Technical Note
ORP/LV-75-8A

RADIOACTIVITY ASSOCIATED WITH GEOTHERMAL WATERS IN THE WESTERN UNITED STATES

Basic Data

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PREFACE

The Office of Radiation Programs of the Environmental Protection Agency carries out a national program designed to evaluate population exposure from ionizing and non-ionizing radiation and to promote development of controls necessary to protect the public health and safety.

Within the Office of Radiation Programs, the Las Vegas Facility (ORP-LVF) conducts in-depth field studies of various radiation sources (e.g., nuclear facilities, uranium mines and mills, and phosphate mills) to provide technical data for environmental impact statement reviews, environmental transport pathways, and dose model verification.

This report presents the results of field studies conducted by ORP-LVF between September 1974 and September 1975. The field studies were conducted to assess the levels of naturally occurring radioactivity in geothermal waters in the western United States. This tabulation of data precedes the estimation of population radiation exposures from existing and planned uses of geothermal resources.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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INTRODUCTION

This study was conducted to provide information on the radiochemical species associated with selected geothermal springs and wells in the western United States. Nearly 140 hot springs and wells were sampled between September 1974 and September 1975 located in Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, and Utah.

The objective of the present study is to enlarge the data information base concerning radionuclide concentrations in geothermal waters and identify potential environmental or health effects that may result from large scale development for energy, recreation, mineral recovery or agriculture. The question of possible public health considerations from the radioactivity associated with the development of geothermal resources was raised in the Environmental Impact Statement for the Geothermal Leasing Program (U.S. Department of Interior, 1973).

Study of the radioactivity in thermal waters and primarily in hot springs, can serve as a first estimate of possible impacts associated with the development of geothermal reservoirs. The radiochemical data have added significance if they can be related to regional hydrogeologic settings. Relationships between geologic conditions and radiochemical species in thermal waters have been reported from New Zealand (Belin, 1959) and from France (Jurain, 1960). The present report is primarily intended to present the radioanalytical results and to discuss sampling methods. A brief discussion of the trends in radon concentration and the correlation of radiochemical species are provided. A more comprehensive interpretive report is in preparation.

Numerous previous investigations have emphasized the gross chemical and trace mineral constituents in geothermal fluids (Hose, 1974; Pearl, 1972; Mariner, 1974). In general, these studies provided data to be used in geothermal reservior resource evaluations. Few previous or ongoing studies of geothermal waters in the United States have emphasized radioactivity; however, data studies of thermal waters developed for spas have often shown them to be enriched in radium and radon relative to adjacent ground water. Recent works include those completed in England (Andrews and Wood, 1974), in Austria (Pohl-Rüling and Scheminsky, 1972), and in Taiwan (Tsai and Weng, 1972). Elevated levels of radioactivity reported by these studies provided incentive for the present study emphasizing thermal waters in the western United States.

Other radiochemical studies of hot springs in England (Andrews and Wood, 1972), in northern Nevada (Wollenburg, 1975), and of steam wells at The Geysers in northern California (Stoker and Kruger, 1975) were oriented toward development of geochemical exploration and evaluation techniques. In addition, these studies provided valuable background information concerning sampling methods and problem approach. In another related radiochemical study by Osmond (1974), uranium isotope activity ratios were used in a mixing-model approach to determine direction of origin, sources, and mixing volumes for spring waters. Mazor (1961) used the radium-radon disequilibrium in Israeli spring waters to detect underground reservoirs of solutions and gases. Also, Arndt and Kuroda (1953) examined factors such as regional geology and stream mechanics (velocity, turbulence, etc.) which influenced radon concentrations in surface waters.

The foregoing studies provide comparable radionuclide data. More importantly, they provide or suggest interpretative methods applicable to the present effort.

SAMPLE COLLECTION

Figure 1 is an index map of the sampling locations. The numerical indices cross-reference the sample locations and the analytical results found in Tables 1 and 2. Criteria for selecting a sampling point included:

1. Availability of geochemical data and reconnaissance surveys of regional geology.

2. Present or potential use for development.

3. Level of geothermal exploration in the area.

4. Temperature (over 38°C in most circumstances).

At each location, samples of water, precipitate and biological material were collected. Water was obtained from flowing sources. Precipitate was sampled on the basis of a ground level gamma survey performed to identify anomalies in the immediate area. Biological material, mostly algae, was obtained from the discharge channels.

The unfiltered water sample was collected in one-gallon, polyethylene cubitainers and immediately preserved with 32 milliliters (ml) of concentrated nitric acid. All water samples were collected from the outlet of the spring or well and special care was exercised to minimize suspended materials.

Gamma surveys were made with a Baird Atomic NE-148a scintillator which read in microroentgens per hour (μR/hr) and was calibrated with radium-226. The survey sought to identify anomalies rather than absolute exposures associated with algal mats or deposited material. This was particularly useful in selecting sampling areas when large spring mounds or apron-like spring deposits were present.

Dissolved radon-222 was sampled using a radon bubbler sample tube as shown in Figure 2. After the glass tube was evacuated using a hand pump, it was inverted so that the longer end containing Valve A was placed inside the spring or well orifice. In the case of spring pools, baths, or cisterns, the sample tube was submerged up to 6 feet. Valve A was opened under water and approximately 10 ml of water were drawn into chamber C of the tube. The valve was then closed and the bubbler withdrawn from the water. Valve B is kept closed and is used only during the de-emanation procedure. At one location, measurements of radon

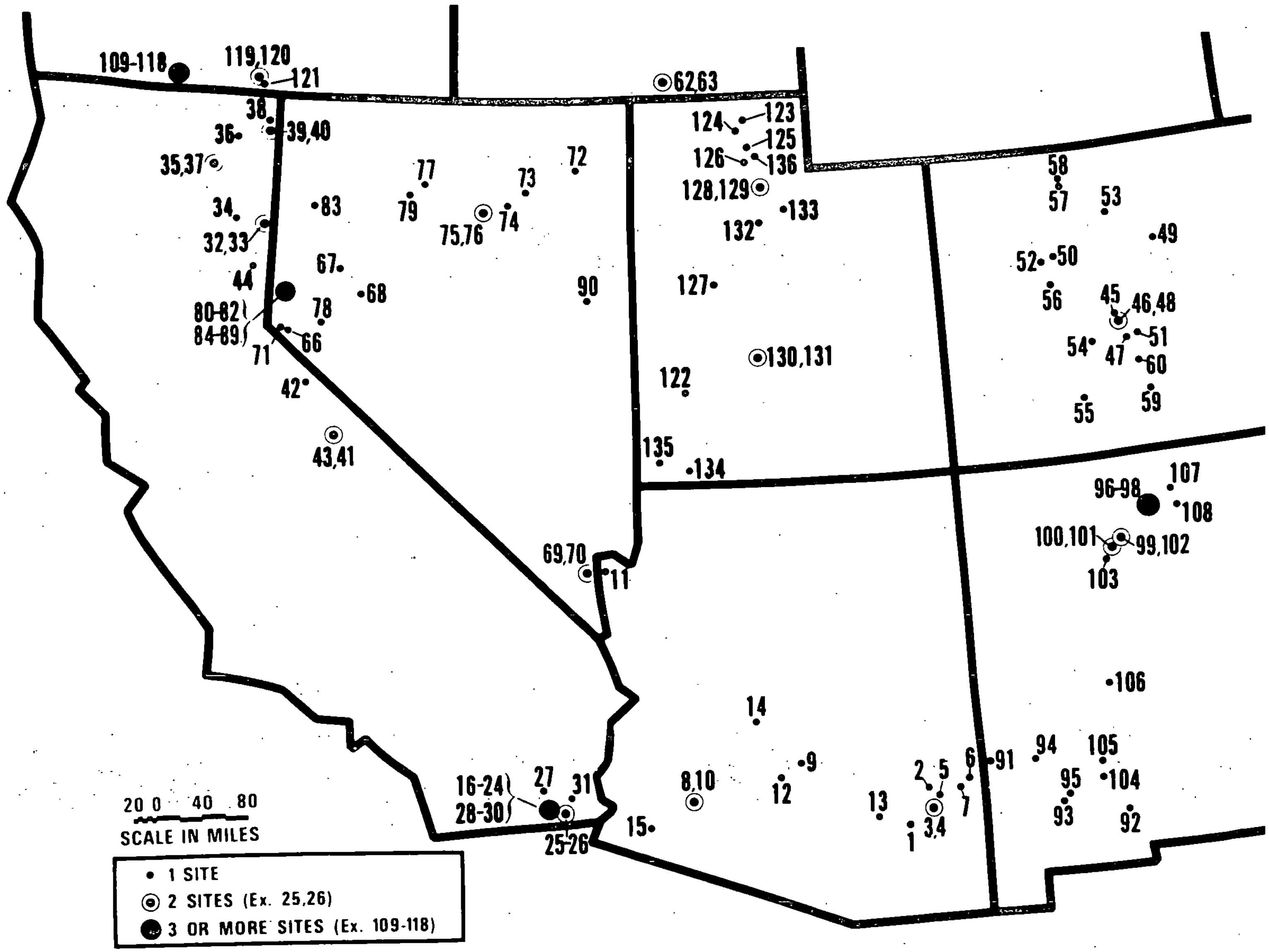

Figure 1
Locations of sampling sites in the western United States

TABLE 1. LOCATIONS AND DESCRIPTIONS OF SAMPLING SITES SHOWN ON FIGURE 1

STATE	COUNTY	NUMBER	SOURCE	LOCATION	LATITUDE	LONGITUDE	SAMPLING POINT TYPE ∇	DATE SAMPLED	WATER USE ∇	TEMP. (°C)	pH
ARIZONA	Cochise	1	Hookers Hot Springs	13S.21E. 6.11	322012	1101416	1	11/20/74	3	52	8.6
	Graham	2	Indian Hot Springs	5S.24E.17.144	325956	1095352	1	11/18/74	5	48	7.6
		3	Lebanon Mineral Bath	8S.26E. 7.21	324524	1094328	2	11/19/74	6	41	8.3
		4	Lukat's Spa	9S.26E. 5.1	324110	1094230	2	11/19/74	6	42	8.3
		5	Mt. Graham Mineral Bath	6S.25E.35.133	325204	1094524	2	11/18/74	6	45	7.7
	Greenlee	6	Clifton Hot Springs	4S.30E.30.42	330313	1091742	1	11/19/74	1	45	7.4
		7	Gillard Hot Springs	5S.29E.27.11	325824	1092058	1	11/19/74	1	82	7.3
	Maricopa	8	Agua Caliente Springs	5S.10W.19			3	11/21/74	2	38	8.1
		9	Buckhorn Mineral Bath	1N. 6E.23.144	332458	1114207	3	11/18/74	6	49	7.82
		10	Hudson Farms, Inc.	5S.10W. 6			3	11/21/74	7	45	8.5
	Mojave	11	One Mile Spring	30N.23W.10.3	355946	1144420	1	09/24/74	1	64	7.5
	Pinal	12	Irrigation well 1481	2 mi west of Arizona City			3	11/20/74	7	32	7.7
		13	111 Ranch, San Manuel	9S.17E.24.443	323745	1103315	2	11/20/74	3	31	7.9
	Yavapai	14	Castle Hot Springs	7N. 1W. 3			1	11/22/74	6	46	-
	Yuma	15	Citrus Valley Dev. irr. well	Tacna			3	11/21/74	7	39	7.7
CALIFORNIA	Imperial	16	Bashford's Hot Mineral Spa	9S.12E. 1.222	332531	1154049	2	02/05/75	6	57	6.4
		17	Del Charro Cattle Feeders	14S.15E.12.3	325641	1152245	2	02/06/75	1	54	7.6
		18	Dickerman & Butters Roads	13S.16E.18	330122	1152155	2	02/06/75	2	51	7.8
		19	Fifield Farm	14S.15E. 6.12	325806	1152727	2	02/05/75	3	52	7.6
		20	Fountain of Youth Spa	9S.12E. 1.31	332504	1154031	2	02/05/75	6	57	6.4
		21	Harry Hoke well	15S.16E. 7.424	325129	1152109	2	02/04/75	8	31	9.0
		22	Holly Hot well	10S. 9E.35	331527	1160023	2	02/05/75	1	59	7.6
		23	Imperial Hot Mineral Spa	9S.12E. 2.112	332534	1154110	2	02/05/75	6	70	6.7
		24	Magnolia Union School	13S.15E.33.11	325857	1152525	2	02/05/75	8	52	7.8
		25	USBR Mesa Well 5-1	16S.17E. 8	324627	1151411	5	02/03/75	1	95	-
		26	USBR Mesa Well 6-1	16S.17E. 8	324627	1151411	5	02/03/75	1	100	7.7
		27	Sinclair #4-Phillips Petrol.	12S.13E. 2	330804	1153701	5	04/15/75	1	100	-
		28	Mulberry Grammar School	13S.15E. 3.33	330238	1152505	2	02/06/75	8	41	8.12
		29	Phegley & Shank Roads	13S.15E.23.431	330005	1152321	2	02/06/75	1	57	7.7
		30	Riata Cattle Feeders	14S.16E.19.32	325458	1152154	2	02/06/75	3	52	7.8
		31	Smith Brothers	13S.18E.33	325952	1150419	3	02/07/75	8	71	6.8
	Lassen	32	Amedee Hot Springs	28N.16E. 8.12	401808	1201150	1	02/25/75	5	87	8.2
		33	Hobo Wells, Inc.	29N.15E.23.43	402114	1201528	4	02/25/75	4	94	7.9
		34	LDS Church, Susanville	29N.12E. 6.14	402418	1203944	3	02/25/75	2	64	7.6

∇ See footnote

TABLE 1. (continued)

STATE	COUNTY	NUMBER	SOURCE	LOCATION	LATITUDE	LONGITUDE	SAMPLING POINT TYPE	DATE SAMPLED	WATER USE	TEMP. (°C)	pH
CALIFORNIA (continued)	Modoc	35	Bassett Hot Springs	38N. 7E.12.42	410842	1210638	1	02/26/75	8	80	8.6
		36	Kelly Hot Springs	42N.10E.29.1	412714	1205004	1	02/26/75	3	90	8.08
		37	Kellogg Hot Springs	38N. 8E.14.33	410736	1210130	4	02/26/75	5	82	8.3
		38	Lake City Mud Explosion	44N.15E.24.13			1	02/26/75	3	91	7.3
		39	Leonard's Hot Springs	43N.16E.13.11			1	02/26/75	3	60	7.6
		40	Surprise Valley Guest Ranch	42N.17E. 6.31			2	02/26/75	8	86	8.0
	Mono	41	Casa Diablo Hot Springs	3S.28E.32.23	373848	1185450	6	02/28/75	1	99	-
		42	Fales Hot Springs	6N.23E.24.421	382103	1192354	4	03/01/75	6	60	6.0
		43	Section 25 on Hot Creek	3S.28E.25.11	373948	1184936	1	02/28/75	1	96	7.89
	Plumas	44	Marble Hot Springs	22N.14E.13.42	394522	1202128	2	02/25/75	3	73	7.6
COLORADO	Chaffee	45	Cottonwood Hot Springs	14S.79W.21.43	384842	1061325	2	09/18/74	4	50	8.4
		46	Hortense Well	15S.79W.24.24	384357	1061006	2	09/18/74	1	84	8.0
		47	Poncha Hot Springs	49N. 8E.15.32	382948	1060436	1	09/18/74	5	71	7.6
		48	Young Life Group Camp	15S.79W.24.24	384357	1061006	4	09/18/74	6	65	7.9
	Clear Creek	49	Radium Hot Springs	3S.73W.36.343	394423	1053043	4	09/16/74	6	39	6.5
	Eagle	50	Dotsero Hot Springs	5S.87W.12.33	393739	1070622	1	09/17/74	1	32	6.8
	Fremont	51	Wellsville Warm Springs	49N.10E.19.22	382916	1055442	1	09/18/74	9	32	7.0
	Garfield	52	Glenwood Hot Springs	6S.89W. 9.14	393300	1071918	4	09/17/74	6	50	6.4
	Grand	53	Hot Sulphur Springs	1N.78W. 3.43	400432	1060638	1	09/16/74	5	45.5	6.6
	Gunnison	54	Waunita Hot Springs	49N. 4E.11.33	383053	1063026	1	09/19/74	3	79	7.7
	Mineral	55	Wagon Wheel Gap	41N. 1E.35.44	374106	1064947	4	09/19/74	5	56	6.8
	Pitkin	56	Penney's Hot Springs	10S.88W.44.21	391333	1071328	1	09/17/74	1	47	6.1
	Routt	57	Routt Hot Springs	7N.84W.18.43	403335	1065100	1	09/16/74	1	64.5	7.5
		58	Steamboat Springs	6N.84W. 8.142	402859	1064947	4	09/16/74	6	39.5	7.8
	Saguache	59	Great Sand Dunes Warm Springs		374700	1055100	3	09/20/74	9	45	8.0
		60	Mineral Hot Springs	45N. 9E.12.13	381002	1055531	2	09/20/74	5	60	6.4
IDAHO	Blaine	61	Condie Springs	1S.21E.14.44			4	07/31/74	3	52	7.3
	Cassia	62	Griffith-Wright well	near Malta			2	03/06/75	1	14	9.3
		63	Raft River Valley Project	near Malta			2	03/06/75	8	92	7.7
	Custer	64	Sunbeam Hot Springs	Challis Nat'l.Fr.	441605	1144453	1	08/02/74	1	76	8.5
	Lemhi	65	Salmon Hot Springs	22N.22E. 3.13	450540	1134810	1	08/01/74	5	-	6.3
NEVADA	Carson	66	Saratoga Hot Springs	14N.20E.21.433	390327	1194431	1	03/01/75	3	52	7.9
	Churchill	67	S.P. Brady Well #1	22N.26E.12.3	394710	1190041	2	03/03/75	1	88	8.1
		68	Stillwater well	19N.31E. 7.3	393112	1183254	2	11/09/74	1	96.7	7.57

TABLE 1. (continued)

STATE	COUNTY	NUMBER	SOURCE	LOCATION	LATITUDE	LONGITUDE	SAMPLING POINT TYPE	DATE SAMPLED	WATER USE	TEMP. (°C)	pH
NEVADA (continued)	Clark	69	Guderian Cave	22S.65E.32	360005	1144430	1	09/24/74	1	50	7.4
		70	Spot Springs	22S.65E.32	360005	1144430	1	09/24/74	1	64	7.3
	Douglas	71	Walley's Hot Springs	13N.19E.22.12	385851	1195002	4	11/09/74	5	61	8.77
	Elko	72	Hot Hole, Elko	34N.55E.21.14	404907	1154619	1	03/05/75	1	58	7.2
		73	Hot Sulphur Springs	38N.62E.33.2	410830	1145730	1	07/31/74	3	-	7.3
		74	Spring (near Carlin)	33N.52E.33.43	404147	1160748	1	03/04/75	1	75	6.8
	Eureka	75	Beowawe Valley - small geyser	31N.48E. 8.4	403405	1163503	6	03/04/75	1	100	8.7
		76	Beowawe Valley - bluff	31N.48E.17.2	403342	1163523	6	03/06/75	1	96	9.38
	Humboldt	77	Golconda Springs	36N.40E.29.43	405740	1172939	1	03/04/75	3	75	6.9
	Lyon	78	Wabuska - Agri-Tech	15N.25E.16.4			2	08/06/74	1	90	8.3
	Pershing	79	Leach Hot Springs	32N.38E.36.4	403612	1173856	1	03/03/75	3	96	8.0
	Washoe	80	Frank Clark's home	19N.19E Reno			2	11/08/74	2	60.6	8.05
		81	Dan Terrill's home	19N.19E Reno			2	11/08/74	2	72.2	7.65
		82	Dr. Biglin's home	19N.19E Reno			2	11/08/74	2	48.3	7.95
		83	Great Boiling Spring	32N.23E.15.2	403942	1192154	1	03/21/75	3	86.0	-
		84	Lawton Hot Springs	19N.18E.13.4	393042	1195426	3	11/08/74	6	47.8	9.13
		85	Mark Twain Motel	19N.19E Reno			2	11/08/74	2	44.4	7.95
		86	Nicara residence	19N.19E Reno			2	11/08/74	2	85.6	8.29
		87	Peppermill Motel	19N.19E Reno			2	11/08/74	2	48.9	8.06
		88	Steamboat Springs	18N.20E.33.1	302318	1194430	6	08/06/74	1	94	7.19
		89	Virginia Lakeshore Apts.	19N.19E.24.23	393000	1194811	3	11/08/74	2	61.1	7.76
	White Pine	90	Monte Neva Hot Springs	21N.63E.24			1	07/30/74	5	-	-
NEW MEXICO	Catron	91	Lower Frisco Hot Springs	12S.20W.23.100	331440	1085253	1	12/05/74	6	35	7.3
	Dona Ana	92	Radium Hot Springs	21S. 1W.10.213			3	12/04/74	6	52.7	6.7
	Grant	93	Faywood Warm Springs	20S.11W.20.243	323320	1075940	1	12/05/74	3	55	7.0
		94	Gila Hot Springs	13S.13W. 5.213	331155	1081211	1	12/05/74	2	64	8.6
		95	Mimbres Hot Springs	18S.10W.13.111	324454	1075008	1	12/05/74	2	61	8.75
	Rio Arriba	96	Arsenic Spring	24N. 8E.24.132	361818	1060308	1	12/03/74	6	37.5	7.1
		97	Iron Spring	24N. 8E.24.132	361818	1060308	1	12/03/74	6	43	6.65
		98	Lithia Hot Spring	24N. 8E.24.132	361818	1060308	1	12/03/74	6	37.8	6.8
	Sandoval	99	Electric Spring	19N. 3E.	355425	1063701	1	12/02/74	1	25	1.6
		100	Jemez Hot Springs	18N. 2E.23	354620	1064125	1	12/02/74	5	59.5	6.5
		101	Soda Dam Hot Springs	18N. 2E.14	354729	1064110	1	12/02/74	1	46.5	6.3
		102	Sulphur Springs	19N. 3E. 4	355429	1063654	1	12/02/74	1	70	2.0
		103	Warm Springs Kaseman #2	16N. 1W. 1.321	353844	1065319	2	12/02/74	5	53	6.4

TABLE 1. (continued)

STATE	COUNTY	NUMBER	SOURCE	LOCATION	LATITUDE	LONGITUDE	SAMPLING POINT TYPE	DATE SAMPLED	WATER USE	TEMP. (°C)	pH
NEW MEXICO (continued)	Sierra	104	Derry Warm Springs	17S. 4W.29.340	324744	1071640	1	12/04/74	3	34	6.85
		105	Ponce de Leon Hot Spring	14S. 4W. 4.122	330740	1071521	1	12/04/74	6	-	-
	Socorro	106	Blue Canyon Well	3S. 1W.16.323	340245	1065706	3	12/04/74	2	31.6	7.4
	Taos	107	Manby Hot Springs	26N.11E.12.121	363030	1054324	1	12/03/74	5	31.5	6.9
		108	Ponce de Leon Hot Spring	24N.13E. 7	361926	1053621	4	12/03/74	5	-	-
OREGON	Klamath	109	CPI storm drain	Klamath Falls			4	11/04/74	1	71	-
		110	Klamath Union High School	Klamath Falls			3	11/05/74	4	82	-
		111	LDS Church	Klamath Falls			3	11/04/74	4	56	7.60
		112	Lucas & Howard Furniture	Klamath Falls			3	11/04/74	8	89	8.42
		113	Mazama Mid-High School	Klamath Falls			3	11/05/74	4	58	8.5
		114	Melo-Bel Dairy	Klamath Falls			3	11/05/74	10	81	8.38
		115	OIT Well #4 (cold)	Klamath Falls			3	11/04/74	2	30	-
		116	OIT Well #5	Klamath Falls			3	11/04/74	4	89	8.6
		117	O'Neill Grammar School	Klamath Falls			3	11/05/74	4	58	7.81
		118	Liskey's Ranch	40S. 9E.34			3	11/06/74	3	85	8.4
	Lake	119	Desert Farms, Inc.	Lakeview			3	11/05/74	4	60	-
		120	Hunter's Lodge	Lakeview			1	11/05/74	6	93	8.5
		121	Barry's Ranch	40S.20E.11			1	11/05/74	3	74	8.27
UTAH	Beaver	122	Thermo Hot Springs	30S.12W.21	381234	1131311	1	09/18/75	1	73	7.25
	Box Elder	123	Crystal (Madsens) Hot Springs	11N. 2W.29.41	413946	1120523	4	09/15/75	6	54	6.1
		124	Stinking Hot Springs	10N. 3W.30.224	413411	1121322	1	09/15/75	6	47	6.5
		125	Utah Hot Springs	7N. 2W.14.431	412056	1120152	4	09/16/75	1	57	6.5
	Davis	126	Hooper Hot Springs	5N. 3W.27.3	410852	1120940	1	09/16/75	3	53	7.1
	Juab	127	Baker (Abraham) Hot Springs	14S. 8W.10	393550	1124531	1	09/17/75	5	83	7.6
	Salt Lake	128	Becks Hot Springs	1N. 1W.14.432	404859	1115606	1	09/15/75	1	54	6.6
		129	Wasatch Hot Springs	1N. 1W.25.42	404726	1115437	1	09/15/75	6	43	7.2
	Sevier	130	Monroe Hot Springs	25S. 3W.15.1	383749	1120714	1	09/17/75	6	46	6.8
		131	Red Hill Hot Spring	25S. 3W.11.313	383835	1120641	1	09/17/75	5	77	6.45
	Utah	132	Saratoga Hot Springs	5S. 1W.25.34	401957	1115448	2	09/17/75	6	43	6.95
	Wasatch	133	Midway Hot Springs	3S. 4E.26.231	403140	1112910	6	09/16/75	1	35	6.65
	Washington	134	Pah Tempe (La Verkin) Hot Springs	41S.13W.25	371152	1131717	1	09/18/75	6	42	6.25
		135	Veyo Warm Spring	40S.16W. 7.132	371916	1134413	2	09/18/75	6	36	7.4
	Weber	136	Ogden Hot Springs	6N. 1W.23.334	411447	1115510	1	09/16/75	1	58	7.23

NOTES:

Sampling Point Type

1 - spring
2 - artesian well
3 - pumped well
4 - cistern
5 - geothermal steam project
6 - fumarole, mudpot

Water Use

1 - not in use
2 - potable
3 - stock watering
4 - space heating
5 - old bath house, not in use
6 - spa, recreational
7 - irrigation
8 - domestic, non-potable
9 - fish hatchery
10 - pasteurization

at the surface and at four feet were 640 (±45) and 680 (±46) pCi/l, respectively. Consecutive measurements of dissolved radon at the surface varied within 9 percent of the mean and were probably indicative of the variability of the sampling and analytical techniques.

Although dissolved radon at the water surface diffuses into the immediate environs of the spring, a state of near equilibrium in the water is probably present. Concentrations in the spring system vary primarily with temperature and pressure (in addition to radioactive decay). Radon concentrations at a shallow depth (one foot or more below the water surface) are believed to be representative of (or related to) conditions at much greater depths.

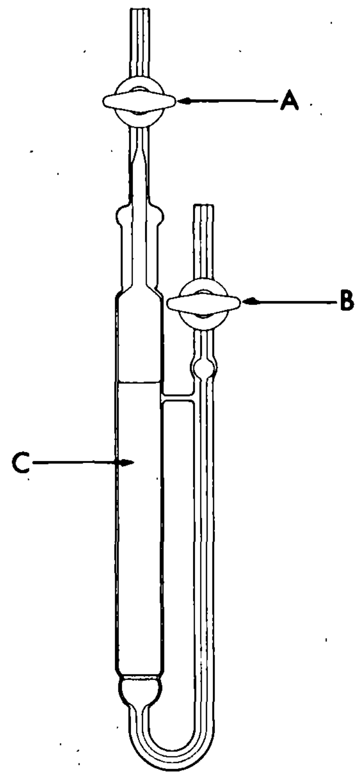

Figure 2
Bubbler used to measure radon dissolved in water

Routine field measurements included temperature and pH. The latter was measured using a Beckman Electromate pH meter with a Sensorex electrode model P/N S200C. In the latter part of the study, chloride concentration (using an Orion specific ion meter with probe 94-17) and specific conductivity (using a Lab-line conductivity cell) were also obtained. Since these measurements were obtained at only a few sample locations, they are not included in Table 1.

SAMPLE ANALYSES

The major portion of the radiochemical analytical work was performed by the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL) in Las Vegas, Nevada. Fifty-six water samples were sent to Mound Laboratory (operated by the Monsanto Research Corporation for the U.S. Energy Research and Development Administration) at Miamisburg, Ohio, for uranium and thorium analyses. The remainder of these analyses and all of the radium and dissolved radon determinations were completed at the EMSL.

The radium and radon analytical procedures used by EPA are found in the Handbook of Radiochemical Analytical Methods (U.S. EPA, 1975). The uranium and thorium isotopes were determined at both laboratories using a similar unpublished modification of a radiochemical procedure developed for plutonium (Talvitie, 1971). The method uses ion exchange, electrodeposition, and alpha spectroscopy. The samples are initially prepared as azeotropic 6M hydrochloric acid solutions. The uranium and thorium are removed from solution with an anion resin and are then eluted separately, followed by electrodeposition from ammonium sulfate for alpha spectrometric counting.

DATA PRESENTATION

The results in Table 2 are reported in units of picocuries per liter (pCi/l), which can be converted to milligrams per liter (mg/l) using Table 3.

TABLE 3. CONCENTRATION CONVERSION FACTORS

1 pCi/l		mg/l
Radium-226	is equivalent to	1.02×10^{-9}
Thorium-232		9.3×10^{-3}
Thorium-234		4.3×10^{-14}
Uranium-234		1.6×10^{-7}
Uranium-238		3.0×10^{-2}

The variability attached to the analytical results is the counting error derived from two sigma counting statistics (95% confidence level) and does not include any analytical or sampling errors. For radon, these errors are approximately 9% of the

TABLE 2. RADIOCHEMICAL ANALYTICAL RESULTS (pCi/l)

NUMBER	LOCATION	^{222}Rn	^{226}Ra	^{234}U	^{238}U	^{230}Th	^{232}Th
	ARIZONA						
1	Hookers Hot Springs	2400 ± 87	.1 ± .059	10. ± .8	3.8 ± .33	.031 ± .029	.034 ± .028
2	Indian Hot Springs	530 ± 51	.66 ± .13	.72 ± .092	.38 ± .063	<0.025	<0.0088
3	Lebanon Mineral Bath	420 ± 37	.3 ± .089	.03 ± .02	.01 ± .016	<0.0089	<0.012
4	Lukat's Spa	240 ± 30	.089 ± .05	.087 ± .036	.042 ± .024	<0.018	0.0079 ± 0.0056
5	Mt. Graham Mineral Bath	1200 ± 63	1.3 ± .17	.23 ± .051	.12 ± .034	<0.035	<0.019
6	Clifton Hot Springs	6500 ± 150	6.9 ± .39	1.4 ± .15	.45 ± .074	.11 ± .044	.2 ± .057
7	Gillard Hot Springs	540 ± 47	.33 ± .093	.26 ± .054	.17 ± .043	.18 ± .053	.28 ± .068
8	Agua Caliente Springs	140 ± 19	.21 ± .076	.084 ± .032	.056 ± .024	<0.022	<0.014
9	Buckhorn Mineral Bath	1200 ± 72	.084 ± .056	1.3 ± .14	.94 ± .11	<0.02	0.016 ± .016
10	Hudson Farms, Inc.	--	.19 ± .067	.12 ± .039	.14 ± .041	<0.023	<0.015
11	One Mile Spring	--	.75 ± .13	.052 ± .032	.029 ± .029	<0.011	<0.0089
12	Irrigation well 1481	850 ± 47	.084 ± .056	4.6 ± .38	3.6 ± .31	<0.036	<0.027
13	111 Ranch, San Manuel	930 ± 53	.084 ± .056	1.6 ± .16	1.0 ± .12	<0.026	<0.012
14	Castle Hot Springs	--	.31 ± .087	.99 ± .12	.42 ± .072	<0.017	<0.0062
15	Citrus Valley Dev. irr. well	1100 ± 53	.66 ± .13	.23 ± .056	.14 ± .044	<0.035	<0.015
	CALIFORNIA						
16	Bashford's Hot Mineral Spa	14000 ± 280	24.0 ± .74	.02 ± .003	<0.10	1.73 ± .40	<0.26
17	Del Charro Cattle Feeders	400 ± 43	.38 ± .099	.29 ± .05	4.91 ± .22	1.62 ± .34	<0.10
18	Dickerman & Butters Roads	740 ± 51	.64 ± .12	.16 ± .03	.08 ± .02	.37 ± .15	<0.12
19	Fifield Farm	300 ± 35	.37 ± .095	.30 ± .07	.18 ± .05	.64 ± .23	<0.10
20	Fountain of Youth Spa	1600 ± 89	1.1 ± .16	3.66 ± .14	1.58 ± .09	4.97 ± .42	.43 ± .13
21	Harry Hoke well	140 ± 29	.11 ± .06	.13 ± .02	.10 ± .01	.97 ± .14	.12 ± .05
22	Holly Hot well	690 ± 57	.22 ± .077	.05 ± .02	<0.10	1.78 ± .38	<0.10
23	Imperial Hot Mineral Spa	14000 ± 260	2.7 ± .25	.21 ± .06	<0.10	.71 ± .22	<0.14
24	Magnolia Union School	120 ± 25	.28 ± .087	.18 ± .03	.08 ± .02	<0.43	<0.17
25	USBR Mesa Well 5-1	*1240 ± 31.93	.25 ± .08	<0.10	<0.10	.80 ± .24	<0.14
26	USBR Mesa Well 6-1	*1287 ± 61.12	190.0 ± 2.0	.12 ± .03	<0.10	2.54 ± .28	<0.10
27	Sinclair #4 - Phillips Petrol.	*10000 ± 42	1500.0 ± 71.0	<0.5	<0.41	.3 ± 0.3	<0.089
28	Mulberry Grammar School	390 ± 42	.54 ± .12	.09 ± .03	<0.10	<0.37	<0.30
29	Phegley & Shank Roads	410 ± 39	.37 ± .094	.09 ± .02	<0.10	<0.44	<0.10

*pCi/kg

TABLE 2. (continued)

NUMBER	LOCATION	^{222}Rn	^{226}Ra	^{234}U	^{238}U	^{230}Th	^{232}Th
	CALIFORNIA (continued)						
30	Riata Cattle Feeders	500 ± 45	.4 ± .097	.19 ± .04	<0.10	1.22 ± .27	<0.30
31	Smith Brothers	1100 ± 55	.85 ± .14	--	--	--	--
32	Amedee Hot Springs	410 ± 56	.084 ± .049	.08 ± .03	.06 ± .02	.61 ± .20	<0.10
33	Hobo Wells, Inc. - spring	32 ± 15	.05 ± .049	.11 ± .02	<0.78	14.29 ± 1.05	1.09 ± .29
34	LDS Church, Susanville	58 ± 21	.13 ± .058	.27 ± .04	.19 ± .04	2.02 ± .39	<0.10
35	Bassett Hot Springs	360 ± 44	.067 ± .042	<0.10	<0.10	1.53 ± .35	<0.90
36	Kelly Hot Springs	54 ± 17	.29 ± .085	.08 ± .02	.06 ± .02	1.83 ± .38	<0.10
37	Kellogg Hot Springs	190 ± 33	.05 ± .046	<0.10	<0.10	.72 ± .25	<0.10
38	Lake City Mud Explosion	150 ± 28	.061 ± .037	<0.10	<0.10	2.59 ± .39	<0.18
39	Leonard's Hot Springs	1700 ± 89	<0.045	.06 ± .02	<0.10	.86 ± .24	<0.10
40	Surprise Valley Guest Ranch	13 ± 13	.056 ± .05	.04 ± .02	<0.10	1.29 ± .43	<0.10
41	Casa Diablo Hot Springs	470 ± 44	2.6 ± .3	--	--	--	--
42	Fales Hot Springs	750 ± 46	30.0 ± .82	1.93 ± .12	.80 ± .08	1.75 ± .38	<0.17
43	Section 25 on Hot Creek	35 ± 12	.25 ± .077	.61 ± .07	.40 ± .06	.61 ± .18	<0.10
44	Marble Hot Springs	100 ± 29	<0.041	<0.10	<0.72	15.37 ± 1.14	<0.17
	COLORADO						
45	Cottonwood Hot Springs	250 ± 94	.68 ± .12	.24 ± .048	.18 ± .041	<0.014	<0.014
46	Hortense Well	1400 ± 73	.12 ± .057	.30 ± .055	.22 ± .047	.027 ± .023	<0.012
47	Poncha Hot Springs	1400 ± 71	.16 ± .067	.041 ± .021	.034 ± .020	.022 ± .016	.02 ± .017
48	Young Life Group Camp	890 ± 57	.14 ± .063	1.9 ± .2	1.7 ± .18	<0.018	<0.017
49	Radium Hot Springs	890 ± 67	17.0 ± .61	.77 ± .11	.33 ± .065	<0.018	<0.016
50	Dotsero Hot Springs	1800 ± 84	1.1 ± .16	1.1 ± .12	.42 ± .068	<0.010	<0.0089
51	Wellsville Warm Springs	580 ± 43	.23 ± .075	4.6 ± .36	2.2 ± .2	.023 ± .019	<0.010
52	Glenwood Hot Springs	300 ± 38	27.0 ± .78	.19 ± .046	.11 ± .035	<0.012	<0.0043
53	Hot Sulphur Springs	510 ± 51	3.2 ± .27	.057 ± .024	.041 ± .021	<0.0069	<0.0085
54	Waunita Hot Springs	140 ± 21	.083 ± .056	.11 ± .035	.078 ± .03	.023 ± .023	<0.018
55	Wagon Wheel Gap	72 ± 15	3.6 ± .28	<0.074	<0.052	<0.018	<0.035
56	Penney's Hot Springs	600 ± 51	1.5 ± .18	.24 ± .057	.12 ± .04	<0.012	<0.0065
57	Routt Hot Springs	530 ± 51	.13 ± .058	.039 ± .030	.034 ± .023	.019 ± .015	.026 ± .015
58	Steamboat Springs	150 ± 29	1.8 ± .2	.084 ± .033	.044 ± .024	<0.01	<0.0047
59	Great Sand Dunes Warm Springs	480 ± 34	.17 ± .071	<0.14	.18 ± .16	<0.044	<0.031
60	Mineral Hot Springs	2100 ± 65	3.6 ± .28	.089 ± .029	.033 ± .018	.12 ± .069	.027 ± .027

TABLE 2. (continued)

NUMBER	LOCATION	^{222}Rn	^{226}Ra	^{234}U	^{238}U	^{230}Th	^{232}Th
	IDAHO						
61	Condie Springs	--	.44 ± .11	.084 ± .031	.018 ± .015	<0.006	<0.0063
62	Griffith-Wright well	260 ± 37	<0.048	.73 ± .10	<0.15	.97 ± .25	<0.10
63	Raft River Valley Project	390 ± 39	.61 ± .12	.08 ± .03	<0.10	.65 ± .38	<0.18
64	Sunbeam Hot Springs	--	.19 ± .069	.018 ± .017	<0.013	<0.012	.0087 ± .0087
65	Salmon Hot Springs	--	8.2 ± .43	.11 ± .034	.10 ± .032	.016 ± .015	<0.0081
	NEVADA						
66	Saratoga Hot Springs	320 ± 30	.23 ± .075	.09 ± .03	<0.10	1.14 ± .25	<0.17
67	S.P. Brady Well #1	--	.47 ± .11	.04 ± .02	<0.10	.67 ± .21	<0.10
68	Stillwater well	410 ± 34	.27 ± .081	<0.025	<0.013	<0.032	.022 ± .019
69	Guderian Cave	2100 ± 69	.35 ± .095	.89 ± .11	.50 ± .079	<0.016	.0049 ± .012
70	Spot Springs	3167 ± 84	1.4 ± .17	.070 ± .029	.052 ± .023	<0.0098	<0.0085
71	Walley's Hot Springs	580 ± 45	.42 ± .10	.029 ± .017	<0.0062	<0.029	<0.022
72	Hot Hole, Elko	180 ± 34	5.8 ± .36	<0.10	<0.10	1.65 ± .34	<0.10
73	Hot Sulphur Springs	--	14.0 ± .55	.078 ± .027	.063 ± .024	.0094 ± .0094	.0094 ± .0094
74	Spring (near Carlin)	510 ± 52	2.3 ± .23	.05 ± .02	<0.10	1.17 ± .30	<0.16
75	Beowawe Valley - small geyser	170 ± 38	.050 ± .043	<0.10	<0.10	.81 ± .26	<0.24
76	Beowawe Valley - bluff	55 ± 23	.16 ± .069	188.38 ± 1.70	148.20 ± 1.51	12.05 ± 1.88	21.46 ±2.52
77	Golconda Springs	460 ± 61	57.0 ± 1.1	181.56 ± 1.90	168.92 ± 1.83	12.04 ± 1.43	12.21 ±1.45
78	Wabuska - Agri-Tech		.47 ± .10	.032 ± .019	.014 ± .013	<0.017	.023 ± .017
79	Leach Hot Springs	41 ± 17	.33 ± .14	<0.10	<0.10	.97 ± .34	.73 ± .30
80	Frank Clark home	300 ± 33	.11 ± .056	.017 ± .016	<0.012	<0.057	<0.039
81	Dan Terrill's home	400 ± 39	.067 ± .050	<0.018	<0.014	<0.024	<0.026
82	Dr. Biglin's home	200 ± 25	.21 ± .070	<0.62	<0.74	<0.057	<0.035
83	Great Boiling Spring		2.1 ± .22	<0.10	<0.10	<0.37	<0.10
84	Lawton Hot Springs	460 ± 41	.095 ± .048	<1.1	<0.88	.061 ± .056	.034 ± .030
85	Mark Twain Motel	800 ± 53	.13 ± .058	.12 ± .036	.068 ± .025	<0.016	<0.012
86	Nicara residence	360 ± 38	.22 ± .078	.018 ± .013	.021 ± .013	<0.042	<0.034
87	Peppermill Motel	980 ± 57	.17 ± .068	.025 ± .017	.020 ± .016	<0.035	<0.031
88	Steamboat Springs	66 ± 15	.40 ± .099	.029 ± .018	.021 ± .016	.065 ± .026	<0.010
89	Virginia Lakeshore Apts.	510 ± 41	.067 ± .052	.028 ± .023	.016 ± .013	.028 ± .024	<0.020
90	Monte Neva Hot Springs	--	140.0 ± 1.8	.018 ± .014	<0.0089	<0.0077	<0.0063

TABLE 2. (continued)

NUMBER	LOCATION	^{222}Rn	^{226}Ra	^{234}U	^{238}U	^{230}Th	^{232}Th
	NEW MEXICO						
91	Lower Frisco Hot Springs	1300 ± 56	3.4 ± .28	1.88 ± .09	.47 ± .05	1.22 ± .35	<0.10
92	Radium Hot Springs	5800 ± 140	.74 ± .13	.32 ± .05	.10 ± .03	.92 ± .22	<0.10
93	Faywood Warm Springs	5600 ± 120	16.0 ± .60	.09 ± .03	<0.10	.81 ± .26	<0.10
94	Gila Hot Springs	660 ± 51	.29 ± .088	1.01 ± .07	.54 .05	.87 ± .26	<0.16
95	Mimbres Hot Springs	2300 ± 85	.48 ± .11	.34 ± .04	.13 ± .03	1.71 ± .34	<0.10
96	Arsenic Spring	5000 ± 100	22.0 ± .70	6.44 ± .22	1.48 ± .10	1.74 ± .40	.91 ± .29
97	Iron Spring	9400 ± 170	38.0 ± .92	9.01 ± .24	1.72 ± .10	1.56 ± .39	<0.25
98	Lithia Hot Spring	--	36.0 ± .90	12.29 ± .42	3.20 ± .21	1.26 ± .32	<0.16
99	Electric Spring	120 ± 20	.94 ± .15	<2.29	<0.30	3.86 ± .63	.83 ± .29
100	Jemez Hot Springs	220 ± 26	8.6 ± .44	.07 ± .01	.05 ± .01	1.85 ± .34	<0.10
101	Soda Dam Hot Springs	450 ± 37	140.0 ± 1.7	.82 ± .07	.38 ± .05	1.05 ± .25	<0.12
102	Sulphur Springs	940 ± 54	.16 ± .069	<0.27	.49 ± .16	4.04 ± .63	1.18 ± .34
103	Warm Springs Kaseman #2	210 ± 26	15.0 ± .58	5.3 ± .41	1.1 ± .12	<0.017	<0.016
104	Derry Warm Springs	530 ± 42	.18 ± .073	12.01 ± .20	5.22 ± .14	.96 ± .25	<0.10
105	Ponce de Leon Hot Spring	1400 ± 68	.66 ± .13	2.70 ± .12	1.30 ± .08	.61 ± .22	<0.10
106	Blue Canyon Well	520 ± 40	.82 ± .14	3.40 ± .13	.75 ± .06	.85 ± .30	<0.10
107	Manby Hot Springs	820 ± 43	.44 ± .10	1.44 ± .08	.75 ± .06	1.40 ± .31	.42 ± .17
108	Ponce de Leon Hot Spring	--	.37 ± .097	.76 ± .06	.18 ± .03	2.83 ± .49	<1.27
	OREGON						
109	CPI storm drain	--	.061 ± .051	.018 ± .017	<0.013	<0.022	<0.017
110	Klamath Union High School	72 ± 17	.38 ± .097	.049 ± .023	.032 ± .020	<0.027	<0.017
111	LDS Church	--	.14 ± .067	<0.018	.023 ± .022	<0.025	<0.015
112	Lucas & Howard Furniture	250 ± 34	.056 ± .047	.015 ± .014	.013 ± .012	<0.028	<0.022
113	Mazama Mid-High School	160 ± 23	.089 ± .047	.039 ± .024	.032 ± .020	<0.022	<0.016
114	Melo-Bel Dairy	--	.24 ± .077	.028 ± .021	<0.0092	<0.022	<0.010
115	OIT Well #4 (cold)	250 ± 31	.13 ± .059	--	--	--	--
116	OIT Well #5	--	.11 ± .060	--	--	--	--
117	O'Neill Grammar School	200 ± 28	.17 ± .069	.13 ± .053	<0.033	<0.028	<0.015
118	Liskey's Ranch	97 ± 19	.073 ± .054	.031 ± .022	<0.012	<0.024	<0.014
119	Desert Farms, Inc.	260 ± 28	.061 ± .051	.017 ± .014	<0.0097	<0.019	<0.019
120	Hunter's Lodge	55 ± 14	.13 ± .064	<0.019	<0.014	<0.027	<0.013
121	Barry's Ranch	--	.072 ± .043	<0.015	<0.0079	<0.017	<0.017

TABLE 2. (continued)

NUMBER	LOCATION	^{222}Rn	^{226}Ra	^{234}U	^{238}U	^{230}Th	^{232}Th
	<u>UTAH</u>						
122	Thermo Hot Springs	600 ± 42	7.5 ± .47	.033 ± .022	<.018	<.019	<.023
123	Crystal (Madsens) Hot Springs	1800 ± 85	410.0 ± 3.7	.96 ± .16	.3 ± .081	.043 ± .033	.022 ± .019
124	Stinking Hot Springs	880 ± 60	80.0 ± 1.3	.038 ± .029	<.019	.021 ± .021	<.022
125	Utah Hot Springs	1200 ± 69	140.0 ± 2.1	.17 ± .055	.12 ± .043	.16 ± .065	.19 ± .065
126	Hooper Hot Springs	1500 ± 69	62.0 ± 1.2	.26 ± .056	.12 ± .038	.11 ± .055	.063 ± .048
127	Baker (Abraham) Hot Springs	1700 ± 67	1.5 ± .18	.039 ± .022	.03 ± .02	.025 ± .02	<.006
128	Becks Hot Springs	1200 ± 67	23.0 ± .72	.09 ± .049	.073 ± .044	.084 ± .037	.026 ± .022
129	Wasatch Hot Springs	160 ± 27	27.0 ± .78	.3 ± .063	.16 ± .044	.024 ± .02	<.013
130	Monroe Hot Springs	250 ± 26	5.2 ± .39	.21 ± .055	.1 ± .035	.066 ± .037	.051 ± .03
131	Red Hill Hot Spring	750 ± 41	6.3 ± .37	.2 ± .069	<.015	.022 ± .019	<.008
132	Saratoga Hot Springs	2600 ± 82	18.0 ± .78	.57 ± .084	.4 ± .067	.049 ± .033	<.009
133	Midway Hot Springs	260 ± 29	.15± .064	1.3 ± .18	.68 ± .12	.26 ± .075	.2 ± .061
134	Pah Tempe (La Verkin) Hot Springs	550 ± 39	47.0 ± 1.0	.39 ± .12	.31 ± .084	.021 ± .021	<.02
135	Veyo Warm Spring	490 ± 35	0.17± .077	1.4 ± .14	.93 ± .1	<.008	<.014
136	Ogden Hot Springs	2200 ± 86	23.0 ± .71	.096 ± .045	.033 ± .023	.05 ± .04	<.017

reported results and were obtained from repetitive sampling at selected locations.

Radon results for samples #25, #26, and #27 are reported in pCi/kilogram of condensate. These results from steam wells were obtained using a high pressure stainless steel pressure bottle and the sampling technique described by Stoker and Kruger (1975). This effort was an initial attempt to obtain samples from superheated, two-phase discharges. Sample #63 was obtained from a pre-existing shallow hot water well at the Raft River Geothermal Project, a co-sponsored drilling effort by the State of Idaho and the U.S. Energy Research and Development Administration. The well serves as a source of water for the drilling operation.

At each sampling point, algae and surface rocks or precipitated material were collected. These samples are being analyzed in radium, uranium and thorium isotopes. Data for these samples will be published in a subsequent report.

DATA INTERPRETATION

A separate report in preparation correlates radiochemical data to other chemical species and relating the radiochemical data to broad hydrogeologic conditions in the areas sampled. A brief summary of our approach and initial findings is presented herein.

In Figure 3, the sample locations are sorted into eight geographical areas according to broadly similar geologic characteristics. This facilitated reduction of the data by reducing the geologic and hydrogeologic variability. At the present time, the geologic characteristics have not been refined whereby the statistical results can be related to specific stratigraphic units. The following regions are recognized:

A. Rio Grande Rift Zone

B. Gila-San Francisco River Drainage Basins

C. Imperial Valley, California

D. Western Utah (Wasatch Front, Great Basin)

E. Northern California (Modoc Plateau, Great Basin)

F. Klamath Falls, Oregon

G. Northern Nevada

H. Reno, Nevada

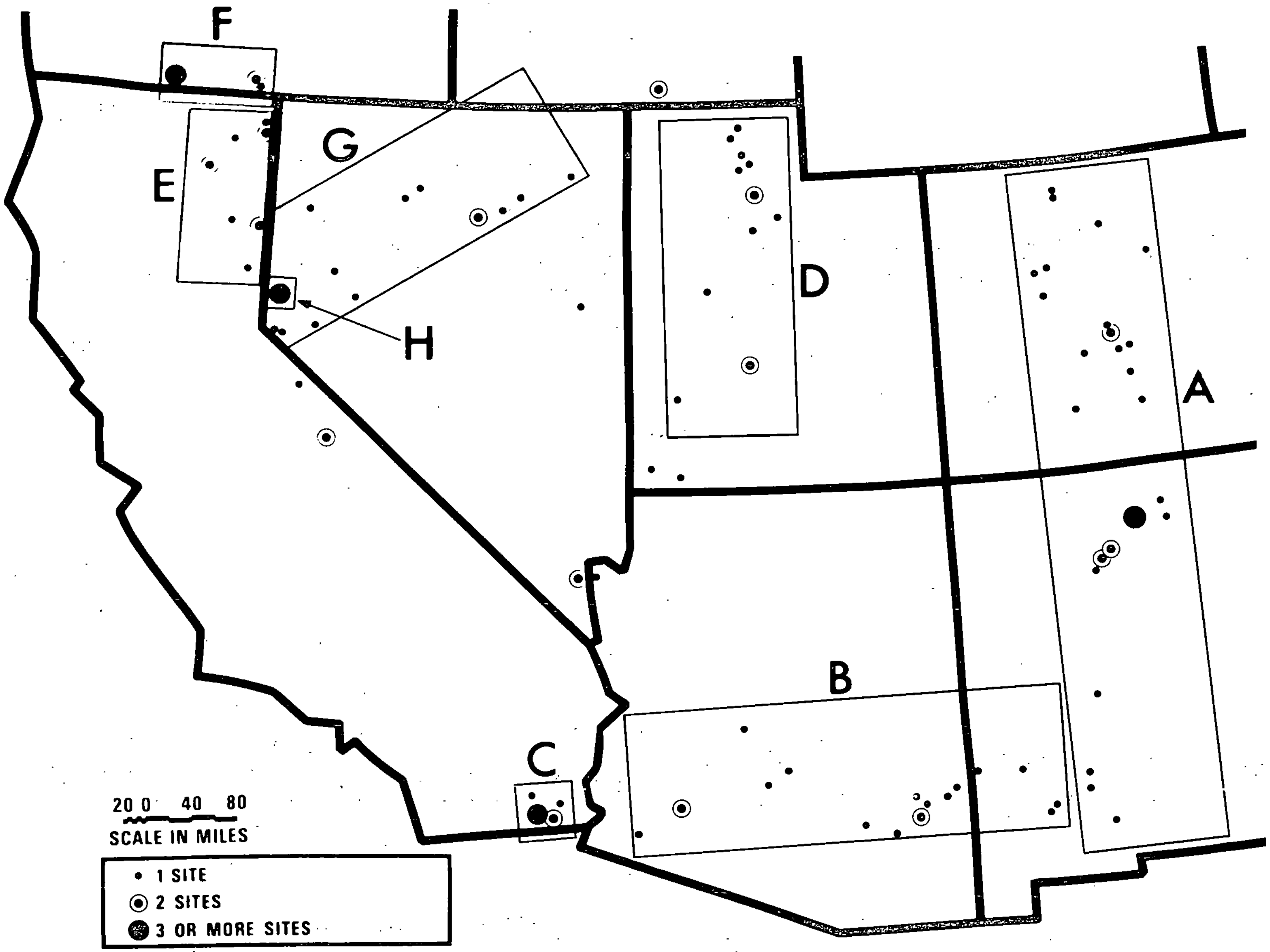

Figure 3
Geographic grouping of sample locations

The statistical analysis utilized gross chemical data from previous studies by Pearl (1972), Summers (1965), Hose and Taylor (1974), Mallory and Barnett (1973), and Mariner et al. (1974). Twenty-six selected parameters were correlated using a BMD series computer program from the University of California (Dixon, 1971).

In addition to data correlation and regression analysis, the radiochemical species were grouped in a cumulative log-normal probability distribution similar to that done by Jurain (1953). Less-than values (below detection limits) particularly for uranium and thorium isotopes were included using a technique described by Denham and Waite (1975).

Attempts at correlating the radionuclide and gross chemical parameters, particularly the geothermometers, have been generally unproductive. The radioisotope data do demonstrate that the range of concentrations are somewhat geographically dependent as shown in Figures 4 and 5. Hopefully, this dependency will be better demonstrated after forthcoming comparisons of these trends to regional geologic features.

The correlation analyses infer that in selected regional areas, silica, chloride, and temperature are not linearly related to the radioactive species. In a few regions, radium-226 and thorium-232 did correlate to silica with r values ranging from 0.7 to 0.98.

Other instances of high linear correlation ($r>0.9$) exist between the parent-daughter pairs of uranium-238/uranium-234, and uranium-234/thorium-230, but not between thorium-230/radium-226 or radium-226/ radon-222. Disequilibrium between certain pairs in the uranium decay series implies that differentiation mechanisms exist. Isotopic differentiation was described by Cowart (1975) who studied uranium-234/uranium-238 ratios for various thermal and non-thermal ground-water systems to derive a leaching model that can be used to study mixing and flow patterns.

Data from the present study show that activity ratios for uranium-234/uranium-238 in each region approximate the average of 1.4 reported by Cowart (1975). In the eight regional groups, the mean uranium-234/uranium-238 ratios ranged from 1.29 to 3.33 (not included are the ratios calculated using less than values).

There is a significant disequilibrium of radon to radium as apparent when comparing concentration scales from Figures 4 and 5. This disequilibrium is the greatest in springs characterized by calcareous deposits (data to be presented in a later report). As noted by Wollenberg (1975) and supported by a cursory examination of local rocks, radium co-precipitated with calcium is believed to be a substantial secondary radon source. Wollenburg (1975) also noted that elevated gamma radiation is preferentially associated with calcareous spring deposits. The initial

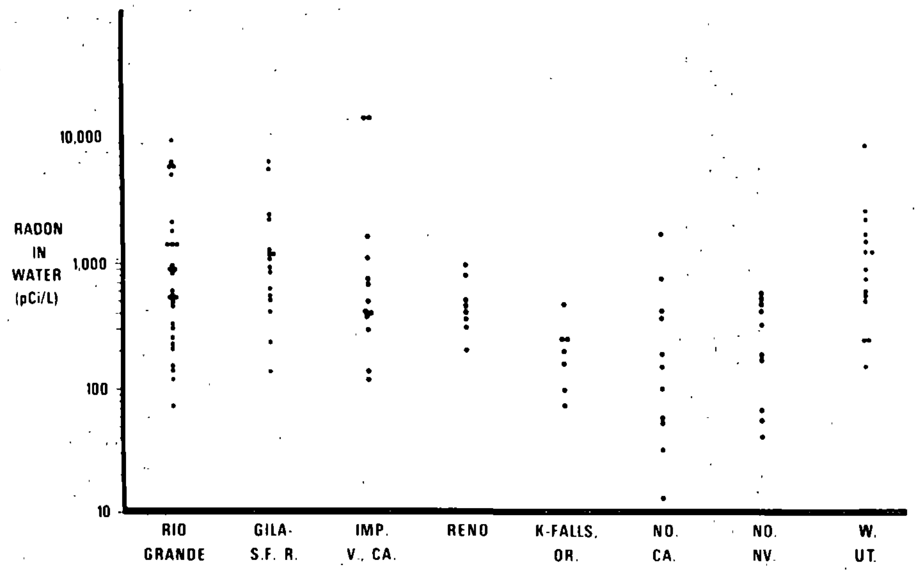

Figure 4
Radon concentrations in water

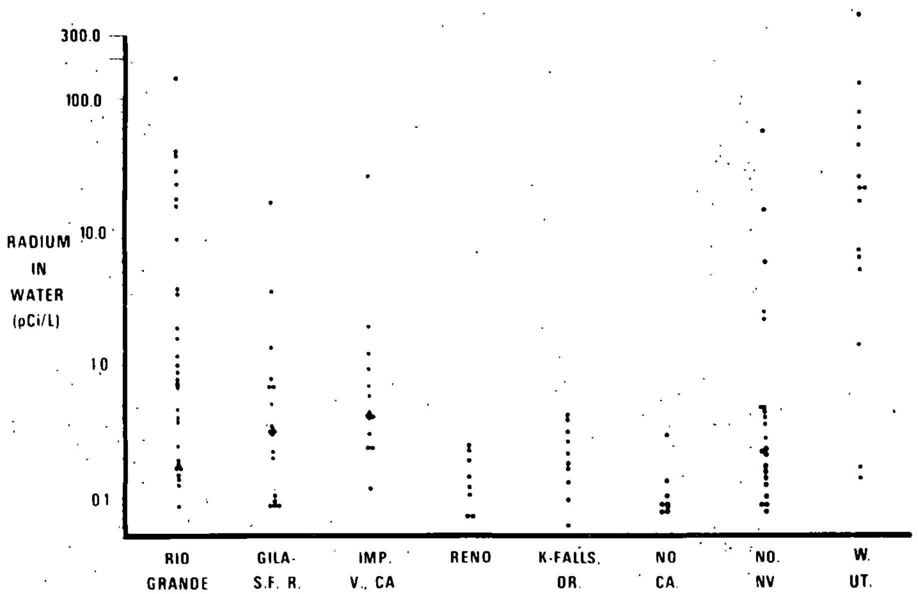

Figure 5
Radium concentrations in water

radiochemical results for the precipitate samples and our gamma surveys confirms this finding.

Much of the radiochemical data approximates a straight line fit on a log-normal frequency distribution plot, examples of which are shown in Figures 6 and 7. According to Denham and Waite (1975), this linearity implies that the data are from a single population. Any change in slope or non-linearity results from the contribution of an outside influence or a variation in the existing source. In the case of ground water, slope changes may be attributable to variations in the flow system, regional rock type or nearby magmatic activity. For example, Jurain (1953) concluded that a change in slope in the log-normal distribution of radon in water was associated with local outcrops of rocks relatively enriched in uranium and thorium.

For the present study, the distributions of each radionuclide were plotted by region. With the exception of the Imperial Valley, the radon distributions approximated a straight line fit. The Imperial Valley radon plot exhibited a change in slope at 700 pCi/l. Whether significant or not, the radon concentration in shallow wells decreased with distance from the San Andreas fault at a rate of about 1600 pCi/l per kilometer. In all of the regions, the uranium-238, uranium-234, and radium-226 plots had slope changes at concentrations of approximately 0.1 pCi/l.

CONCLUSIONS

To date, the statistical correlation has not disclosed any definitive association of radioactive and gross chemical species in the thermal waters sampled.

From a public health viewpoint, radium-226 is the isotope of most concern in drinking water. The quantities of uranium and thorium isotopes are not significant in the springs sampled with the exception of samples #76 and #77 where the results are extremely high for ground water. No explanation can be given other than sampling or analytical error.

Many of the geothermal waters sampled contained quantities of radium above the proposed drinking water standard of 5 pCi/l (U.S. EPA, 1975). This standard was developed for drinking water supplies serving populations of any size and based upon risk from a fatal cancer per million exposed persons. The former Federal Radiation Council (FRC) recommended that radium ingestion from all sources (water and food) was not to exceed 20 pCi/day. The FRC guidance for water supplies was as follows:

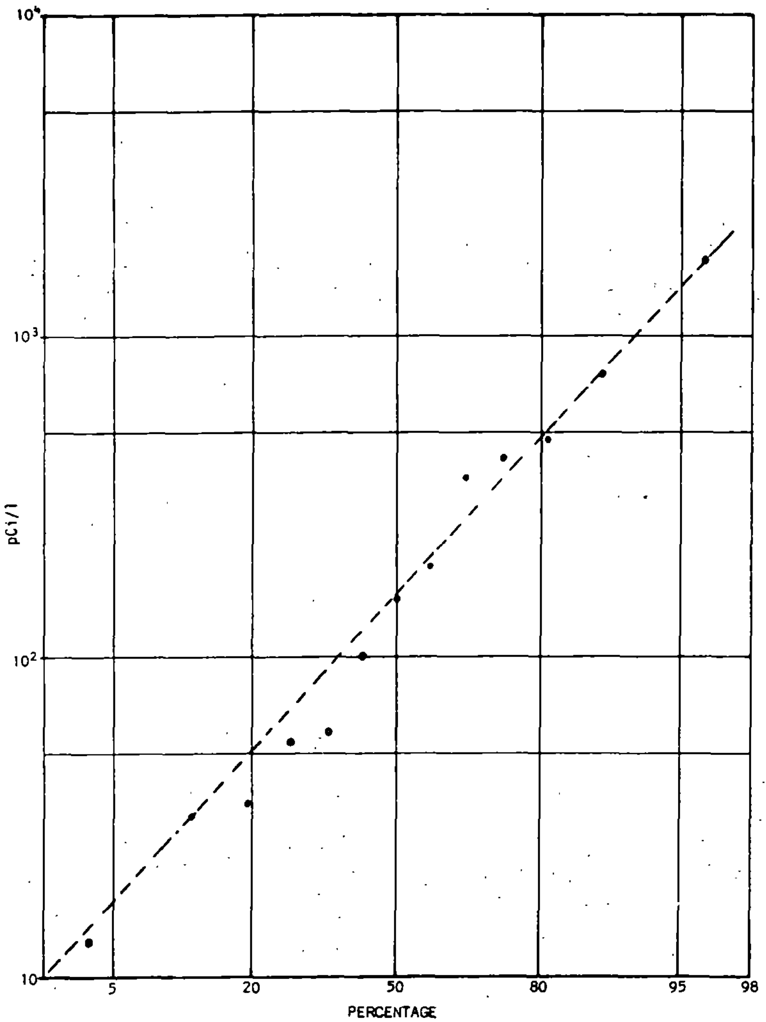

Figure 6
Log-normal cumulative frequency distribution for radon-222 in hot springs in northern California

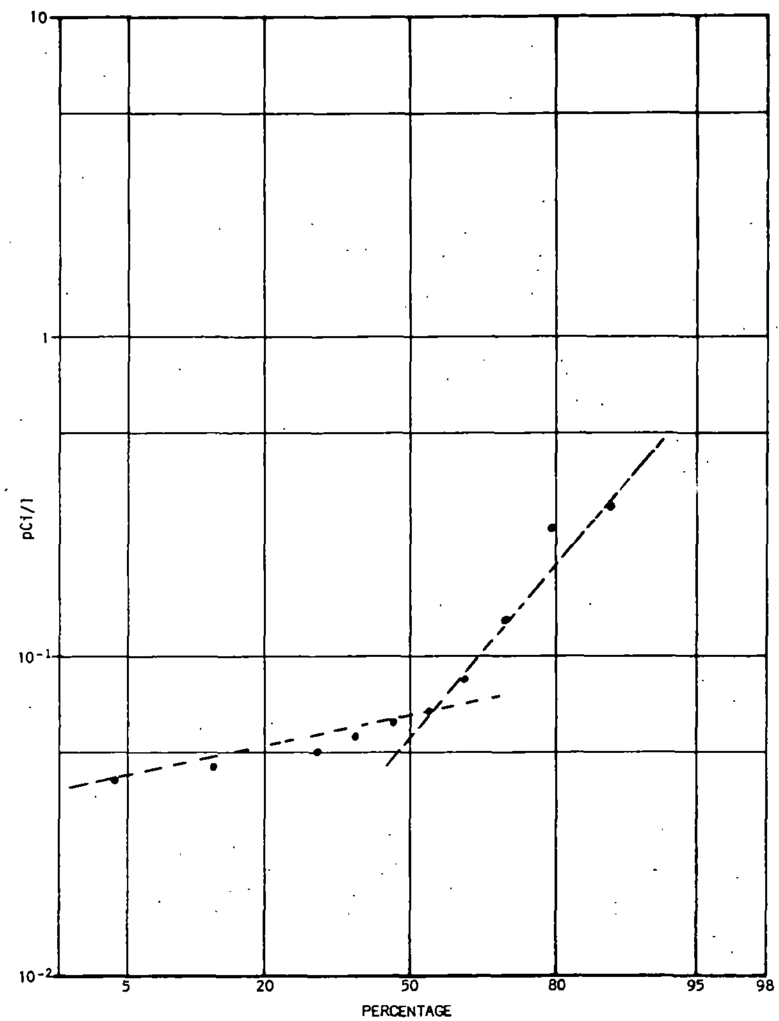

Figure 7
Log-normal cumulative frequency distribution for radium-226 in hot springs in northern California

Range	Concentrations	Action
I	0-2 pCi/l	Periodic confirmatory surveillance.
II	2-20 pCi/l	Quantitative surveillance and routine control.
III	20-200 pCi/l	Evaluation and application of additonal control measures.

At the present time, there are no Federal standards for dissolved radon in water. However, most of the waters sampled are non-potable because of obnoxious tastes and odors, an excessive concentration of dissolved solids, alkalinity, and other non-radioactive constitutents. Therefore, ingestion by the general public is not likely. In the Reno, Nevada area, the wells supplying hot potable water to private residences and motels contain less than 5 pCi/l of radium-226 (Figure 5).

Inhalation of radon daughters inside recreational facilities (spas, mineral baths) space-heated using thermal waters represent a potential exposure to workers. No measurements have been made to quantify this exposure. However, maintenance of a warm, humid environment in spas, baths, etc. is contradictory to control using ventilation techniques as described by Johnson et al (1973) and Aldrich et al (1975). Therefore, it is unlikely that ventilation is used or even desirable from an industry standpoint. Use of geothermal waters in radiators and heat exchangers for space heating and hot house agriculture represents a lesser problem.

The possible environmental impacts that could result from a large development of steam or hot water will depend upon the operational technology and type of utilization. The quantities of radium and radon present in the thermal waters sampled may represent only a small fraction of what may be available once the hydrologic system has been fully developed. An individual evaluation of each project may be necessary to identify potential problems.

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16. ABSTRACT

This report presents the radioanalytical results on water samples obtained from approximately 140 hot springs and shallow wells in eight western states. Sample locations were selected upon current or potential use as a geothermal heat source. Specific nuclide analyses were completed for radium-226, uranium-234, uranium-238, thorium-230, thorium-232, and dissolved radon-222. Accompanying these results is a brief overview of trends and rough correlations of radiochemical data with other inorganic data from previous studies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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