ATTACHMENT 1

A Case Study: Pilot Testing of Uranium In Situ Leaching at the Smith Ranch Project

A CASE STUDY:

PILOT TESTING OF URANIUM IN SITU LEACHING AT THE SMITH RANCH PROJECT

by

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Abstract

During the last twenty years, In Situ Leaching (ISL) of uranium emerged as an economically attractive and environmentally preferred means for extracting uranium ores in the United States. Successful application of the technology requires extensive knowledge of the stratigraphic, geochemical, and geological nature of the particular uranium deposit. An integral and key component of such studies is often the design and operation of a modest sized field test of the ISL process. Historically such tests were a prerequisite for issuance of commercial licenses and permits by state and federal regulatory agencies.

During the 1980s, two successful pilot scale wellfields were operated at Rio Algom's Smith Ranch Project near Casper, Wyoming. More than 131 tonnes uranium as U_30_8 were produced during these tests without violation of stringently enforced environmental rules. The first of these wellfields was successfully reclaimed and the associated ground water restored to approved conditions. The second is presently being maintained on standby awaiting commercial production from adjacent areas. Post-operational coring of the ore zones in both wellfields confirmed the effectiveness of ISL. The project is now licensed for commercial ISL operations and pre-construction activities for a 907 tonnes U_30_8/yr operation are nearing completion.

The design, operation, and restoration/reclamation of these pilot tests will be described as a case study.

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1. INTRODUCTION

The Smith Ranch uranium properties of Rio Algom Mining Corp. (RAMC) are in the final development stage leading to commercial production via In Situ Leaching (ISL). With proven reserves exceeding 16 350 tonnes (36 million lbs.) U_30_8, Smith Ranch is among the largest uranium projects in the United States and will operate at a rate of 907 tonnes (two million pounds) U_30_8 per year. Potential reserves will add significantly more proven reserves, and a commercial project life exceeding twenty years is likely.

Originally conceived as an underground mine, plans for Smith Ranch were reconsidered in the late 1970s as dramatic changes in the uranium market were occurring. Laboratory studies promptly demonstrated the amenability of the ore to alkaline ISL lixiviates. Following confirming studies, an extensive field testing program was initiated in 1981 and continued until 1991. Not only did these tests clearly demonstrate the excellent compatibility of the ore with the ISL system but provided an opportunity to test numerous variations in the process flow sheet and to demonstrate the post-mining restoration of native ground waters within the ore body to acceptable quality .

This paper is a discussion of this field testing program which consisted of two separate and distinct pilot ISL operations. Given the duration and scope of this program, it is not possible to cover every aspect of the work. The focus will be narrowed to the wellfield performance during both the production and ground water restoration phases.

2. REGIONAL GEOLOGICAL SETTING

2.1. Location

The Smith Ranch Project is located in the southern portion of the Powder River Basin near Douglas, Wyoming, in the western United States (Figure 1).

The Powder River Basin is a structural basin open to the north, bounded on the south by the Laramie Range and Hartville uplift, on the east by the Black Hills, and on the west by the Big Horn Mountains and the Casper Arch. The Basin includes an area of approximately 3 100 hectares (12 000 square miles) (Figure 2).

The Smith Ranch Project encompasses 22 027 hectares (54 068 acres) of which 6 600 hectares (16 200 acres) are licensed for commercial ISL operations (Figure 3). Adjoining the project at its eastern boundary is the Highland ISL Uranium Project. Developed and originally operated by Everest Minerals Corporation, this ISL uranium project has continuously operated at a rate of 454 tonnes (one million pounds) $U_3 0_8$ per year since January, 1988.

2.2. Topography

The present day topography of the Powder River Basin is the result of uplift in Pleistocene time when rejuvenated streams began down-cutting and excavating thick sequences of Oligocene, Miocene and Pliocene age sediments. The topography of the permit area is characterized by gently rolling upland areas, broad stream valleys, steep sided draws and rounded ridge crests.

2.3. Regional Geology

All of the important uranium deposits in the Powder River Basin are in Tertiary strata, that is, Paleocene Fort Union formation and Eocene Wasatch formation (Figure 4 and Figure 5). At the end of Cretaceous time, structural uplifts developed and continental deposition began during Paleocene time. Most of the basal Paleocene Fort Union formation rocks were derived from erosion of Cretaceous shales and sandstones and hence are mostly fine-grained clastics. By late Paleocene time erosion had cut into the crystalline core of ancestral Laramie Mountains and intermittent loads of arkosic sediments poured into the southern end of the present Powder River Basin.

FIGURE 1

LOCATION MAP

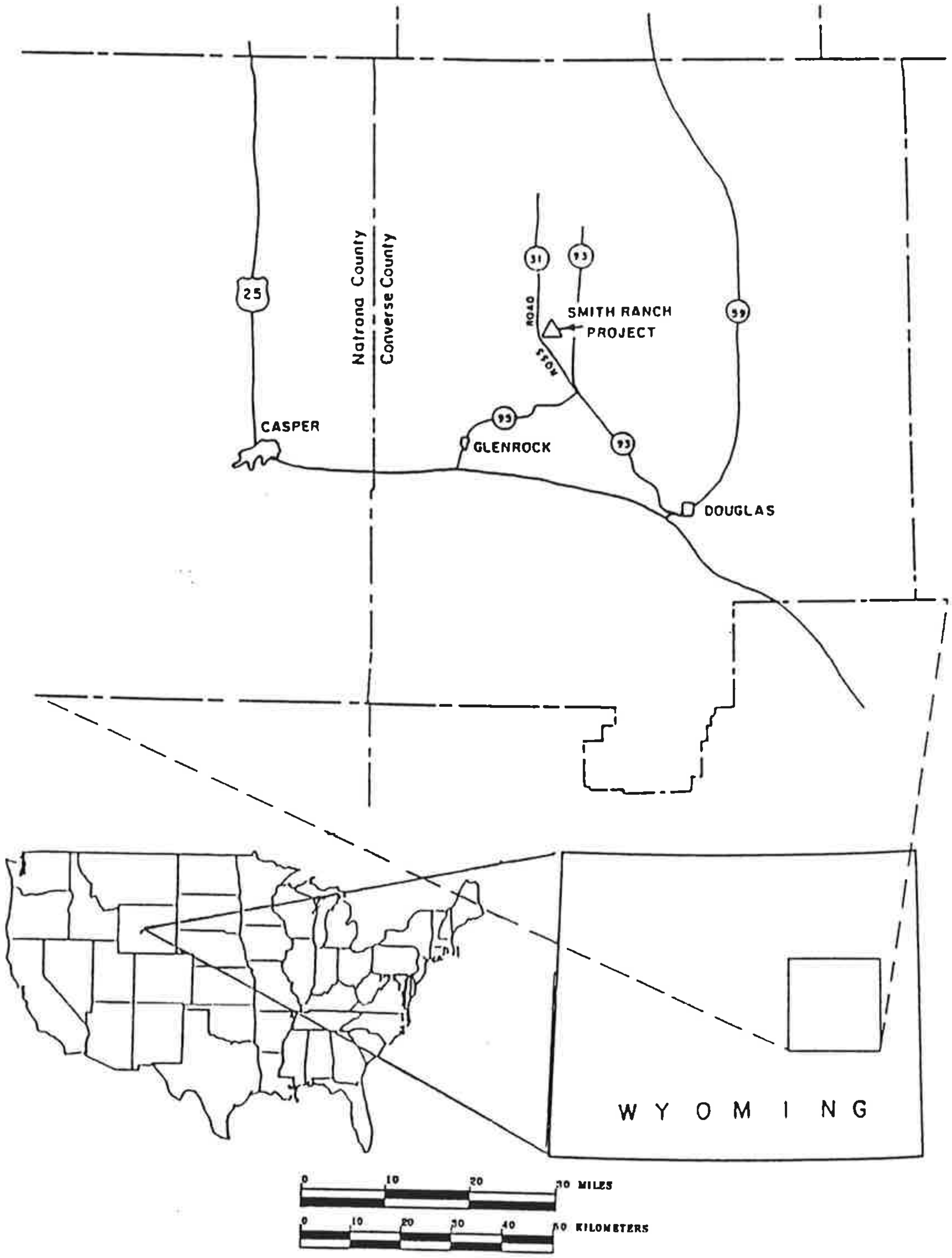


FIGURE 2

PHYSIOGRAPHY IN THE POWDER RIVER BASIN

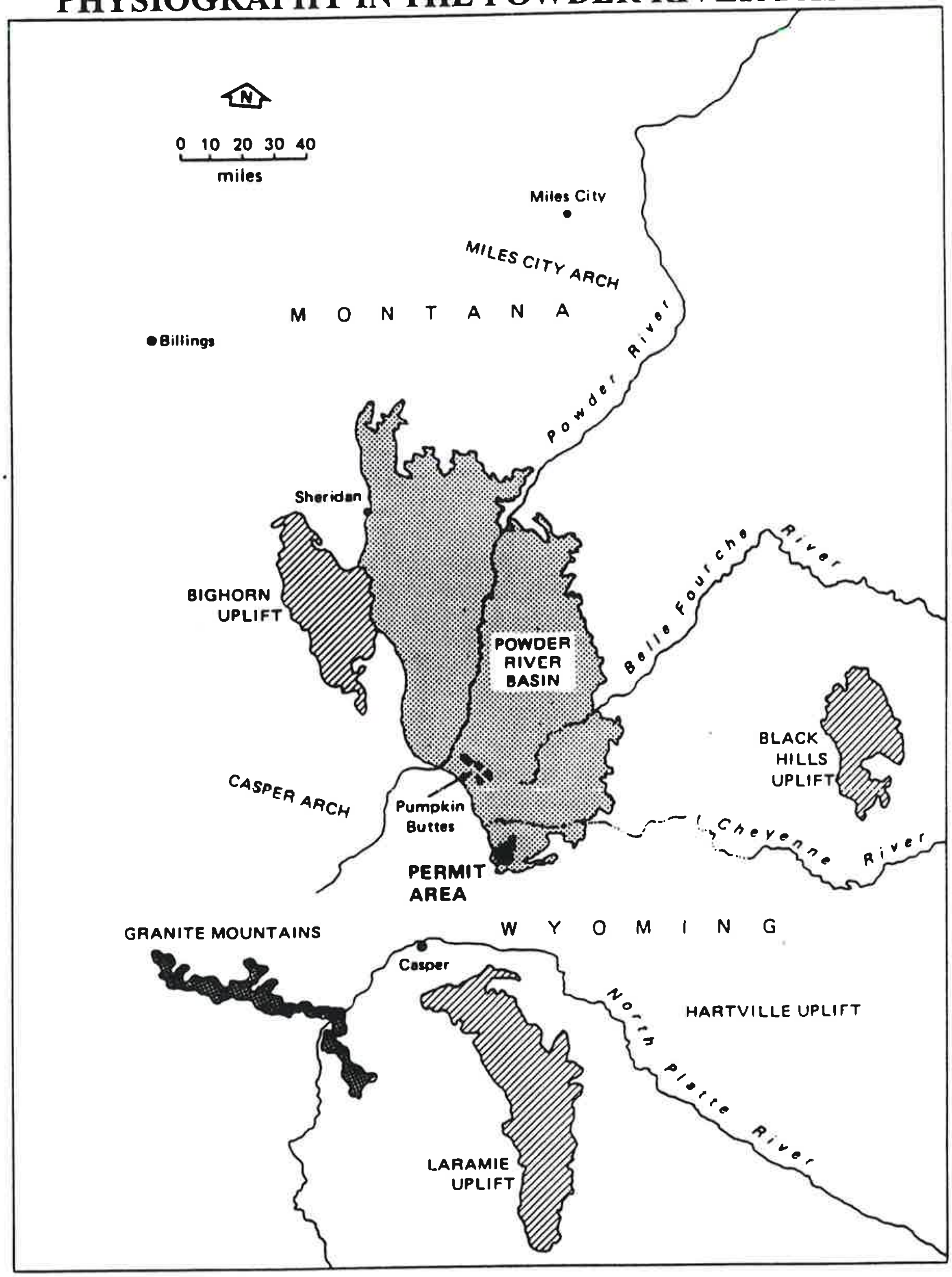
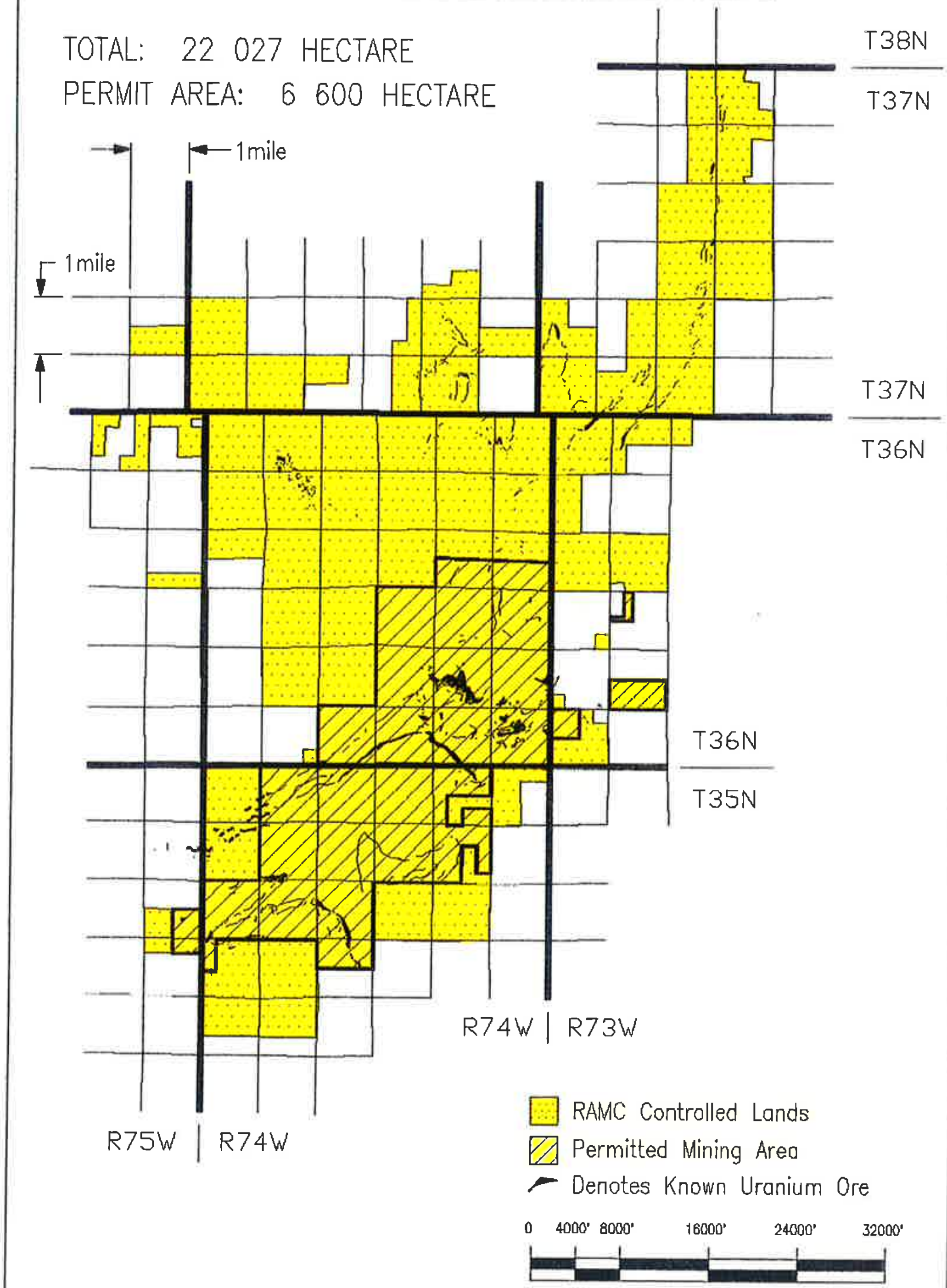
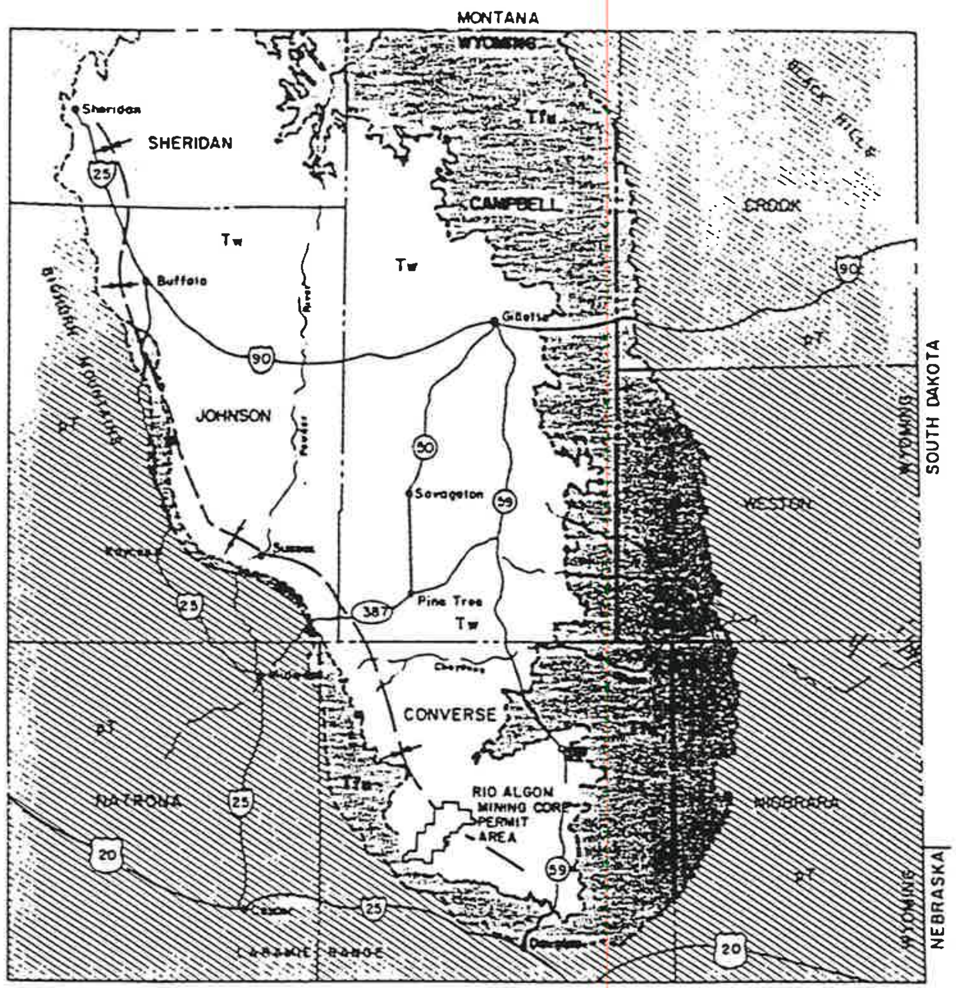


FIGURE 3

SMITH RANCH LAND HOLDINGS





LEGEND

Tw	WASATCH FORMATION: IRREGULARLY STRATIFIED CLAYSTONES, SILTSTONES, AND SANDSTONES, WITH MINOR THIN LIMESTONES AND COALS.
Tfu	FORT UNION FORMATION: INTERBEDDED CLAYSTONES, SILTSTONES, AND SANDSTONES WITH THICK COAL BEDS.
pT	PRE-TERTIARY ROCKS (UNDIVIDED)
	GEOLOGIC CONTACT, APPROXIMATELY LOCATED
	SYNCLINAL AXIS, POWDER RIVER BASIN (LOCATED ON SURFACE OF PRECAMBRIAN BASEMENT COMPLEX)
	FAULTS, APPROXIMATELY LOCATED

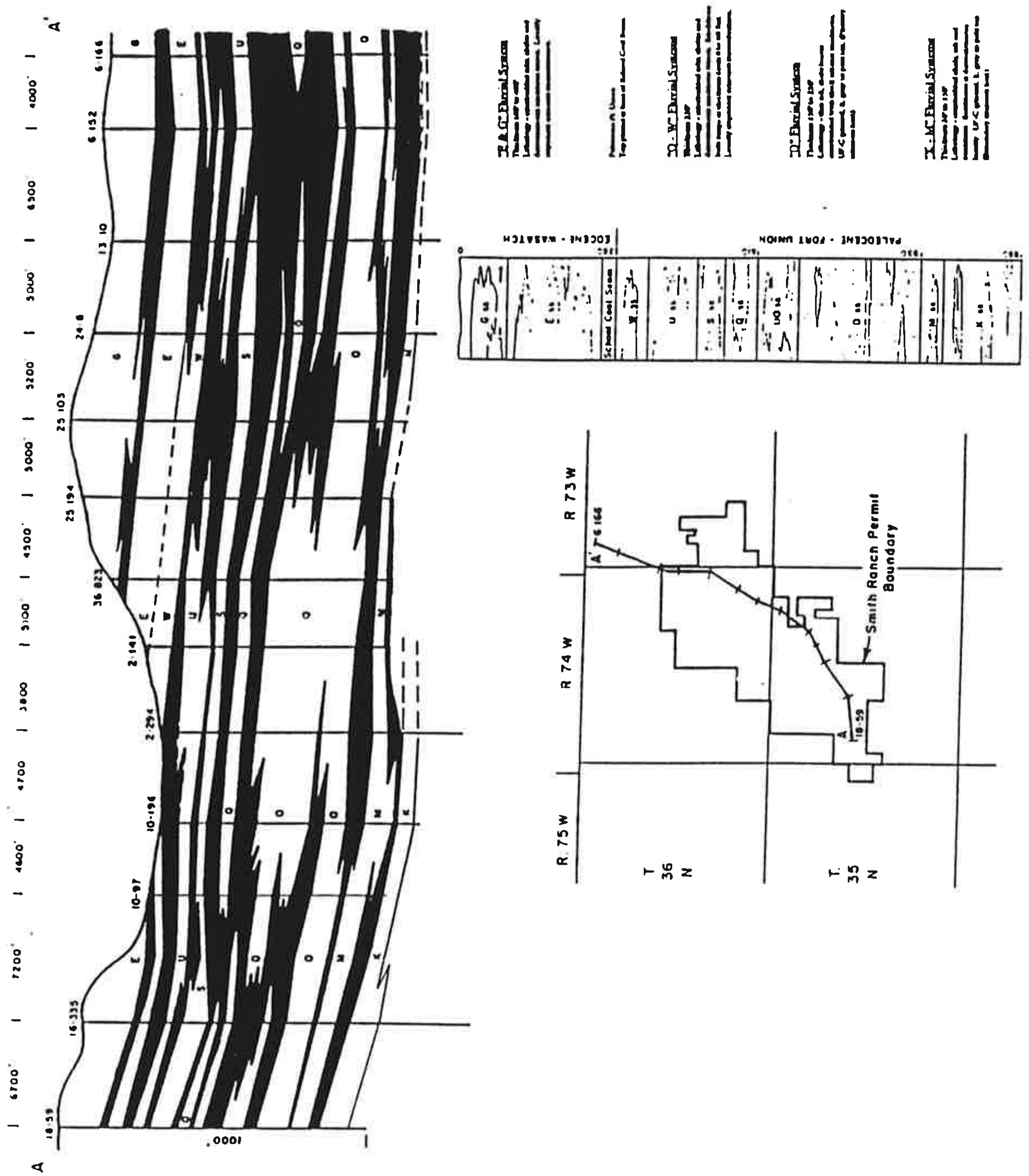
(MODIFIED FROM SHARP AND GIBBONS, 1964; SHARP ET AL., 1964)

FIGURE 4

GENERALIZED GEOLOGIC MAP OF POWDER RIVER BASIN POST-TERTIARY FORMATIONS

FIGURE 5

GEOLOGIC SECTION



In late Paleocene to early Eocene time the Powder River Basin underwent further subsidence with corresponding uplift of the surrounding mountain blocks. Deposition during this period was primarily by large, meandering streams with associated coal swamps.

In early Eocene time large amounts of coarse clastics eroded from the highlands forming large fans and braided stream deposits. Deposition of the Wasatch formation in the Powder River Basin was cyclic with periods of quiescence allowing coal swamps formation followed by periods of uplift and rejuvenation of the coarse clastic cycle. Sedimentary studies show the Granite Mountains to be the main source of clastic material with minor clastics provided from the ancestral Laramie Mountains and Hartville uplift.

Following deposition of the Wasatch formation, minor subsidence of the Powder River Basin resulted in a northerly regional dip of about 1½ degrees in the Eocene and earlier rocks. Degradation of the area continued from middle to late Eocene with the development of a mature topography which later was buried by Oligocene deposits.

During the Oligocene, Miocene and Pliocene times large deposits of sandstones and tuffaceous sediments collected in the Powder River Basin. Vulcanism was incessant during this period with streams choked by volcanic ash. A major regional uplift took place near the close of Pliocene time and rejuvenated streams began erosion and down-cutting of the existing sediments. This erosion continued and brought about the present topography.

2.4. Local Geology

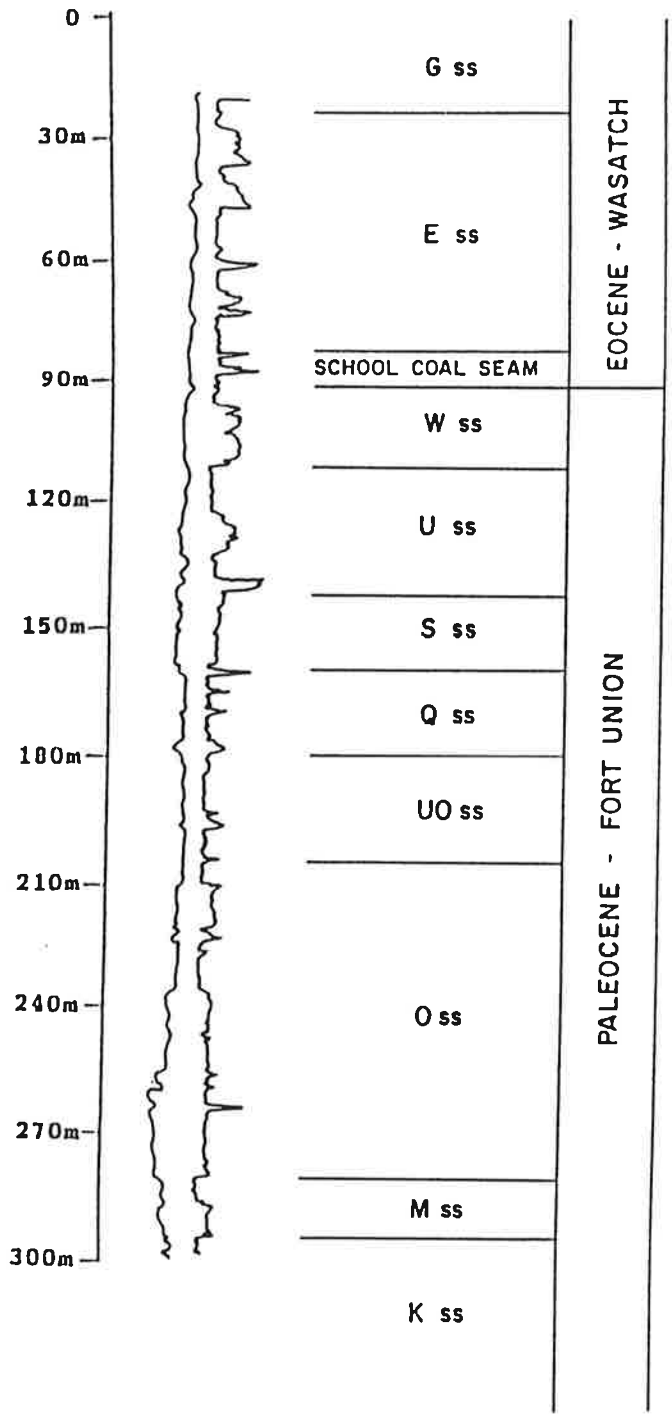
Within the permit boundary the host sandstones for uranium mineralization are the arkosic sandstone units of the upper Paleocene Fort Union formation and lower sandstone units of the Eocene Wasatch formation. The Wasatch formation is the youngest bedrock unit throughout the permit area. Thickness ranges from 61 to 91 meters (200 to 300 feet) in the northern and southern portions of the permit area to 152 meters (500 feet) in the central area. The Fort Union formation is over 305 meters (1 000 feet) thick. However, only the upper 183 to 213 meters (600 to 700 feet) contains the arkosic sandstone units with associated uranium mineralization.

RAMC has named the major sandstone and shale units within permit area. Sandstone units from youngest to oldest are G, E, W, U, S, Q, UO, O, M and K. The reference for contact between the Fort Union and Wasatch formations is the base of the School Coal seam or the correlatable lignite zone present throughout permit area (Figure 6).

Resources for the permit area are primarily in the Paleocene Fort Union formation. The O, M, and K sandstone units account for the bulk of resources while Q, S, and U sandstone units locally contain significant leachable reserves. The E sandstone of the Eocene Wasatch formation contains lesser resources. Thickness of these sandstone units ranges from 3 to 60 meters (10 to over 200 feet) with the O sandstone the thickest and most persistent.

FIGURE 6

RAMC SANDSTONE ZONING
SOUTH POWDER RIVER BASIN



The ore occurs as typical Wyoming roll fronts, tightly crenulating and C shaped in cross section. Typically a favorable disequilibrium ratio is encountered with a chemical/radiogenic uranium ratio of 1.1 or more. The sandstone units, depending upon thickness, inter-bedded shales, and high lime zones, can contain 1 to 20 mineral fronts with the O sandstone unit being the most complex.

3. THE FIELD TESTS

Two ISL field tests were conducted at Smith Ranch. Both used mild alkaline lixiviate systems and uranium recovery via ion (anionic) exchange resins. Test objectives were (1) to obtain hydro-metallurgical information for economic analysis of ISL and (2) to satisfy Wyoming Department of Environmental Quality (WDEQ) requirements for commercial licensing. The WDEQ requires a field test as a condition for issuance of a commercial ISL mining license. Until recently, this test had to be performed at the proposed commercial site to demonstrate environmentally acceptable operating methods, post-mining ground water quality restoration, and surface reclamation.

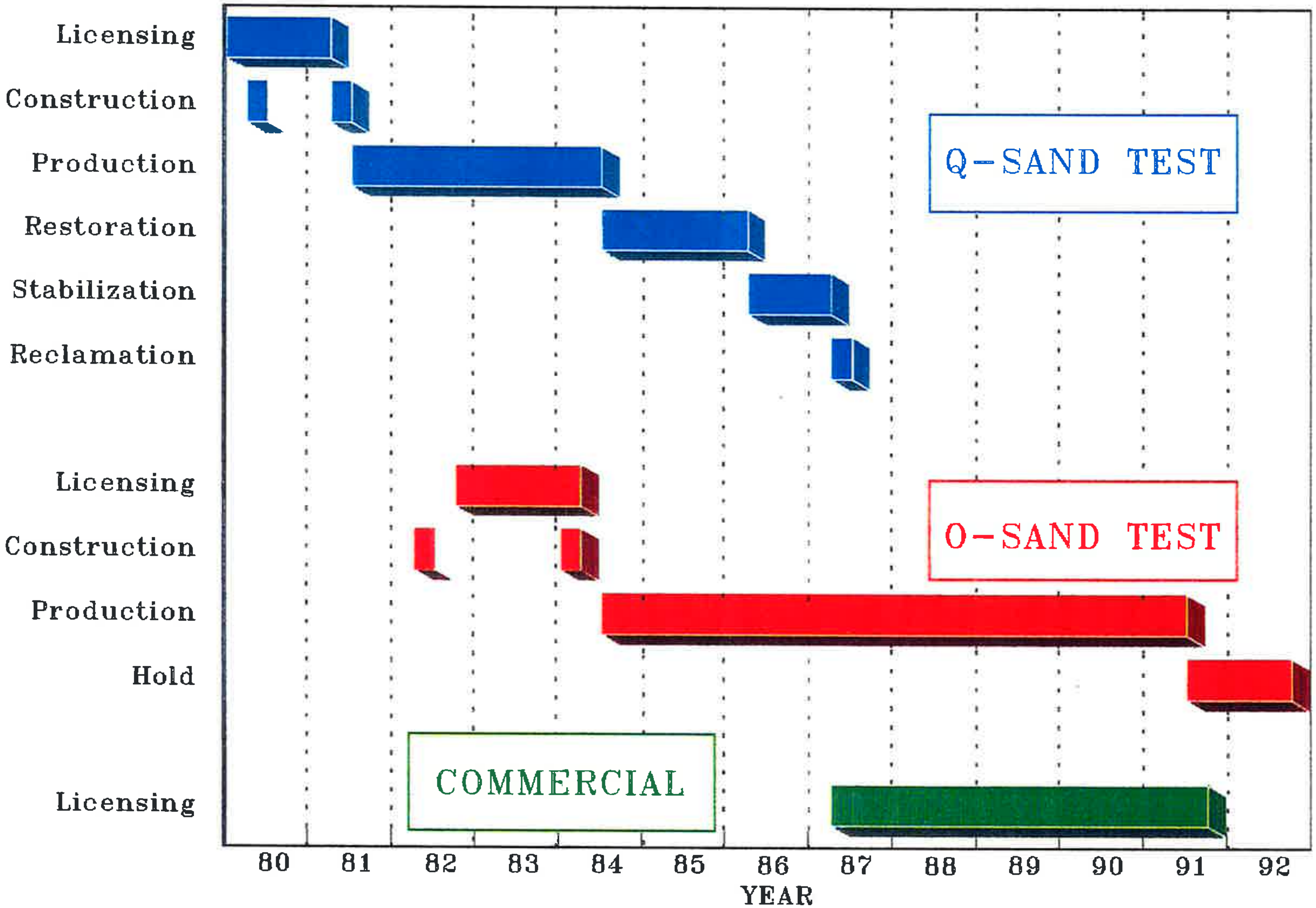
Both tests employed sodium bicarbonate and carbon dioxide lixiviate combined with oxygen as the oxidant. Hydrogen peroxide was briefly tested as the oxidant. The chemical selectivity of alkaline carbonate systems for uranium solubilization, coupled with an attractive environmental compatibility, had clearly emerged as the chemistry of choice. Most uranium bearing aquifers in New Mexico, Texas, and Wyoming are of potable water quality and suitable for use as human drinking water or, at the minimum, for use by livestock (cattle, hogs, sheep). Some early test work which considered introduction of sulfuric acid into such high quality ground waters was highly controversial. To gain regulatory and public approval for pilot scale use of this or any acid in such ground waters would have been difficult in the late 1970s. Today, such approval is unlikely in the United States.

Fortunately, the geochemical and chemical characteristics of the uranium roll front deposits were such that excellent productivity was achieved with alkaline lixiviates. An added benefit of this chemistry was the modest disturbance of the natural geochemical and ground water environment. The post-leaching restoration of ground waters proved much easier and less expensive with the alkaline lixiviate.

The Smith Ranch Project field tests were designed and operated to simulate closely commercial conditions. As shown in Figure 7, these efforts began in 1980 and continued for over a decade. The Q-Sand test operated from October, 1981 through November, 1984, with ground water restoration continuing until May, 1986. The WDEQ certified complete aquifer stability and ground water restoration for the Q-Sand in August, 1987. The O-Sand test began in August, 1984 and production continued into 1991 when the test was placed on hold, pending the start of commercial operations.

The concluding effort of this testing program was post operational core sampling within both wellfields to assess the leaching effectiveness. Each test is discussed in the following sections.

FIGURE 7
SMITH RANCH FIELD TESTS
CHRONOLOGY



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4. Q-SAND

Uranium mineralization in the area of the Q-Sand pilot patterns occurs in one to three discrete roll fronts (sub-rolls). These sub-rolls, Q-1 through Q-3 (ascending), are present depending upon the thickness of the sand in any given area and thus are stratigraphically controlled. In areas of little sand, such as the western edge of the pilot area, all the mineral is confined in one zone. Where the sand has scoured downward and the thickness is greater, separate sub-rolls develop. Many times they are indistinguishable. As in most roll front systems, the sub-rolls interweave within one another while generally following the "mega-roll front" system of which they are a part.

The pilot area is unique in that two separate "lobes" of the Q-Sand roll system coalesce in this area. A southern lobe rolls to the north while a western lobe moves north-northeast. This western lobe comes around a wedge out of the Q-Sand through a paleochannel and meets the southern lobe. Mineralization in this area is from both fronts and thus grades are quite rich.

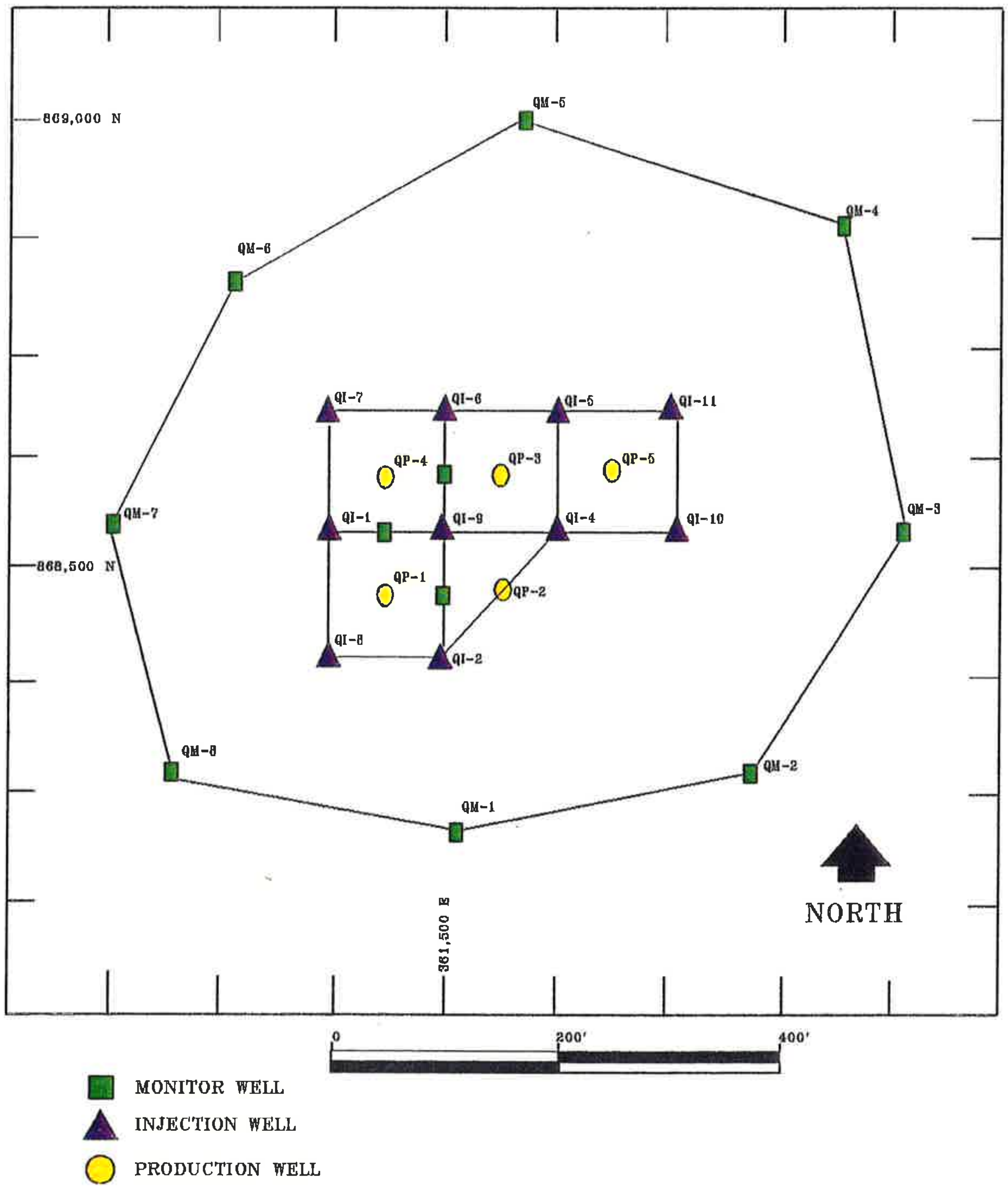
The Q-Sand wellfield was located in Section 36, T36N R74W and consisted of five production patterns. Eight ore zone monitor wells surrounded the wellfield. Within the wellfield additional monitor wells were completed in overlying and underlying aquifers.Four patterns were five-spots. The remaining pattern (QP-2) lacked one injector from being a full five-spot (Figure 8). Pattern spacing was nominally 30 meters (100 feet) between injectors. However, the well spacing ranged from 26 meters to 33 meters due to local topography and vertical drill hole deviations (Figure 9). Ore depth is 137 to 152 meters (450 to 500 feet).

All wells, including monitor wells were piped into a wellfield "header house" where all injection and recovery well flow meters, pressure indicators, and flow controls as well as sample ports and oxygen mixers were located. Each monitor well contained a submersible pump for sampling at the header house. Injection and recovery well pipelines were buried 1.5 meters below ground level to avoid freezing. Pregnant and barren lixiviate were pumped via buried pipeline (1.5 meters) between the header house and ion exchange facility.

Wells were completed open hole, i.e., no screen or perforated pipe was placed across the completion interval. The depth and size of this interval were determined from exploration and development drilling. A pilot hole was drilled to within one meter of the top of this interval, logged, then reamed, casing set and cemented in place. The hole was then deepened to one meter below the bottom of the completion interval. The hole was cleaned by air surging and back flowing.

When productivity or injectivity became unacceptable during operations, wells were cleaned with hydrochloric acid or simply brushed with a stiff bristle brush and back flowed. Poor injectivity was due to calcite scaling and deposition of fines on the well bore. Completion intervals remained open and were not subject to significant caving. Calcite scaling was reduced by using carbon dioxide instead of sodium bicarbonate for lixiviate makeup. Sodium exchanges with calcium clays and gradually builds up in the system causing

FIGURE 8
IN-SITU R&D PROJECT WELL PATTERN
Q-SAND DEPOSIT
SECTION 36 - T36N, R74W
CONVERSE COUNTY, WYOMING



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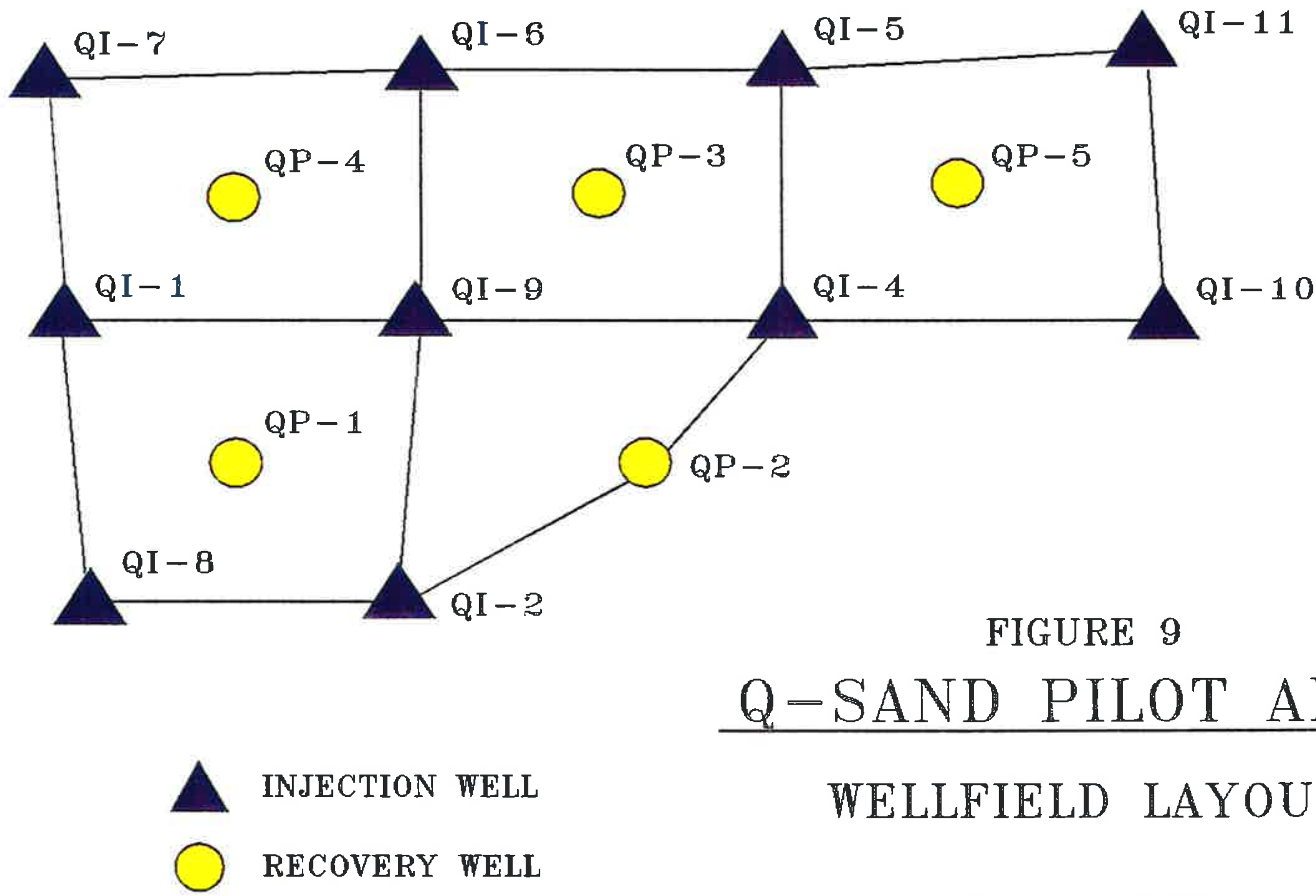

FIGURE 9

Q-SAND PILOT AREA

WELLFIELD LAYOUT

NOT TO SCALE

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precipitation of calcite in many locations. Carbon dioxide injection relies on cations already present in the system as counter ions.

Production of the Q-Sand pilot wellfield began in October, 1981. Within two weeks, fluid flow rates were stabilized among the five recovery and ten injection wells. Throughout the test, more water was recovered than was injected to maintain a localized depression in the natural hydrostatic pressure of the ore zone. This created a pressure gradient which caused surrounding native ground water to flow toward the wells. Water levels in the surrounding monitor wells were measured monthly to evaluate the shape of this cone of depression. The influx of native waters around the perimeter confines the lixiviate within the wellfield and, hence, within the uranium bearing sands. This simple system of overproducing the wellfield is a key to controlling the lixiviate movement within the ore body and to protecting the surrounding waters from unwarranted and unnecessary perturbation.

License conditions for the test limited total injection to a maximum of 6.3 L/S (100 gpm). As shown in Figure 10, fluid injection averaged about 5.8 L/S (92 gpm) until the latter stages of the production phase in 1984. Fluid recovery during the same period averaged about 6.2 L/S (98 gpm) with net purge of near six (6) percent.

Uranium response to the alkaline lixiviate was prompt (Figure 11). In less than one month, the uranium concentration of the produced fluid reached a maximum of near 200 mg U_30_8/L before onset of the characteristic log-normal decline. By late 1983, the uranium concentration had decreased to 20 mg U_30_8/L, a concentration at which most commercial operations would cease. At this point, the cumulative average uranium concentration was 90 mg U_30_8/L. This average is applicable to commercial design.

A second useful comparison is the normalized volume of fluid pumped to recover the economic uranium concentrations. We describe this fluid volume as the number of reservoir pore volumes. The reservoir pore volume is defined as the area inside the perimeter injection wells times the average height of the completion intervals times the formation porosity times a horizontal and vertical sweep efficiency. Using a vertical sweep efficiency of 100% and a horizontal sweep efficiency of 110%, the reservoir pore volume for this test is 11.7 x 10^6 liters (3.1 x 10^6 gallons). As shown in Figure 12, 36 pore volumes of fluid were produced when the uranium concentration diminished to 20 mg/L.

The somewhat erratic nature of the uranium concentration profile is normal with the small variations resulting from flow distribution changes within the wellfield as individual injection wells were fouled with calcite scale, cleaned, and returned to normal operating conditions. The upturn in production in mid-1983 (27 pore volumes) and in January, 1984 (40 pore volumes) was a direct result of rearranging the operating wells. As shown in Figure 13, several injection wells were converted to recovery wells (Phase 2) in mid-1983 followed by a second conversion (Phase 3) in January, 1984. These changes altered the predominant fluid flow paths within the wellfield and expedited recovery of the uranium. The advantage is that more uranium was recovered at higher concentrations and, hence, at lower

FIGURE 10
Q-SAND FLOW RATES

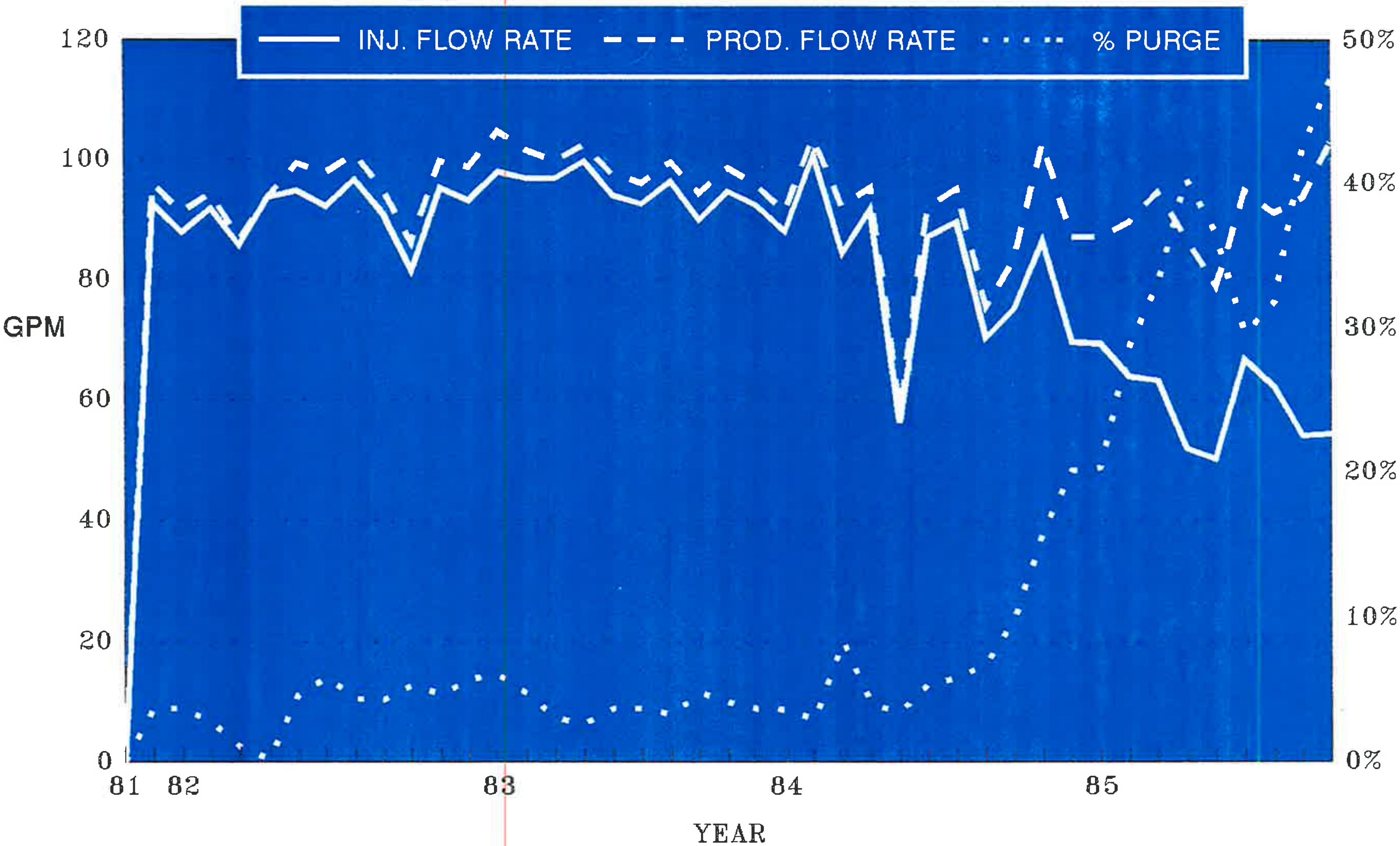

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FIGURE 11
Q-SAND PRODUCTION HISTORY

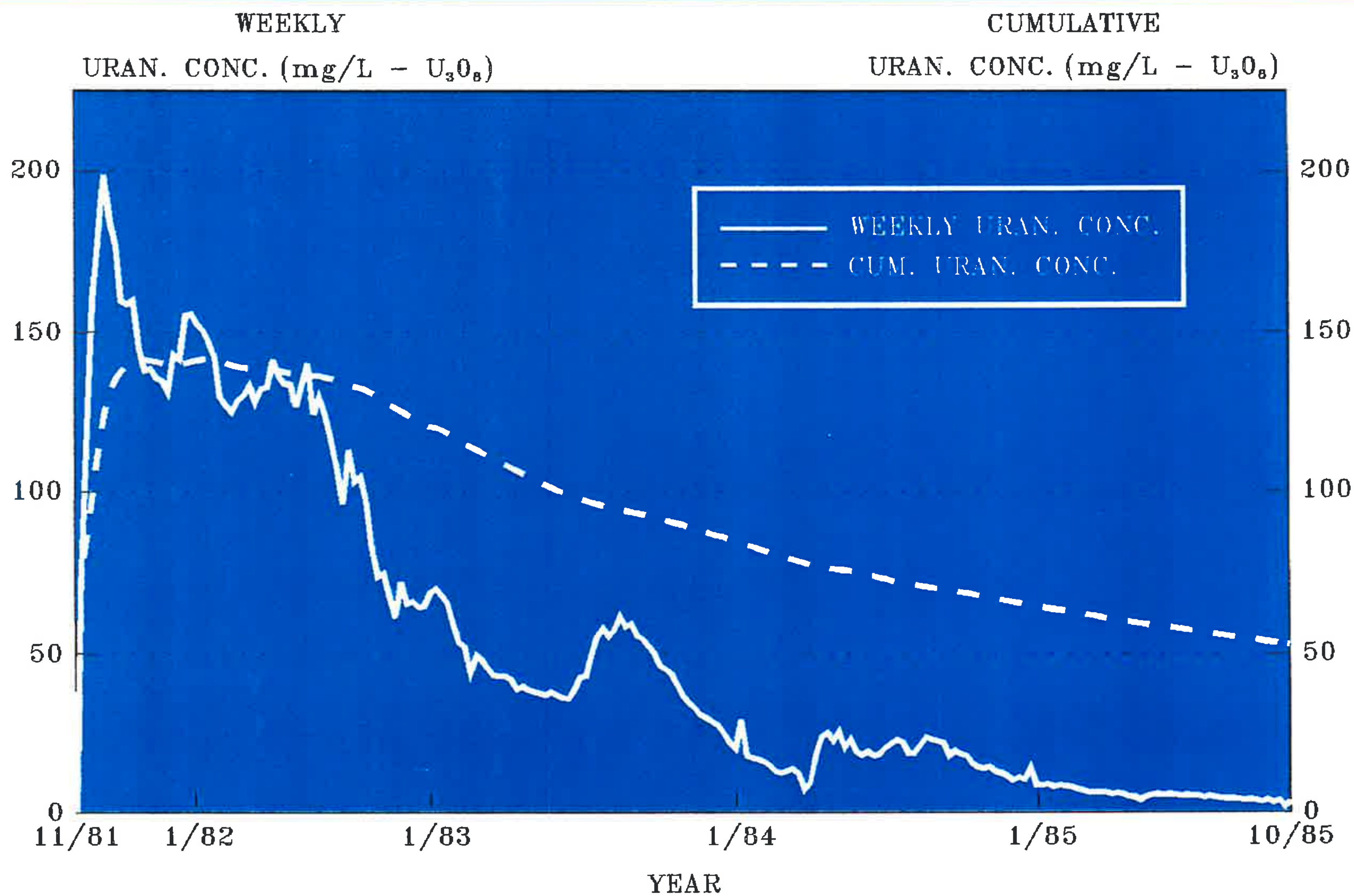

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FIGURE 12
Q–SAND PRODUCTION HISTORY

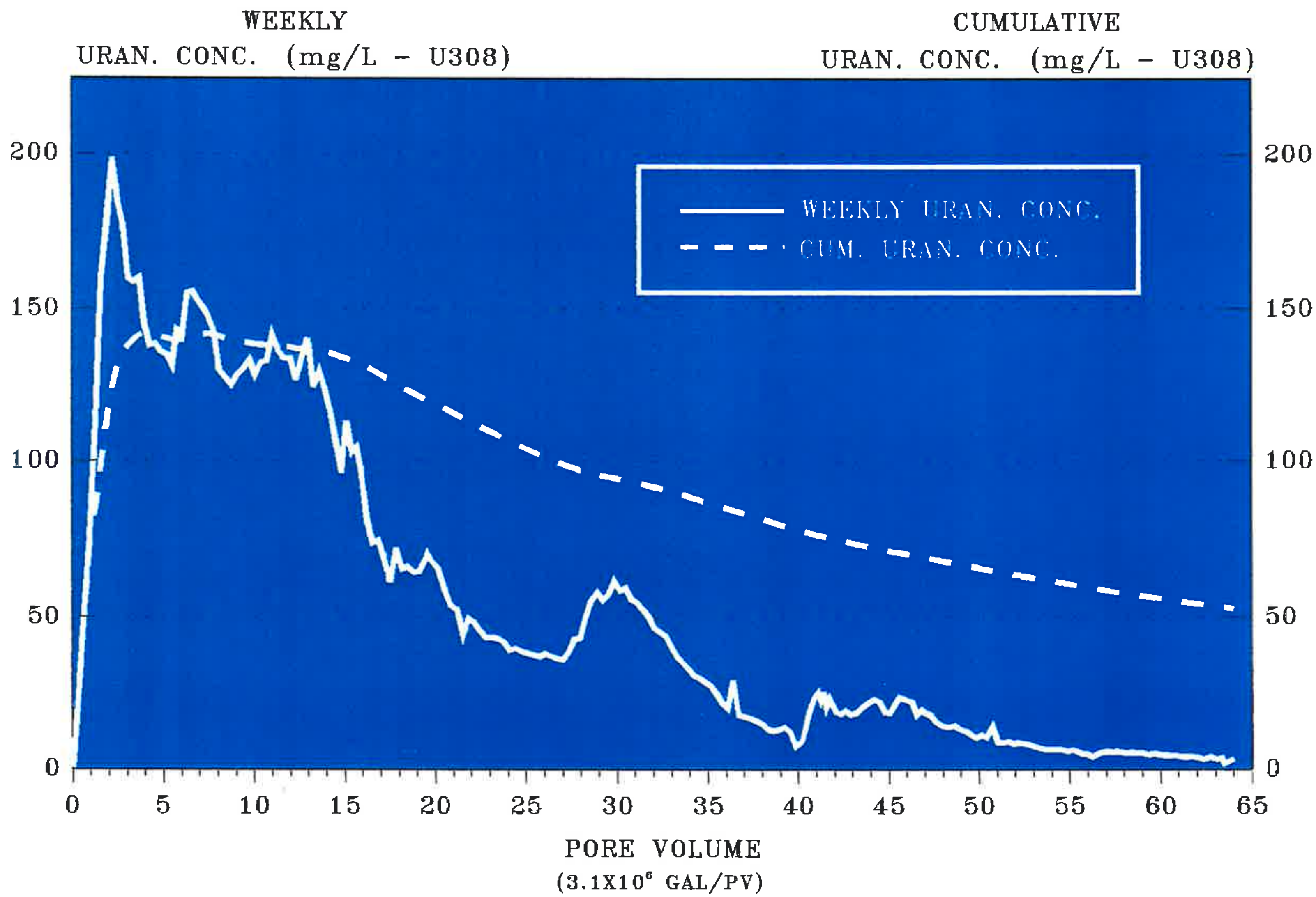

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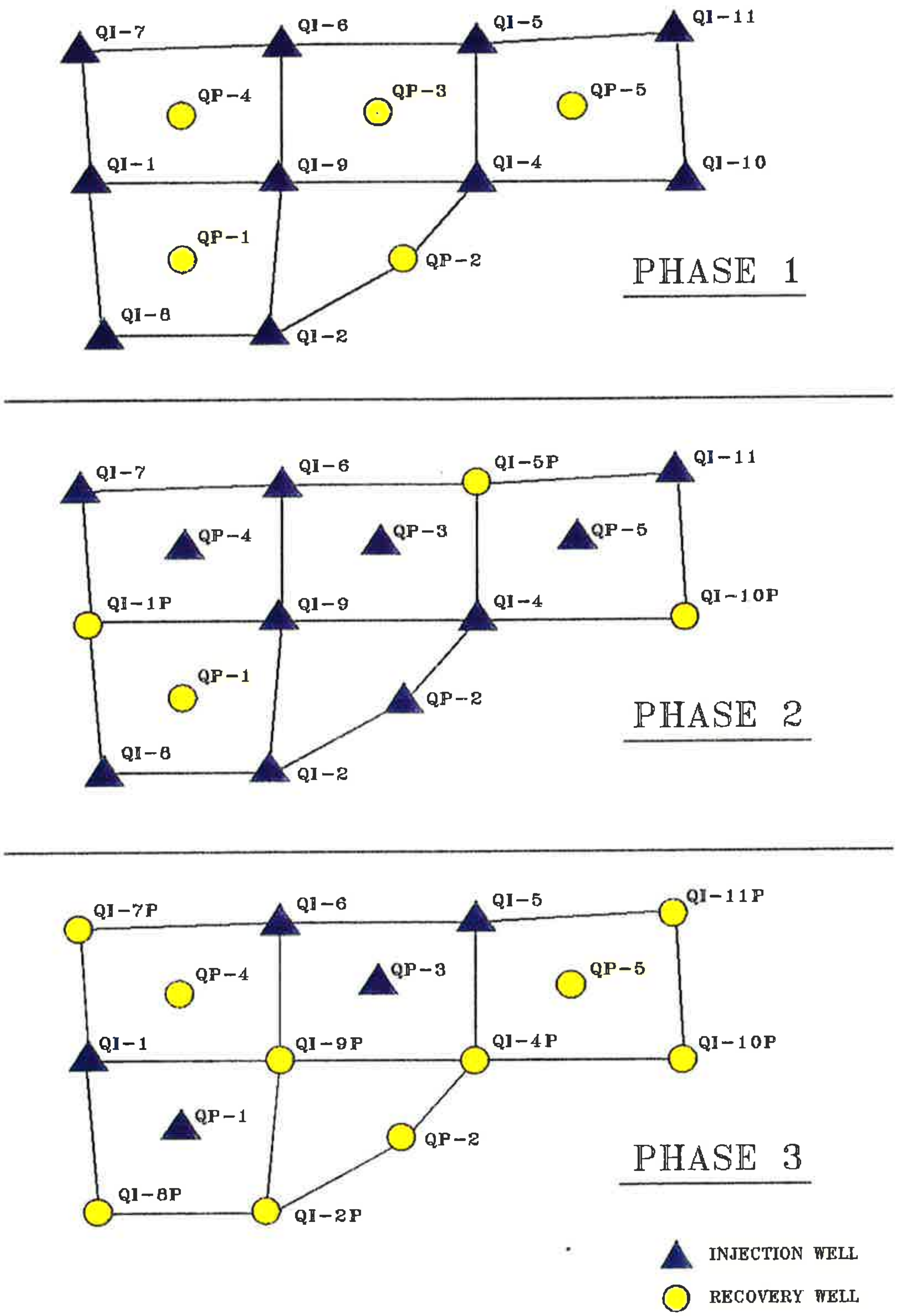
FIGURE 13
Q-SAND PILOT AREA PRODUCTION SEQUENCE



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cost. The uranium productivity of all recovery wells throughout the test is shown in Figure 14. Only one of the original wells, QP-2, did not respond well and this is attributed to flow limitations of its associated injection wells and the influx of native ground water along its uncovered side.

The uranium was stripped from the recovered fluids by conventional anionic exchange resins in a closed three-stage upflow system. As shown in Figure 15, the extraction efficiency throughout the production phases exceeded 99% with uranium leakage through the system averaging less than 2 mg $U_3 0_8$/L. Higher leakages occurred initially, but a downward trend is clear during the first year as the operating personnel gained experience with the equipment. In August, 1984, the three-stage ion exchange system was reassigned to service the O-Sand test which was starting. A new atmospheric two-stage upflow ion exchange system was installed in the Q-Sand circuit. Again, we see changes in the uranium leakage as the operators gained control of the new equipment. Estimated reserves for this pilot area were 52.9 tonnes (116 540 pounds) $U_3 0_8$. Sixty-seven percent of this reserve (35.5 tonnes) was recovered during the test.

It is a condition of every pilot and commercial ISL license in the United States that the native ground water must be returned to conditions at or near the original quality. These requirements are set by the regulatory agency and are specified for each major constituent and all metal components of the water.

Restoration of the Q-Sand ground water was accomplished by Ground Water Sweep (GWS). When applicable, GWS has proven to be the most economical means for restoration. Water from wellfield areas with the most elevated Total Dissolved Solids (TDS) levels is selectively removed and treated for disposal. A small portion of the treated water may be reinjected into the wellfield to maintain hydrologic control. Net water withdrawal from the wellfield is increased from a few percent during operations to thirty or more percent during restoration. This causes a strong flow (sweeping) of native ground water into and through the wellfield. This replaces the lixiviate, returning the ore zone water to near original conditions.

If ideal plug flow conditions occurred in the reservoir, the restoration would require the net withdrawal of only one pore volume of lixiviate. This, of course, was not the situation and multiple pore volumes were required for a successful restoration. Minimizing this water volume is the key to a cost effective restoration.

Restoration of the Q-Sand wellfield began in November, 1984 and was completed in May, 1986. During this period about 20 pore volumes (pv) of water were produced and treated by ion exchange for uranium removal. Half the water was reinjected for hydrologic control and the remainder (10 pv) was disposed. Restoration of major water constituents to acceptable conditions is shown in Figures 16 and 17. The specific conductance dropped from 3 000 micro-mhos/cm to below the restoration target of 827 micro-mhos/cm in 6.8 pv, carbonate from 1 100 mg/L as HCO_3 to 294 mg/L as HCO_3 also in 6.8 pv, and uranium from about 20 mg $U_3 0_8$/L to 3.6 mg $U_3 0_8$/L in 4.8 pv. Other key constituents responded more

FIGURE 14
Q-SAND PRODUCTION HISTORY
INDIVIDUAL WELL DATA

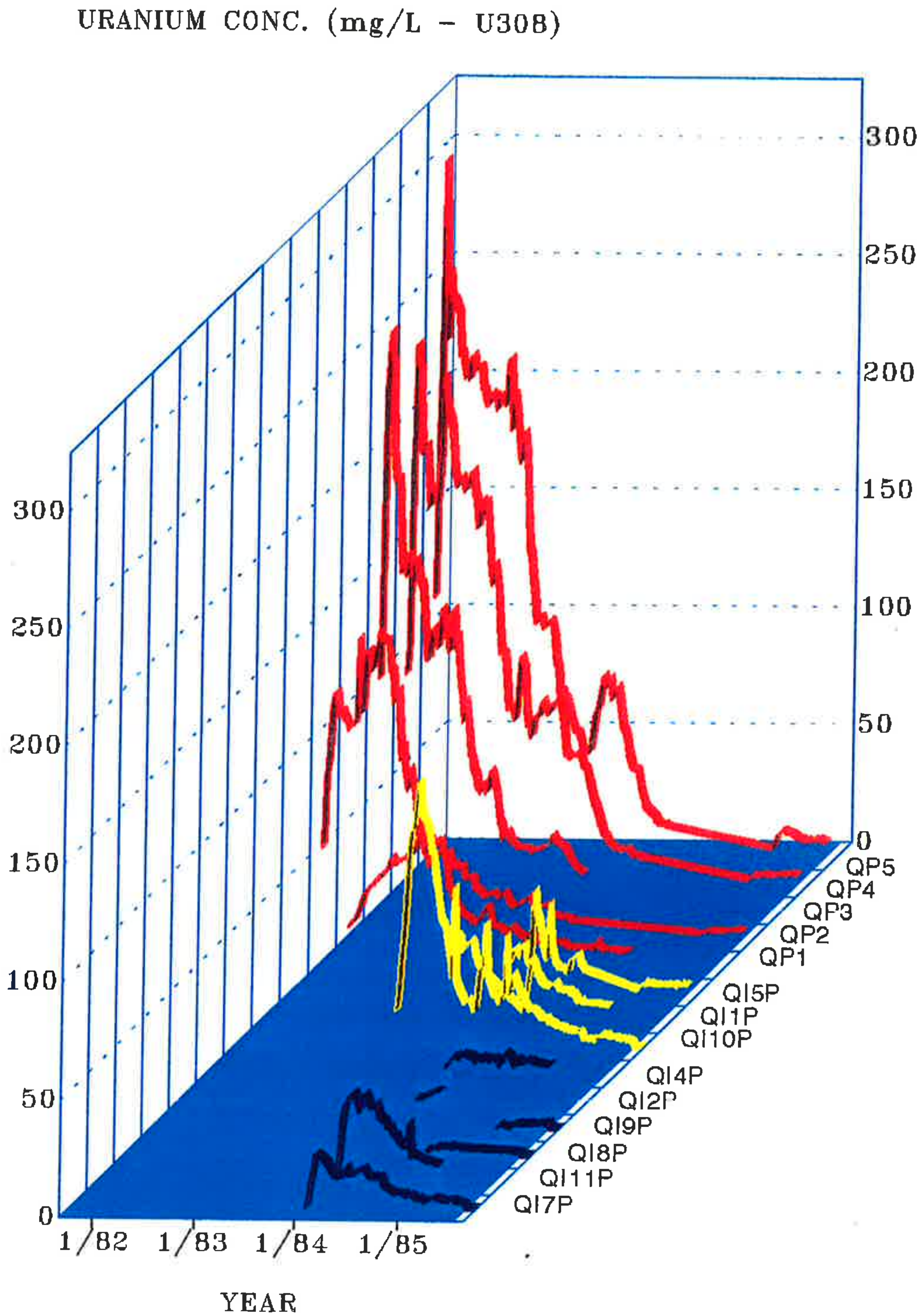

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FIGURE 15
Q—SAND PILOT
ION EXCHANGE EXTRACTION EFFICIENCY

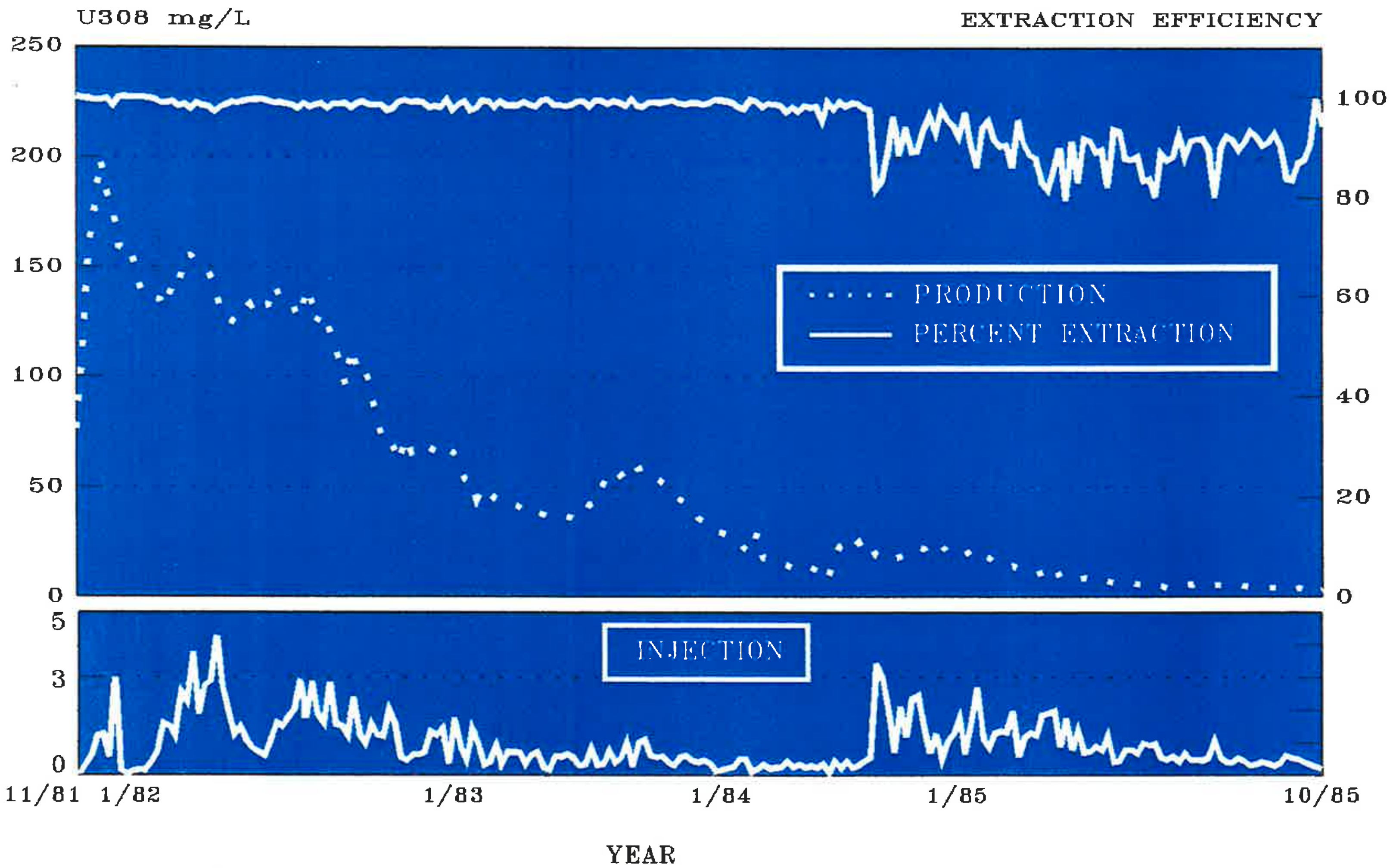

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FIGURE 16
Q-SAND RESTORATION DATA

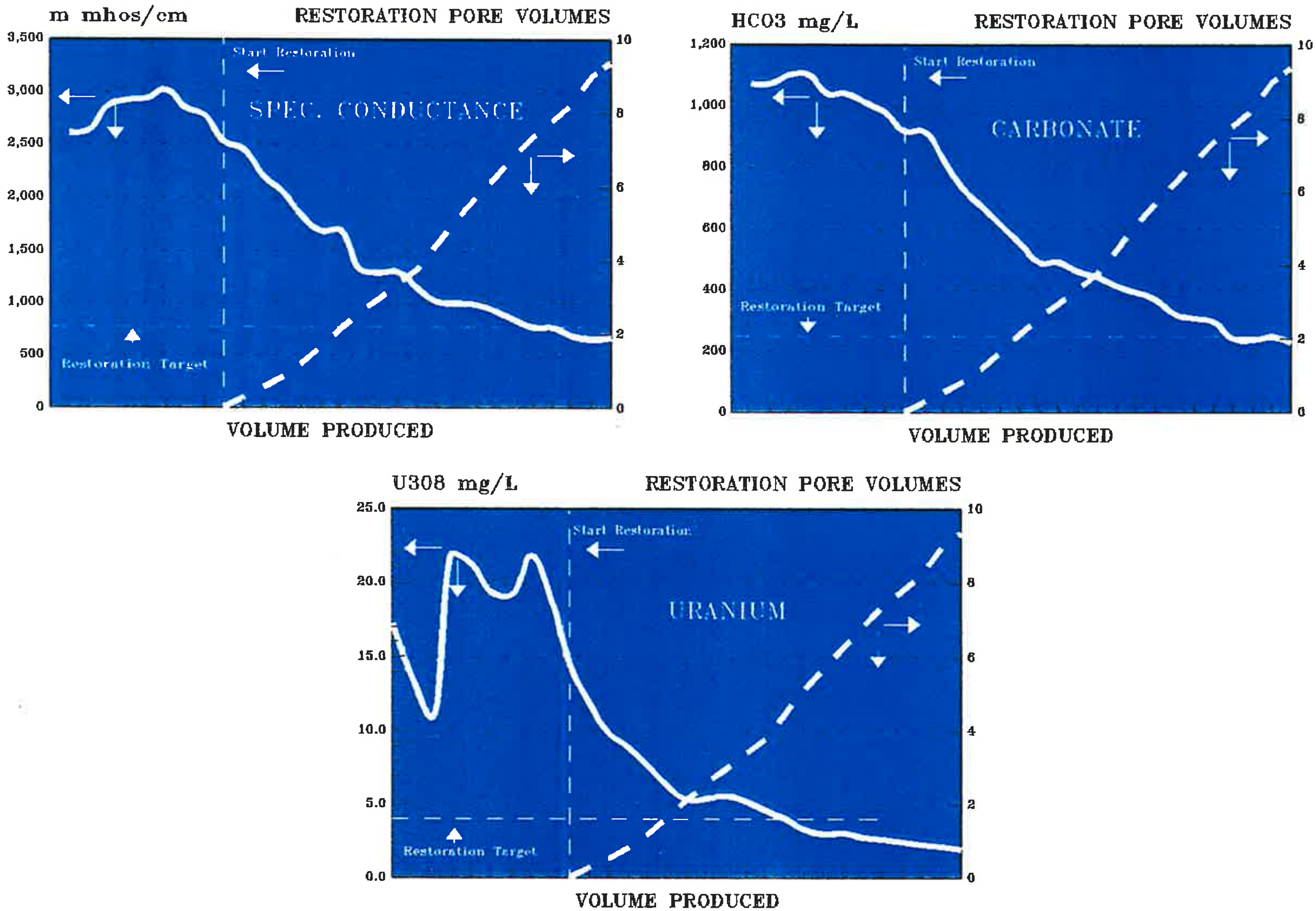

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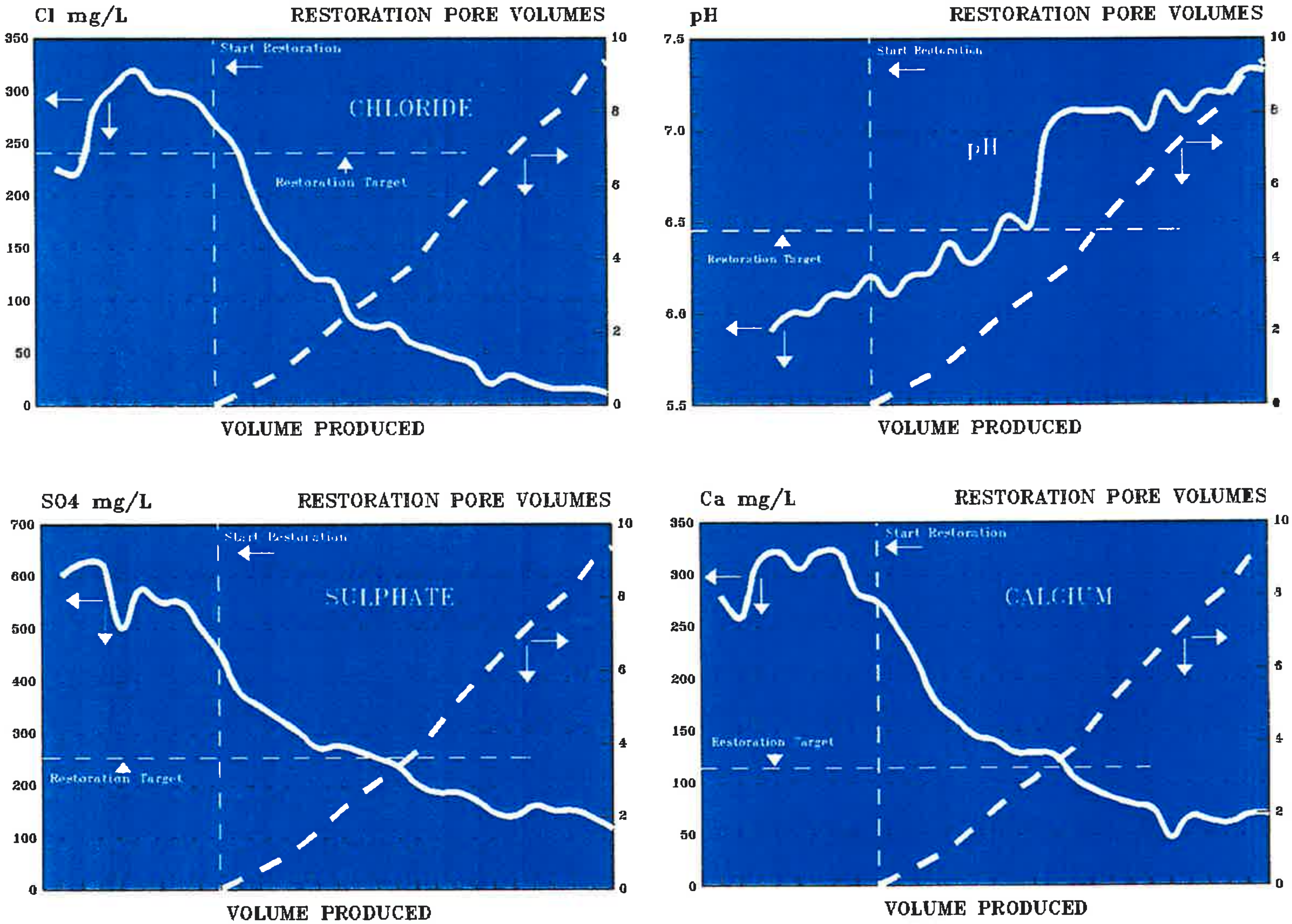
FIGURE 17
Q-SAND RESTORATION DATA



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quickly: calcium reached its target value in 3.5 pv, sulphate in 3 pv, pH in 3 pv, and chloride in slightly more than 1 pv.

All water quality targets were achieved with less than 7 pv of net water withdrawn. Ten (10) pv were withdrawn to insure the restored water quality was both stable and at acceptable conditions.

To certify that restoration is complete, the wellfield area must be left in a quiescent condition for 12 months, subject only to monthly water sampling which tests the water quality and its stability. In May, 1987, final water samples were collected and analyzed. These data, shown in Table 1, document the successful restoration of the Q-Sand ground waters.

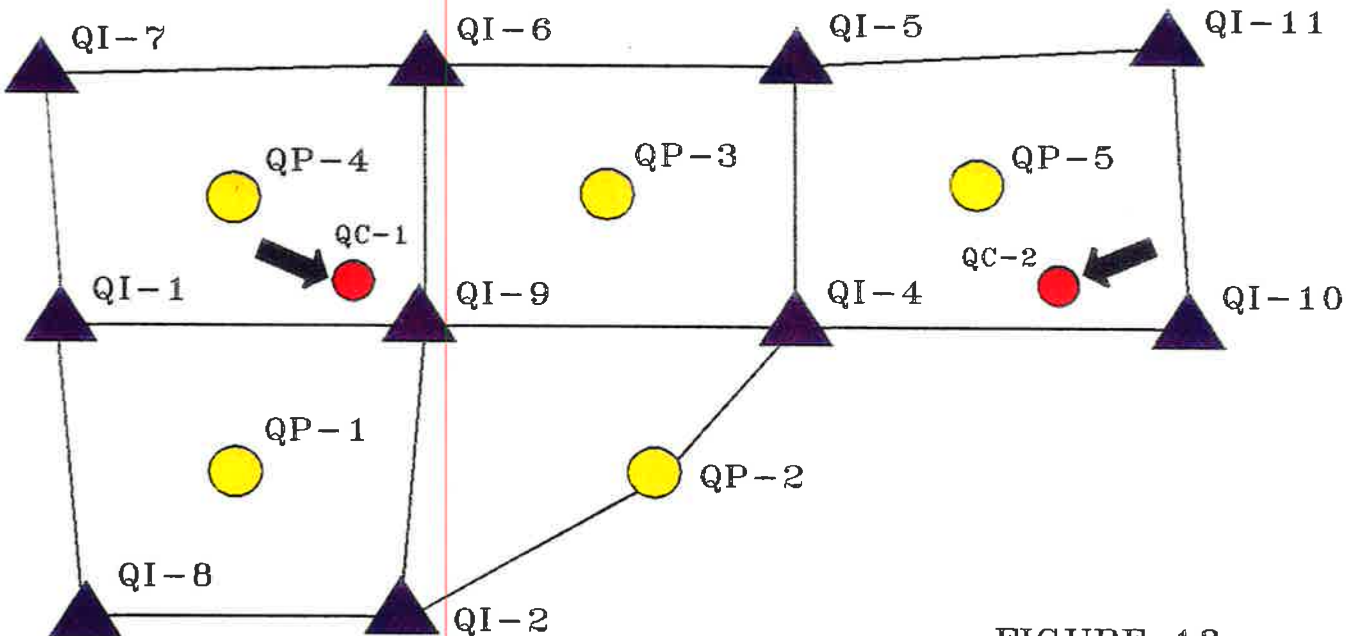
TABLE 1. Q-SAND ISL PILOT RESTORATION SAMPLES

	RESTORATION TARGET VALUES (1)	AQUIFER STABILITY DEMONSTRATION ANALYSES (2)								
		QP-2	QP-4	QP-5	QI-5	QI-7	QI-8	QI-9	QI-10	**8 WELL AVG.**
		5/87	5/87	5/87	5/87	5/87	5/87	5/87	5/87	**5/87**
Arsenic	**0.05**	0.004	0.003	0.007	0.003	0.006	0.007	0.006	0.026	**0.008**
Boron	**0.54**	0.09	0.12	0.15	0.16	0.15	0.15	0.13	0.16	**0.14**
Iron	**0.3**	0.17	0.23	0.02	0.1	0.06	1.22	0.05	0.03	**0.24**
Manganese	**0.09**	0.03	0.07	0.08	0.09	0.05	0.03	0.05	0.04	**0.06**
Radium-226	**923**	230	382	556	475	292	492	608	778	**477**
Selenium	**0.029**	0.006	0.002	0.004	0.001	0.001	0.003	0.005	0.002	**0.003**
Thorium 230	**5.62**	3.6	4.4	4.7	2.5	3.6	3.0	2.7	2.5	**3.00**
Uranium	**3.7**	0.8	1.9	4.3	1.7	0.7	0.6	0.7	0.9	**1.45**
Bicarbonate	**294**	234	244	268	273	239	268	278	229	**254**
Calcium	**120**	77	66	83	82	71	80	93	75	**78**
Carbonate	**16**	0	0	0	0	0	0	0	0	**0**
Chloride	**250**	18	15	17	17	11	16	17	11	**15**
Magnesium	**26**	20	17	18	18	20	20	19	18	**19**
Potassium	**23**	8	8	8	8	7	8	9	7	**8**
Sodium	**41**	39	54	42	38	26	43	39	22	**38**
Sulphate	**250**	135	127	131	127	111	131	139	119	**128**
Conductivity	**827**	656	661	670	666	608	691	622	563	**642**
TDS	**571**	460	431	466	449	384	472	490	389	**443**
pH	**6.5-8.6**	7.04	7.02	6.97	6.63	7.07	7.02	6.75	7.2	**6.96**

(1) Restoration target values as approved by NRC in License Amendment No. 11 and Wyoming DEQ in a letter of July 23, 1984.

(2) All values are mg/liter except RA-226 and TH-230 (pCi/L), pH, and conductivity.

In September, 1990, two cores were cut within the wellfield area. Locations are shown in Figure 18. Core recovery was excellent, averaging 98.5%. Core intervals and recovery for both holes, as well as the completion interval for the nearest production well, are shown in Table 2.



INJECTION WELL

RECOVERY WELL

CORE HOLE

FIGURE 18

Q-SAND PILOT AREA

WELLFIELD LAYOUT AND CORE HOLE LOCATIONS

NOT TO SCALE

Attachment 1

TABLE 2.

Hole	Core Interval	Internal Cut	Core Recovered	Percent Recovery	Offset Well	Completion Interval
QC-1	146-154m	8m	7.76m	97	QI-9	146-153m
QC-2	140-153m	13m	13m	100	QI-10	142-157m

Upon retrieval, the core was immediately sealed in plastic tubing to retard oxidation. Under controlled conditions, it was split, described, and photographed. Individual 0.3 meter (one foot) sections were assayed for radiometric and chemical uranium.

Core QC-2 was located 9 meters west-northwest of injection well QI-10 in the direction toward QP-5. Chemical assays (Figure 19) indicate that the mineable uranium was leached from the shallower sands but that substantial quantities of mineral remain in a zone below 148 meters. Mineral at the top of the interval (above 144 meters) is a lower wing feature of an overlying ore zone. The ore at 144 meters is contained in a thin lignite or coal bed and not amenable to leaching. The mineral directly below (145m - 148m) is a sub-roll in a generally clean sand and was effectively leached. A thin, continuous clay layer at the base of this sand is uranium rich and isolates the underlying sands where the mineral was not effectively contacted by the lixiviate. The lixiviate preferred to move through the upper portions of the completion interval. This preferential flow through the upper portions of a thick completion interval also occurred in the O-Sand.

The second core, QC-1, was located 7.5 meters west-northwest of injection well QI-9 toward recovery well QP-4. Nearly all mineral was leached from this core (Figure 20). The only significant residual mineral was found at 152 meters in a thin lignite and clay rich zone. Excluding this lignitic uranium, apparent recovery is well in excess of 90%.

Based on these core assays and visual observations, the Q-Sand pilot was successful in both oxidizing the ore sands and removing the uranium. Except in lower portions of QC-2, all remnant uranium was associated with clays and/or organics. These materials are either preventing or hampering mobilization of the mineral around them. The high leaching efficiency achieved in QC-1, where the sand and completion intervals were not as thick as in QC-2, demonstrates the benefits of smaller completion zones. As the thickness of the completion interval increases, so do the chances for preferential flow in selected horizontal sub-intervals. With preferential flow some mineralized zones are bypassed and left unleached, as seen in the lower portion of QC-2.

Where mining has been efficient, residual grades are less than 0.005% U3O8. These "tail" assays are much less than tailings from many conventional acid mills. Horizons containing clay galls and organic debris retain most of the associated mineral. These intervals have low relative permeability and high oxidant consumption capabilities. Both characteristics make it extremely difficult to oxidize and mobilize the uranium mineral. Recognition of these

FIGURE 19
SMITH MINE – Q PILOT
CORE HOLE QC-2 – eU308 vs cU308

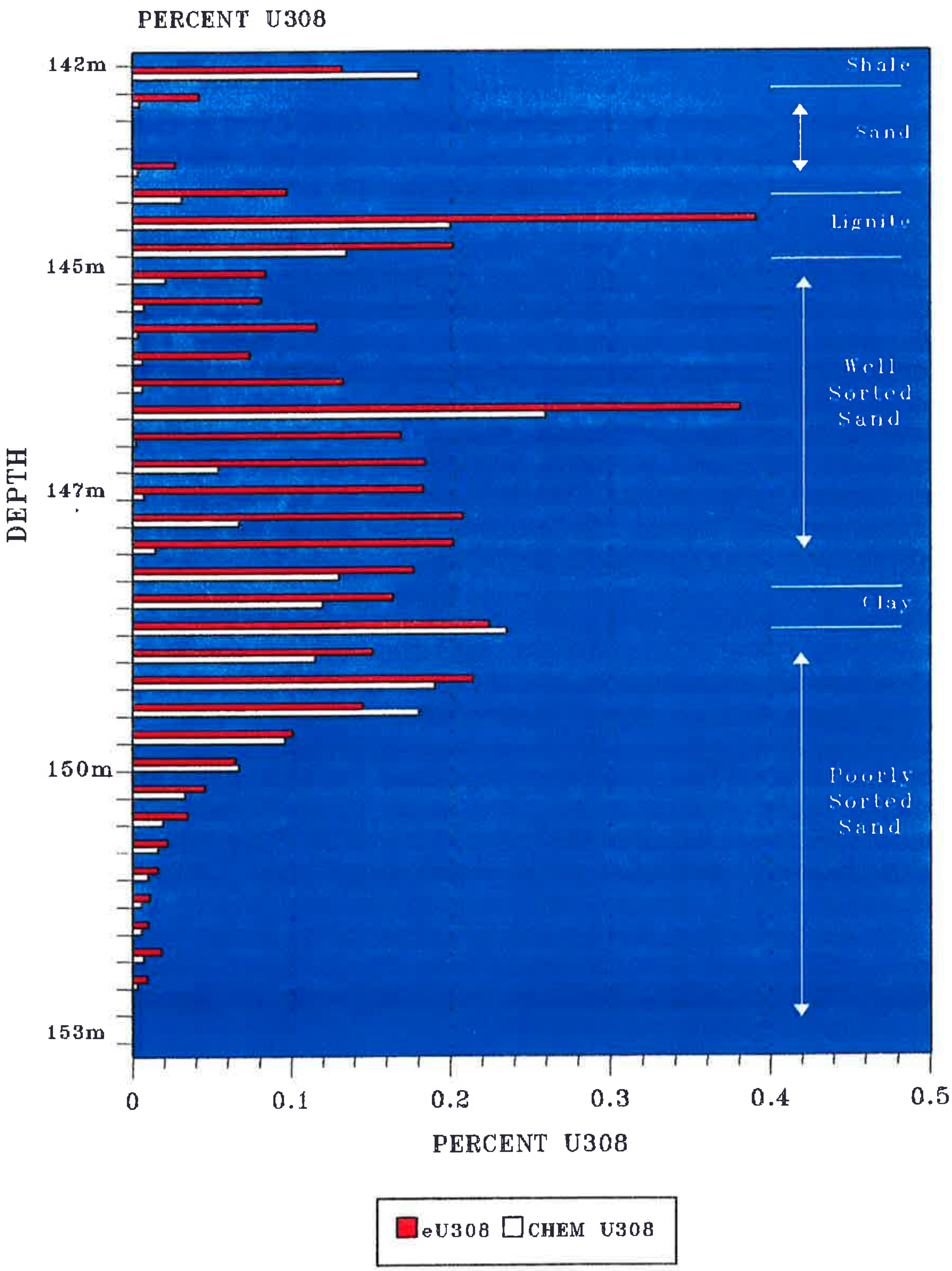
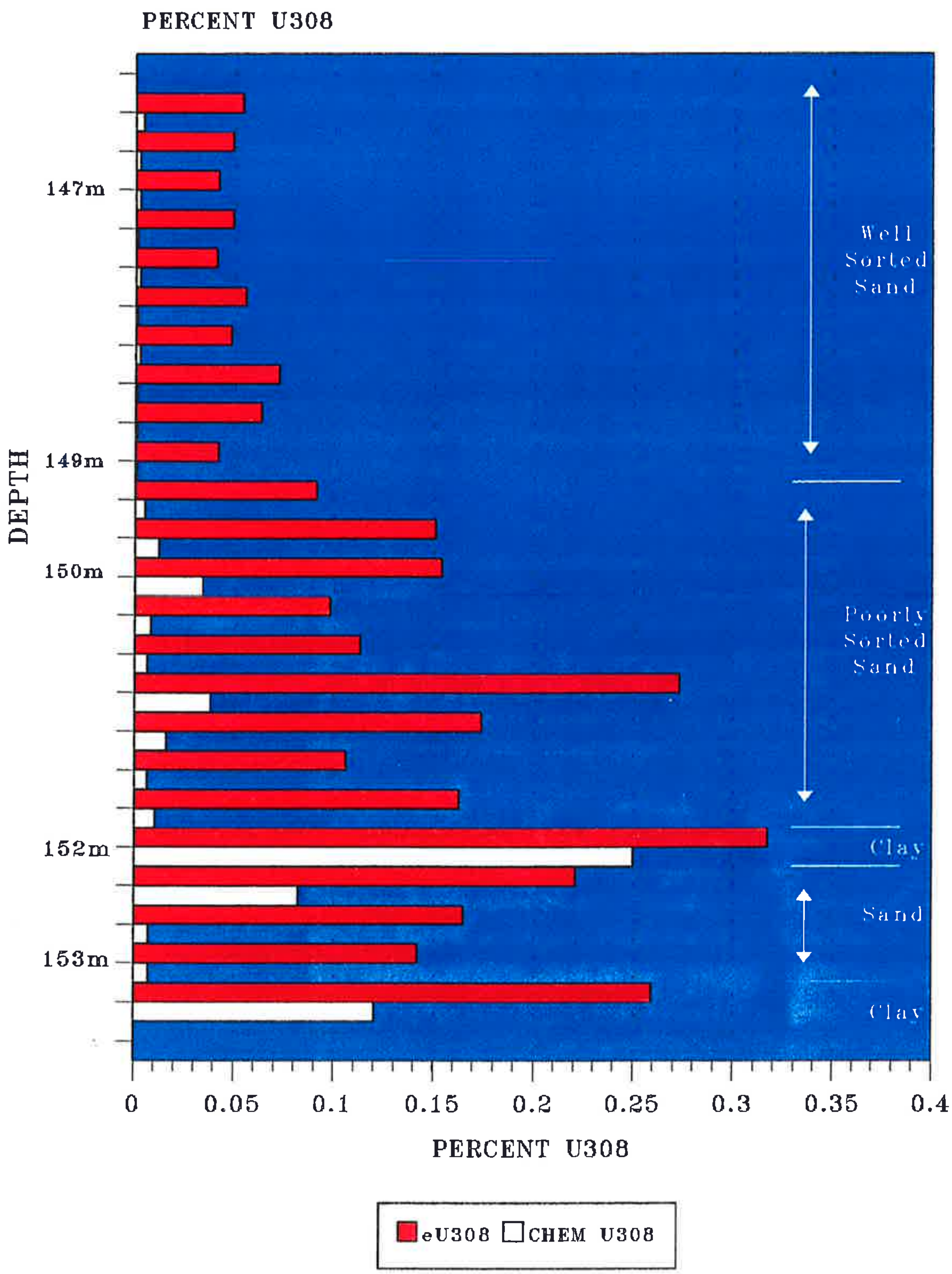


FIGURE 20

SMITH MINE – Q PILOT

CORE HOLE QC-1 – eU308 vs cU308



zones is critical in determining mineable reserves. They are commonly less than one meter (three feet) thick, relatively high grade, and associated with organics, clays, high calcium zones, and low permeability zones. However, such impermeable zones are sometimes difficult to identify on electric logs. The first two characteristics, thickness and grade, must be relied upon heavily. That is, thin, high grade (>1%) mineralized zones are likely to be organic rich and not amenable to leaching. Such zones should not be counted as mineable reserves.

Studies of the Q-Sand pilot test ended with the coring program. The operating wells have been plugged and abandoned. Operating information obtained in this test influenced the design and operation of the O-Sand test.

5. O-SAND

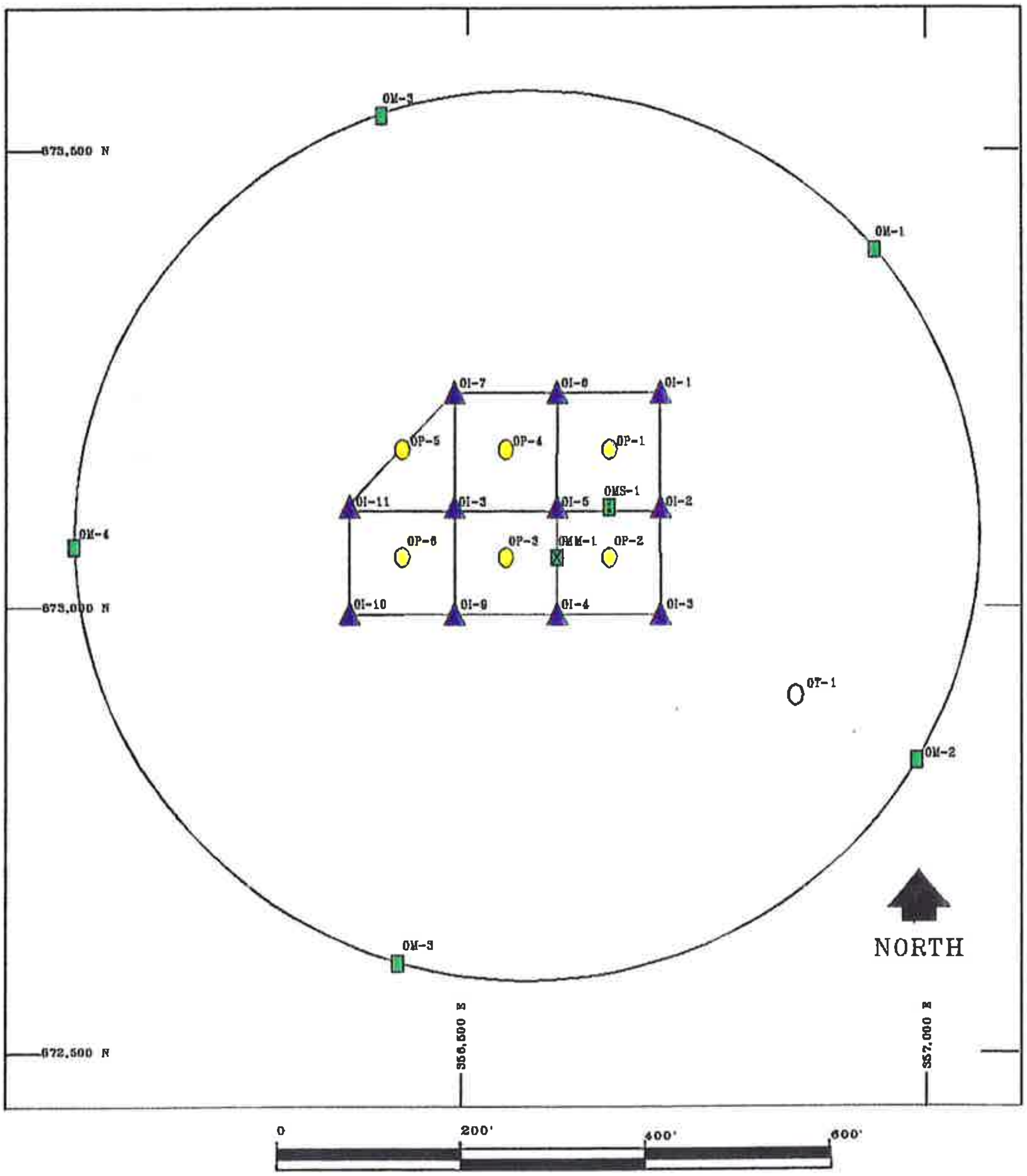
The O-Sand is the thickest and most prolific uranium mineral host in this area of the South Powder River Basin. It is composed of fluvial sands, silts and clays. The Smith Ranch area is near the depositional axis of the basin and clay horizons are not as well developed as they are toward the basin margins. Due to this, the O-Sand is nominally 76 to 92 meters (250 to 300 feet) thick at Smith Ranch, whereas at the adjacent Highland property (away from the axis) the O-Sand exists as at least four distinct sands. This lack of distinct, continuous interbedded clay zones presents unique challenges to mining the O-Sand at Smith Ranch.

The O-Sand wellfield is located in Section 26, T36N R74W. Six production patterns make up the wellfield with five five-spots and one half five-spot which lacks an injector (Figure 21). Pattern spacing is 36.6 meters (120 feet) between injectors. Surrounding the wellfield are five ore zone monitor wells. Within the wellfield one monitor well is completed in the first aquifer above the ore zone and a second in the first underlying aquifer. Production is from the O-4 through O-7 sands which are in the lower half of the O-Sand proper at a depth from 198 meters (650 feet) to 229 meters (750 feet). Open hole completion intervals range from 20 to 26 meters (66 to 85 feet) with a mean of 21.6 meters (71 feet).

Uranium mineralization occurs within four sub-rolls. Each sub-roll is a unique individual roll front yet interrelated with the others. These fronts are typically narrow and very sinuous, repeatedly passing back and forth across one another. Thus, in some instances, all four sands contain ore grade mineralization in the same drill hole. This characteristic has led many ISL operators to assume that the ore grade mineral is much thicker and wider than it is.

Design features were similar to the Q-Sand test. Five-spot wellfield patterns with open hole completions were used. All pipelines were buried to avoid winter freezing. Conventional anionic exchange resins and equipment were used for uranium recovery. Oxygen, sodium bicarbonate, and carbon dioxide were the leaching chemicals, while hydrogen peroxide was the yellowcake precipitation reagent. Regulatory requirements were similar to the total lixiviate injection rate limited to 9.5 L/S (150 gpm) rather than 6.3 L/S

FIGURE 21
O-SAND WELL PATTERN
SECTION 26 - T36N, R74W
CONVERSE COUNTY, WYOMING



MONITOR WELL

INJECTION WELL

PRODUCTION WELL

LOWER ZONE MONITOR WELL

UPPER ZONE MONITOR WELL

120 FT. SPACING BETWEEN INJECTION WELLS

(100 gpm). Operating and monitor wells were drilled and cased during July, 1982. Water quality sampling and hydrologic testing information for the license application was subsequently gathered.

Regulatory approval to operate was received in mid-1984 and test operations began in August, 1984. A prompt response to the alkaline lixiviate followed as the uranium content of the produced fluids quickly rose to a peak of 105 mg U_30_8/L (Figure 22). Production continued at a high rate until early 1986 when the uranium concentration dropped to 40 mg U_30_8/L. This drop occurred as a higher wellfield purge flow rate was being tested. The increased flow of native ground waters diluted the effectiveness of the leaching. A reduction in the purge flow rate to $\pm 5\%$ and an increased bicarbonate concentration of the injection fluid restored the uranium concentration to above 70 mg U_30_8/L in late 1986.

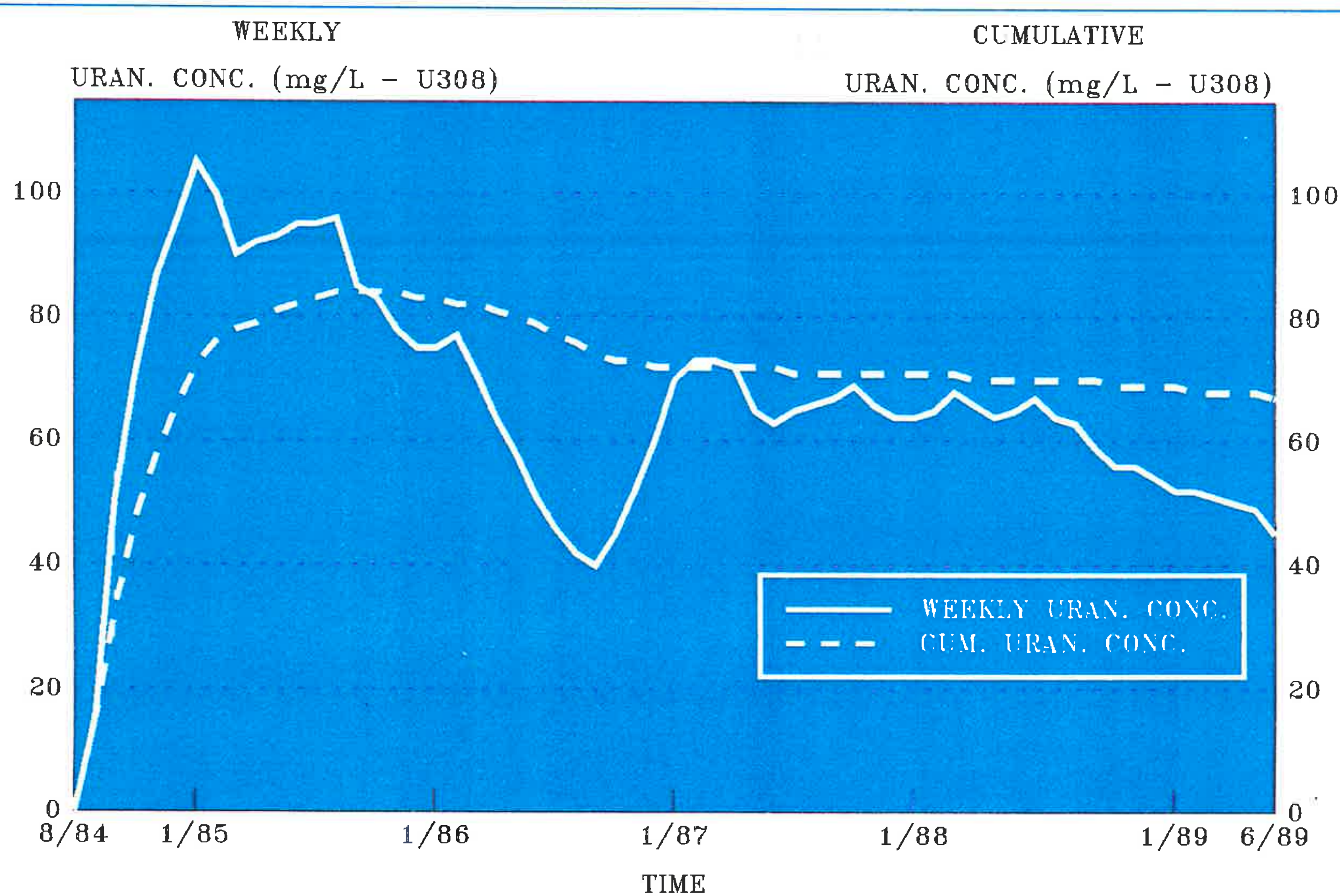
From August, 1984, through June, 1989, uranium production averaged 67 mg U_30_8/L. In early 1987, the cumulative average uranium concentrations for the six recovery wells were: OP-1 - 82 mg/L, OP-2 - 53 mg/L, OP-3 - 76 mg/L, OP-4 - 81 mg/L, OP-5 - 60 mg/L, and OP-6 - 66 mg/L. These relatively uniform averages and the steady, almost flat, uranium concentration profile are likely to result from the wide completion intervals employed in the wells.

The reservoir pore volume was calculated to be 80 x 10^6 liters (12.1 x 10^6 gallons), about four times that of the Q-Sand test. With only a fifty percent increase in the authorized injection rate (9.4 L/S vs. 6.3 L/S), a significantly longer period of economic production was expected. If the O-Sand performance is viewed on a pore volume rather than time basis (Figure 23) we see that at 30 pv, the uranium concentration had dropped to 45 mg U_30_8/L with a cumulative average of 67 mg U_30_8/L. These values compare with Q-Sand test values of 60 mg U_30_8/L and 90 mg U_30_8/L, respectively, at the same pore volumes (Figure 12). The larger completion intervals of the O-Sand wellfield are likely the cause of the lower values. Large completion intervals in these sedimentary sandstones are susceptible to preferential flow through one or more of the sub-roll front sand units. As each sand unit is depleted of uranium, it continues to accept lixiviate to the detriment of other mineralized sands. Lixiviate is now traveling through barren or near-barren sands only to dilute the uranium concentration from mineralized zones when it arrives at the recovery well. Thus, the wellfield never achieves the very high peak uranium concentration and the economic life is prolonged as these barren zones continually divert lixiviate from the mineralized zones. The different and distinct shapes of the uranium concentration profiles of the two tests are a measure of dilution's impact on the O-Sand performance.

Production of the O-Sand pilot continued into 1991 at which time the test was placed on hold pending the start of commercial operations. Estimated reserves for the six patterns are 136 tonnes (300 000 pounds) uranium of which 71% of the reserves have been recovered.

To assess the testing program and to aid planning for commercial development of this area, five cores were cut within the area in 1990. The location of each hole is shown in Figure 24. Each was offset to a nearby production well with only hole OC-1 located outside

FIGURE 22
O-SAND PRODUCTION HISTORY

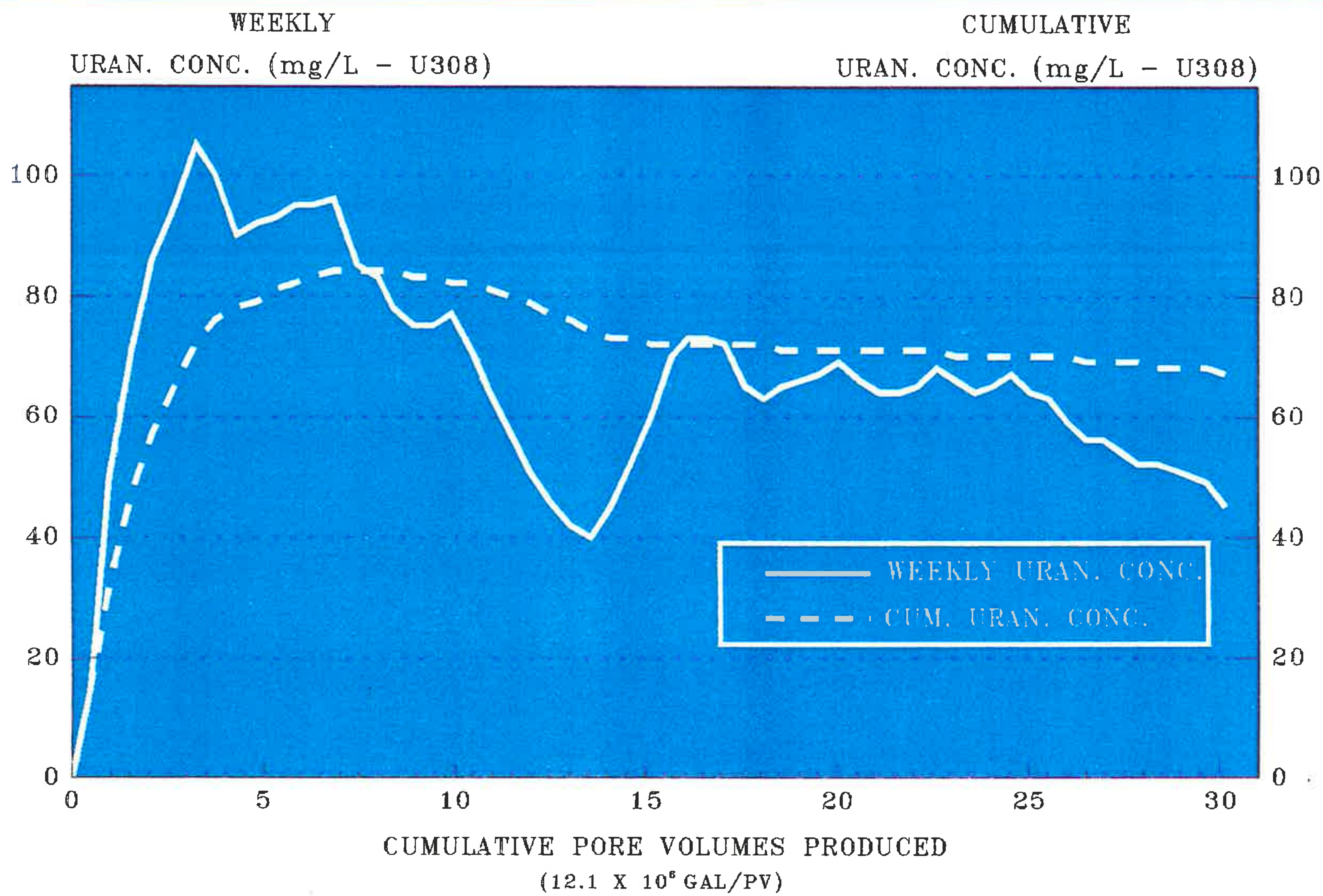


-33-

Attachment 1

Attachment 1

FIGURE 23
O-SAND PRODUCTION HISTORY



Attachment 1

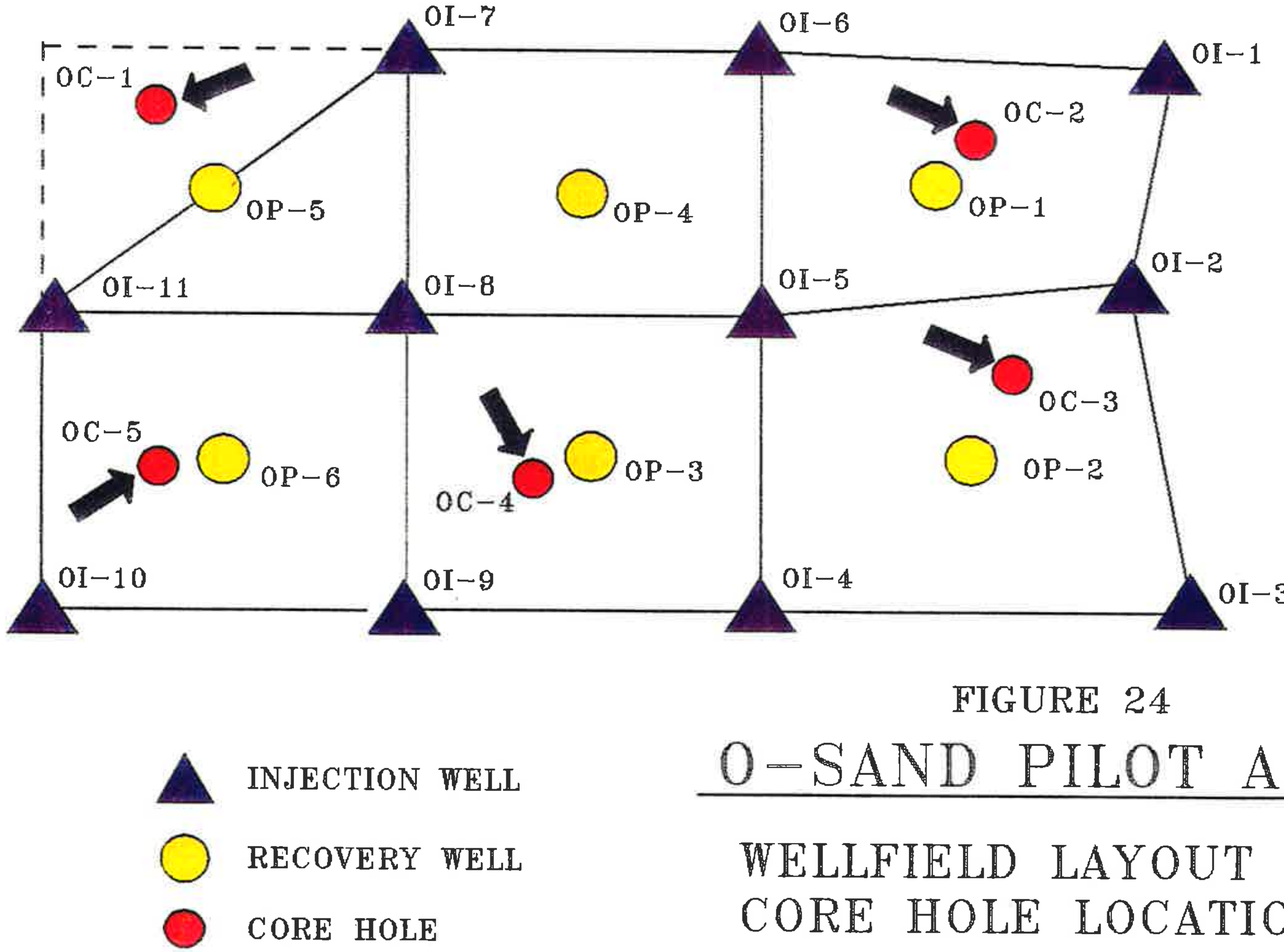


FIGURE 24

O-SAND PILOT AREA

WELLFIELD LAYOUT AND CORE HOLE LOCATIONS

NOT TO SCALE

a pattern. Each core was cut from above the completion zone of the nearby production well and through the production zone (the O-4 through O-7 sands). This allowed inspection of the overlying mineralized sands and provided information concerning possible vertical migration of lixiviate.

The first cores were cut with a 4.6 meter, 7.6 cm diameter Christensen core barrel which resulted in poor recoveries. Subsequent cores were cut with a shorter (3 meter) core barrel and recovery ranged from 92% to 100% with an average of 97%. The core was immediately sealed in plastic tubing to retard oxidation. Under controlled conditions, it was split, described, and photographed. The gamma log mineralized intervals were assayed for radiometric and chemical uranium. A reduced sample (hole OC-1) and an oxidized sample (hole OC-4) were also subjected to petrographic analysis (Table 3).

TABLE 3.

	Hole OC-4	Hole OC-1
Oxidation State	Oxidized	Reduced
% eU3O8 - radiometric	0.12	0.16
% U3O8 - chemical	0.002	0.35
Intergranular Clay	1.2 %	4.0 %
Visible Pore Space		
Primary	7.6 %	8.0 %
Secondary	13.2 %	10.0 %

The sands in both are conducive to solution mining. There is sufficient porosity. The intergranular clays which provide lithification for these sands are relatively stable illite or a mixed layer of illite/smectite. No chemical uranium was detected in the oxidized sample but was found to be associated with the intergranular grain coating clay in the reduced sample. These results reveal interesting differences between the oxidized and reduced samples. While uranium has been quantitatively removed from the oxidized sample, the reduced sands are still enriched in uranium. The reduction in intergranular clays in the oxidized sample indicates the clays have been mobilized during leaching. This is consistent with the general observation that oxidized sands are less lithified than reduced ones where clays are the matrix "cement". This characteristic will affect both borehole wall stability and fluid flowpaths during leaching operations.

Chemical analyses of the five cores indicate that mineable uranium minerals remain in only certain vertical and horizontal zones. Two cores (OC-2 and OC-3) contain ore grade mineral in the lower portion of the cored interval whereas the other two cores (OC-4 and OC-5) are extensively oxidized and nearly void of mineralization. The fifth core (OC-1) is located outside the wellfield and exhibited no lixiviate contact. It does, however, contain significant uranium reserves which will be exploited by future commercial operations.

By design, cored intervals were wider than completion intervals of adjacent wells to facilitate sampling of the shallower zones to test for vertical movement of the lixiviate. The only evidence of vertical movement was found in OC-3 where the uranium was leached up to one meter above the well completion interval. In general, the lixiviate remained confined to the completion intervals.

In the intervals where leaching was most efficient, residual grades were below 0.01% U_3O_8. The best example is OC-3 (205 to 207 meters). This zone, along with another in OC-2 (212 to 221 meters), are intervals of significantly high eU_3O_8 values which show total U_3O_8 depletion. Many intervals show only partial oxidation and leaching of ore grade intercepts. Based on the remnant ore and coloration of the core samples, leaching has been more efficient in the southern three patterns (OP-2, OP-3, and OP-6). In the other patterns indications are that only partial oxidation and leaching of the lower sub-rolls has occurred. Additional reserves within these patterns will be recovered during commercial operations.

Similar to the Q-Sand areas, thin intervals of high grade mineral were encountered which were not leached. They are intimately related to lignites, clays, or other sediments of low permeabilities and can occur anywhere within a sand. Characteristically they are thin (less than one meter thick) and relatively high grade (>1%) when compared to the mineral in the rest of the hole.

The O-Sand pilot test, like the Q-Sand before it, has demonstrated the amenability of the Smith Ranch uranium ores to ISL mining. In addition, the feasibility of mining thick, multiple roll-fronts has been proven. These tests provide a solid data base from which commercial plans are being developed.

6. SUMMARY OF TEST FINDINGS

Like conventional mining, the goal of ISL mining is to produce the economically optimum quantity of the mineral resource and to achieve this production in an environmentally sound and acceptable manner.

The two field pilot tests at Smith Ranch have demonstrated that:

- ISL uranium mining can be successfully operated under stringent environmental regulations with excellent productivity.
- The uranium minerals are amenable to the environmentally benign oxygen and carbon dioxide fortified lixiviate.
- Equally important, the tests have provided valuable information applicable to increasing uranium recovery at lower costs. These long duration tests clearly show that uranium in relatively clean sands can be quantitatively leached, leaving behind mineral grades below 0.01%. Conversely, these tests clearly prove that uranium

resources associated with organic rich shales and clays are not mineable reserves for alkaline ISL operations.

Understanding and applying these concepts in the planning of commercial operations can result in significant savings in wellfield investments.

- The impact of wide completion intervals for injection and recovery wells is demonstrated by comparison of the two tests. While the narrow completion intervals of the Q-Sand lead to more efficient uranium recovery, the problem remains as to the best design of completion intervals in thick ore zones such as the O-Sand. Upon careful inspection, these thick sedimentary ore zones are often found to consist of several distinct sub-rolls within a larger mega-roll framework. A sub-roll or group of sub-rolls is usually within the efficient completion interval thickness (2 to 7 meters) and can be leached independent from the other sub-rolls.

- Finally, the advantage of rearranging operating wells during production was illustrated in the Q-Sand test. By changing injection wells to recovery wells, and vice versa, the movement of lixiviate within a wellfield can be redirected to expedite uranium recovery.

7. CONCLUSIONS

The objectives of the Smith Ranch field testing program were to demonstrate environmentally sound mining methods, restore the altered ground water to regulatory standards, and develop the technical and operational basis for a commercial ISL project. In every respect, the Q and O-Sand tests were unparalleled successes. More than 131 tonnes U_30_8 of uranium were recovered without a single violation of the stringent Wyoming and Federal rules. The ground waters of the Q-Sand area were restored using ground water sweep to demonstrate not only the technical but also the economic viability of restoration. The engineered systems withstood the harsh Wyoming winters. The low cost lixiviate chemicals (oxygen and carbon dioxide) and open hole well completions were shown to be both effective and applicable to commercial operations. Wellfield productivity in terms of both recovery and cumulative average uranium concentrations provided a firm base for developing the long term, large scale mine plan which accompanies commercial operations.

Conventional anionic exchange resins systems (upflow and downflow) were shown to function well as was the hydrogen peroxide induced precipitation of yellowcake. All such information contributes to an optimized commercial process design.

Perhaps the most important feature of any pilot program is the opportunity to assess critically design concepts and to then seek means to improve these concepts. While the wellfield performance of both tests was excellent, coring of the wellfields provided not only confirmation of extremely high recoveries in selected sands but provided equally important insight into why some uranium was still in place. This information is invaluable to our continuing search for the optimum wellfield design.

These pilot tests have provided a wealth of information which enhances our commercial planning and greatly reduce the risks inherent with new mines.

BIOGRAPHY

Dennis E. Stover

Dr. Dennis E. Stover is the Director, ISL Technology for Rio Algom Mining Corp. After earning a Ph.D. in Chemical Engineering at the University of Michigan, he joined Atlantic Richfield Company where he worked on the development of In Situ uranium leaching technology and the Clay West Project, the first commercial scale In Situ project. Prior to assuming his present position in 1989, he spent eleven years as the Chief Engineer for Everest Minerals Corporation.

Dr. Stover's involvement with energy spans more than a quarter century and has covered a broad spectrum of emerging technologies. Starting with basic research in hydrocarbon fuel cells and advanced battery systems, his contributions cover such diverse topics as copper electrorefining, in-situ coal gasification, electroless nickel deposition, in-situ thermal stimulation of heavy oil production, and biological process for groundwater restoration.

An author of several papers regarding in situ uranium leaching, he holds six patents relating to this technology.

BIOGRAPHY

Dayton A. Lewis

Dayton Lewis is the Senior Geologist - ISL Mining for Rio Algom Mining Corporation. While studying engineering and earning his B.S. in Geology from Texas A&I University, he began working in 1979 with Fisher, Harden & Fisher, In-Situ Leaching Consultants and later for Everest Minerals Corporation. Both firms are recognized as early leaders in the development of in-situ leach technology. Prior to joining Rio Algom in 1990, he spent seven years with Everest where he attained the position of Senior Geologist and worked on projects in Texas, Wyoming and New Mexico.

His specialization is the exploration for, and exploitation of, uranium ore bodies amenable to in-situ leaching technology. In addition, he has experience in ground water remediation of contaminated sites through the environmental business activities of both FHF and Everest. Ongoing fields of research include computerized geologic mapping techniques and ore reserve calculations, ground water modeling, and application of ISL technology to other mineral resources.

Attachment 1