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VERTICAL CONTAMINATION IN THE UNCONFINED GROUNDWATER AT THE HANFORD SITE, WASHINGTON

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SUMMARY

Disposal to the ground at Hanford of large volumes of low- and intermediate-level wastes in the local unconfined groundwater flow system has raised concern about the movement and distribution of this waste. Previous work produced information on the horizontal movement of the waste, but little or no information exists on its vertical distribution within the unconfined groundwater flow system.

In 1975 Phase I of a study was started to determine vertical distribution of contaminants in three existing wells (699-28-40, 699-31-31, and 699-37-43). Because of negative results, only one well that produced positive results (699-31-31) was chosen for Phase II. Phase II consisted of tests conducted on this well by a testing company, with samples cross-checked by two different laboratories. Phase III was a cooperative study with Rockwell Hanford Operations, which included the installation, testing, and sampling of piezometers. The data were then analyzed using predictive codes and models in order to determine if vertical movement did occur.

The present groundwater flow system shows some vertical contamination. However, concentrations are relatively higher near the surface of the flow system, indicating possible radial flow patterns from the groundwater mounds known to have developed under the chemical processing area disposal sites. Upward flow from deeper aquifers may be diluting the contaminant and masking a possible downward migration of contaminants.

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INTRODUCTION

The Hanford Site is located in the south-central portion of Washington State near the city of Richland (Figure 1). The area was taken over by the U. S. Government in the 1940's as a site to produce weapons-grade nuclear products. Nine production reactors were constructed on the site, of which only one is presently operating. In addition to the reactors, two chemical separations areas were constructed near the center of the site.[1]

Activities on the site since 1944 have resulted in the disposal to the ground of large volumes of chemically and radioactively contaminated waste water. This water percolates laterally and downward through 50 to 100 m (150 to 300 ft) of unconsolidated sands, gravels, and silt until it eventually reaches the water table. Absorption and ion exchange reactions between the waterborne wastes and the earth materials effectively remove some of the longer lived and potentially more hazardous radionuclides[2] (i.e., ^{90}Sr, ^{137}Cs, and ^{239}Pu).

Other radionuclides, such as ^{106}Ru, ^{60}Co, ^{99}Tc, and ^{3}H, and non-radioactive constituents such as NO_3^- have poor exchange characteristics and move through the ground at various rates until they enter the groundwater flow system. Once in the flow system they generally travel in a down-gradient direction. The concentrations of these constituents in the groundwater are reduced by radioactive decay, ion exchange, diffusion and hydrodynamic dispersion as they move through the flow system.

The disposal of large quantities of water in the separations areas (34,000 ℓpm; up to 9,000 gpm), has resulted in groundwater mounds being superimposed on the natural flow system.[3] These mounds have increased the water-table gradient toward the river and have generated a potential for vertical gradients to form and drive contaminants to lower levels in the unconfined groundwater flow system.[4]

The work reported here was undertaken to ascertain whether or not the vertical components of flow beneath the groundwater mounds had resulted in contaminants being distributed vertically within the flow system, thereby presenting a path to the environment that was not being monitored.

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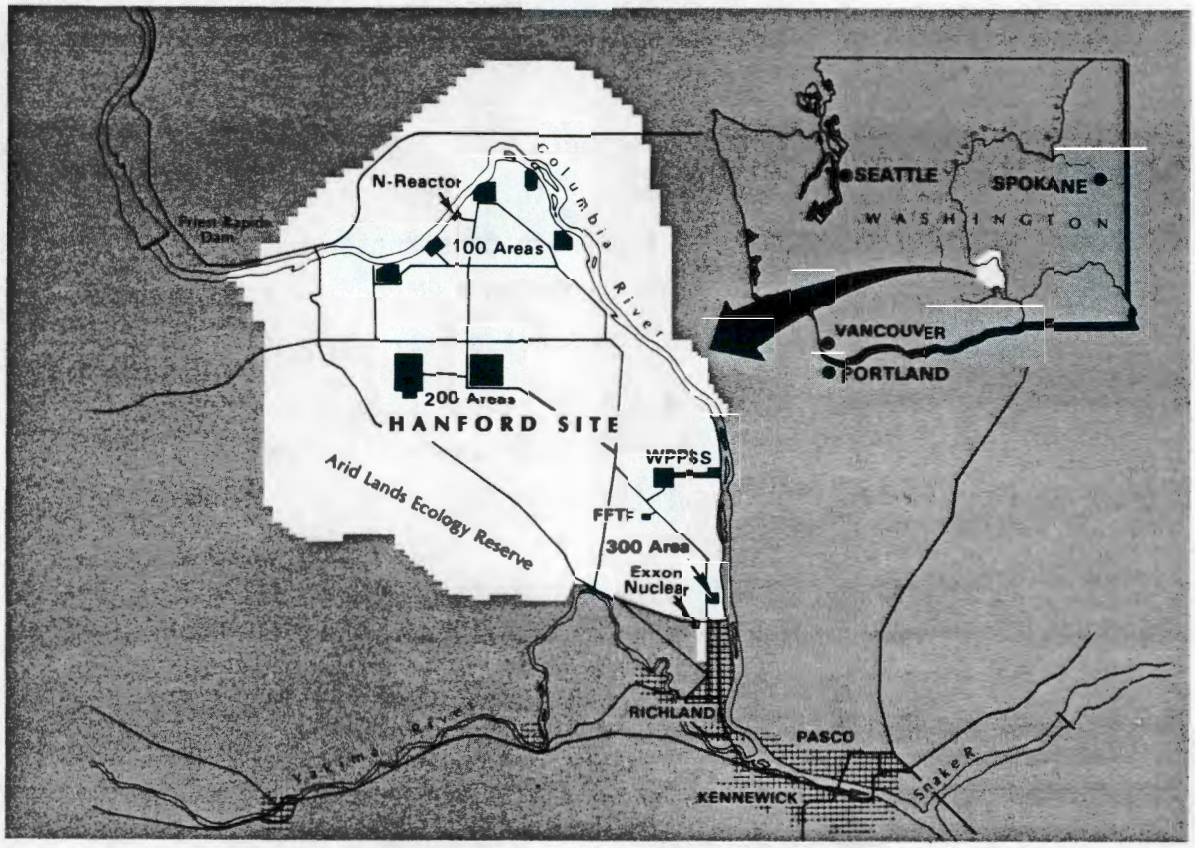

FIGURE 1. The Hanford Site

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CONCLUSIONS AND RECOMMENDATIONS

The present groundwater monitoring program, which samples the upper portions of the unconfined groundwater flow system, is appropriate because it samples that portion of an aquifer containing the most concentrated levels of contaminants. Hanford-originated contaminants do exist at trace levels at depths in the flow systems and should be sampled. However, because of the lower levels of contaminants, these deeper wells need not be sampled as frequently as the upper unconfined flow system.

Concentrations of contaminants are relatively higher near the surface of the unconfined flow system. The reasons for these higher concentrations are numerous and complex. The preferred path for the mounded water appears to be a radial flow pattern rather than a vertical flow.

An increase in potentiometric head with depth may be a factor in preventing the downward migration of contaminants being introduced at the mound locations. The effect of this upward movement of ground water should, theoretically, increase as the Columbia River is approached. This concept is supported by data from Well 699-40-1.

A concentration history of Well 699-40-1 (Figure 2), shows a marked increase in tritium concentration following remedial work, which included the removal of a set of piezometers and the shortening of the water column. Upward vertical flow of uncontaminated ground water may have diluted the concentrations of contaminants, which may have caused the low readings obtained prior to rehabilitation work.

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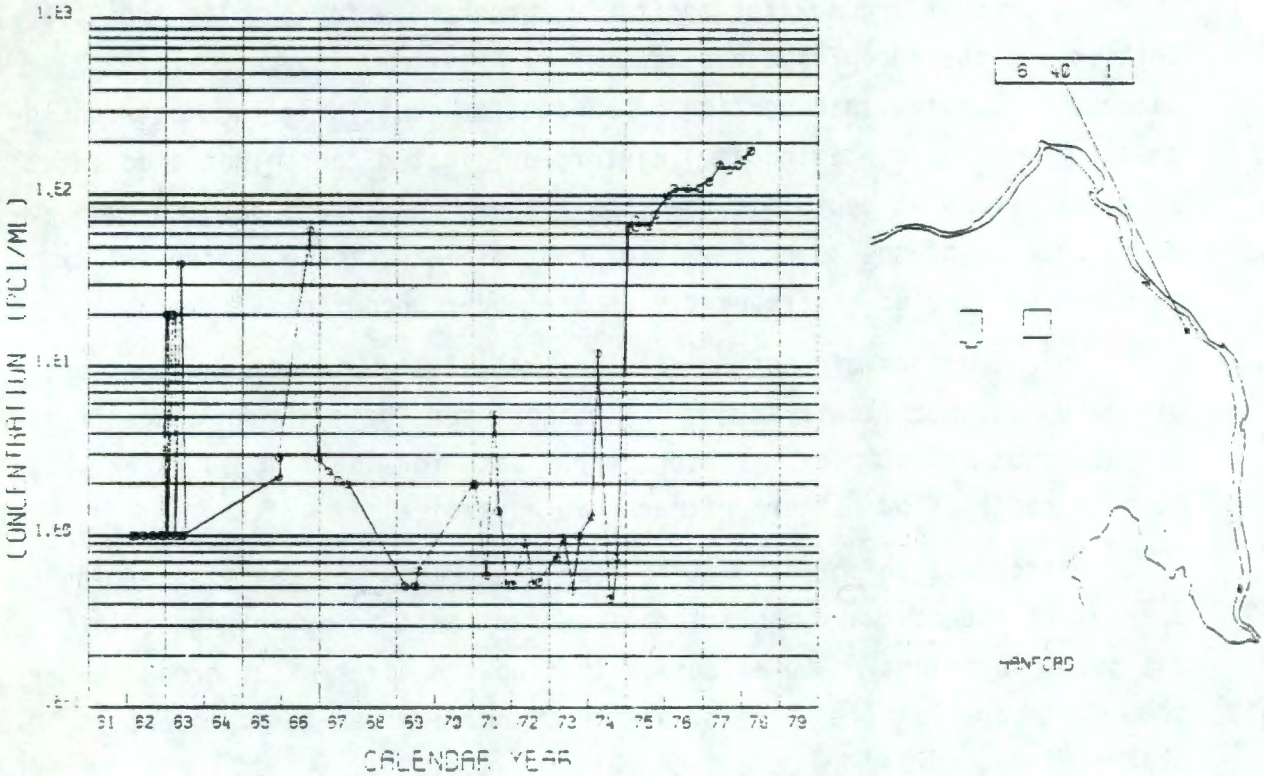

FIGURE 2. Concentration History of Tritium in Well 699-40-1

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BACKGROUND

Since 1944, more than 5.3×10^{11} ℓ ($>14 \times 10^{10}$ gal) of process and cooling water containing low-level waste has been disposed to the ground near the separations areas. This disposal has had a significant effect on the water table. In addition, significant quantities of mobile chemical and radioactive contaminants have entered the water table and have been carried with the ground water in a down gradient direction toward the Columbia River. The Pacific Northwest Laboratory (PNL) carries out an extensive groundwater monitoring program to ascertain the dispersion and impact of these constituents on the environment.

GROUNDWATER MONITORING PROGRAM

The routine groundwater monitoring program is designed to assess the distribution and concentration of contaminants of Hanford origin in the ground water and to determine the impacts on man from the wastes transported via this pathway. To accomplish this, an extensive sampling and analysis effort is maintained. For example, in 1977 PNL conducted 2675 analyses from 939 samples obtained from 240 wells[3] (Figure 3). (These analyses do not include analysis of the wells sampled for Rockwell Hanford Operations within the separations areas.) In addition, special sampling and analyses are made in response to unusual circumstances, i.e., unusual analytical results and special requests from other contractors.

A program of well maintenance is conducted to ensure that quality groundwater sampling structures are preserved and that samples used in the program represent the groundwater flow system at a specific location. The monitoring program maintains a comprehensive data base, which supplies most of the groundwater data for the Hanford groundwater models. In addition, the program carries out supporting studies to aid in the definition of problem areas and to answer specific questions that are not within the scope of the routine program.

The definition of the vertical distribution of contaminants within the Hanford groundwater flow system is one of those special supporting

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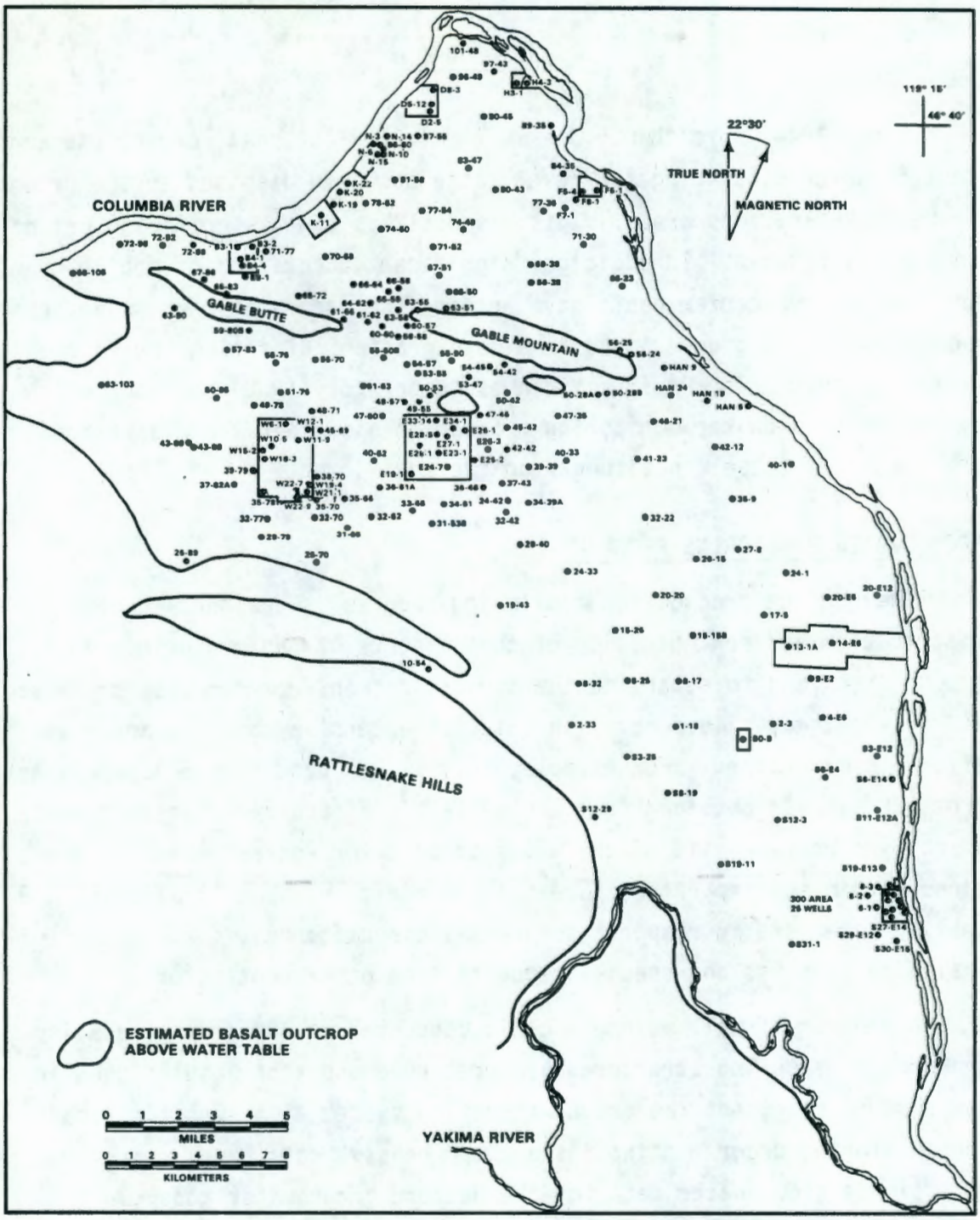

FIGURE 3. Wells Sampled for Contaminants in the Ground Water at Hanford

studies. This study was carried out in three phases: Phase I started in 1975 and included analyses from three wells; Phase II used one well, with the analyses conducted by two laboratories; and Phase III was undertaken cooperatively with RHO and consisted of the installation of piezometers in selected wells and the testing of the piezometers. This type of testing was intended to determine if contaminants did in fact move vertically as well as horizontally.

SAMPLING AND ANALYSIS

The routine program currently collects samples from about 240 wells. Depending upon the location, the groundwater samples are analyzed for tritium, gross beta (as ^{106}Ru), the gamma spectrum, and the nitrate ion. These analyses yield information on those contaminants most commonly found in the ground water. The samples are generally collected using submersible pumps installed in wells, tapping the upper 13 to 20 m (approximately 40 to 60 ft) of the unconfined aquifer.

WELL MAINTENANCE PROGRAM

In 1974, a program was begun to upgrade all of the wells used for groundwater monitoring on the Hanford Site. The wells available on the site had been drilled for a number of purposes, including monitoring, geological investigations, and hydrological investigations. The multipurpose nature of many of the wells and their different construction and completion methods resulted in a variety of structures that are not always compatible with good monitoring criteria.

In the early 1960s a program was begun to install piezometers at various depths within the aquifer system at Hanford. These piezometers were made of 1-1/2-in. ABS plastic pipe, with plastic well screens that were set opposite perforated zones in the well casing and then isolated by backfilling with fine sand.[5] A high percentage of those installations failed because the plastic pipe collapsed when the wells were backfilled with sand or pumped for sampling. The structures proved to be inadequate for sampling because water did transfer through the fine sand, resulting in cross-contamination.

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Starting in 1974 as part of the well maintenance program, these plastic piezometer tubes were removed and the wells were returned to their original specifications. Subsequent changes in water chemistry after rehabilitating the wells points out the need for eliminating the potential for transfer of contaminants from one portion of the aquifer to another and for removing the possibility of interaquifer transfer, which is a result of inadequately constructed wells. However, these wells, in their existing condition, could provide a means of determining the actual vertical distribution of contaminants within the Hanford groundwater flow system.

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METHODOLOGY

Several techniques were used in the past to determine if contaminants were reaching the lower levels of the unconfined aquifer system. These studies utilized deep samplers, which had special apparatuses to open sample containers at depth. Piezometers were installed at specific depths and isolated in individual large-diameter wells, and clusters of small-diameter wells were drilled to different depths. Only the individually drilled piezometers provided reproducible data.

PHASE I

The first phase was started in May 1975, with analyses completed in August 1975. This phase utilized three existing wells located in or near the known tritium and gross beta plumes. These wells were specifically constructed to allow sampling of the ground water at various depths below the surface of the water table. The locations of Wells 699-28-40, 699-31-31, and 699-37-43 are shown in Figure 4. The completion schedules for the wells are shown in Figure 5. Figure 6 shows the geologic logs of the wells.

The zones sampled in this phase were isolated using a packer assembly similar to the system illustrated in Figure 7. This packer system originally used a small submersible pump between the inflatable packers; however, sanding problems forced the use of an "air-lift" sampling technique. A great deal of difficulty was experienced with this system because the packers were short-lived and had a stong tendency to leak. These leakages placed doubt on the validity of the testing.

This phase of the study pointed out that some contamination was present at depth in Well 699-31-31, as shown by total β at 94 m (270 ft) being 46 pCi/ℓ, versus 177 pCi/ℓ at 184 m (530 ft). For details see Table 1 and the Appendix.

PHASE II

The second phase concentrated on Well 699-31-31, the only Phase I well that showed positive results. Phase II work essentially duplicated

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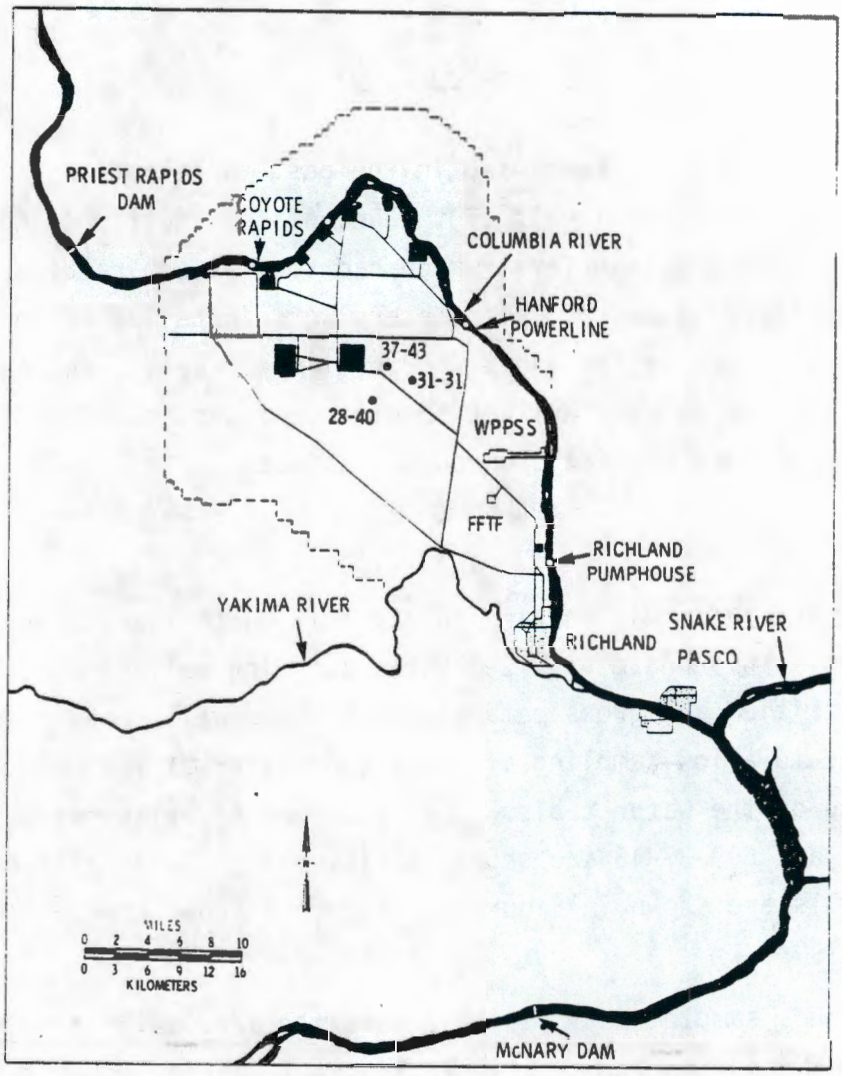

FIGURE 4. Location of Wells 699-28-40, 699-31-31, and 699-37-43

Phase I, with the exception that replicate samples were analyzed for key contaminants by two different laboratories (PNL's Physical Sciences Department and the U. S. Testing Company). The well cleanout and packer installation was contracted to a well drilling and testing company, which had wide experience and success with use of their packers in various well testing and operating activities. The isolated zones were pumped at low rates to avoid excess stress on the well and aquifer, thereby avoiding possible bypass and cross contamination.

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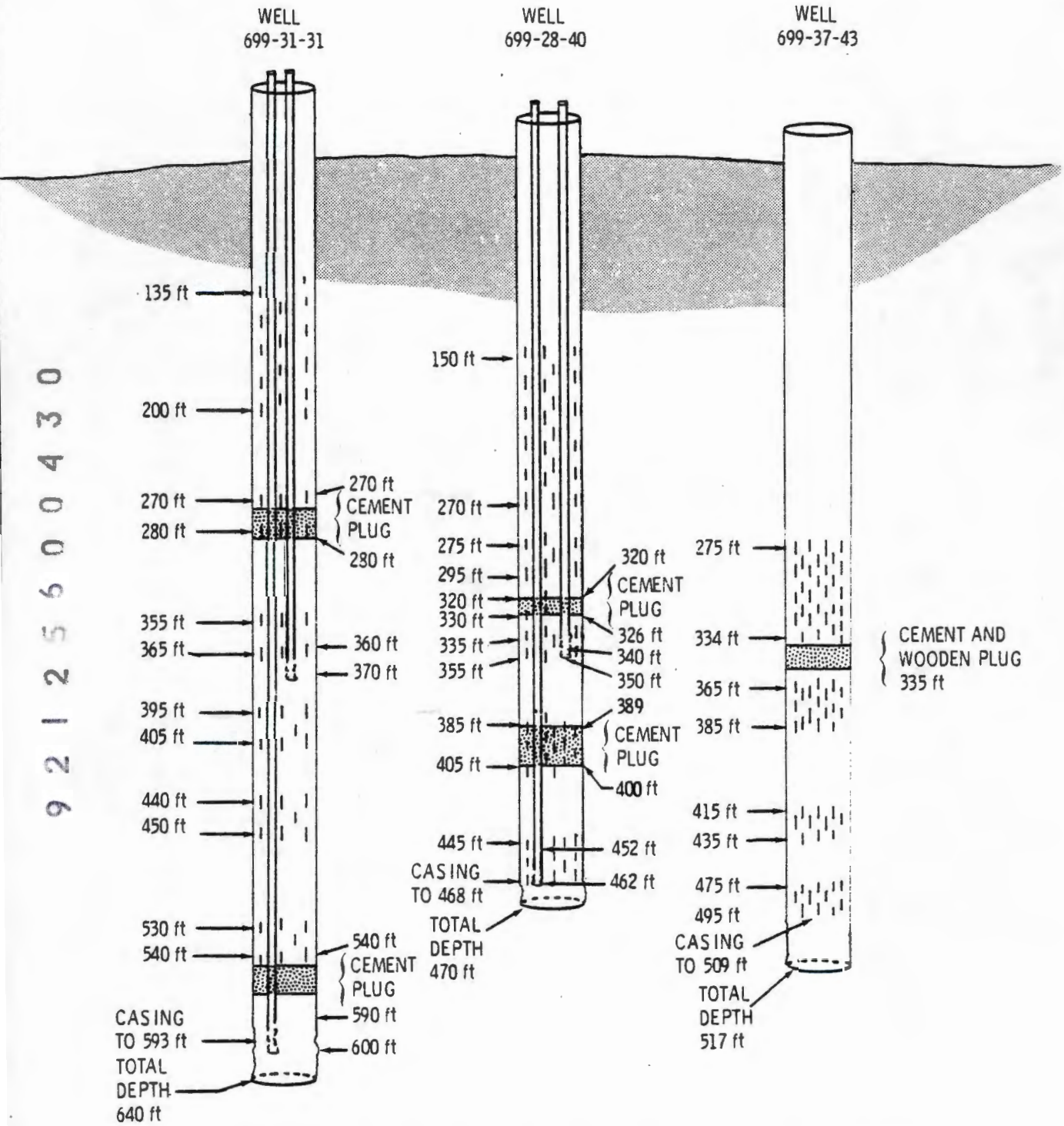

FIGURE 5. Completion Schedules of Well 699-31-31, 699-28-40, and 699-37-43

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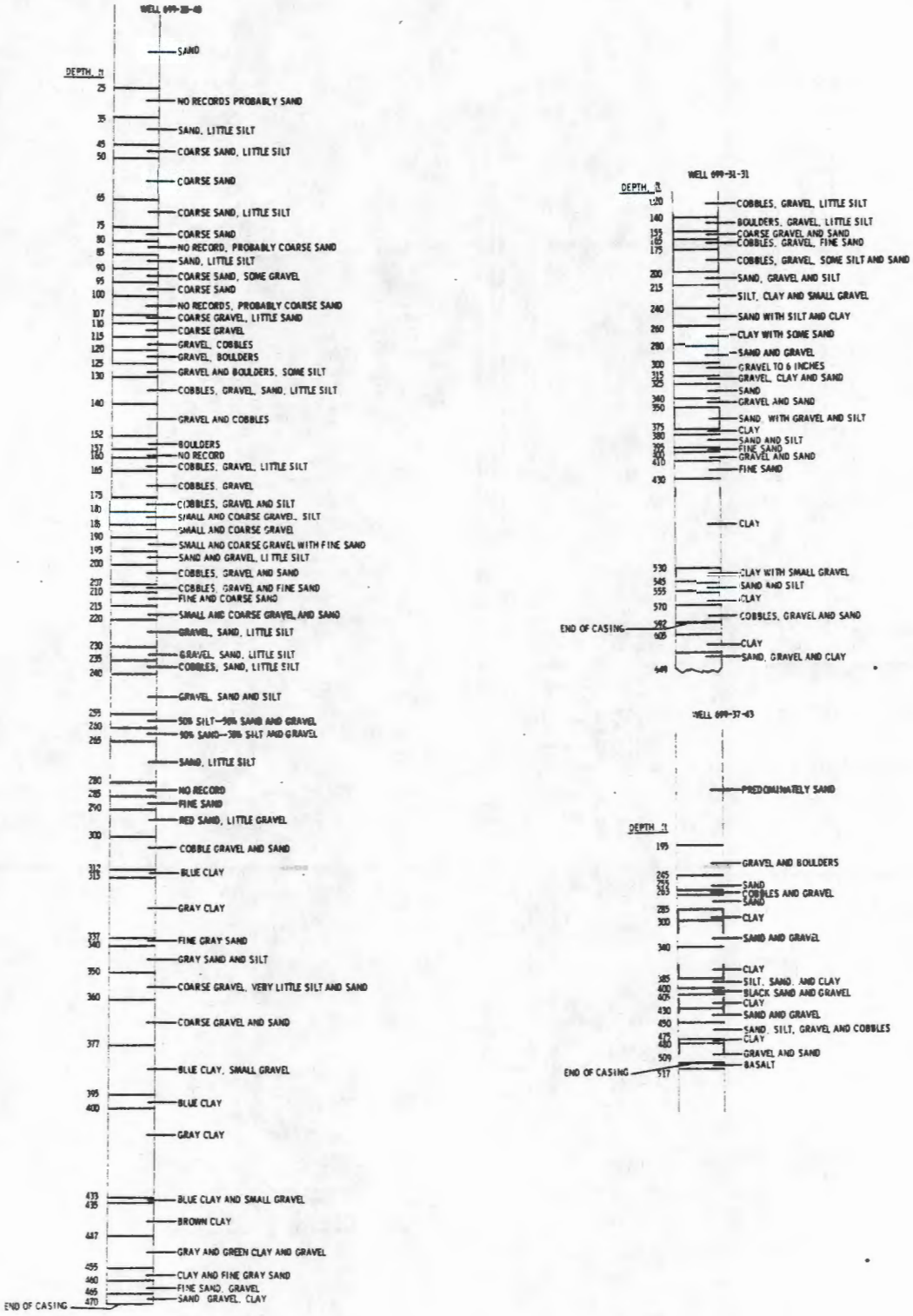

FIGURE 6. Geologic Logs of Wells 699-28-40, 699-31-31 and 699-37-43

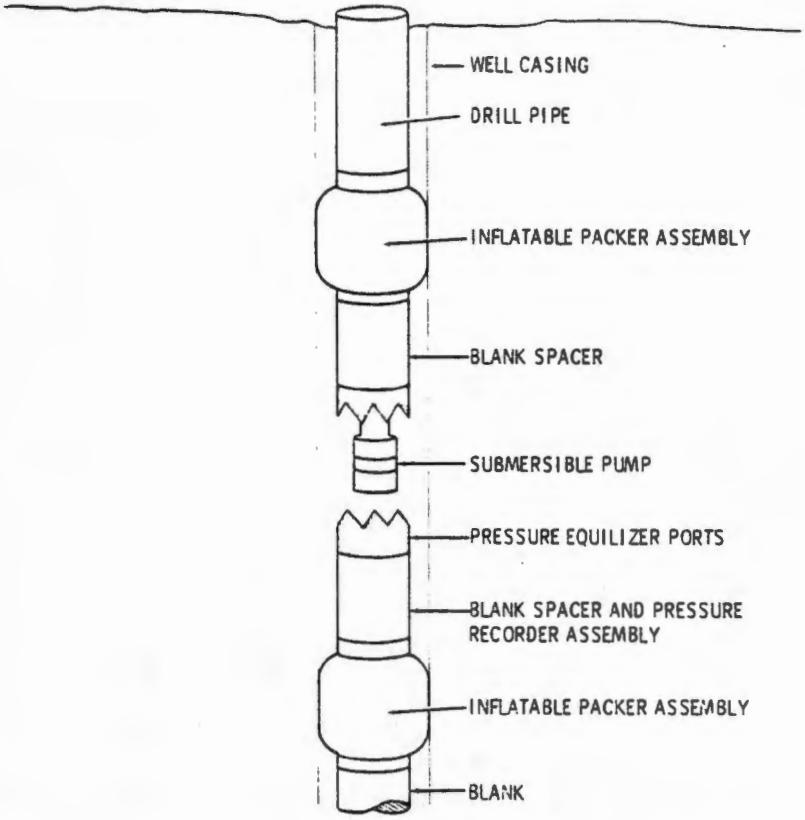

FIGURE 7. Packer Assembly

Phase II work started with the brushing, swabbing, and cleaning of Well 699-31-31. A downhole television system was used to examine the borehole, which showed that the brushing and swabbing were effective in removing scale and thus permitting a tight seal of the packer elements. The visual inspection showed that perforations listed as being at 108 m to 110 m (355 ft to 360 ft) below the land surface[6] were actually 108 m to 111 m (355 ft to 365 ft) below land surface. This second phase of the study was completed in June 1976, with sample analyses completed by August 1976.

Data from Phase II confirmed the data obtained from Phase I (see Table 2 and the Appendix). Contamination of the lower portion of the unconfined aquifer had occurred; however, concentrations of individual

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TABLE 1. Selected Contamination Results for Wells 699-28-40, 699-31-31, and 699-37-43, May 1975

Well No.	Depth, ft	Constituents, pCi/ℓ: Total β as ^{106}Ru	^{3}H	^{60}Co	Gamma Scan ^{106}Ru
699-31-31	270-284	46 ± 15	3.3×10^5	55 ± 26	210 ± 160
28-40	280-290	7.3 ± 4.5	<720	<41	<120
37-43	287-301	8 ± 5.7	1600 ± 630	<87	<190
699-31-31	350-364	32 ± 15	6.2×10^5	69 ± 27	170 ± 160
28-40	340-350	6.8 ± 4.9	<560	<48	<210
37-43	365-383	7.4 ± 5.6	<790	35 ± 24	<120
699-31-31	395-409	14 ± 14	1.5×10^5	37 ± 25	160 ± 160
28-40	400-410	6.5 ± 5	<640	<37	<110
37-43	415-433	7.3 ± 4.9	<560	27 ± 23	<150
699-31-31	--	--	--	--	--
28-40	450-460	8.4 ± 6	<640	<43	<110
37-43	465-483	5.8 ± 5.7	<710	<36	<250
699-31-31	530-545	177 ± 27	1.4×10^6	110 ± 29	160 ± 140
699-31-31	600	72 ± 19	6.5×10^5	58 ± 26	--

constituents appeared to be greater near the surface of the water table. Based on this knowledge and the criticism that complete isolation of a portion of an aquifer using inflatable packers is not assured, a broader based program was planned for Phase III of this study.

PHASE III

The third phase of this study was undertaken in cooperation with the Atlantic Richfield Hanford Company (ARHCO), which is now the Rockwell Hanford Operation (RHO). As part of an offsite migration program, several wells were selected by the ARHCO (RHO) staff for the installation of permanently installed piezometers. These piezometers were installed in existing wells after alterations were made to the wells to insure adequate vertical isolation (Figure 5). The wells were then sampled using air-lift techniques, so that an adequate sample volume could be obtained from the small-diameter boreholes. An adequate sample volume was needed to assure that the samples were representative of the aquifer at that location. These samples were then analyzed for standard water quality

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TABLE 2. Phase I and Phase II Contamination Results for Well 699-31-31

Date	Depth, ft	Total β as ^{106}Ru, pCi/ℓ	^{3}H, pCi/ℓ	^{60}Co, pCi/ℓ	Ca, ppm	Na, ppm	NO_3-N, ppm
May 1975	Water Surface (at ~150 ft)	193 ± 26	1.5×10^6	160 ± 40	47	34	15.4
June 1976[a]		120	1.6×10^6	65 ± 6	47	32	13
June 1976[b]		92 ± 8	$1.8 \times 10^6 \pm 17{,}000$	--	--	--	15
May 1975	270-280	46 ± 15	3.3×10^5	55 ± 26	14.9	46.9	3.4
June 1976[a]		110	1.6×10^6	43 ± 5	26	34	13
June 1976[b]		67 ± 7	$1.84 \times 10^6 \pm 8{,}300$				16.5
May 1975	355-365	32 ± 13	6.24×10^5	69 ± 27	21.5	44.6	6.5
June 1976[a]		140	1.6×10^6	46 ± 5	22.5	34	11.5
June 1976[b]		78 ± 7	$1.92 \times 10^6 \pm 2.9 \times 10^4$				17.5
May 1975	395-405	14 ± 10	1.45×10^5	160 ±160	9.8	49	0.67
June 1976[a]		93	1.6×10^6	45 ± 5	21.5	34	0.35
June 1976[b]		50 ± 6	$1.44 \times 10^6 \pm 1.3 \times 10^4$				16.5
May 1975	535-545	64 ± 26	3.71×10^5	62 ± 26	16.8	51.6	--
June 1976[a]		<75	4.3×10^5	5.2 ± 5.6	18.2	50	3.5
June 1976[b]		33 ± 6	$4.58 \times 10^5 \pm 1.4 \times 10^4$				4.5
May 1975	Below 575	72 ± 12	6.59×10^5	110 ± 29	21.5	46.9	6.7
June 1976[a]		<75	9.9×10^5	35 ± 6	30	46.5	9.0
June 1976[b]		53 ± 7	$9.44 \times 10^5 \pm 1.2 \times 10^4$				9.5

[a] Analysis by PNL's Radiological Sciences Department.
[b] Analysis by U. S. Testing Company.

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parameters plus selected radionuclides. The wells showed some contamination with depth; however, the vast majority of contaminants were found to be in the upper portions of the aquifer system. Data obtained during Phase III are contained in Table 3.

Rockwell Hanford Operations (RHO) Work

For several years RHO researchers have studied the flow of contaminants into the ground water and the resulting stratification of the waste. Several unpublished reports were generated, which have very limited distribution.[7,8,9,10] The information and data appear to have been either lost in old files or destroyed. Therefore, in 1976 an intense

TABLE 3. Phase III Contamination Results, July 1977

	pH	Conductivity, μmohs/cm	HCO_3, mg/ℓ	CO_3, mg/ℓ	Cl, mg/ℓ	SO_4-S, mg/ℓ	NO_3-N, mg/ℓ	Dissolved Solids mg/ℓ
Well 699-10-E-12								
74 ft (Surface)	7.5	250	120	0	5.7	8	3.8	243.0
360 ft	7.9	350	188	0	14.2	1	0.05	361
Well 699-14-38								
112 ft (Surface)	8.05	300	132	0	3.5	9.0	0.2	229
178 ft	8.1	290	134	0	3.0	8.5	0.3	250
380 ft	7.95	250	135	0	3.5	8.5	0.5	280.0
Well 699-28-40								
157 ft (Surface)	7.75	350	133	0	7.5	18.5	3.1	311.0
340 ft	7.9	250	139	0	1.5	8	<0.05	208.0
468 ft	7.75	220	106	0	3.5	8	0.05	177
Well 699-31-31								
128 ft (Surface)	7.5	500	110	0	10.7	19.5	14.4	370
360 ft	7.7	360	127	0	9.5	25	<0.05	348
590 ft	8.0	250	152	0	3.5	1	<0.05	247
Well 699-32-72								
209 ft (Surface)	7.9	350	88	14.44	43.4	8.5	4.5	210
465 ft	7.3	400	144	0	18.5	10.5	0.1	202
Well 699-38-65								
322 ft (Surface)	7.5	450	133	0	9.7	12	13.6	396
460 ft	8.0	350	153	0	4.5	7.5	0.4	262
Well 699-50-42								
59 ft (Surface)	8.6	500	0	28.9	35.5	75	0.4	377
110 ft	7.7	350	112	0	28.4	10	0.75	197
Well 699-51-75								
192 ft (Surface)	8.1	400	97	18	15.6	14.5	4.4	220
370 ft	8.0	350	139	0	10.7	11	0.2	212
Well 699-53-55A								
174 ft (Surface)	7.9	400	83	0	25.5	8.5	<0.05	278
330 ft	8.0	450	96	0	25.7	5.5	0.2	300
Well 699-67-51								
124 ft (Surface)	7.7	480	128	0	13.5	5.5	0.3	170
184 ft	11.3	350	0	72	8.0	23.5	0.05	1119
Well 699-96-49								
36 ft (Surface)	7.6	400	92	0	32	19.5	1.7	238
79 ft	7.6	350	87	0	21	14.5	0.6	203
Well 699-S12-29								
84 ft (Surface)	7.9	400	74	0	9.2	14.5	3.6	281
147 ft	7.6	350	72	0	12	16	0.1	252
180 ft	8.1	500	124	0	23.5	9.5	0.3	308

ND - Not Detected.
*Large error percentage noted - the nuclide may not be present.

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TABLE 3. (Continued)

B mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	K mg/ℓ	Na mg/ℓ	^{60}Co pCi/ℓ	^{106}Ru pCi/ℓ	^{134}Cs pCi/ℓ	^{137}Cs pCi/ℓ	^{3}H pCi/ℓ
<0.05	22	6.8	7.1	20.5	.05	ND	ND	ND	
0.06	12	3.7	8.6	55.0	.016	ND	ND	ND	
<0.05	25	9.2	6.5	11.5	.011	ND	ND	.023	
<0.05	26.5	7.5	44	11.5	.025	ND	ND	ND	
<0.05	34.5	46.5	49.5	22.5	.17	ND	ND	ND	
<0.05	23.5	9.2	5.8	17.5	1.5	.03	ND	ND	3.7×10^5
<0.05	18.5	7.0	4.6	12.5	.011	ND	ND	ND	
<0.05	9.5	2.0	2.6	24	.05	ND	ND	ND	
0.05	26.5	10.5	8.0	12.0	52	13	.045	ND	3.8×10^5
<0.05	19	8.5	6.5	28	11	1.4	ND	ND	3.0×10^5
0.06	5	1.0	5.8	42	.032	ND	ND	ND	
0.15	32	9.4	4.0	12	.0051	.014	ND	.019	1.3×10^7
<0.05	35	10	4.5	14	ND	ND	ND	ND	9.8×10^5
<0.5	34.5	17.7	5.7	16	.19	.017	ND	ND	2.7×10^6
<0.5	26.5	11.6	5.3	14	.0051	ND	ND	ND	
<0.05	41	2.2	8	18	.028	ND	ND	ND	
<0.05	12	9	4.5	15	.021	ND	ND	.025	
<0.05	35	12	4	8	.0030	ND	ND	.050	
<0.05	35	8.4	5	12	.0035	ND	ND	ND	
2.55	37	12.5	8.5	12.5	ND	ND	.0039*	ND	
0.2	37	13	8.5	13.0	ND	.023	ND	ND	
0.25	125	6.8	5	16	.16	.037	ND	.015	
0.7	340	<0.1	18	31	.024	.019*	ND	ND	9.8×10^4
0.1	21	7.2	4.5	11	.026	ND	ND	.016	1.8×10^6
<0.05	17	6.4	5	6.5	.012	ND	ND	ND	6.5×10^5
0.1	37	8	6	13.5	.024	ND	ND	.013*	
0.1	27	8	8	15	.0017	.022	ND	.13	
0.1	47.5	14	8	14	.0080	ND	ND	.030	

9 2 1 2 5 6 0 0 4 3 6

program was started in cooperation with PNL to establish a network of piezometers. The work involved the installation of piezometers at selected well sites within the Hanford Site. Twenty-eight well sites were selected for rehabilitation, piezometer installation, and hydraulic testing during FY-1977. During FY-1978 an additional 12 wells are scheduled to be rehabilitated, have piezometers installed and be hydraulically tested (Figure 8). The final series, scheduled for FY-1979, will complete the rehabilitation, installation of piezometers and hydraulic testing of any remaining wells.

Study Description

The assessment of data for long-term prediction of potential contaminant migration in the ground water involves the identification of the characteristics that are pertinent to evaluating the subsurface system of fluid flow and contaminant transport. The objective of the study was to establish a piezometric network that would be able to differentiate and assess the boundary between artificial recharge at Hanford and the natural groundwater flow systems.

The most promising and potentially useful computer codes and models identified in FY-1976 were adapted to the specific predictive needs of the Hanford Site, and their accuracy was tested against actual groundwater flow and contaminant data.[11] With model availability firmly established and their predictive capability strengthened, the models can be used to predict groundwater and contaminant movement resulting from future Hanford operations and/or local agricultural developments. These detailed impact studies would allow for the proper hydrologic management of the Hanford groundwater flow systems, which would minimize any doubts as to the present or future consequences of radiological contamination underlying the Hanford Site. By recognizing all data requirements and having the most suitable computer systems available to handle this information, maximum credibility would be achieved in the use of predictive modeling results.

Planning for the long-term groundwater management program and evaluating the computer codes and data base available for groundwater

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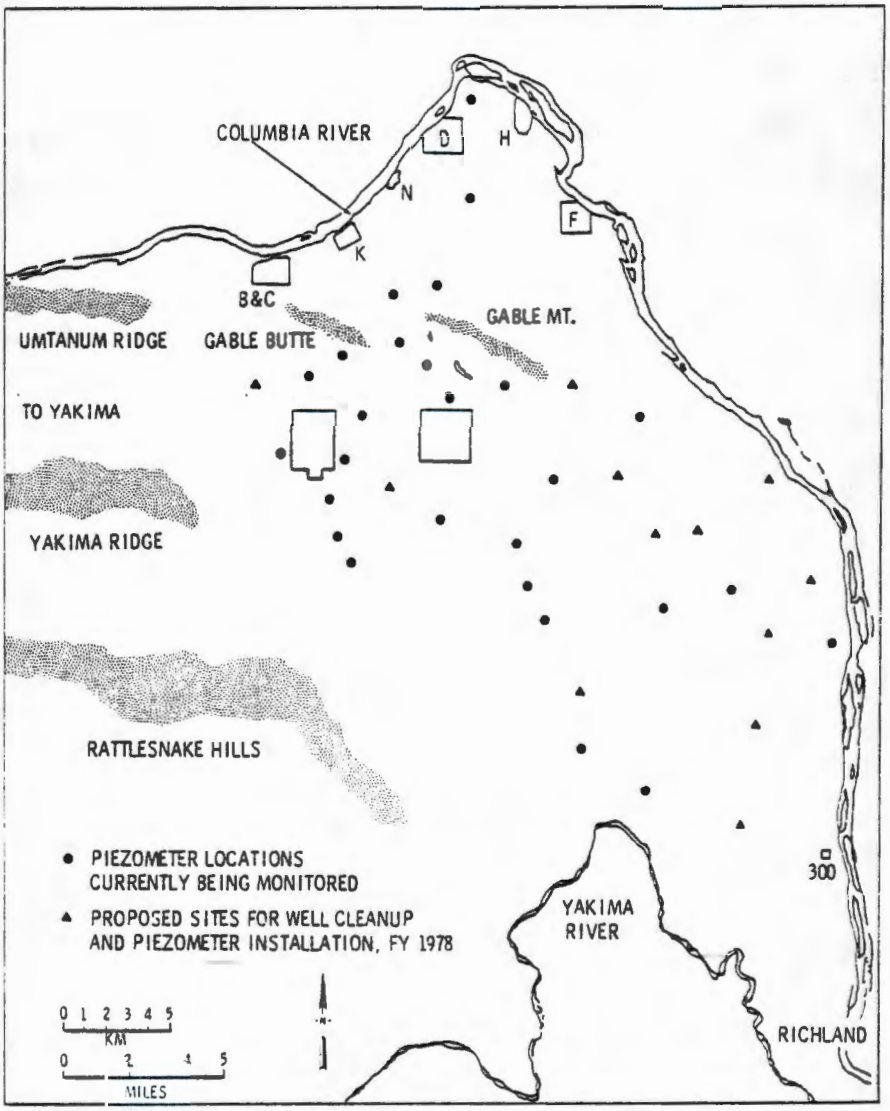

Existing Piezometers		Proposed Piezometers
Well Number	Well Number	Well Number
699-20-39	699-67-51	699-56-E4
699-17-5	699-55-70	699-02-33
699-65-59	699-51-75	699-S18-E2
699-S12-29	699-60-60	699-09-E2
699-50-53	699-96-49	699-20-E12
699-46-21	699-39-79	699-40-1
699-28-40	699-32-72	699-33-22
699-31-31	699-38-70	699-26-15
699-38-65	699-25-70	699-50-85
699-22-70	699-44-64	699-32-62
699-14-38	699-31-53A	699-27-8
699-10-E12	699-83-47	699-54-37
699-53-55A	699-15-15A	
699-50-42	699-S14-20	

FIGURE 8. Present and Proposed Piezometer Locations (RHO)

9 2 1 2 5 6 0 0 4 3 8

management of high-level waste areas was completed in FY-1976. Model development, testing and adaption, and data base improvements will continue until 1981. Hydrological studies of high-level waste areas and the definition of impacts of onsite and offsite activities on waste-management programs will continue through FY-1982 if funding is available.

9 2 1 2 5 6 0 0 4 3 9

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9 2 1 2 5 6 0 0 4 4 0

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APPENDIX

GRAPHS OF SELECTED WELLS SHOWING CONCENTRATION VERSUS DEPTH

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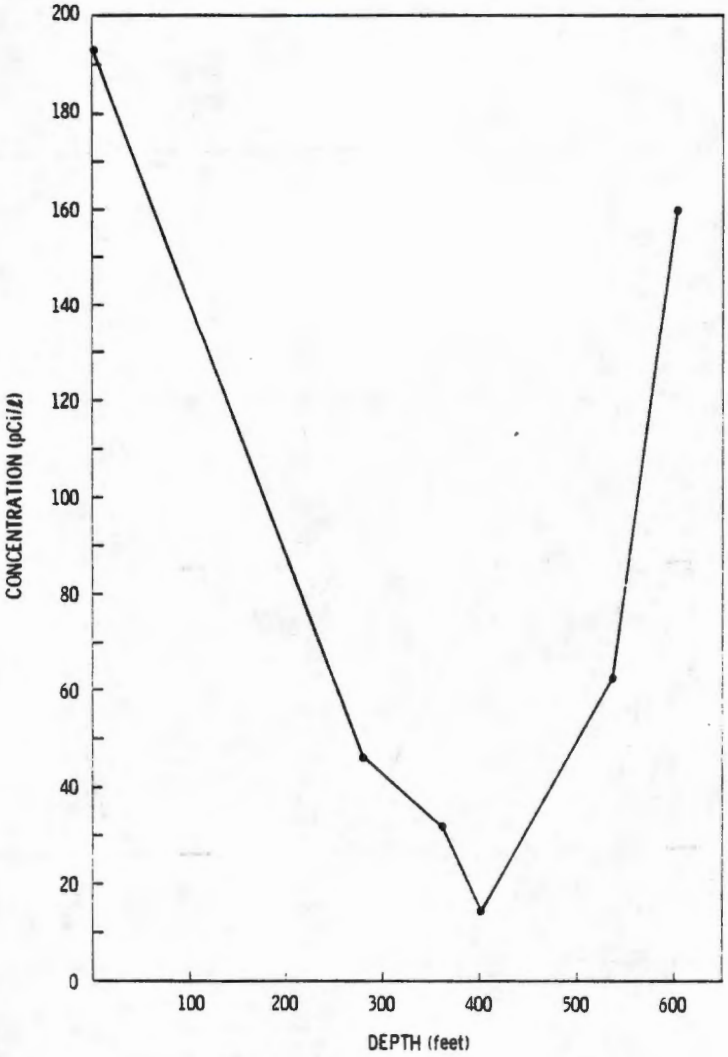

FIGURE A.1. Concentration of Total Beta in Well 699-31-31 in 1975

9 2 1 2 5 6 0 0 4 4 4

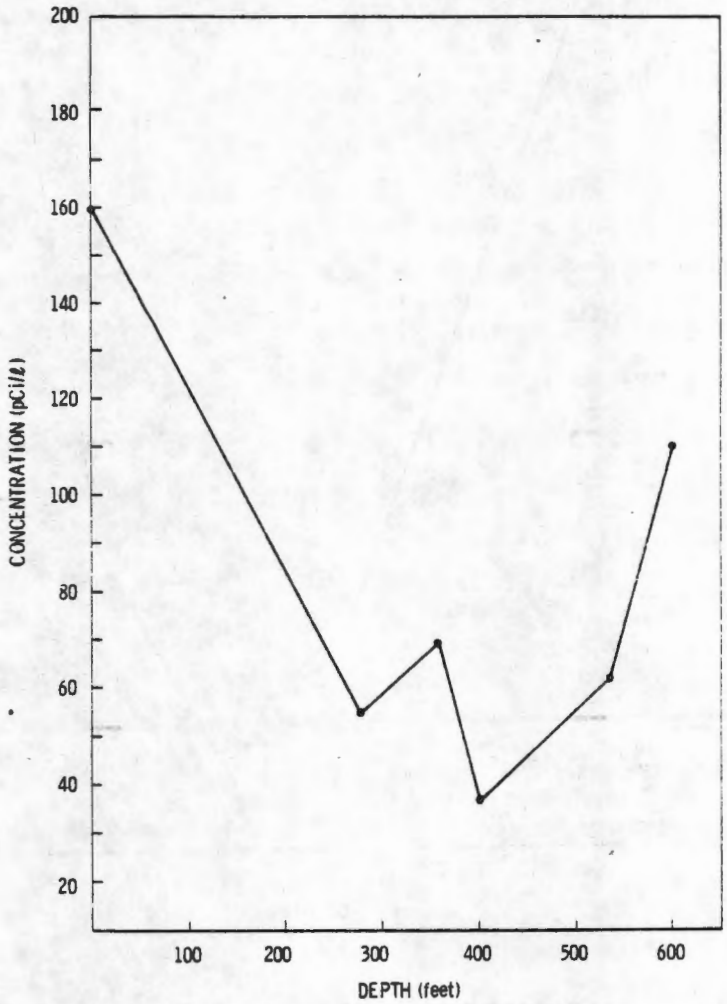

FIGURE A.2. Concentration of ^{60}Co in Well 699-31-31 in 1975

9 2 1 2 5 6 0 0 4 4 5

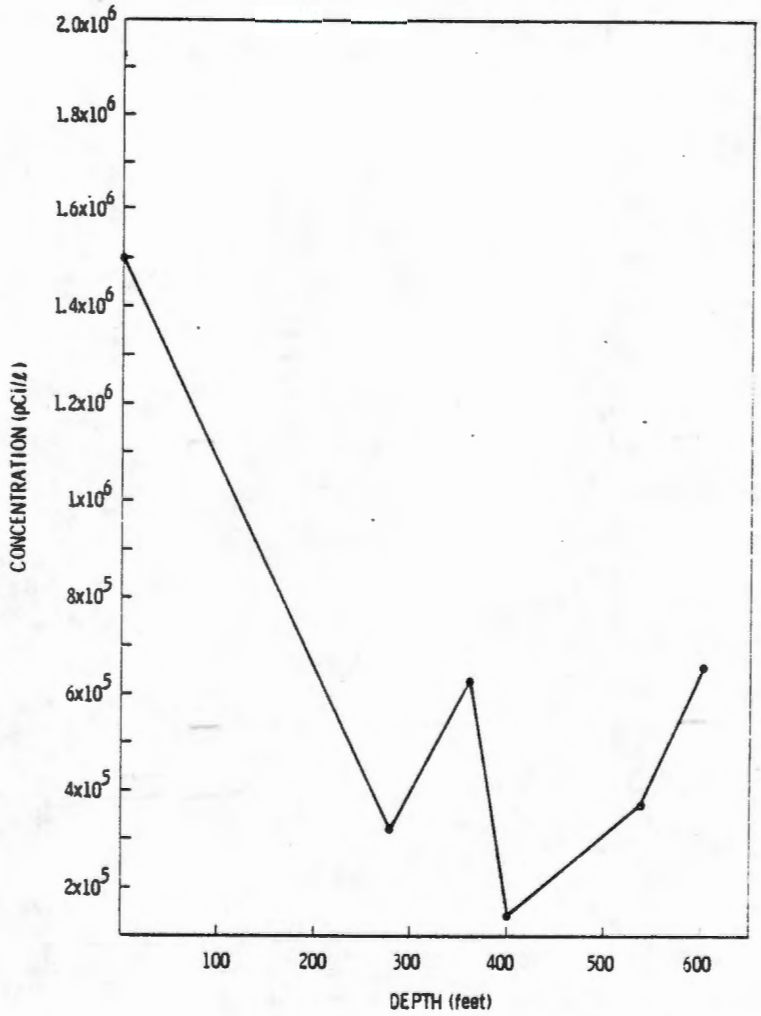

FIGURE A.3. Concentration of Tritium in Well 699-31-31 in 1975

9 2 1 2 5 6 0 0 4 4 6

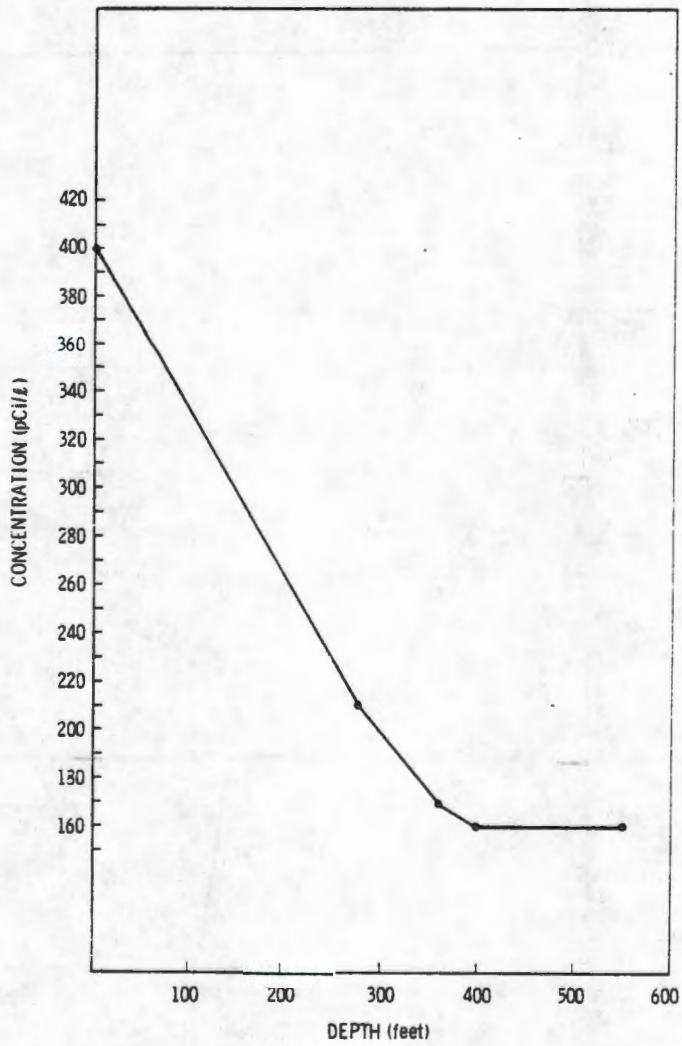

FIGURE A.4. Concentration of ^{106}Ru in Well 699-31-31 in 1975

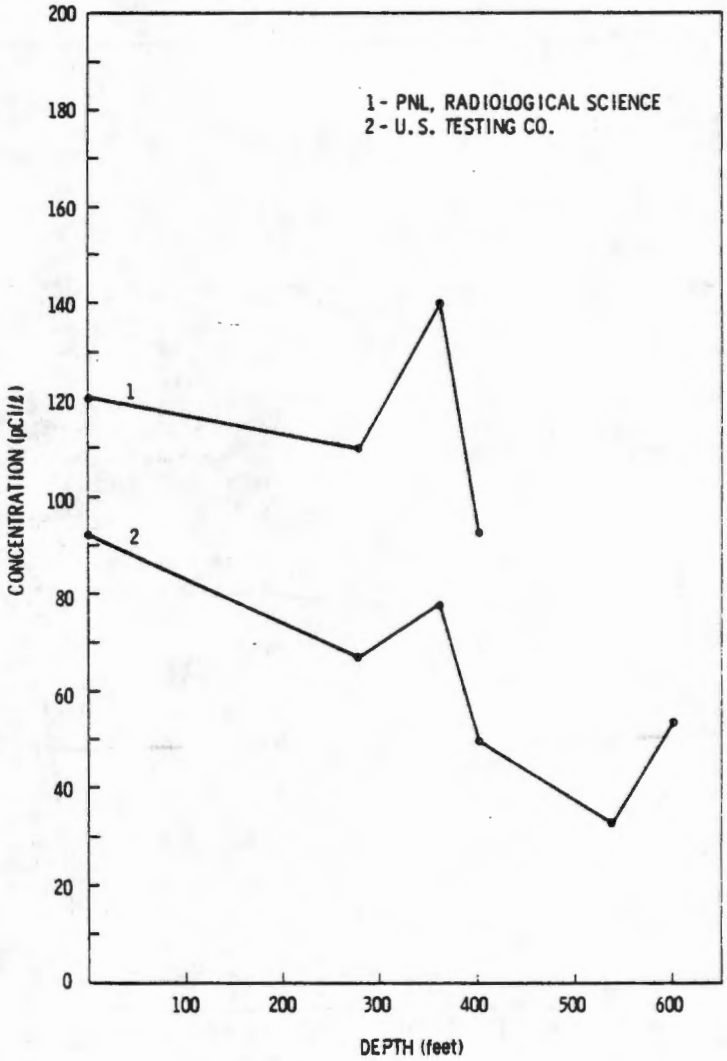

FIGURE A.5. Concentration of Total Beta in Well 699-31-31 in 1976

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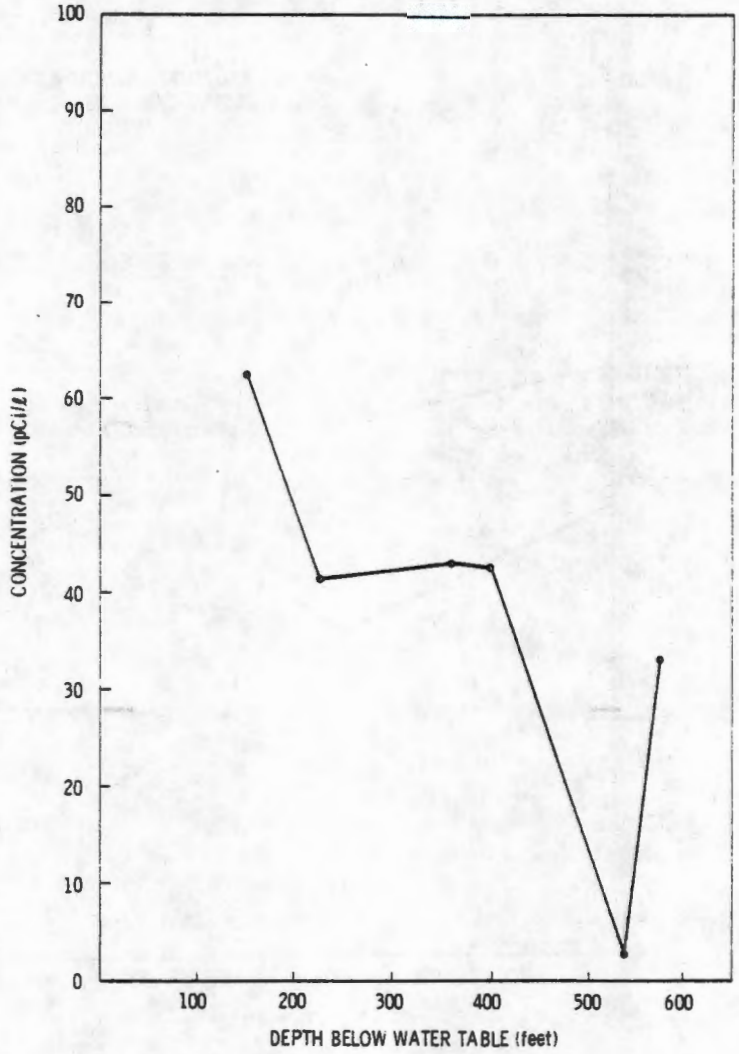

FIGURE A.6. Concentration of ^{60}CO in Well 699-31-31 in 1976

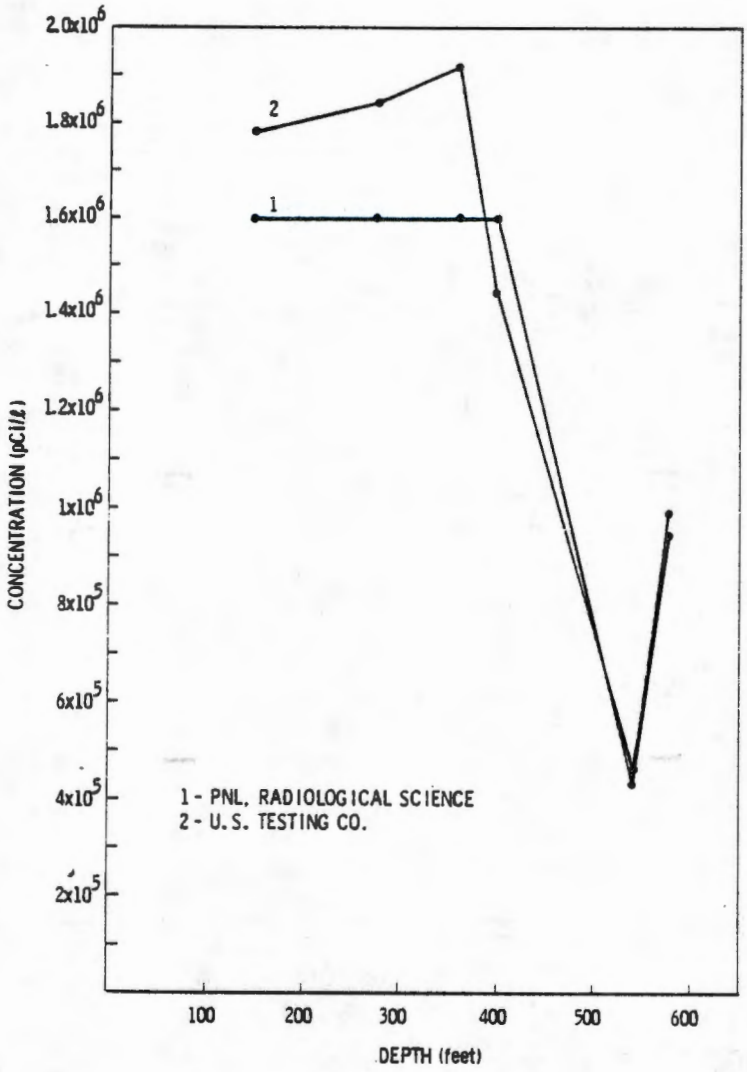

FIGURE A.7. Concentration of Tritium in Well 699-31-31 in 1976

9 2 1 2 5 6 0 0 4 4 9

9 2 1 2 5 6 0 0 4 5 0

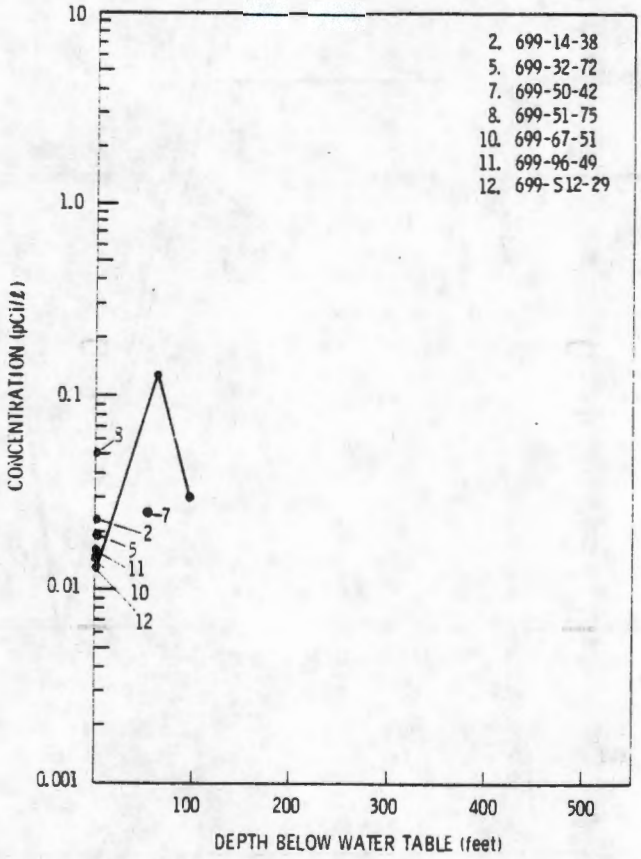

FIGURE A.8. Concentration of ^{137}Cs in Selected Wells in 1977

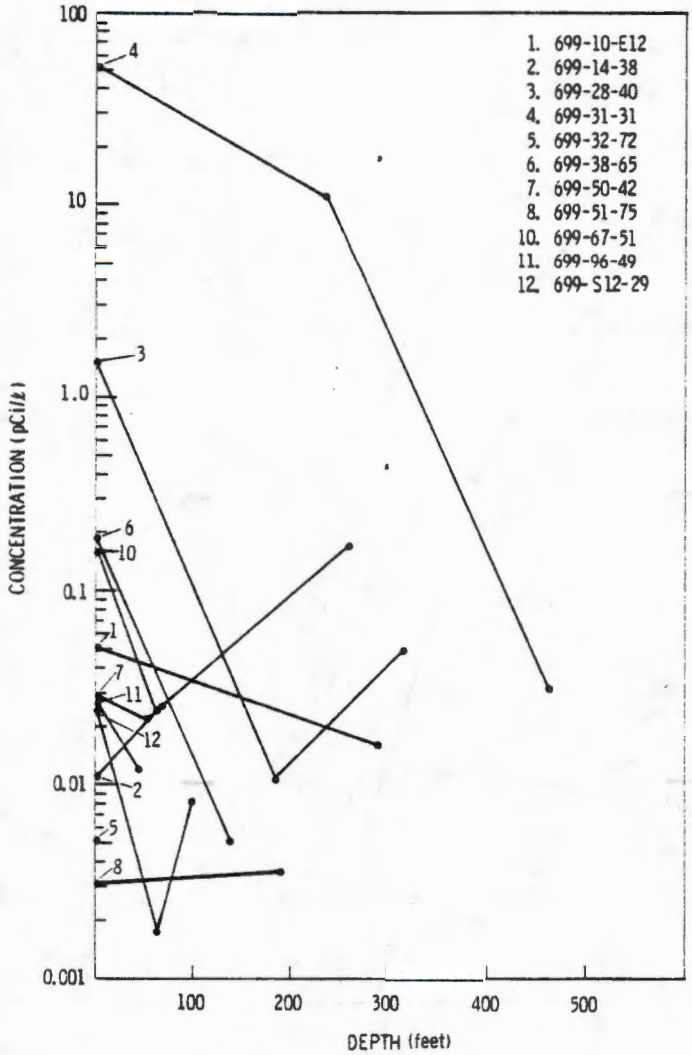

FIGURE A.9. Concentrations of ^{60}Co in Selected Wells in 1977

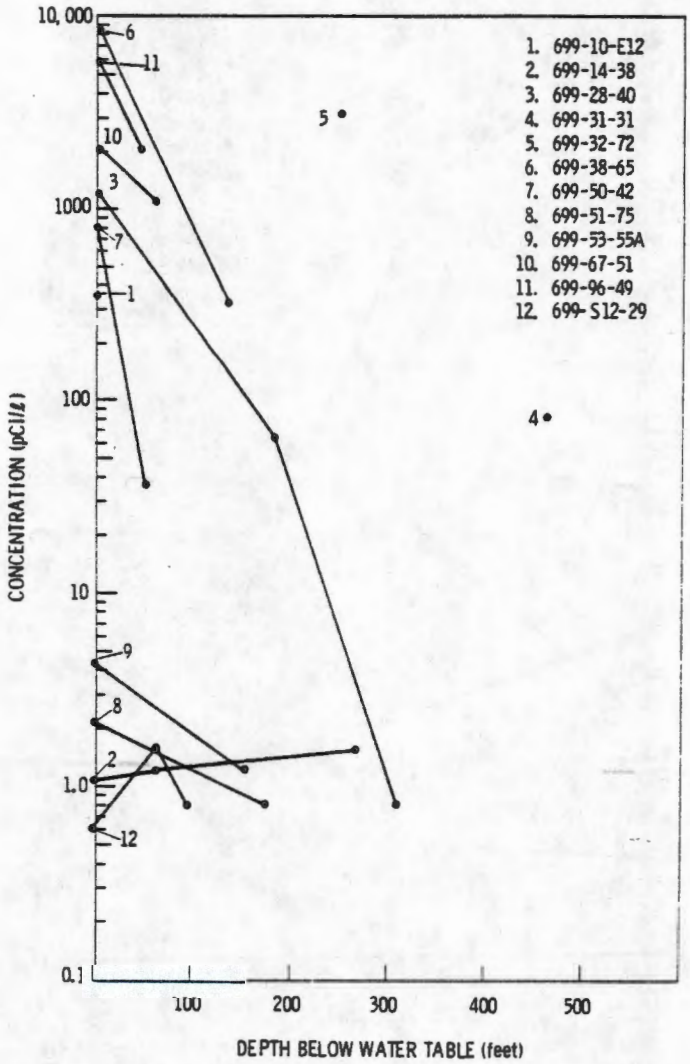

FIGURE A.10. Concentration of Tritium in Selected Wells in 1977

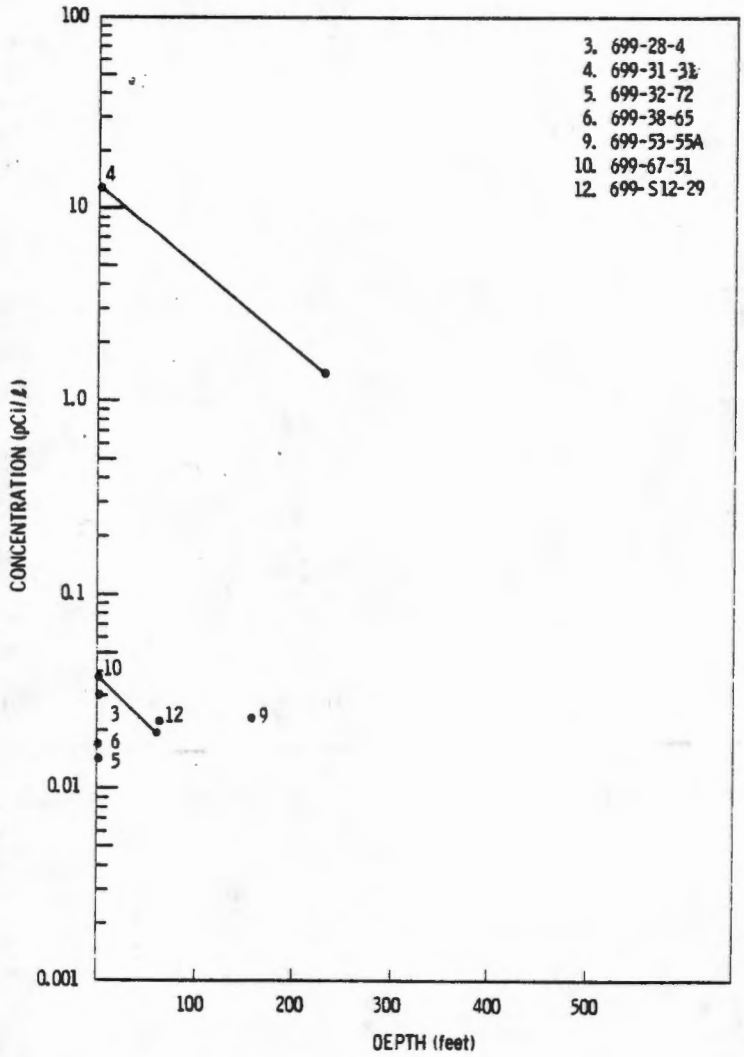

FIGURE A.11. Concentration of ^{106}Ru in Selected Wells in 1977

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