/22/75	35.2	227			0.638	F
1P	7/18/75	35.8	234	0.947		0.693	F
1P	8/ 7/75	35.0	229	0.936		0.634	F
1P	9/26/75	34.8	229	1.010		0.719	F
1P	10/24/75	35.1	229	0.804		0.494	F
1P	11/20/75	35.0	229	0.914		0.590	F
1P	12/23/75	36.1	227	0.794		0.736	F
1P	1/30/76	36.2	233	0.987		0.714	F
1P	2/20/76	35.3	233	0.988		0.717	F
1P	4/ 1/76	36.3	234	0.950		0.751	F
1P	4/16/76	36.4	234	0.963		0.707	F
1P	5/26/76	35.0	250	0.799		0.642	F
1P	6/24/76	35.2	248	0.787		0.680	F
1P	7/14/76	36.4	244	0.941		0.726	F
1P	8/12/76	36.4	247	0.898	A1	0.726	F
				0.844	A2		
1P	9/15/76	36.4	247	0.827	A1	0.702	F
				0.861	A2		
1P	10/15/76	36.1	258	0.837		0.725	F
1P	11/17/76	36.1	250	0.934		0.727	F
1P	12/14/76	36.3	249	0.969		0.700	F

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* INCA -1P	1/12/77	35.7	248	0.948		0.723	F
1P	2/16/77	35.6	225	0.826		0.692	F
1P	3/16/77	35.8	245	0.828		0.718	F
1P	4/12/77	35.2	225	0.907		0.691	F
1P	5/11/77	36.4	230	0.870		0.708	F
1P	6/ 8/77	35.5	230	0.849		0.662	F
1P	7/ 6/77	35.5	230	0.781		0.678	F
1P	8/11/77	36.0	235	0.869		0.734	F
1P	9/11/77	36.0	230	0.929		0.721	F

SAN ANDREAS FAULT (SAN BERNARDINO AREA)

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
AROW -1W	10/19/74	80.0	590	0.231	A	5.280	C G
		79.5		0.765	B	10.000	D G
						6.000	A
						7.820	B G
* AROW -1P	10/19/74	80.0	1530	0.320		8.660	G
1P	12/10/74	79.9	1530			11.160	A1
1P	3/18/75	79.0	1530	0.294		8.770	A2
1P	4/22/75	78.8	1530	0.284		8.370	A2
1P	6/ 3/75	80.0	1540	0.306		10.620	A1
1P	8/26/75	80.0	1540	0.390		10.480	A1
1P	9/30/75	79.7	1540	0.304		7.760	A2
1P	10/29/75	79.6	1530	0.319		8.060	A1
1P	11/25/75	79.7	1535	0.373		8.890	A1
1P	1/ 7/76	78.9	1540	0.327		8.460	A1
1P	2/ 4/76	79.3	1535	0.307		8.180	A1
1P	3/ 9/76	79.0	1530	0.308		8.360	A1
1P	4/ 7/76	79.3	1530	0.319		8.420	A1
1P	4/26/76	79.1	1540	0.321		8.410	A1
1P	6/ 2/76	80.1	1550	0.281		7.950	A1
						8.160	A2
1P	6/29/76	80.9	1530	0.394		11.390	A1
						12.040	A2
1P	7/27/76	79.8	1550	0.299		8.240	A1
						8.170	A2
1P	8/30/76	80.1	1520	0.276		7.510	A1
						8.270	A2
1P	9/30/76	80.6	1550	0.281		8.200	A1
						10.310	A2
1P	10/28/76	79.6	1550	0.333		9.470	A1
						9.440	A2
1P	12/28/76	80.0	1550	0.361		10.260	A1
						10.560	A2

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* AROW -1P	2/ 2/77	80.6		0.363		8.420	A1
1P	3/ 9/77	81.7	1600	0.308		7.610	A1
1P	5/11/77	78.0	1590	0.268		8.390	A1
1P	6/ 5/77	79.5	1590	0.298		8.220	A2
1P	7/ 4/77	81.0	1580	0.246		6.010	A2
1P	8/ 9/77	80.0	1580	0.276		8.570	A2
1P	9/15/77	79.5	1580	0.284		8.930	A2
WATR -1P	3/18/75	65.8	1660	0.733	X	2.290	F
1P	4/22/75	64.8	1660	0.649		1.920	F
1P	6/ 3/75	67.8	1665	0.638	?	1.980	F
1P	8/26/75	67.5	1660	0.760		2.410	F
1P	9/30/75	67.3	1640	0.295		2.310	F
1P	10/29/75	67.2	1650	0.580		1.960	F
1P	11/25/75	66.2	1670	0.695		2.070	F
1P	1/ 7/76	66.1	1645	0.671		2.030	F
1P	2/ 4/76	66.2	1670	0.370		1.650	F
1P	3/ 9/76	66.6	1645	0.818		2.480	F
WATR -2P	4/ 7/76	69.7	1650			0.182	F
						0.175	F
* SAMA -1P	3/19/75	38.0	1255	1.170		0.253	F
1P	4/22/75	39.5	1250	0.580		0.401	F
1P	6/ 3/75	41.5	1250	1.870		0.609	F
1P	8/26/75	40.4	1250	1.730		0.490	F
1P	9/30/75	38.8	1255	1.600		0.339	F
1P	10/29/75	36.0	1265	1.620		0.353	F
1P	11/25/75	33.3	1270	1.280		0.219	F
1P	1/ 7/76	32.3	1260	0.884		0.166	F
1P	2/ 4/76	32.3	1260	0.791		0.152	F
1P	3/ 9/76	35.5	1230	1.110		0.238	F
1P	4/ 7/76	38.3	1230	0.756		0.161	F
1P	4/28/76	38.8	1240	1.130		0.250	F
1P	6/ 2/76	40.2	1240	0.910		0.206	F
1P	6/29/76	41.1	1240	1.080		0.257	F
1P	7/27/76	39.2	1280	1.130		0.247	F
1P	8/30/76	37.5	1300	1.040		0.242	F
1P	9/30/76	38.0	1280		L	0.459	F
1P	10/28/76	37.5	1260	0.935		0.204	F
1P	12/28/76	34.7	1290	1.110		0.241	F
1P	2/ 3/77	36.4	1250	1.570		0.361	F
1P	3/ 9/77	37.3	1300	2.120		0.570	F
1P	5/11/77	37.8	1350	0.496		0.124	F

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* SANA -1P	6/ 5/77	41.9	1300	2.070	A1	0.604	F
				2.170	A2		
1P	7/ 4/77	40.8	1300	2.200		0.603	F
1P	8/ 9/77	38.0	1310	1.590		0.343	F
1P	9/16/77	35.5	1350	2.010		0.456	F

MISSION CREEK, BANNING FAULTS

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* DSRT -1W	8/ 7/74	42.0	1450	0.551		5.170	G
1W	9/26/74	42.0	1470	0.574		3.690	A1 G
						3.430	A2 G
1W	12/11/74	42.0	1490	0.238		5.960	A1
1W	3/19/75	41.4	1475	0.700		5.340	A2
1W	4/23/75	39.4	1470	0.572		4.830	A1
1W	6/ 5/75	40.8	1490	0.570		9.270	A1
						8.410	A2
1W	8/14/75	40.0	1470	0.526	A1 E	5.280	A1
				0.674	A2		
1W	10/ 1/75	41.0	1460	0.646		6.280	A1
1W	10/30/75	40.0	1460	0.635		5.440	A1
1W	11/25/75	38.7	1450	0.591		8.650	A1
						7.350	A2
1W	1/ 8/76	37.3	1460	0.633		5.110	A1
1W	2/ 4/76	37.9	1460	0.640		5.260	A1
1W	3/ 9/76	39.2	1460	0.634		5.450	A1
1W	4/ 7/76	39.1	1460	0.619		5.210	A1
1W	4/28/76	38.9	1450	0.600		5.090	A1
1W	6/ 3/76	39.0	1460	0.596		4.290	A1
						4.460	A2
1W	6/30/76	40.3	1430	0.449		4.840	A1
1W	7/28/76	39.6	1450	0.595		8.260	A1
						5.230	A2
1W	8/30/76	41.7	1450	0.572		5.470	A1
1W	9/30/76	40.0	1460	0.595		4.930	A1
1W	10/28/76	40.0	1430	0.609		6.070	A1
1W	12/29/76	40.0	1420	0.599		4.730	A1
1W	2/ 3/77	40.6	1450	0.587		3.790	A1
						4.180	A2
1W	3/ 9/77	40.0	1500	0.567		4.530	A1
1W	5/11/77	39.6	1430	0.597		5.580	A1
1W	7/ 3/77	40.3	1495	0.569		4.240	A1
						4.910	A2
1W	8/ 8/77	41.1	1500	0.551		5.560	A2
1W	9/15/77	41.1	1500	0.596		6.090	A2

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
PALM -1W	6/27/75	22.0		0.342			
* PALM -1P	8/ 7/74	41.5	316	0.064			
1P	9/26/74	40.5	314	0.058		4.990	A1 G
						5.290	A2 G
1P	12/11/74	40.6	313			3.920	A2
1P	3/19/75	39.6	313	0.057		4.470	A1
						4.360	A2
1P	4/23/75	40.0	315	0.053		4.640	A2
1P	6/ 4/75	40.0	313	0.050	?	4.730	A2
1P	8/26/75	40.6	317	0.060		5.580	A2
1P	10/ 1/75	40.4	318	0.065		6.100	A1
						6.010	A2
1P	10/30/75	40.0	319	0.052		4.510	A2
1P	1/ 7/76	39.1	318	0.050		4.330	A2
1P	2/ 4/76	39.7	320	0.058		4.550	A2
1P	3/ 9/76	38.9	320	0.055		4.410	A2
1P	4/ 7/76	39.7	313	0.057		4.980	A2
1P	4/28/76	40.0	320	0.056		4.800	A2
1P	6/ 2/76	40.3	333	0.053		5.180	A2
1P	6/30/76	40.6	330	0.048		5.700	A1
						7.740	A2
1P	7/28/76	40.6	338	0.053		5.460	A2
1P	8/31/76	40.6	330	0.055		5.550	A2
1P	9/30/76	40.3	345	0.050		5.590	A2
1P	10/28/76	40.0	328	0.049		4.290	A2
1P	12/28/76	39.4	330	0.054		5.330	A2
1P	2/ 3/77	39.7	330	0.047		4.220	A2
1P	3/ 9/77	40.3	320	0.078		7.830	A1
						7.920	A2
1P	6/ 5/77	40.8	322	0.056		9.470	A2
1P	7/ 3/77	40.5	328	0.062		8.760	A2
1P	8/ 8/77	40.5	322	0.061		8.430	A2
1P	9/15/77	40.3	340	0.056		7.760	A2

SAN ANDREAS FAULT (IMPERIAL VALLEY)

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
DOSP -1W	12/11/74	28.8	2045				
1W	2/ 5/76	28.2	2110	0.928			
1W	6/ 3/76	28.8	2050	0.948			

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
DOSP -1W	6/30/76	28.7	1910	0.794			
DOSP -1P	12/11/74	27.0	1680				
1P	3/20/75	27.3		0.657		0.245	F
1P	4/24/75	28.0	1610	0.574		0.246	F
1P	6/ 4/75	27.8	1620	0.823		0.348	F
1P	8/27/75	28.1	1560	0.923		0.307	F
1P	10/ 1/75	27.8	1530	0.779		0.242	F
1P	10/31/75	27.2	1525	0.666		0.249	F
1P	11/26/75	26.7	1550	0.783		0.234	F
1P	1/ 8/76	26.2	1575	0.538		0.168	F
1P	2/ 5/76	26.2	1570	0.614		0.210	F
1P	3/10/76	26.9	1580	0.526		0.183	F
1P	4/ 8/76	27.4	1580	0.509		0.170	F
1P	4/29/76	27.3	1580	0.612	A	0.219	F
		28.0	1730	0.624	B		
1P	6/ 3/76	28.6	1590	0.795		0.359	F
1P	6/30/76	28.6	1560	0.643		0.342	F
1P	7/28/76	28.4	1550	0.660		0.286	F
1P	8/31/76	29.2	1520	0.815		0.329	F
1P	10/ 1/76	27.9	1500		L	0.275	F
1P	10/29/76	27.8	1530	0.666		0.245	F
1P	12/29/76	27.8	1560	0.488		0.194	F
HMIN -1P	11/27/74	63.0	5700	5.470	X	0.234	F G
1P	12/10/74	71.0	5700	0.797	E	0.156	A2
1P	1/24/75	68.0	5700	12.200	A1	0.114	A2
		68.0		12.600	A2		
1P	1/30/75	67.0	5700	5.060	?	0.086	A2
1P	2/ 6/75	70.0		10.200		0.184	A2
1P	3/19/75	69.5	5700	6.020	?	0.109	A2
1P	4/23/75			7.360		0.202	A2
1P	6/ 4/75	68.0				0.289	A2
1P	7/24/75	68.5	5700	9.880	A1	0.240	A2
		67.6		5.800	B		
* HMIN -1W	3/19/75	74.7		40.600	X	0.796	A2
1W	4/23/75	71.1	5700	47.700		1.480	A2
1W	6/ 4/75	71.1				1.360	A2
1W	7/24/75	71.0		47.600	A1	1.540	A2
				45.300	A2		
1W	8/28/75	70.0	5800	46.000	A1	2.170	A2
1W	10/ 2/75	72.3	5800	26.200		1.300	A2
1W	11/ 1/75	71.9	5900	41.600		2.960	A2
1W	11/26/75	70.3	5900	45.900		2.200	A2

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* HMIN -1W	1/ 8/76	71.1	5800	46.700		1.400	A1
						1.840	A2
1W	2/ 5/76	71.1	5800	44.400		1.170	A1
						1.010	A2
1W	3/10/76	71.1	5800	44.900		2.980	A1
						2.390	A2
1W	4/ 8/76	64.7	5800	44.600		1.700	A2
1W	4/29/76	69.4	5800	43.700		1.110	A2
1W	6/ 4/76	76.4	5900		NC		
1W	7/29/76	76.2	5900		NC		
1W	11/29/76	70.6	5800	42.700		3.200	A2
1W	12/29/76	70.0	5600	42.100		1.120	A2
1W	2/ 4/77	74.4	5800	46.100		5.020	A1
1W	3/10/77	74.4	5500	32.000		6.000	A1
						1.980	A2
1W	5/12/77	71.0	5500	110.000		3.070	A1 E
						1.330	A2
1W	6/ 4/77	75.3	5800	37.900	A1	6.400	A1
				38.800	A2		
1W	7/ 2/77	75.8	5800	58.300	A1	51.100	A1 E
				86.600	A2	71.600	A2 E
1W	8/ 8/77	76.1	5800		NC		
1W	9/14/77	75.6	5900		NC		
* BASH -1W	3/20/75	63.0	5300	24.400	X	3.580	A2
1W	4/23/75	56.1	5300	15.000		5.160	A1
						4.740	A2
1W	6/ 4/75	58.9	5350			3.760	A2
1W	7/24/75	61.0	5400	22.300		2.440	A2
1W	7/25/75	60.0	5300	18.400		1.860	A1
						1.630	A2
1W	8/28/75	61.0	5300	16.000		2.720	A2
1W	10/ 3/75	62.0	5200	18.900		2.590	A2
1W	10/31/75	55.0	5300	22.700		4.590	A2
1W	11/26/75	54.4	5300	7.110		7.090	A1
						4.720	A2
1W	1/ 8/76	54.8	5250	23.000		7.280	A1
						5.270	A2
1W	2/ 5/76	53.9	5200	23.100		4.180	A2
1W	3/10/76	57.5	5300	11.800		5.010	A1
						3.340	A2
1W	4/ 8/76	58.7	5200	22.500		3.408	A1
						2.520	A2
1W	4/29/76	60.1	5300	23.300		2.330	A1
						4.640	A2
1W	6/ 4/76	61.0	5300	24.100		2.750	A2
1W	7/ 1/76	62.2	5400	17.000		3.170	A1

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP. DEG C	COND μMHO	RADON DPM/G	NOTE	HELIUM μCC/G	NOTE
* BASH -1W	7/28/76	61.7	5900	19.200		2.140	A2
1W	8/31/76	62.2	5700	15.700		2.280	A1
1W	10/ 1/76	62.2		21.300	A1	6.780	A1
				22.600	A2	5.980	A2
1W	10/29/76	60.0	5500	16.000		4.740	A1
						4.560	A2
1W	12/29/76	52.8	5400	21.400		2.820	A2
1W	2/ 4/77	57.8	5400	21.800		3.510	A2
1W	3/10/77	57.2	5200	22.100		3.610	A2
1W	5/12/77	54.5	5200	20.700		2.000	A1
						2.280	A2
1W	6/ 3/77	61.4	5200	14.000		1.860	A1
						1.410	A2
1W	7/ 2/77	63.3	5100	16.300		8.050	A1
						6.860	A2
1W	8/ 7/77	63.3	5100	19.300		3.630	A1
						3.550	A2
						4.290	F
1W	9/14/77	63.3	5200	16.200	A1	3.600	A2
				16.400	A2		
FOYS -1W	4/24/75	57.0		2.440		0.432	A2
1W	10/ 1/76	57.2	8000				
* FRNK -1P	12/10/74	31.0	6300	2.360		0.357	F G
						0.377	F
1P	1/24/75	31.0	6300	2.340	A1	0.365	F1
				2.300	A2	0.369	F2
1P	1/29/75	24.0	6200	2.280		0.364	F
1P	2/ 6/75	31.0	6150	2.560		0.355	F
1P	3/19/75	31.2	6100	2.300		0.354	F
1P	4/23/75	31.5	6200	2.170		0.345	F
1P	6/ 4/75	30.0	6200	2.110		0.334	F
1P	7/24/75	31.0	6200	2.190		0.344	F
1P	8/27/75	31.4	6300	2.430		0.341	F
1P	10/ 2/75	31.4	6200	2.080		0.351	F
1P	10/31/75	31.4	6300	2.200		0.360	F
1P	11/26/75	31.3	6350	2.460		0.354	F
1P	1/ 8/76	31.4	6400	2.380		0.350	F
1P	2/ 5/76	31.0	6300	2.380		0.355	F
1P	3/10/76	31.0	6500	2.420		0.321	F
1P	4/ 8/76	31.5	6500	2.470		0.365	F
1P	4/29/76	31.5	6700	2.240		0.358	F

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON NOTE DPM/G	HELIUM NOTE µCC/G
* FRNK -1P	6/ 3/76	31.4	6700	2.320	0.368 F
1P	7/ 1/76	31.9	6800	2.200	0.350 F
1P	7/28/76	31.6	7000	2.240	0.359 F
1P	8/31/76	31.6	7000	2.150	0.363 F
1P	9/30/76	31.6	6900	2.290	0.370 F
1P	10/29/76	31.4	6800	2.180	0.369 F
1P	12/30/76	31.4	6800	2.430	0.370 F
1P	2/ 3/77	31.5	6800	1.500	0.328 F
1P	3/10/77	31.7	6200	2.210	0.364 F
1P	5/12/77	30.9	6200	2.200	0.365 F
1P	6/ 4/77	31.4	6200	1.810	0.361 F
1P	7/ 3/77	31.5	6200	1.320 E	0.359 F
1P	8/ 8/77	31.2	6200	2.330	0.427 F
1P	9/14/77	31.0	6400	2.200	0.364 F
WIST -1P	1/24/75	16.0		0.198	
1P	1/29/75	16.0		0.445	
WIST -6P	1/24/75	15.0		0.392	0.045 A1 G
* CO2W -1W	11/27/74	40.0	31700	0.075 X	0.041 F1 G
					0.045 F2 G
					0.051 F3
1W	12/10/74	40.0	31600	0.068	0.044 F1 G
					0.046 F2
1W	1/23/75	39.5	31200	0.078 A1	0.038 F
				0.070 A2	
				0.068 A3	
				0.062 A4	
1W	1/29/75	40.0	31000	0.067	0.044 F
1W	2/ 6/75	40.0	30900	0.072 A1	0.042 F
				0.077 A2	
1W	4/24/75	39.5	30900	0.115	
1W	7/25/75	40.0	31000	0.081	0.022 F
1W	8/28/75	41.0	31400	1.300	0.031 F
1W	10/ 2/75	40.0	31300	0.069	0.023 F
1W	11/ 1/75	40.1	31100	0.063	0.041 F
1W	11/27/75	40.3	32250	0.083 A1	0.041 F
				0.080 A2	
1W	1/ 8/76	39.9	32300	0.071 A1	0.031 F
				0.115 A2	
1W	2/ 6/76	39.8	32000	0.066	0.030 F
1W	3/10/76	39.0	32100	0.064	0.033 F
1W	4/ 8/76	39.3	31600	0.085	0.034 F

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* CO2W -1W	4/30/76	39.8	31800	0.073		0.032	F
1W	6/ 3/76	40.5	32550	0.064		0.021	F
1W	7/ 2/76	40.6	34000	0.064		0.030	F
1W	7/29/76	40.6	33800	0.069		0.018	F
1W	9/ 1/76	40.7	33300	0.049		0.015	F
1W	10/ 1/76	40.6	34500	0.061		0.019	F
1W	10/29/76	40.3	34500	0.065		0.029	F
1W	12/29/76	38.6	34300	0.059			
1W	2/ 4/77	38.3	34200			0.028	F
1W	3/10/77	38.8	31500	0.070		0.043	F
1W	5/12/77	38.9	31500	0.072		0.046	F
1W	6/ 4/77	39.7	31000	0.094		0.033	F
1W	7/ 2/77	40.0	30500	0.114		0.027	F
1W	8/ 7/77	40.0	31000	0.076	A1	0.034	F
				0.084	A2		
1W	9/15/77	39.6	30500	0.088	A1	0.025	F
				0.083	A2		
NILA -1W	11/27/74	44.0	3800	0.138	X	0.916	F G
1W	12/10/74	44.0	3790	0.341		1.360	A2
NILA -2W	3/10/76	26.7	2870	0.377	X		
2W	4/ 8/76	26.0	2830	0.014		1.710	A2
2W	4/29/76	26.7	2830	0.022		1.850	A2
2W	5/21/76	40.3	2960	0.311	A1	2.040	A2
				0.313	A2		
2W	6/ 4/76	44.3	3055	0.383		1.940	A2
2W	7/ 2/76	43.9	3130	0.347		2.040	A2
2W	7/29/76	43.9	3010	0.397		2.090	A2
2W	9/ 1/76	42.2	3090	0.356		2.110	A2
2W	10/ 1/76	38.6	3120	0.322		2.150	A2
2W	10/29/76	40.3	3120	0.319		3.050	A1
						3.740	A2
2W	12/30/76	40.0	3060	0.375		2.320	A2
2W	2/ 4/77	39.4	3100	0.320		2.110	A2
2W	3/10/77	38.3	3000	0.336		5.570	A1
						3.110	A2
2W	6/ 4/77	41.0	3000	0.321		3.470	A1
						3.060	A2
2W	7/ 2/77	40.8	3000	0.304		4.570	A2
2W	8/ 7/77	40.6	3000	0.276	A1	2.160	A2
				0.306	A2		
2W	9/14/77	40.6	3090	0.312		2.190	A2

RADON AND HELIUM IN THE LIQUID PHASE : SOUTHERN NETWORK

* = PRIMARY SAMPLING NETWORK   L = SAMPLE LOST
E = ANALYTICAL ERROR SUSPECTED   NC = NO SAMPLE COLLECTED
? = VALUE UNCERTAIN BY ±20-40% FOR DECAY CORRECTION
F = SAMPLE COLLECTED IN 1720 GLASS FLASK
G = SAMPLE ANALYZED ON HE3/HE4 MASS SPECTROMETER
X = ALL DATA THIS SITE EXCESS RADON, CORRECTED FOR RA226
A1,A2,...= DUPLICATE SAMPLES
A,B,...= SAMPLES COLLECTED AT DIFFERENT TIMES, OR USING DIFFERENT PROCEDURE OR SAMPLER

APPENDIX 2

GEOCHEMICAL DATA: LIQUID PHASE

The following table lists the accumulated measurements of conductivity, D/H and O^{18}/O^{16} ratios, Ra-226, and Pb-210 in the network water samples. Conductivity is tabulated in units of 10^{-6} mhos/cm. The isotopic data are tabulated as delta values relative to Standard Mean Ocean Water (SMOW), the international isotopic water standard maintained by the International Atomic Energy Agency in Vienna. The delta values are units of per mil, and are defined as:

$$\delta = [(R_{sample}/R_{SMOW}) - 1] \times 10^3$$

where R is the D/H or O^{18}/O^{16} ratio.

The Ra^{226} data tabulated here are measured on 20-liter samples except in a few cases when the activities are so high that there is no blank problem in measurements on 1-liter samples. All Pb^{210} measurements are made on 20-liter water samples collected in plastic containers and stripped of radon in the field immediately after collection.

ANALYTICAL DATA : LIQUID PHASE   SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND MU-MHO	DELTA D PER MIL	DELTA O18 PER MIL	RA226 DPM/KG	PB210 DPM/KG
ELSINORE FAULT							
* ELSI -1W	11/ 8/74	40.0	710	-59.0	-8.44		
1W	10/22/75	40.0	680				0.432
1W	12/21/76	38.9	690			0.058	
* MURI -1W	11/ 6/74	54.0	1270	-55.1	-7.61		
1W	4/23/76	52.8	1275				0.167
1W	12/21/76	50.6	1330			0.015	
* ATIB -1W	11/21/74	38.0	495	-53.4	-8.39		
1W	11/18/75	38.2	500				0.063
1W	12/14/76	38.5	530			0.069	
* WARN -1P	11/ 6/74	57.0	484	-64.0	-9.40		
1P	12/21/76	56.9	550			0.075	
ACAL -2S	11/ 6/74	37.0	510	-71.7	-9.90		
SAN JACINTO FAULT							
EDEN -2P	8/ 7/74	32.0	456			17.000	
2P	10/19/74	30.0	455	-62.4	-9.01		
2P	1/ 3/75	25.0	451	-63.0	-9.08		
* EDEN -1P	8/ 7/74	38.0	433			7.400	
1P	10/19/74	37.0	436	-63.6	-9.14		
1P	1/ 3/75	35.0	431	-63.6	-9.07		
1P	2/28/75	35.8	430	-63.2	-9.12		
1P	11/20/75	37.0	425				2.534
1P	1/30/76	36.0	425			10.590	
1P	2/20/76	35.2	426			45.690	
1P	2/16/77	36.0	430			0.092	
* SOBO -1P	10/20/74	37.8	313	-59.8	-9.00		
1P	12/14/76	37.9	339			0.089	
* INCA -1P	3/14/75	35.2	233	-64.0	-9.45		
1P	12/14/76	36.3	249			0.076	

ANALYTICAL DATA : LIQUID PHASE   SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND MU-MHO	DELTA D PER MIL	DELTA O18 PER MIL	RA226 DPM/KG	PB210 DPM/KG
SAN ANDREAS FAULT (SAN BERNARDINO AREA)							
AROW -1W	10/19/74	80.0	590	-55.1	-8.37		
* AROW -1P	10/19/74	80.0	1530	-64.0	-8.99		
1P	12/10/74	79.9	1530	-64.1	-9.05		
1P	4/28/76	79.1	1540				0.141
WATR -1P	3/18/75	65.8	1660	-64.1	-8.85		
SANA - CR	3/19/75	24.0	610	-59.2	-8.70		
* SANA -1P	3/19/75	38.0	1255	-71.6	-10.34		
MISSION CREEK, BANNING FAULTS							
* DSRT -1W	12/11/74	42.0	1490	-83.2	-10.39		
1W	10/30/75	40.0	1460				0.167
* PALM -1P	12/11/74	40.6	313	-78.3	-10.88		
SAN ANDREAS FAULT (IMPERIAL VALLEY)							
DOSP -1W	12/11/74	26.8	2045	-91.8	-11.24		
1W	6/ 3/76	28.8	2050	-91.4	-11.15		
DOSP -1P	12/11/74	27.0	1680	-93.4	-11.47		
1P	3/20/75	27.3		-95.0	-11.61		
1P	4/24/75	28.0	1610	-94.6	-11.60		
1P	6/ 3/76	28.6	1590	-95.5	-11.47		
HMIN -1P	11/27/74	63.0	5700	-71.6	-8.38	55.000	
1P	2/ 6/75	70.0		-72.3	-8.48		
* HMIN -1W	4/23/75	71.1	5700	-73.5	-8.79		
1W	6/ 4/75	71.1		-73.1	-8.87		
1W	11/ 1/75	71.9	5900				2.660
1W	1/ 8/76	71.1	5800			99.950	
1W	2/ 5/76	71.1	5800			146.000	
1W	12/29/76	70.0	5600			92.600	
PILL -1W	11/27/74	73.0	4690	-74.2	-8.88		

ANALYTICAL DATA : LIQUID PHASE SOUTHERN NETWORK

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND MU-MHO	DELTA D PER MIL	DELTA O18 PER MIL	RA226 DPM/KG	PB210 DPM/KG
* BASH -1W	3/20/75	63.0	5300	-72.7	-8.74	92.100	
1W	4/23/75	56.1	5300	-73.1	-8.74		
1W	1/ 8/76	54.8	5250			91.830	
1W	3/10/76	57.5	5300			95.700	
1W	12/29/76	52.8	5400			100.000	
FOYS -1W	4/24/75	57.0		-69.3	-8.30		
* FRNK -1P	12/10/74	31.0	6300	-70.0	-8.35		
1P	1/24/75	31.0	6300	-69.6	-8.32		
1P	4/23/75	31.5	6200	-70.3	-8.37		
WIST -1P	1/24/75	16.0		-35.5	-3.44	56.000	
WIST -6P	1/24/75	15.0		-48.2	0.32	70.000	
* CO2W -1W	11/27/74	40.0	31700	-78.8	-5.29	6.890	
1W	2/ 6/75	40.0	30900	-79.3	-5.35		
1W	4/24/75	39.5	30900	-79.3	-5.38		
1W	2/ 6/76	39.8	32000			6.270	
1W	10/ 1/76	40.6	34500			7.930	
MILA -1W	11/27/74	44.0	3800	-67.0	-7.89	2.400	
MILA -2W	3/10/76	26.7	2870	-67.5	-8.04	6.290 E	
2W	5/21/76	40.3	2960			3.410	
2W	6/ 4/76	44.3	3055			2.740	
2W	9/ 1/76	42.2	3090	-67.5	-8.01		
2W	10/ 1/76	38.6	3120			3.510	
2W	2/ 4/77	39.4	3100	-67.5	-8.04		

* = PRIMARY SAMPLING NETWORK
E = ANALYTICAL ERROR SUSPECTED

APPENDIX 3

SOIL RADON MEASUREMENTS

(By D. Macdougall)

RADON ALPHA-TRACK DATA : SOUTHERN NETWORK

SITE	DATE IN	DATE OUT	TRACKS/ CM2 HR	
ELSINORE FAULT				
MURI	7/22/76	8/24/76	11.5	
	8/24/76	9/22/76	9.5	W
	9/22/76	10/20/76	2.8	W
	10/20/76	12/21/76	3.7	W
	12/21/76	1/21/77	4.9	W
	1/21/77	2/25/77	5.4	W
	2/25/77	4/ 1/77	9.9	W
	4/ 1/77	5/ 3/77	13.8	
	5/ 3/77	6/ 9/77	14.6	
	6/ 9/77	7/ 6/77	10.1	
	7/ 6/77	8/11/77	10.8	
	8/11/77	9/16/77	6.4	W
ATIB	6/26/76	7/22/76	56.2	
	7/22/76	8/24/76	63.3	
	8/24/76	9/22/76	90.4	
	9/22/76	10/22/76	81.0	
	10/22/76	12/21/76	89.8	
	12/21/76	1/21/77	47.8	W
	1/21/77	2/25/77	48.9	W
	2/25/77	4/ 1/77	95.2	
	4/ 1/77	5/ 3/77	80.7	
	5/ 3/77	6/ 8/77	110.0	
	6/ 8/77	7/ 6/77	48.0	
	7/ 6/77	8/12/77	73.8	
	8/12/77	9/16/77	120.0	
SAN JACINTO FAULT				
EDEN	6/24/76	7/14/76	136.0	
	7/14/76	8/12/76	97.1	
	8/12/76	10/ 9/76	214.0	
	10/ 9/76	10/15/76	96.8	
	10/15/76	11/17/76	127.0	
	11/17/76	12/14/76	123.0	
	12/14/76	1/12/77	163.0	W
	1/12/77	2/16/77	194.0	
	2/16/77	3/16/77	165.0	
	3/16/77	4/12/77	170.0	
	4/12/77	5/11/77	132.0	
	5/11/77	6/ 8/77	143.0	
	6/ 8/77	7/ 6/77	131.0	
	7/ 6/77	8/10/77	115.0	
	8/10/77	9/11/77	137.0	

RADON ALPHA-TRACK DATA : SOUTHERN NETWORK

SITE	DATE IN	DATE OUT	TRACKS/ CM2 HR
SAN ANDREAS FAULT (SAN BERNARDINO AREA)			
AROW	7/27/76	8/30/76	5.5
	8/30/76	9/30/76	0.7
	9/30/76	10/28/76	2.2
	10/28/76	11/29/76	0.9 W
	11/29/76	12/28/76	1.1 W
	12/28/76	2/ 2/77	1.3 W
	2/ 2/77	3/ 9/77	1.5 W
	3/ 9/77	5/11/77	1.0 W
	5/11/77	6/ 5/77	1.9 W
	6/ 5/77	7/ 4/77	1.6 W
	7/ 4/77	8/ 9/77	0.5 W
	8/ 9/77	9/15/77	1.2 W
SAN ANDREAS FAULT (IMPERIAL VALLEY)			
NILA	7/ 1/76	7/29/76	37.4
	7/29/76	9/ 1/76	52.9
	9/ 1/76	10/ 1/76	46.1
	10/ 1/76	10/29/76	46.3
	10/29/76	11/29/76	39.5 W
	11/29/76	12/30/76	24.9 W
	12/30/76	2/ 4/77	55.8
	2/ 4/77	3/10/77	49.8
	3/10/77	5/12/77	52.4
	5/12/77	6/ 4/77	49.2
	6/ 4/77	7/ 3/77	31.9
	7/ 3/77	8/ 7/77	55.6 N
	8/ 7/77	9/14/77	95.0
IMPERIAL FAULT			
HOLT	7/29/76	9/ 1/76	23.6
	9/ 1/76	10/ 2/76	17.2
	10/ 2/76	10/29/76	17.3
	10/29/76	11/29/76	12.9 W
	11/29/76	12/30/76	5.1 W
	12/30/76	2/ 4/77	5.3 W
	2/ 4/77	3/10/77	11.2
	3/10/77	5/13/77	17.4
	5/13/77	6/ 3/77	15.8

RADON ALPHA-TRACK DATA : SOUTHERN NETWORK

SITE	DATE IN	DATE OUT	TRACKS/ CM2 HR
HOLT	6/ 3/77	7/ 3/77	15.1
	7/ 3/77	8/ 7/77	29.5
	8/ 7/77	9/13/77	50.0
ROSS	7/ 2/76	7/29/76	49.6
	7/29/76	9/ 1/76	40.1
	9/ 1/76	10/ 2/76	44.8
	10/ 2/76	10/29/76	44.0
	10/29/76	11/29/76	35.1
	11/29/76	12/30/76	37.2
	12/30/76	2/ 4/77	49.6
	2/ 4/77	3/10/77	57.3
	3/10/77	5/13/77	50.4
	5/13/77	6/ 3/77	35.9
	6/ 3/77	7/ 3/77	41.4
	7/ 3/77	8/ 7/77	51.3
	8/ 7/77	9/13/77	62.2
S-31	7/ 2/76	7/29/76	26.8
	7/29/76	9/ 1/76	35.2
	9/ 1/76	10/ 2/76	26.7
	10/ 2/76	10/29/76	25.4
	10/29/76	11/29/76	24.0
	11/29/76	12/30/76	28.5
	12/30/76	2/ 4/77	33.8
	2/ 4/77	3/10/77	39.0
	3/10/77	5/13/77	38.4
	5/13/77	6/ 3/77	29.6
	6/ 3/77	7/ 3/77	30.4
	7/ 3/77	8/ 7/77	35.2
	8/ 7/77	9/13/77	48.0

W = WATER CONDENSED ON FILM
N = NEW HOLE, SAMPLING LOCATION CHANGED

TECHNICAL REPORT NO. 2

ADDITIONAL TASK: RADON, HELIUM, AND GEOCHEMICAL MONITORING ON THE PALMDALE UPLIFT

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ADDITIONAL TASK: RADON, HELIUM, AND GEOCHEMICAL MONITORING ON THE PALMDALE UPLIFT

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ABSTRACT

This report covers the first ten months of radon and helium monitoring along the San Andreas fault in the Palmdale area. From a study of 21 possible well and spring locations, a primary network of eight sites, including seven wells and one natural hot spring (33°C) spaced along a 50 mile stretch of the fault from Lake Hughes to Big Pines, has been selected. The parameters being measured include temperature, conductivity, dissolved radon activity and helium concentration, He^3/He^4 isotope ratios, Ra^{226} activity, and D/H and O^{18}/O^{16} ratios in the water. Radon and helium are measured at monthly intervals at the eight primary sites, and occasionally at other secondary locations. During the past six months our major effort has been devoted to the analysis of samples which had been stored for helium analysis on the portable helium mass spectrometer, pending addition of a vacuum-line system for removal of all gases but helium and neon. This system has been put into operation; all helium analyses have been completed and the data are tabulated and presented graphically in this

report together with the accumulated radon measurements.

The Palmdale area well samples show no pronounced coherence of radon and helium fluctuations or strong seasonal variations, in contrast to the one hot spring site (Warm Springs) which has a strong helium-radon covariance and a large, apparently seasonal, effect of minimum helium and radon concentrations in the month of April. Only one site, the Palmdale Water District Well #17 (PDLE-1W) shows an apparent correlation of monitored parameters with seismic activity. In this well pronounced one-month spikes of increased temperature, conductivity, helium, and radon activity were observed on September 9 of this year, three days after a swarm near Juniper Hills with a maximum magnitude of 2.7. Similar high values of these four parameters were observed in November 1976, the first time the well was sampled, about three weeks after a magnitude 2.6 earthquake near Pearblossom. Unfortunately both these "geochemical events" may be related to sporadic well usage immediately before sampling, despite the fact that all wells are flushed with several well-volumes of water and brought to constant temperature before samples are taken. Large-scale pumping experiments requiring pumping and disposal of volumes of the order of 10^5 liters of water are required to study this possibility; these experiments are planned for the near-future when arrangements can be made to accomodate the required water volumes.

1. INTRODUCTION

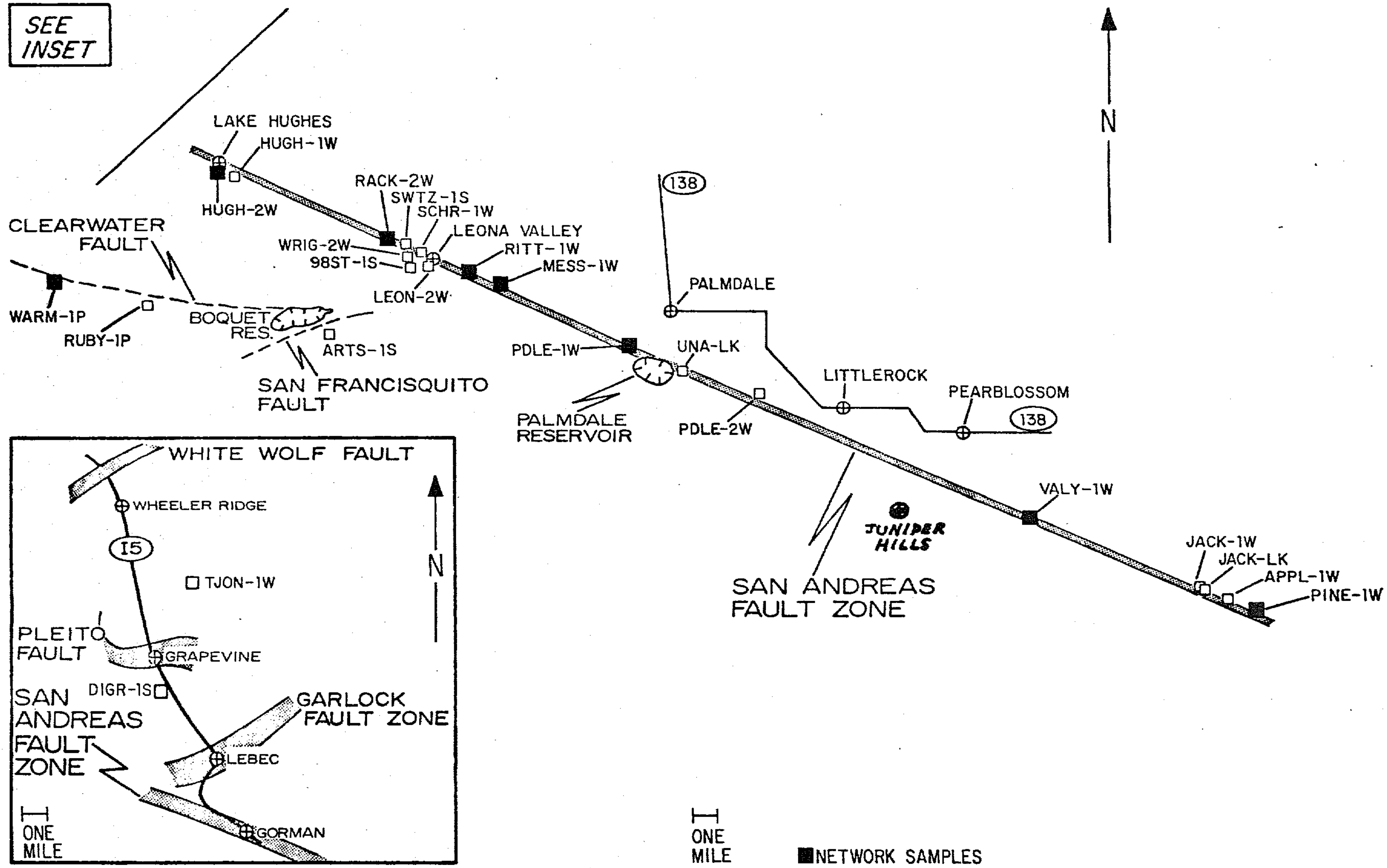
Our first report on the Palmdale area monitoring program (TR No. 1, April 1977) described the initial survey of wells and springs in this area for radon and helium concentrations, He^3/He^4 isotopic ratios, and D/H and O^{18}/O^{16} measurements on the waters. Some 21 possible monitoring sites were studied, and 8 locations were selected for regular monthly radon and helium monitoring. Report No. 1 included the initial helium concentration and isotope ratio analyses, both measured on the helium-isotope mass spectrometer, the D/H and O^{18}/O^{16} data, and the radon results from the first several months of monitoring. Samples collected for monthly helium measurements were stored in the initial copper-tube pinchclamp samplers until conversion of the portable helium mass spectrometer to precision laboratory analysis could be completed.

Since submission of the first report, the new vacuum-line inlet system for the portable helium spectrometer has been completed and put into operation. Details of the system are included in the accompanying report (TR No. 7, October, 1977) on radon and helium monitoring on the "Southern Network", i.e. the area from San Bernardino to the Mexican border. Briefly, the analytical procedure consists of total gas extraction from 20 grams of water (collected in the copper tubing), followed by removal of all gases but helium and neon by adsorption on charcoal at liquid-nitrogen temperature and reaction with a getter. The He-Ne fraction is then admitted to the spectrometer for peak height measurement of He^4 in comparison with calibrated standards measured before and after each sample. By measuring helium in the pure He-Ne fraction rather than in the total extracted gas (as is done with measurements made in the field), a routine laboratory precision of 1% in the helium measurements has been achieved. (The overall errors are probably somewhat larger because of the general difficulties in sampling helium in a representative fashion, especially in the Palmdale area where helium concentrations are considerably lower than in the other areas being monitored).

During the present period of work the major emphasis has thus been on analyzing the entire set of Palmdale network samples for helium concentrations, while continuing the monthly radon analyses as usual. This objective has been achieved, and in this report we present graphs and tabulations of the helium and radon concentrations in the eight network sites for the period from November, 1976, to September, 1977.

2. SAMPLING NETWORK

Figure 1 shows the Palmdale network monitoring sites, and other sampling locations we have investigated. There are eight "Primary Network" sites; 7 wells along the San Andreas fault, and one hot spring, "Warm Springs", on the Clearwater Fault just west of the San Andreas at the north end of the monitoring section, southwest of Lake Hughes. Although not directly on the San Andreas fault, the Warm Springs site contains the "hottest" water found in the area (33°C), and is an important control for comparison with the well data, since there are no thermal springs along the fault trace in this area.


SEE INSET
N
LAKE HUGHES
HUGH-1W
HUGH-2W
RACK-2W
SWTZ-1S
SCHR-1W
LEONA VALLEY
RITT-1W
MESS-1W
WRIG-2W
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CLEARWATER FAULT
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JACK-1W
JACK-LK
APPL-1W
PINE-1W
WHITE WOLF FAULT
WHEELER RIDGE
I5
TJON-1W
N
PLEITO FAULT
GRAPEVINE
DIGR-1S
SAN ANDREAS FAULT ZONE
GARLOCK FAULT ZONE
LEBEC
GORMAN
ONE MILE
ONE MILE
NETWORK SAMPLES

Figure 1

TABLE 1: PALMDALE AREA PRIMARY NETWORK

SITE CODE	LOCATION	WELL DEPTH (FEET)	TEMPERATURE (°C)	CONDUCTIVITY (μMho/cm)
WARM-1P	Warm Springs	-	33	1920
HUGH-2W	Lake Hughes Well	270	15	600
RACK-2W	Rackett Ranch Well	115	17	900
RITT-1W	Ritter Ranch Clubhouse Well	∿100	12-20	800
MESS-1W	Messer Ranch Well	90	17	1100
PDLE-1W	Palmdale Water Dist. Well #17	400	19	1400
VALY-1W	Valyermo Well	152	17	600
PINE-1W	Big Pines Well	230	8.5	400

The previous report (TR No. 1) listed the characteristics of all 21 possible monitoring sites we investigated in the Palmdale area. Table 1 summarizes the most important data on the eight primary network sites. The choice of these sites for primary network was based on location, spacing, availability for routine sampling, and representation of different groundwater aquifers as inferred from stable isotope data (D/H and O^{18}/O^{16} ratios), conductivity, temperature, etc., as described in the previous report.

3. HELIUM AND RADON MEASUREMENTS

The accumulated helium and radon measurements in the spring and well waters are tabulated in Appendix 1. The radon measurements are made by alpha scintillation counting after total radon extraction from one-liter water samples; these data are tabulated in dpm/gram of water. The helium measurements are tabulated in units of 10^{-6}ccSTP of helium/gram of water. Temperature and conductivity data are also tabulated for all samples.

The monthly helium and radon results are plotted for each of the eight primary network sites in Figures 2 through 9. The radon activities in these waters vary by almost a factor of ten, from about 0.2 dpm/g at Warm Springs (WARM-1P) to 1.9 dpm/g at Rackett Ranch Well (RACK-2W), a range which is quite similar to that observed along the Elsinore, San Jacinto, and San Andreas faults in our Southern network. Helium concentrations in the Palmdale waters are, however, lower by factors of 10 to 100 than concentrations in the Southern network, with the exception of the single hot spring - Warm Springs - in which helium is supersaturated relative to atmospheric solubility (0.045×10^{-6} ccSTP/g) by a factor of about 100. The next-warmest water in the Palmdale network is the Palmdale Well #17, PDLE-1W, at 19°C, which is supersaturated by almost a factor of 10 in helium. The remaining waters range in supersaturation from a factor of 4 (HUGH-2W) down to 1.5 (PINE-1W), as described in our previous report.

The Palmdale well samples do not show any pronounced coherence of radon and helium fluctuations; nor does there appear to be any significant seasonal effect, with the possible exception of helium in PINE-1W which appears to have a maximum concentration in June and July. The hot spring sample, WARM-1P, does, however, show both a strong helium-radon covariance and a large seasonal effect, in which both helium and radon exhibit pronounced minima in April, with no corresponding variation in temperature. The Lake Hughes well, HUGH-2W, also has a strong helium minimum in March-April, but its radon activity has remained essentially constant since January. The Rackett Ranch Well, RACK-2W, had a very low radon activity in February of this year compared to the remainder of the record; this corresponded with an exceptionally low water temperature 14.6°C, vs. about 17°C for the rest of the year. This effect probably reflects a sample of stagnant well water in which significant decay of radon had occurred prior to sampling, as there is no accompanying fluctuation in the helium concentration.

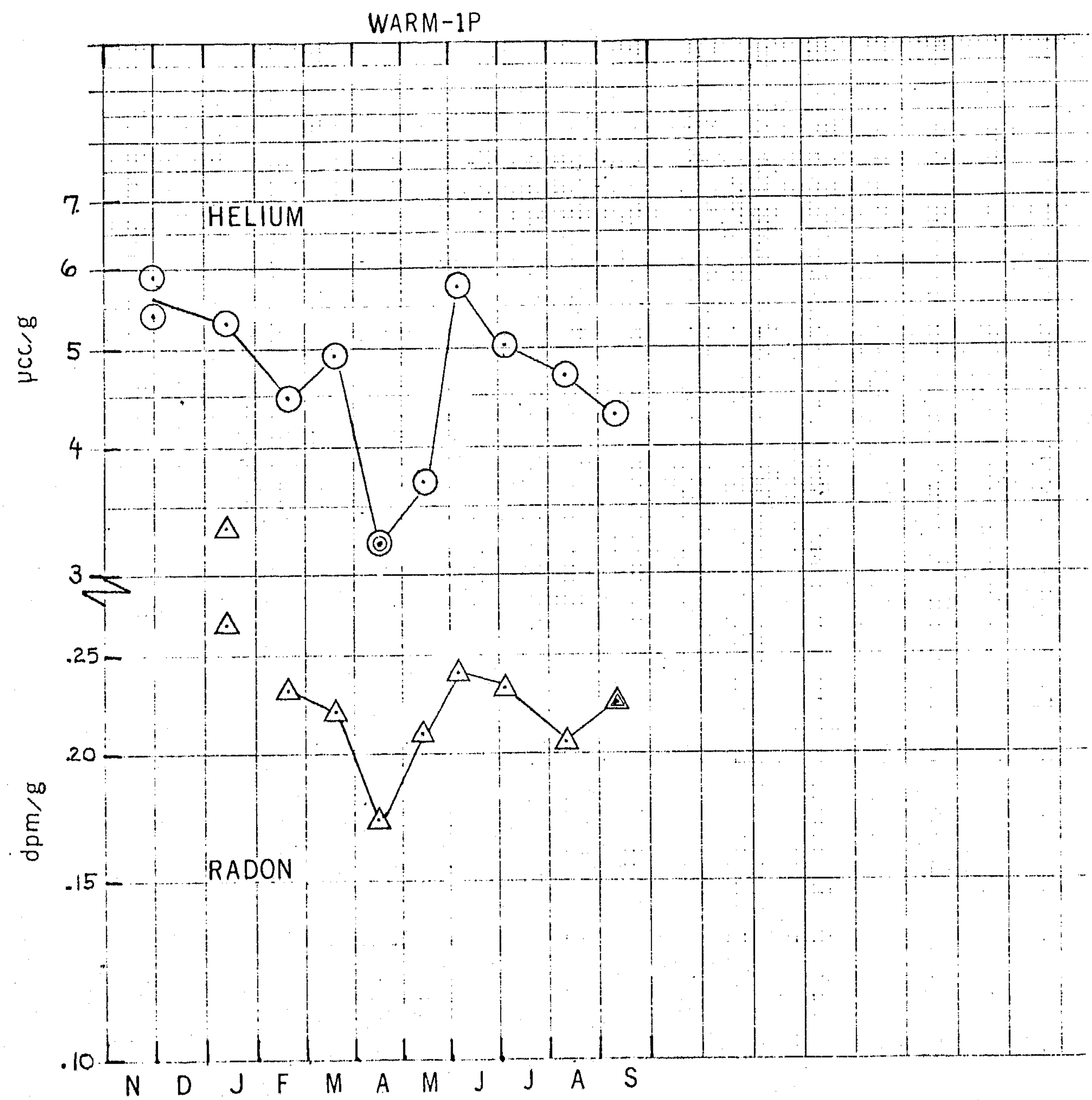

Figure 2

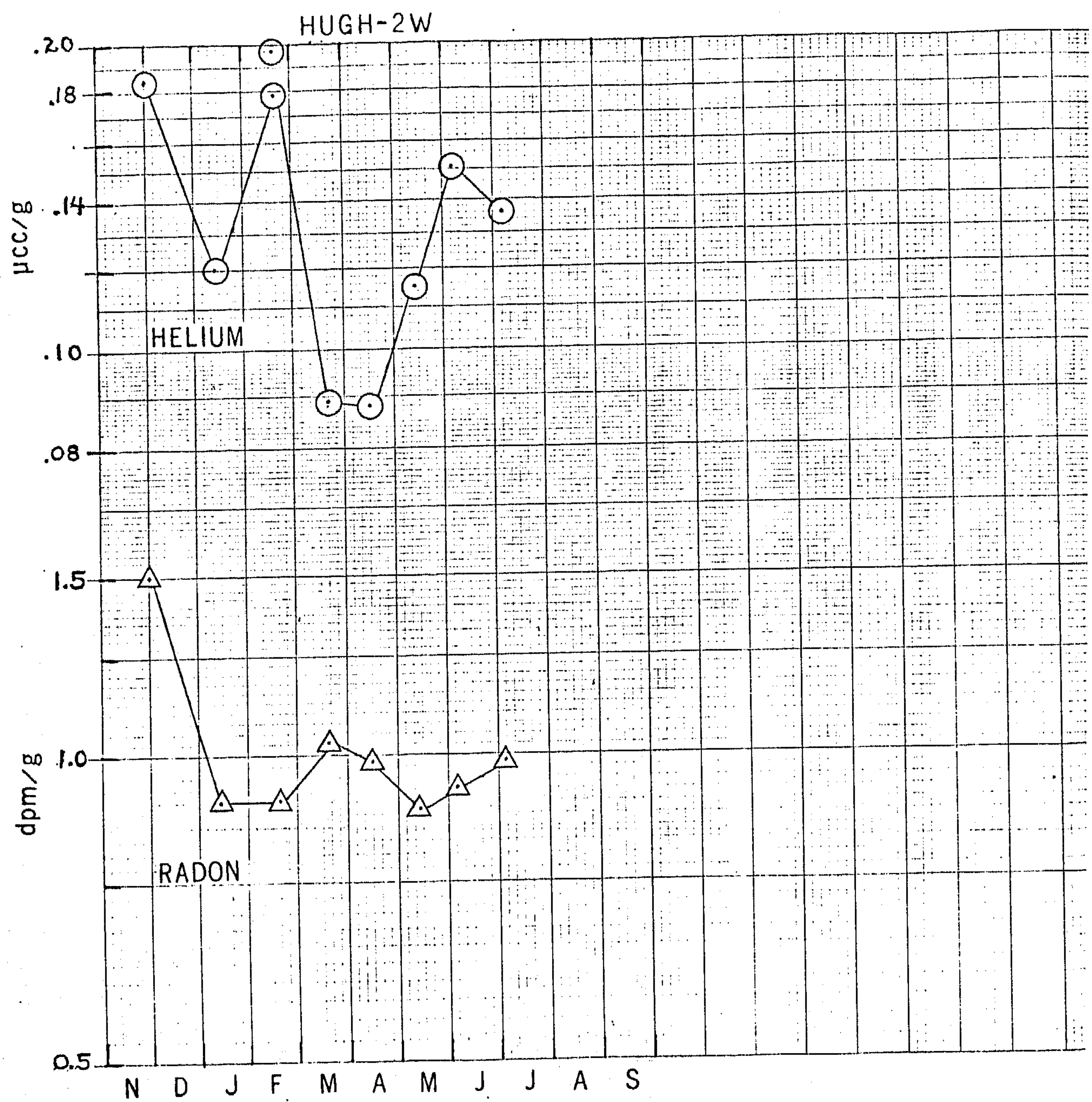
HUGH-2W
.20
.18
.14
.10
.08
μcc/g
HELIUM
1.5
1.0
0.5
dpm/g
RADON
N
D
J
F
M
A
M
J
J
A
S

Figure 3

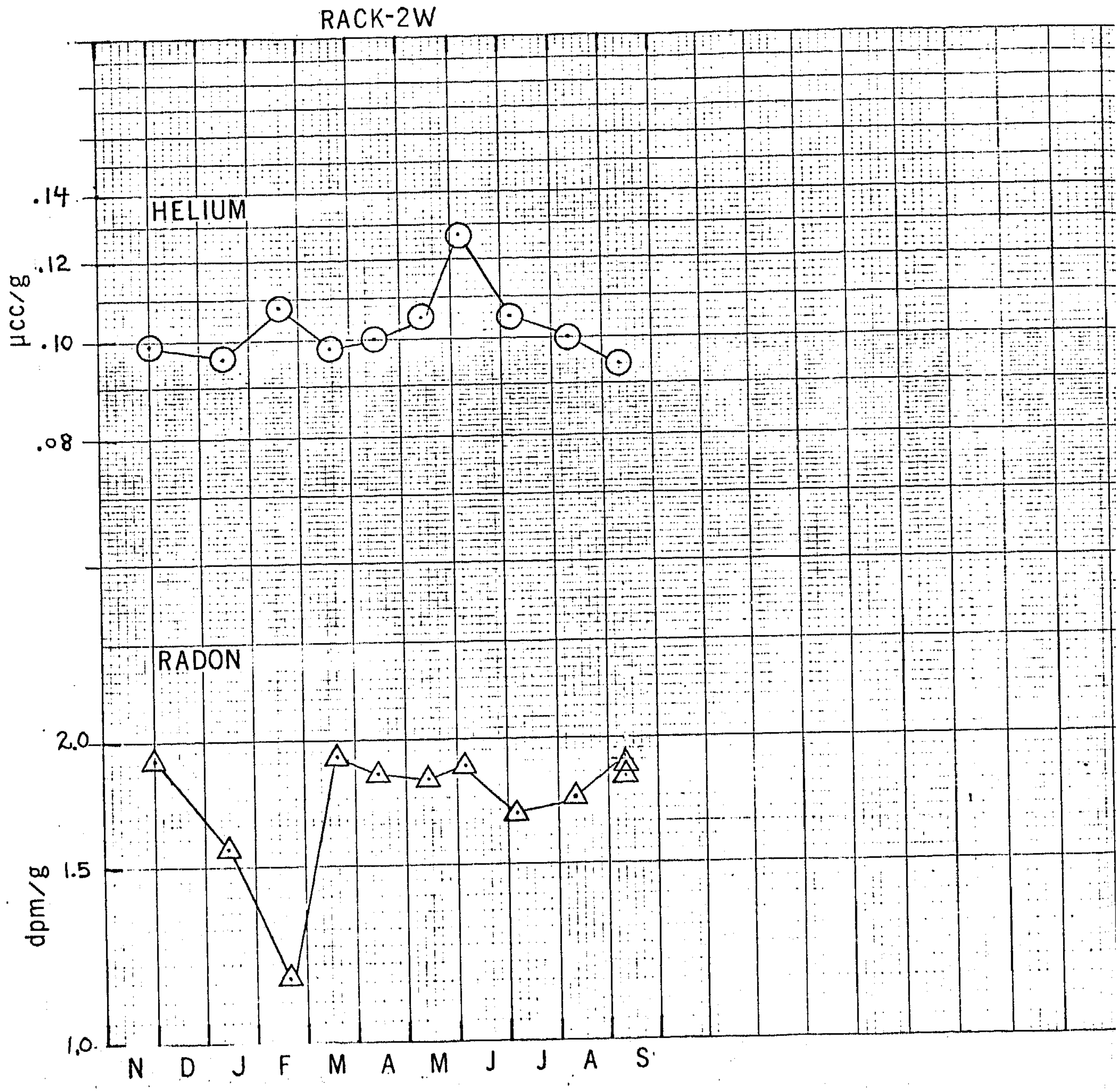
RACK-2W
HELIUM
μcc/g
.14
.12
.10
.08
RADON
dpm/g
2.0
1.5
1.0
N D J F M A M J J A S

Figure 4

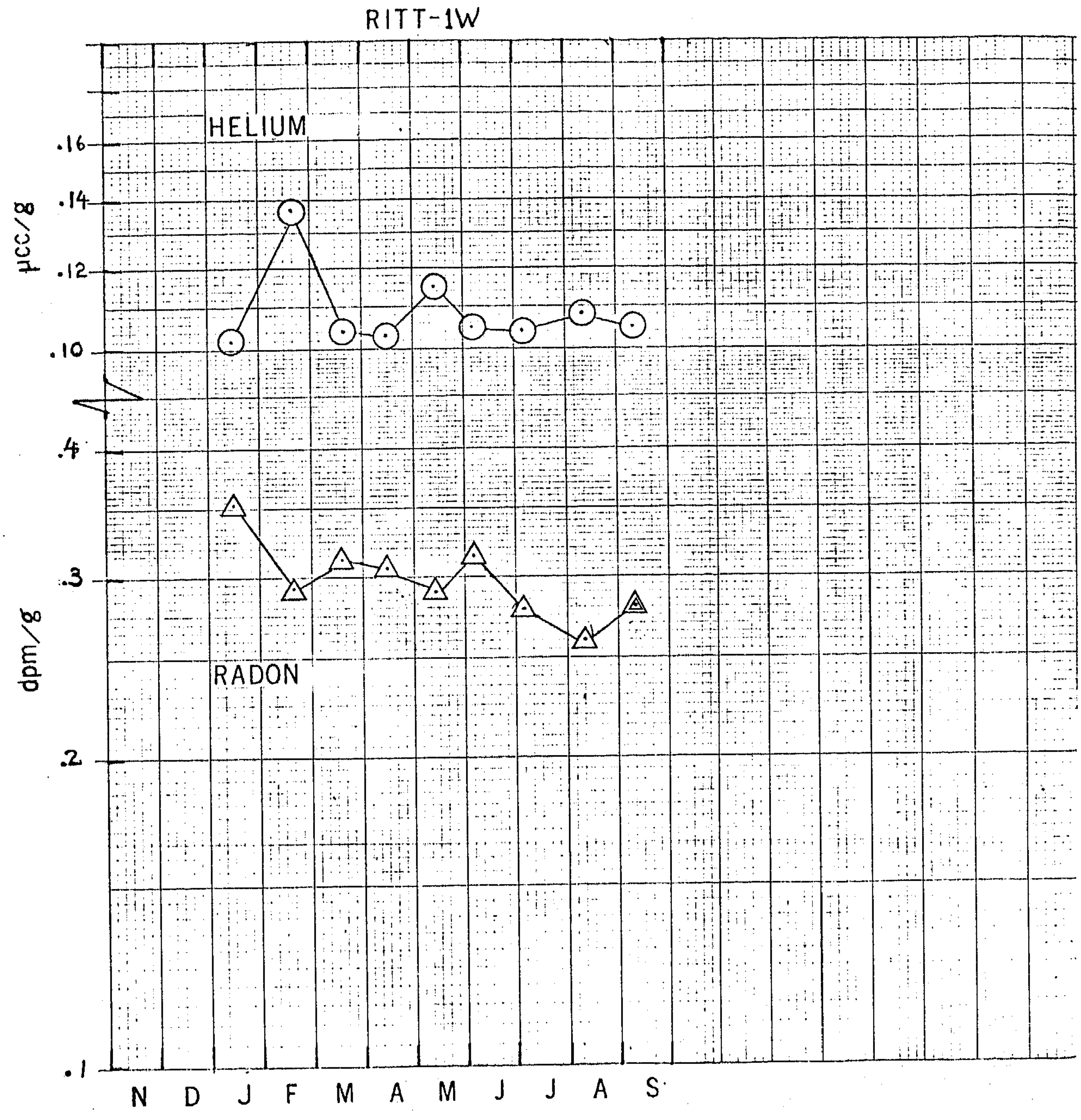

Figure 5

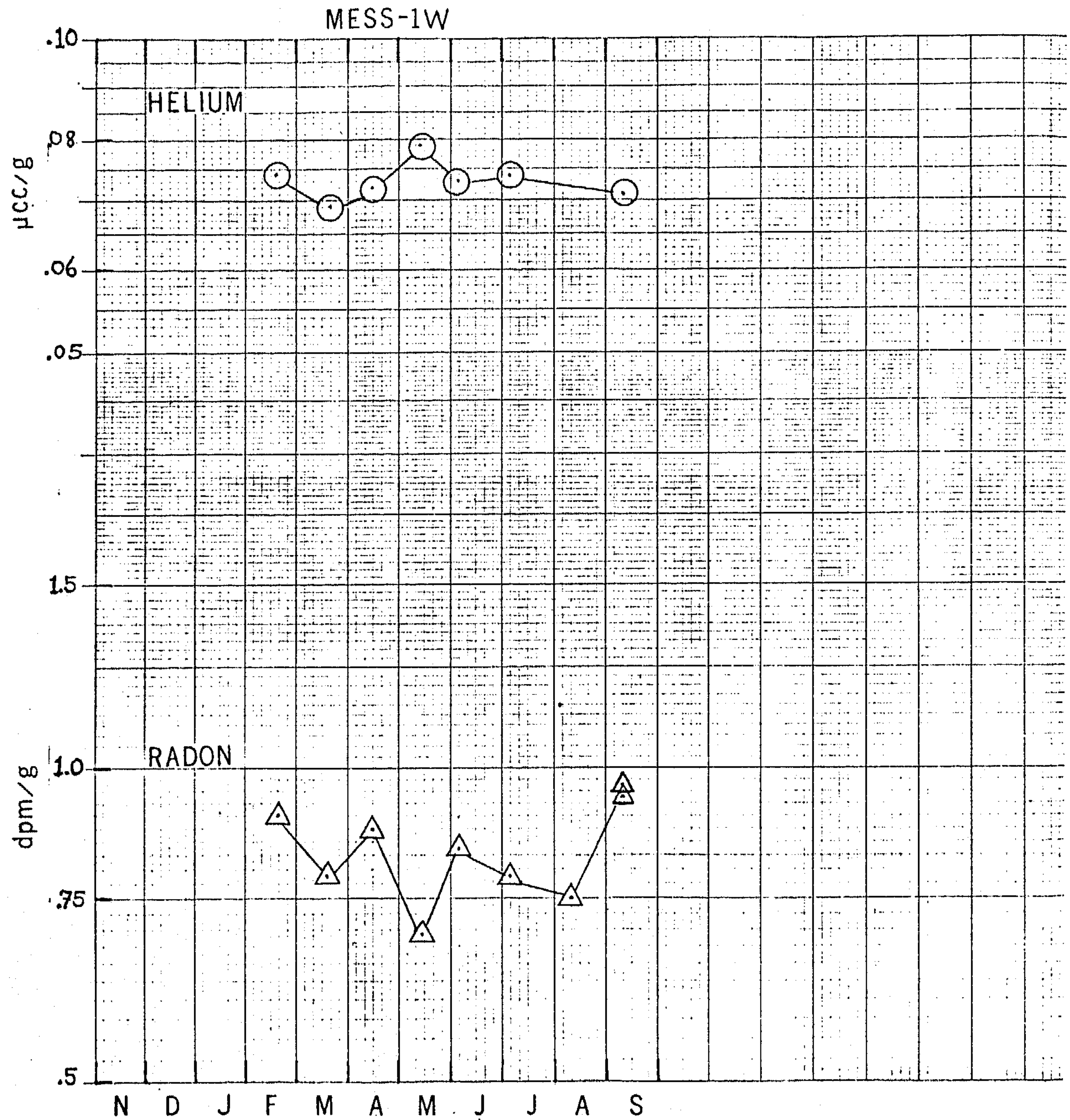
MESS-1W
HELIUM
μcc/g
.10
.08
.06
.05
1.5
RADON
dpm/g
1.0
.75
.5
N
D
J
F
M
A
M
J
J
A
S

Figure 6

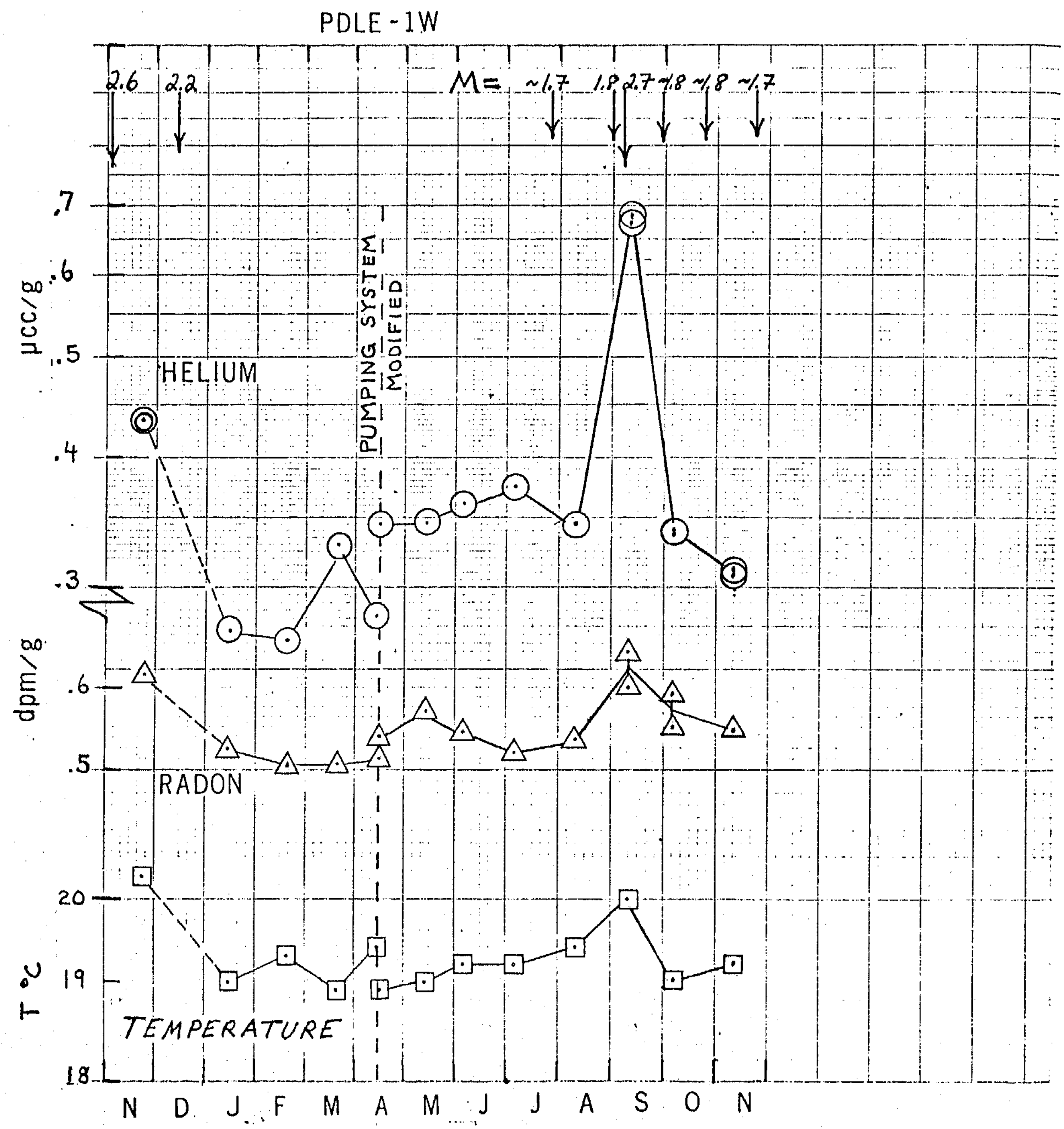
PDLE-1W
M=
2.6
2.2
~1.7
1.8
2.7
~1.8
~1.8
~1.7
PUMPING SYSTEM MODIFIED
μcc/g
.7
.6
.5
.4
.3
HELIUM
dpm/g
.6
.5
RADON
T °C
20
19
18
TEMPERATURE
N D J F M A M J J A S O N

Figure 7

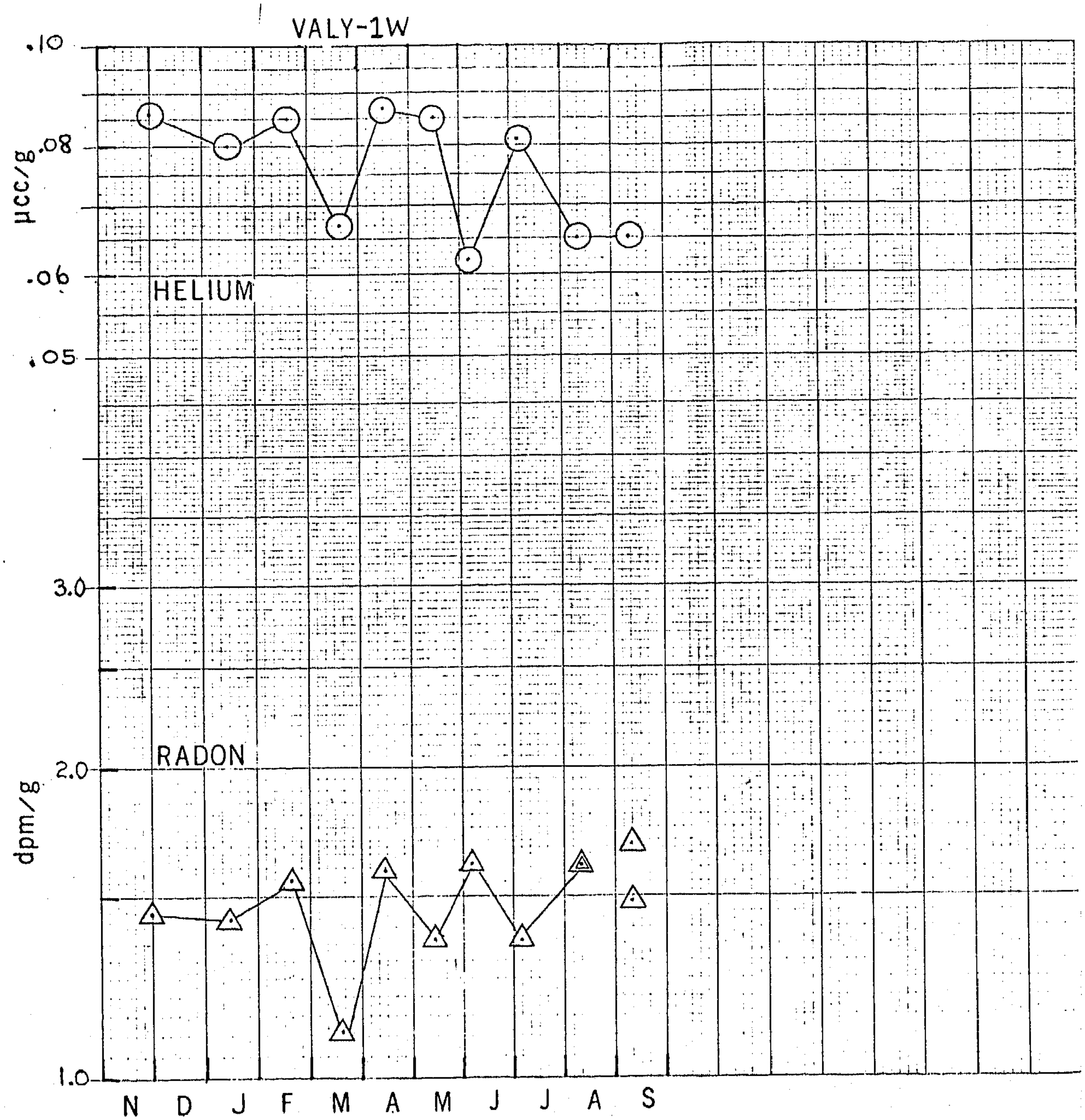
VALY-1W
.10
.08
μcc/g
.06
.05
HELIUM
3.0
2.0
RADON
dpm/g
1.0
N
D
J
F
M
A
M
J
J
A
S

Figure 8

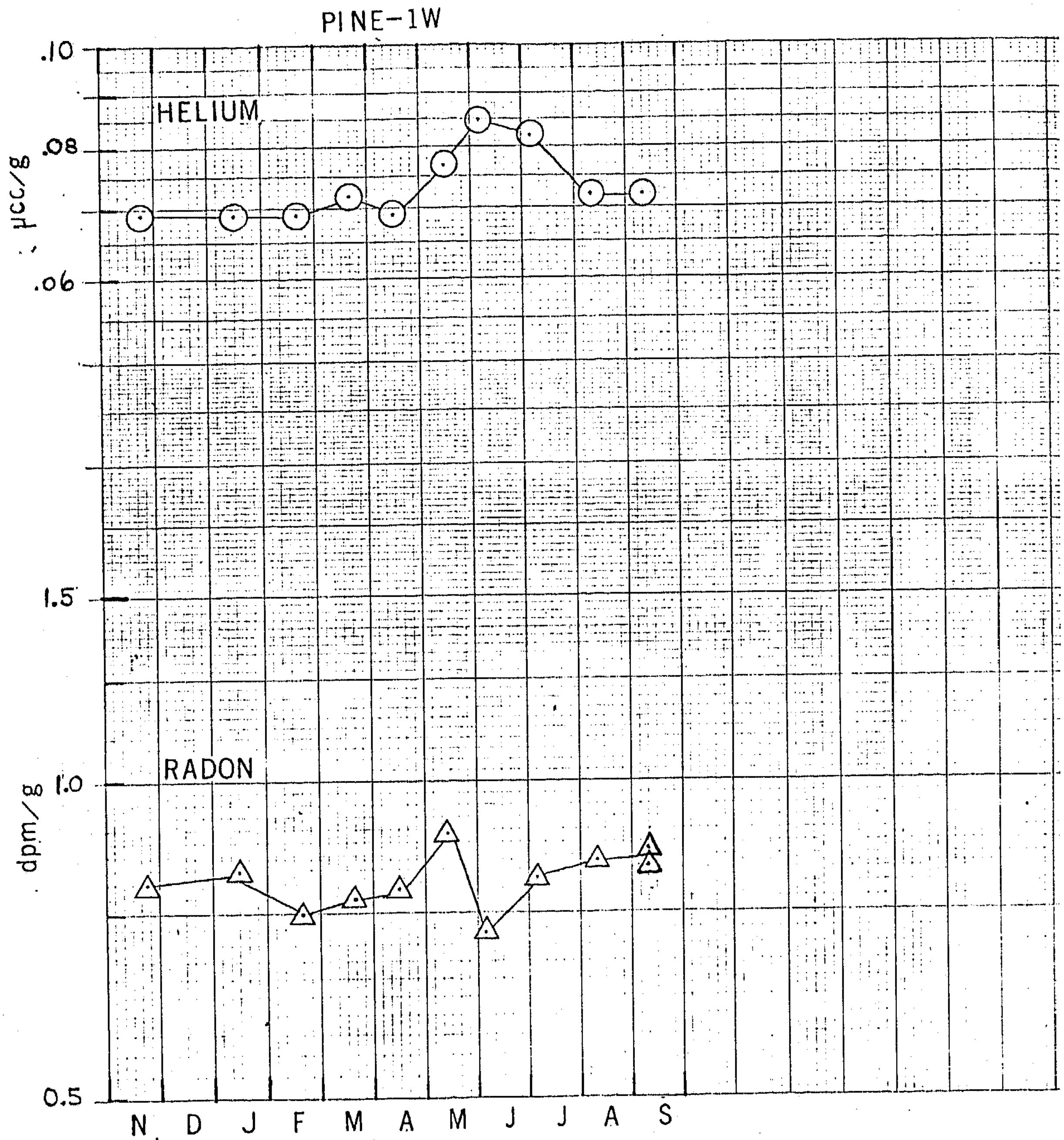

Figure 9

4. POSSIBLE CORRELATIONS WITH SEISMIC ACTIVITY

Since the inception of radon and helium monitoring in November, 1976, seismic activity has centered around the Juniper Hills-Valyermo area, southeast of Palmdale on the San Andreas. Only one of our monitoring sites, the Palmdale Water District Well #17 (PDLE-1W), shows a possible correlation of radon and helium variations with seismic events. This well is about 25 km northwest of the Juniper Hills area, on the San Andreas (Figure 1). Karen McNally, who has been monitoring seismic activity in the field during the past year, has kindly provided us with the records of the principal events; the dates and magnitudes of these events are indicated in Figure 7 above the helium, radon, and temperature records. All of these earthquakes occurred near the Juniper Hills-Valyermo area except for the magnitude 2.6 event on November 3, 1976, which had an epicenter close to Llano, about 10 km east of Pearblossom and about 10 km north of the fault trace.

The monitoring record for this well is unfortunately interrupted by a change in the pumping system in April of this year. Prior to this time chlorine was injected at depth in the well with an accompanying introduction of air bubbles which stripped out some of the gases; on April 14 the system was modified so that this air contamination no longer occurred. As shown by the breaks in the record on this date, the measured He and Rn contents increased by about 20% and 5% respectively when the air stripping was eliminated (samples collected 13 April and 14 April, before and after the modification; data tabulated in Appendix 1).

The largest magnitude event in the Juniper Hills area occurred during a swarm on 6 September when an M=2.7 event was recorded. Our samples were collected three days later, on September 9, and as shown in Figure 7, a very large helium concentration spike was observed at this time, accompanied by a smaller radon and temperature increase. The conductivity of the water also increased, by about 14% relative to previous measurements, at this time.

In Figure 7 the radon and helium records have been extended to include the most recent measurements made. Table 2 lists the complete record of temperature, conductivity, radon and helium data, for the period from July 5 to November 9. It is clear that a significant change in all these parameters occurred, with a maximum signal in helium concentration which increased by a factor of two relative to the previous baseline. A similar apparent correlation can be seen in the data for 23 November, 1976, when high helium, radon, and temperature values are observed after the November 3 M=2.6 event; here, however, there are no earlier data for comparison and only the decrease by January, 1977, can be observed. The Valyermo Well (VALY-1W, Figure 8), although much closer to the actual epicentral locations, shows no evidence of any correlation with these events. It should be noted, however, that the Palmdale well has much higher conductivity and helium concentration, a higher temperature, and a lower radon activity, and is clearly sampling different water. (This is also shown by the differences in D/H and O^{18}/O^{16} ratios in the two waters, as described in TR #1; these data are listed in Appendix 2).

TABLE 2: JULY TO NOVEMBER MEASUREMENTS ON PALMDALE WELL #17 (PDLE-1W)

DATE (1977)	TEMP. (°C)	CONDUCTIVITY (μMho/cm)	RADON (dpm/g)	HELIUM (μcc/g)
July 5	19.2	1395	0.52	0.40
				0.38*
August 10	19.4	1400	0.54	0.35
September 9	20.0	1600	0.60	0.69
			0.65*	0.66*
October 6	19.0	1405	0.59	0.34
			0.55*	0.34*
November 9	19.2		0.55	0.31
				0.31*

*Duplicate sample collections.

Unfortunately, there are irregularities in the pumping history of the PDLE-1W well prior to sampling which are difficult to avoid, and which may, in fact, be correlated with the He, Rn, temperature, and conductivity spikes in the November, 1976, and September, 1977 samples. This well is normally sampled after pumping for 30 to 50 minutes, which is sufficient to flush several well-volumes of water through the system at a pumping rate of 360 liters/minute, and to bring the water to constant temperature. We have three sampling dates on which it is known that the pump had been off for 16 hours to 2 days prior to sampling: April 14, October 6, and November 6, 1977, and all of these samples show average baseline values for all parameters. On two occasions, however, the pump had been operated for several hours prior to our sampling; these occasions are, of course, the 23 November, 1976, and the 9 September, 1977, collections. No pumping data are available prior to the other collections. Thus there is a distinct possibility that pumping some 40,000 liters of water through this well finally brings up a different water source which is always higher in helium, radon, etc. In order to test this possibility, we have to sample the well over several hours at some period when the reservoir can accomodate up to 10^5 liters of water. It is hoped that arrangements can be made to do this at the next sampling time; and we plan to make such tests at as many wells as possible during the rest of the year. In the meantime, the apparent correlation of monitoring parameters with seismic activity has to be regarded as probably coincidental.

5. OTHER MEASUREMENTS

The stable isotope data (measured by J. O'Neil at USGS, Menlo Park), and Ra^{226} measurements on network samples are tabulated in Appendix 2. These data and the He^3/He^4 isotope ratio measurements were discussed in the previous Palmdale Network report (TR No. 1). At the present time we are beginning measurements of dissolved nitrogen and argon (collected during the extraction of helium, and stored in breakseals). The application of these measurements to the understanding of the helium and radon variations is discussed in detail in the accompanying report on the results from the Southern network (TR No. 7).

6. ACKNOWLEDGEMENTS

We wish to thank Dr. Karen McNally for detailed discussions of the seismic record from her field monitoring program, and Dr. Don Anderson for alerting us to the September earthquake swarm. The continued helpful assistance of the well owners, supervisors, rangers, and other persons at the well sites is gratefully acknowledged.

LIST OF TECHNICAL REPORTS PREVIOUSLY SUBMITTED

Additional Task: Radon, Helium, and Geochemical Monitoring on the Palmdale Uplift, H. Craig, J.E. Lupton, Y. Chung, R.M. Horowitz

No. 1 SIO Reference Number 77-6 April 1977

APPENDIX 1

RADON AND HELIUM TABULATIONS: LIQUID PHASE

The accumulated measurements of helium concentrations and radon activities in the liquid phase are listed in the following table, together with collection dates and water temperature and conductivity. Sampling locations are listed from northwest to southeast along the San Andreas. The primary network locations are marked with asterisks before the site codes. Helium concentrations are tabulated in units of 10^{-6} ccSTP/gram of water; radon activities in dpm/gram of water.

RADON AND HELIUM IN THE LIQUID PHASE : PALMDALE AREA

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* WARM -1P	11/ 4/76	29.2	2000				
1P	11/30/76	33.0	1990		L	5.900	A1 G
						5.400	A2 G
1P	1/13/77	32.3	2000	0.268	A1	5.310	A2
		32.3		0.334	A2		
1P	2/18/77	33.3	1920	0.231		4.480	A2
1P	3/18/77	33.3	1920	0.219		4.930	A2
1P	4/14/77	33.0	1920	0.173		3.210	A1
						3.220	A2
1P	5/13/77	34.0	1920	0.209		3.700	A1
						3.700	A2
1P	6/ 6/77	33.5	1920	0.240		5.770	A2
1P	7/ 4/77	32.5	1920	0.232		5.030	A2
1P	8/10/77	31.8	1920	0.206		4.700	A2
1P	9/10/77	34.2	1920	0.226	A1	4.300	A2
				0.224	A2		
HUGH -1W	11/24/76	17.1	900	0.646		0.094	A2
* HUGH -2W	11/24/76	15.1	610	1.500		0.184	A1
2W	1/13/77	14.6	620	0.901		0.119	A2
2W	2/18/77	15.2	510	0.903		0.177	A1 G
						0.197	A2
2W	3/18/77	15.6	620	1.030		0.089	A2
2W	4/14/77	15.0	530	0.986		0.088	A2
2W	5/13/77	15.6	610	0.884		0.115	A2
2W	6/ 7/77	15.6	605	0.928		0.151	A2
2W	7/ 4/77	15.7	610	0.944		0.136	A2
2W	8/10/77	17.0	620		NC		NC
2W	9/10/77	16.5	620		NC		NC
* RACK -2W	12/ 1/76	16.8	850	1.910		0.094	A1 G
						0.099	A2
2W	1/14/77	16.8	900	1.560		0.096	A2
2W	2/17/77	14.6	810	1.160		0.108	A2
2W	3/17/77	16.9	880	1.930		0.098	A2
2W	4/13/77	17.2	900	1.850		0.100	A2
2W	5/12/77	16.8	895	1.830		0.105	A2
2W	6/ 6/77	17.7	900	1.880		0.127	A2
2W	7/ 5/77	17.2	850	1.690		0.105	A2

RADON AND HELIUM IN THE LIQUID PHASE : PALMDALE AREA

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND μMHO	RADON DPM/G	NOTE	HELIUM μCC/G	NOTE
* RACK -2W	8/ 9/77	17.2	900	1.740		0.100	A2
2W	9/10/77	17.9	900	1.890	A1	0.094	A2
				1.830	A2		
WRIG -2W	11/30/76	14.0	500	0.417		0.050	A2
96ST -1S	11/24/76	14.4	605	0.379		0.072	A2
* KITT -1W	11/24/76	14.0	790				
1W	12/ 1/76	13.0	790	0.302		0.090	A2
1W	1/14/77	13.0	800	0.353		0.099	A1 G
						0.102	A2
1W	2/17/77	12.0	800	0.293		0.137	A2
1W	3/17/77	12.5	800	0.312		0.104	A2
1W	4/13/77	14.5	790	0.306		0.103	A2
1W	5/12/77	15.5	800	0.290		0.115	A2
1W	6/ 6/77	17.2	800	0.314		0.105	A1
1W	7/ 5/77	17.8	790	0.278		0.104	A2
1W	8/10/77	20.5	800	0.259		0.108	A2
1W	9/10/77	19.5	800	0.283	A1	0.105	A2
				0.280	A2		
* MESS -1W	11/24/76	14.0	1100				
1W	2/18/77	17.4	1110	0.902		0.073	A1 G
						0.076	A2
1W	3/18/77	17.2	1110	0.789		0.069	A2
1W	4/14/77	16.7	1100	0.872		0.072	A2
1W	5/13/77	16.7	1095	0.693		0.079	A2
1W	6/ 7/77	17.2	1100	0.838		0.073	A2
1W	7/ 5/77	17.2	1100	0.784		0.074	A2
1W	8/10/77	18.3	1105	0.750			
1W	9/ 9/77	16.9	1110	0.962	A1	0.071	A2
				0.938	A2		
PDLE -2W	11/23/76	16.5	420	0.789		0.070	A2
* PDLE -1W	11/23/76	20.3	1450	0.619		0.430	A1 G
						0.440	A2 G

RADON AND HELIUM IN THE LIQUID PHASE : PALMDALE AREA

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND µMHO	RADON DPM/G	NOTE	HELIUM µCC/G	NOTE
* PDLE -1W	1/14/77	19.0	1360	0.522		0.273	A2
1W	2/17/77	19.3	1350	0.504		0.267	A2
1W	3/17/77	18.9	1390	0.507		0.330	A2
1W	4/13/77	19.4	1300	0.512		0.282	A2
1W	4/14/77	18.9	1390	0.537		0.345	A1
						0.346	A2
1W	5/12/77	19.0	1310	0.568		0.339	A1
						0.347	A2
1W	6/ 7/77	19.2	1350	0.543		0.471	A1
						0.362	A2
1W	7/ 5/77	19.2	1395	0.519		0.400	A1
						0.375	A2
1W	8/10/77	19.4	1400	0.535		0.345	A2
1W	9/ 9/77	20.0	1600	0.600	A1	0.691	A2
				0.648	A2	0.661	A4
* VALY -1W	11/30/76	14.8	560	1.440		0.105	A1 G
						0.086	A2
1W	1/14/77	14.0	570	1.420		0.080	A2
1W	2/17/77	15.4	595	1.660		0.085	A2
1W	3/17/77	14.7	600	1.110		0.067	A2
1W	4/13/77	16.7	580	1.690		0.087	A1
1W	5/12/77	15.8	595	1.360		0.085	A2
1W	6/ 6/77	16.7	595	1.620		0.062	A2
1W	7/ 5/77	17.8	590	1.360		0.081	A2
1W	8/ 9/77	17.5	595	1.600	A1	0.065	A2
				1.610	A2		
1W	9/ 9/77	16.7	590	1.680	A1	0.065	A2
				1.480	A2		
* PINE -1W	11/23/76	8.9	460	0.800		0.069	A1 G
						0.067	A2
1W	1/14/77	8.3	460	0.823		0.069	A2
1W	2/17/77	8.6	343	0.746		0.069	A2
1W	3/17/77	8.3	355	0.774		0.072	A2
1W	4/13/77	8.3	435	0.789		0.069	A2
1W	5/12/77	8.3	325	0.891		0.077	A2
1W	6/ 6/77	8.6	415	0.718		0.085	A2
1W	7/ 5/77	8.3	400	0.809		0.082	A2
1W	8/ 9/77	8.3	458	0.840		0.072	A2
1W	9/10/77	8.9	450	0.863	A1	0.072	A2
				0.829	A2		

RADON AND HELIUM IN THE LIQUID PHASE : PALMDALE AREA

```
* = PRIMARY SAMPLING NETWORK                L = SAMPLE LOST
E = ANALYTICAL ERROR SUSPECTED             NC = NO SAMPLE COLLECTED
? = VALUE UNCERTAIN BY ±20-40% FOR DECAY CORRECTION
F = SAMPLE COLLECTED IN 1720 GLASS FLASK
G = SAMPLE ANALYZED ON HE3/HE4 MASS SPECTROMETER
X = ALL DATA THIS SITE EXCESS RADON, CORRECTED FOR RA226
A1,A2,...= DUPLICATE SAMPLES
A,B,...= SAMPLES COLLECTED AT DIFFERENT TIMES, OR USING DIFFERENT
         PROCEDURE OR SAMPLER
```

APPENDIX 2

GEOCHEMICAL DATA: LIQUID PHASE

The following table lists the accumulated measurements of conductivity, D/H and O^{18}/O^{16} ratios, Ra^{226}, and Pb^{210} in the network water samples. Conductivity is tabulated in units of 10^{-6}mhos/cm. The isotopic data are tabulated as delta values relative to Standard Mean Ocean Water (SMOW), the international isotopic water standard maintained by the International Atomic Energy Agency in Vienna. The delta values are units of per mil, and are defined as:

$$\delta = [(R_{sample}/R_{SMOW}) - 1] \times 10^3$$

where R is the D/H or O^{18}/O^{16} ratio. These stable isotope ratio measurements were made by Dr. J. O'Neil of the U.S. Geological Survey, Menlo Park, California.

ANALYTICAL DATA LIQUID PHASE : PALMDALE AREA

SAMPLE	DATE MM/DD/YY	TEMP DEG C	COND MU-MHO	DELTA D PER MIL	DELTA O18 PER MIL	RA226 DPM/KG	PB210 DPM/KG
* WARM -1P	11/ 4/76	29.4	2000	-66.6	-9.99		
1P	11/30/76	33.0	1990	-67.4	-9.86		
HUGH -1W	11/24/76	17.1	900	-56.3	-7.52		
* HUGH -2W	11/24/76	15.1	610	-62.0	-9.15		
* RACK -2W	12/ 1/76	16.8	850	-63.9	-9.00		
2W	2/17/77	14.6	810			0.186	
WRIG -2W	11/30/76	14.0	500	-61.2	-9.08		
98ST -1S	11/24/76	14.4	605	-60.8	-9.00		
* RITT -1W	11/24/76	14.0	790	-62.2	-9.09		
* MESS -1W	11/24/76	14.0	1100	-65.2	-9.14		
POLE -2W	11/23/76	16.5	420	-73.4	-10.20		
* POLE -1W	11/23/76	20.3	1450	-72.0	-9.87		
1W	1/14/77	19.0	1360			0.050	
* VALY -1W	11/30/76	14.8	560	-75.6	-10.46		
1W	1/14/77	14.0	570			0.460	
* PINE -1W	11/23/76	8.9	460	-82.2	-12.39		
1W	2/17/77	8.6	343			0.129	

* = PRIMARY SAMPLING NETWORK
E = ANALYTICAL ERROR SUSPECTED
DELTA D AND DELTA O18 VALUES MEASURED BY J. O'NEIL