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DALHART POST SHOT INVESTIGATION

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Dalhart Post Shot Investigation

ABSTRACT

Multiple radioactive isotopes tracers are used in borehole operations in the petroleum industry and these tracers are monitored by gamma ray spectroscopy logging tools. The nuclear test Dalhart, U4u, was executed at a depth of 2100 ft on October 13, 1988. This test has multiple radioactive isotopes or fission products associated with it and knowledge of the distribution of these isotopes is desirable for the Nuclear Test Program. A slant post shot hole was drilled in late August, 1990 to sample the geologic material from the collapsed zone or chimney above Dalhart. This 9 7/8 inch borehole was drilled at approximately 19 degrees from the vertical toward the Dalhart execution depth. This borehole started at approximately 734 ft due south of the Dalhart event. Drilling circulation was lost at a slant depth of 1030 ft (980 ft True Vertical Depth, TVD). A 30 ft core was cut at a slant depth of 1722 ft (1628 ft TVD) which was within the collapsed zone and above the original static water level (1667 ft TVD). This core was cut too high in the collapsed zone and contained no radionuclide material from the test. Drilling was completed to 2280 ft (2156 ft TVD). The water level was encountered at a depth of 1603 ft (1513 ft TVD). A Halliburton 1 11/16 in diameter TracerScan gamma-ray-spectroscopy log was run inside the drill string at a speed of 10 ft/min. Spectra were obtained from TD to the surface. Radioactive material produced by the test was present from TD to 1850 ft (1746 ft TVD). Spectra were acquired at 0.25 ft depth intervals and averages recorded digitally every ten ft and thirty ft were displayed on the blue line log together with the total observed gamma ray and casing collar locater signal. Also a DOE high intensity gamma log, which contains two small Geiger counter detectors, was run by Atlas Wireline Services from TD to the surface. This log did not detect any radioactive activity in the hole. The gamma-ray photo peaks on the spectroscopy log were used to determine the depths for sampling with the Hunt sidewall sampling tool. Eleven samples were acquired from the depth interval 2212 ft to 1823 ft (2089 to 1721 ft TVD). None of these samples contained enough activity to be measured with normal drillback survey instruments. An onsite intrinsic Ge detector showed that each sample contained ^{137}Cs, ^{125}Sb and ^{106}Ru. The samples were sent to Los Alamos to determine the radionuclide content at each depth. These analyses were compared with the spectral data obtained from the spectroscopy log and the radionuclide distribution was mapped.

INTRODUCTION

A radionuclide investigation was undertaken to study the subsurface nuclear waste movement from an underground nuclear detonation. This detonation occurred at a depth of 2100 ft in hole U4u. This detonation was below the static water level that had a vertical depth of 1667 ft. The common methods of radionuclide transport are injection from the detonation, groundwater leaching migration and colloidal transport. Immediately following an underground nuclear detonation, a cavity forms where the device was. Initially vaporized material consisting of rock, material associated with the device and products of the fission and fusion processes fill this cavity. As this vapor cools and condenses elements collect on the ceiling, walls and the floor of the cavity. Normally separation occurs between radioactive refractory elements and the more volatile ones. Ideally the refractory elements settle into the bottom of the cavity where puddle glass forms and the volatile elements are distributed in the ceiling and walls of the cavity. This separation is not complete though and refractory elements like zirconium and others are present in other locations than only in the puddle glass. Also volatile elements like iodine and others are present throughout and even in the puddle glass. So the main concentration of refractory elements is in the puddle glass and the concentration of volatile elements is outside the puddle glass (Thompson,ed., 1991).

The lithostatic pressure above the cavity eventually overcomes the cavity strength and the cavity collapses. The materials initially condensed on the cavity ceiling fall to the cavity floor and eliminate some of the spatial separation between volatile and refractory elements. To confuse the situation even further, movement of materials over a short distance during detonation is possible by injection into the rocks beyond the cavity. Then there is the possibility of active groundwater leaching and transport of various materials long after detonation. Also colloids might be present and radioactive material may attach themselves to these colliods and be moved by colloidal transport again long after detonation.

SUBSURFACE CONDITIONS

A nuclear device is put into an emplacement hole that generally has a diameter of 96 in and a depth that varies from 600 to 1000 ft. This hole is geologically characterized and the physical properties are determined by samples and well logs. The depth of the hole depends on the yield of the device. If the hole goes below the static water table (many holes do not because of a deep static water level) the bottom of the hole is lined and cemented in with steel casing that has a bottom plug. The working point of U4u was at a depth of 2100 ft and the static water level was at a depth of 1667 ft. Then the casing has the water blown out of it so the hole is dry. The device is then generally placed in the bottom of the hole. The device is in a canister with a large rack around and above it. The rack contains the diagnostic instruments and other experiments. Many cables go from the surface to the rack. The device and equipment are stemmed with alternating layers of coarse gravel and fine material and two or three special plugs of two-part epoxy are placed in the emplacement hole well outside the melt zone of the device. This stemming and special plugs are designed to contain the explosion and keep all radioactive particles from escaping to the atmosphere. Fig. 1 shows the various conditions described.

An underground nuclear explosion's energy is released in about 0.1 usec and the temperature in the immediate vicinity of this detonation is raised to several million degrees Kelvin. The pressure is also increased in the vicinity of the detonation to many kilobars (Germain and Khan, 1969). At these temperatures and pressures the materials associated with the device and the surrounding rock are vaporized and melted. The cavity around the device expands nearly spherically within a few milliseconds to a radius that is dependent primarily on the yield and secondarily on the lithostatic pressure and water content. The cavity radius in U4u grew to approximately 200 ft. The cavity is lined with melted rock and other materials and the surrounding rock is fractured out to distances that are several times the initial cavity radius (see fig 2). The rock reacts hydrodynamically a short distance from the device and for a brief time of a few tens of milliseconds after detonation. The shock energy propagates in all directions and a bulge occurs at ground surface where surface fractures are formed. After the cavity ceases to expand the molten shel. begins to drain downward to form a glass puddle in the bottom of the cavity. The ground surface returns to a position near its original level.

At a later time of few minutes to a few days, the lithostatic pressure overcomes the competency of the cavity and the cavity collapses to form a chimney above the device. The material in the chimney is broken rock and breccia. The chimney may or may not continue to the surface to form a crater depending on the device yield and the competency of the overlying rock. In the case of U4u a large crater was formed at the surface. The chimney has a radius that is similar to the cavity radius but most craters are not perfectly circular (Houser, 1970, Teller and others, 1968). An example of a chimney and crater is shown in Fig 3.

The location of the emplacement hole U4u and the post shot hole U4u-PS2a is shown in Fig 4. The post shot hole starts at 734 ft north of hole U4u and has a diameter of 9 7/8 inches. This hole was drilled at approximately 19 degrees from vertical toward the U4u working point. The drilling fluid was a bentonite gel mud that had a viscosity of 52 to 53 poise and a weight of 9.0 to 9.2 #/gal. The drill pipe had an internal diameter of 4.5 inches and a weight of 16.5 pounds per ft. Drilling fluid circulation was lost at a slant depth of 1030 ft (vertical depth (VD) of 972 ft) and was never recovered again. Therefore no drill cuttings or any radioactive material ever returned to the surface and this safety feature is standard procedure. It is assumed that the drill bit entered the chimney at this depth. Drilling continued with no returns of drill cuttings to a total depth of 2280 ft slant (2156 ft VD) and approximately 18, 840 barrels of drilling mud were lost during the entire drilling operation.

CORE RECOVERY

At a slant depth of 1722 ft (VD 1625 ft) a 30 ft core was cut with reasonable core return (29.5 ft). This location was within the collapsed or chimney zone and above the original static water level (1667 ft vertical) and above the present static water level of 1741 ft (1644 ft VD). The core was examined at the drill site with an intrinsic germanium detector and no radioactivity was found. It was also examined at the laboratory with more sophisticated equipment and again no radiation was found. This core was cut too high in the chimney were no radioactivity existed.

LOGGING PROCEDURES AND RESULTS

Drilling ended at 2280 ft (2156 ft VD) and standard procedures for preforming gamma logging and sidewall sampling were followed. The logging and sampling were completed within the drill pipe because of subsurface instability. The logging total depth 2218 ft (2094 ft VD) because one length (approximately 30 ft) of drill pipe was removed and because of equipment (approximately 30 ft of drill bits, collars and Hunt sidewall sampler) at the end of the drill pipe. A gamma-ray log was obtained using Halliburton Logging Services' Tracerscan* 1-11/16 in diameter spectroscopy tool which was run at 10 ft/min while drilling fluid was pumped through the drill pipe. The log was run from 2218 ft to the surface and part of the total gamma-ray log and the sample depths chosen from this log are shown in Fig 5. Radioactive material was detected from 2218 to 1850 ft (2094-1746 ft VD). Above this depth the gamma-ray log showed only low levels of natural radioactivity. This had been confirmed by the core obtained at 1722 -1752 ft (1625-1653 ft VD) which had only natural radiation. Some of the possible radionuclides which might be present in this hole are listed in Table 1. Also static gamma-ray logs of 5 min duration were recorded at approximately 30 depths. The analysis of the static and moving spectroscopy results from this gamma-ray log are discussed in another section. Also at this time a Dept of Energy (DOE) high intensity gamma log that consists of two very small Geiger-Muller detectors was run by Atlas Wireline Services in the drill pipe while drilling fluid was pumped. This log detected no radioactivity which showed that no extremely high levels of radioactivity were present.

* A mark of Halliburton Logging Services, Inc

ACQUISITION AND ANALYSIS OF SAMPLES

The total counts gamma log from the Tracerscan tool was used to determine the depths for sampling with the Hunt sidewall sampling tool. This tool is located in the bottom 30 ft of the drill pipe. At a selected location a port opened and a scraper was extended to contact the borehole wall. The drill pipe is moved upward one or two ft and formation material is scraped into an integral receptacle. The sample is brought inside the drill pipe and the port is closed and the sample is brought to the surface by a wireline. The drill pipe is then moved upward to another sampling location and another sample is collected after the sample container is put back into the tool. Once the drill pipe moves upward it generally can't return to a previous sample location. The sample locations and the Tracerscan total counts gamma log are displayed in Fig. 5. Eleven samples were taken with the Hunt sampling tool over the slant depth interval of 2212 ft to 1823 ft (2088 ft to 1721 ft VD). These samples were surveyed in the field with an intrinsic germanium detector and each sample was found to contain ^{137}Cs, ^{125}Sb, and ^{106}Ru. These samples were sent back to the laboratory for further analysis and Tables 2 and 3 lists these results.

TRACERSCAN SPECTROSCOPY ANALYSIS

The 1-11/16 in diameter TracerScan gamma-ray spectroscopy tool is approximately 14 ft long and contains a 1 x 8 in NaI(Tl) scintillation detector (Gadeken and others, 1988). The downhole electronics converts the analog pulses to two 256 channel spectra which are transmitted uphole and recorded at 0.25 ft depth intervals. The Low spectrum has am energy range of 0-350 keV and is used to stabilize the tool and to expand the low energy portion of the gamma-ray spectrum for more precise data analysis. The High spectrum has an energy range of 0-3000 Kev and is used for data analysis above 350 keV. Some of the spectra displayed below show distortion in the low energy (350 keV) of the High spectrum due to the elevated count rates and the limited telemetry bandwidth. However, the 13 windows used to compute the relative nuclide concentrations by a weighted least squares (WLS) algorithm are not in a perturbed spectral region. This is demonstrated in Fig 6 which shows a representative static spectrum taken at a depth of 1928 ft (1820 ft VD). The Low spectrum is above and the High spectrum below. The dashed vertical lines indicate the boundaries of the 13 windows. Note the 60 keV peak from the ^{241}Am stabilization source in the tool and the prominent 662 keV ^{137}Cs peak in the High spectrum.

The most abundant radioactive isotopes found in the laboratory analysis of the Hunt sidewall samples were ^{125}Sb, ^{3}H (tritium), ^{137}Cs, and ^{106}Ru. Tritium does not emit gamma photons and so cannot be assayed using a gamma-ray spectrometer. The other 3 nuclides emit the majority of their gamma photons in the 400 to 700 keV energy range. The data in Table 3 shows that the average relative proportions of ^{137}Cs : ^{125}Sb : ^{106}Ru are 13 : 1.0 : 1.7, respectively (this statement disregards detector efficiency). The abundances of the other nuclides is reduced by a factor of 5 or more relative to these. Consequently, the WLS analysis of the TracerScan gamma-ray spectroscopy data was limited to 3 post shot nuclides (137Cs,125Sb and 106Ru) plus the natural radioactive background of potassium (K), uranium (U) and thorium (Th).

The estimation of isotope concentrations using the WLS technique was described previously (Gadeken and others, 1988). The sensitivities for the post shot nuclides were found using the 1-dimensional nuclear transport code, ANISN,as was done previously (Gartner and others, 1990) in a different context. The sensitivity for the KUTh component was found earlier (Gadeken and others, 1991). The total gamma-ray log (Fig 5) shows radioactivity levels in excess of 10,000 API units. These high count rates made it necessary to perform dead time corrections on the experimental spectral data. The effects of pulse pile up were accounted for by appropriate adjustment of the isotope sensitivity matrices (Gartner and others, 1990). The experimental High spectrum in Fir 6 is duplicated in Fig 7 (upper) and overlaid with a composite spectrum containing the 4 components (137Cs, 125Sb, 106Ru and KUTh). The lower portion of Fig 7 graphically shows the relative amounts of the individual components as estimated using WLS algorithm.

Two sets of TracerScan data were analyzed for this paper. There were 31 static measurements. The results of the WLS concentration measurements are tabulated in Table 4.

The other TracerScan data set was the spectra obtained by averaging the continuous log data over 10 ft intervals. The WLS estimates are shown graphically in Fig 8 in standard log format. The left-hand track shows the continuous and averaged gamma rays overlaid as well as the Fit-Error curve showing the quality of the WLS estimates. The right-hand track displays the concentration estimates for the 4 individual components. Note that while the fine structure is suppressed, the medium scale structure (on the order of tens of feet) is fairly well reproduced. The Fit-Error curve is reasonably small which shows that 10 ft averaging resulted in better statistical precision and that the physical model (uniform distribution of isotopes within the formation) is quite good.

CONCLUSIONS

This paper has discussed laboratory and logging gamma-ray spectroscopy results for the Dalhart post shot investigation. The concentration estimates are in reasonable agreement considering the widely different volumes interrogated by the 2 techniques. There was difficulty in this comparison in absolute terms due to different units used in the laboratory and field measurements as well as due to questions of efficiency for the two different detectors used. However, the agreement in relative terms is good. The analysis reported herein has demonstrated that detailed concentration estimates for post shot nuclides can be done as a function of depth. It would not be difficult to extend this effort so that real-time calculations could be done as logging was performed.

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ACKNOWLEDGEMENTS

TABLES AND FIGURES

TABLE I

The following radionuclides may be present in postshot debris obtained within a few weeks of the event. Items * may be present after a few months. A prominent gamma ray (kev) used to identify the radionucide is listed.

7Be	52.93	d	477.56	*
46Sc	83.82	d	889.26	*
47Sc	3.35	d	159.4	
48Sc	1.82	d	1311.7	
54Mn	312.5	d	834.81	*
59Fe	44.6	d	1099.3	*
58Co	70.85	d	810.75	*
60Co	5.271	y	1332.46	*
87Y	3.32	d	484.7	
88Y	106.66	d	898.04	*
89Zr	3.27	d	909.1	
95Zr	64.05	d	756.71	*
92mNd	10.15	d	934.46	
99Mo	2.77	d	739.48	
103Ru	39.45	d	497.08	*
105Ru	1.473	d	319.	
106mAg	8.41	d	717.34	
122Sb	2.7	d	564.	
124Sb	60.2	d	602.72	*
127Sb	3.875	d	473.2	
132Te	3.25	d	522.65	
134Cs	2.062	y	604.66	*
137Cs	30.0	y	661.6	*
140Ba	12.8	d	537.35	
141Ce	32.5	d	145.44	*
143Ce	1.38	d	293.26	
144Ce	284.6	d	133.5	*
147Nd	11.04	d	531.1	
156Eu	15.15	d	1242.42	
160Tb	72	d	1177.94	*
181Hf	42.4	d	482.	*
182Ta	115	d	1121.3	*
183Ta	5	d	246.06	
187W	23.9	h	479.53	
188W	69.4	d	155.03	*
196Au	6.18	d	355.73	
198Au	2.696	d	411.8	
233Pa	27.0	d	311.89	*
235U	7.04E8	y	185.7	*
237U	6.75	d	208.	
239Np	2.35	d	277.62	

Those radionuclides which may be identified by gamma ray spectroscopy years after a nuclear event include the following:

54Mn	312.5	d	834.81 (100)			
60Co	5.271	y	1332.46 (100)	1173.21 (100)		
106Ru	368	d	511.8 (20)	621.8 (10)		
125Sb	2.77	y	427.95 (30)	463.5 (10)	600.8 (18)	636.15 (11)
134Cs	2.06	y	604.66 (98)	569.29 (15)	795.76 (85)	
137Cs	30.0	y	661.6 (85)			
144Ce	284.6	y	133.6 (11)			
147Pm	2.62	y	121.7 (0.008)			
152Eu	13.3	y	344.28 (26)	121.78 (28)	778.91 (13)	964.13 (15)
			1112.1 (13)	1408.01 (21)		
154Eu	8.59	y	723.3 (20)	1274.02 (40)	873.20 (12)	996.30 (10)
			1004.76 (18)			
155Eu	4.68	d	105.3 (22)			
235U	7.04E8	y	185.7 (54)			

TABLE II

Sample #	A	B	C	D
	Drilled Depth	Depth (FT)	Sb-125	H-3
1	1823	1721	9.2E+1	1.6E+4
2	1848	1743	6.2E+1	4.8E+4
3	1888	1782	7.0E+2	3.6E+4
4	1910	1805	3.9E+2	5.2E+4
5	1937	1828	1.4E+4	8.4E+4
6	2089	1972	6.5E+3	2.2E+5
7	2117	2004	1.8E+4	1.0E+5
8	2144	2024	3.2E+3	8.2E+4
9	2168	2046	1.8E+4	8.7E+4
10	2212	2088	1.3E+4	1.2E+5
11	2212	2088	2.7E+4	1.8E+5

A	Drilled Depth
B	Verticle Depth
C	γ's/min/g dry weight (427.95 Kev γ)
D	pCi/ml

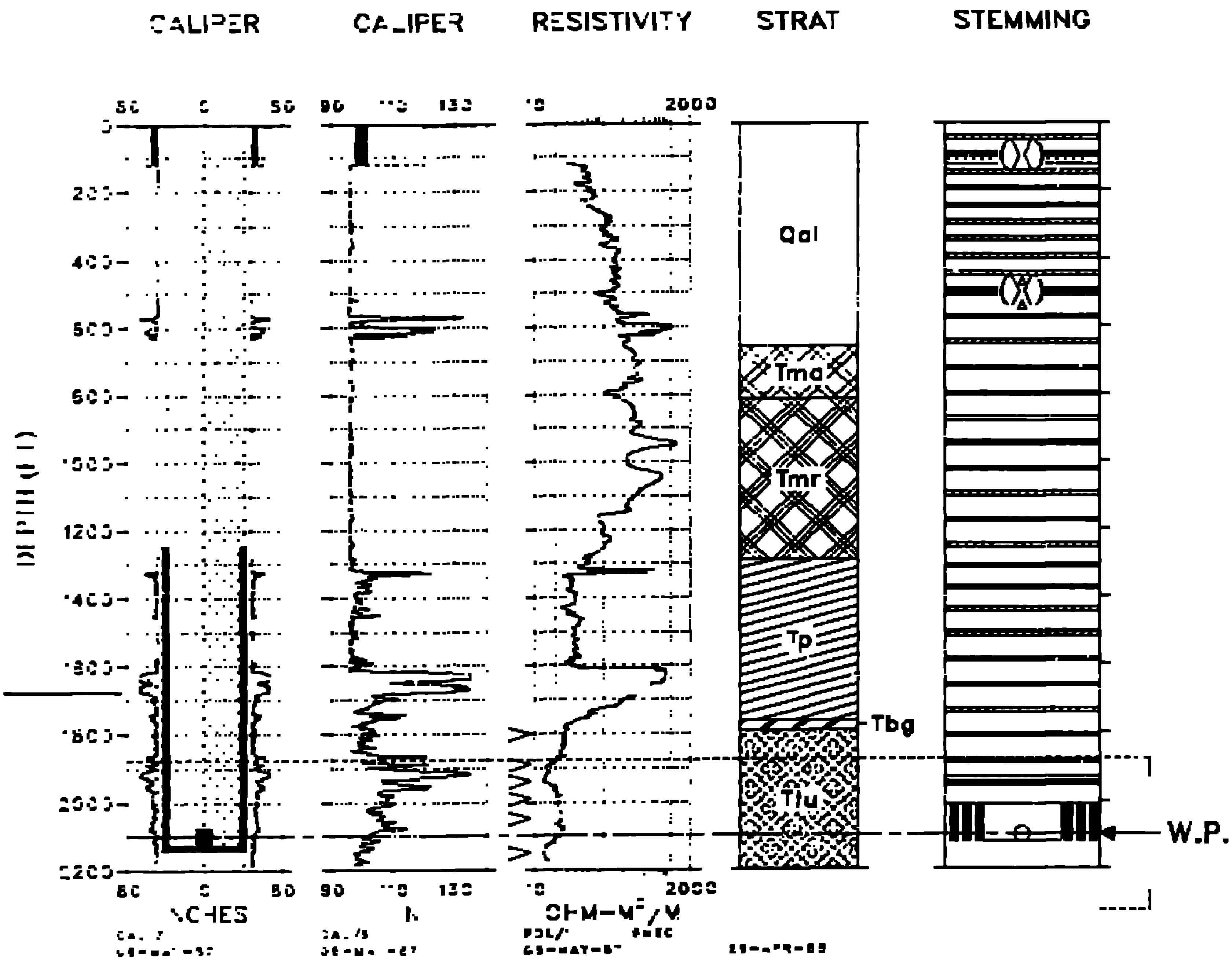
TABLE III

	A	B	C	D	E	F	G	H	I	J
[illegible]	[illegible]	Depth Ft	Sb-125/Sb-125	H-3/Sb-125	Cs-137/Sb-125	Cs-134/Sb-125	Ru-106/Sb-125	Zn-65/Sb-125	Co-60/Sb-125	Mn-54/Sb-125
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.7E-1	1.1E-0		2.2E-1	1.1E-1
[illegible]	[illegible]	[illegible]	[illegible]	7.7E-2	8.7E-0	2.2E-1	1.2E+0		6.1E-1	2.1E-1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5E-2	1.4E-1	1.3E+0		6.8E-2	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.2E-1	1.1E-1	[illegible]		7.6E-2	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.2E-1	1.0E-1	1.0E+0	1.6E-2	1.1E-1	1.1E-2
[illegible]	[illegible]	[illegible]	[illegible]	3.4E-1	1.1E-1	1.2E-1	4.1E+0	3.0E-2	5.3E-1	2.3E-1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.6E-1	2.4E-1	1.3E-0	5.7E-2	3.4E-1	2.1E-2
[illegible]	[illegible]	[illegible]	[illegible]	2.4E-2	5.1E-0	3.9E-2	1.5E+0		3.1E-2	
[illegible]	[illegible]	[illegible]	[illegible]	4.8E-0	8.1E-0	7.0E-2	1.6E+0	7.5E-3	4.2E-2	4.7E-3
[illegible]	[illegible]	[illegible]	[illegible]	9.2E-0	2.2E-1	1.8E-1	2.8E+0	1.3E-2	6.4E-2	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	6.7E-0	1.4E-1	1.2E-1	1.2E+0	1.4E-2	8.6E-2	8.9 -3

A	Drilled Depth
B	Vertical Depth
C	γ's/min/g dry weight relative to 427.95 Kev γ of Sb-125
D	pc/ml of 3H relative to 427.95 Kev γ of Sb-125
E	661.6 Kev γ's/min/g relative to 427.95 Kev γ of Sb-125
F	795.76 Kev γ's/min/g relative to 427.95 Kev γ of Sb-125
G	621.8 Kev γ's/min/g relative to 427.95 Kev γ of Sb-125
H	1115.45 Kev γ's/min/g relative to 427.95 Kev γ of Sb-125
I	1332.46 Kev γ's/min/g relative to 427.95 Kev γ of Sb-125
J	834.81 Kev γ's/min/g relative to 427.95 Kev γ of Sb-125

All counting date from March 1991

U4U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CALIPER
RESISTIVITY
STRAT
STEMMING
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90 110 130
10 2000
DEPTH (FT)
0
200
400
500
600
800
1000
1200
1400
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2200
Qal
Tma
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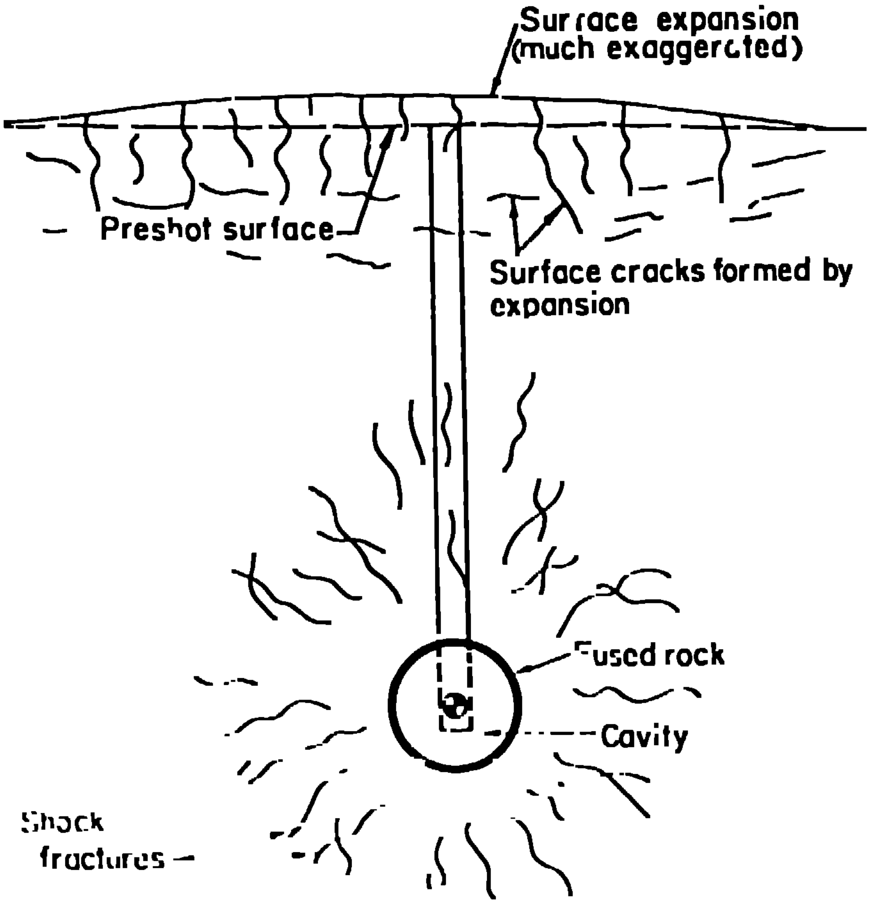
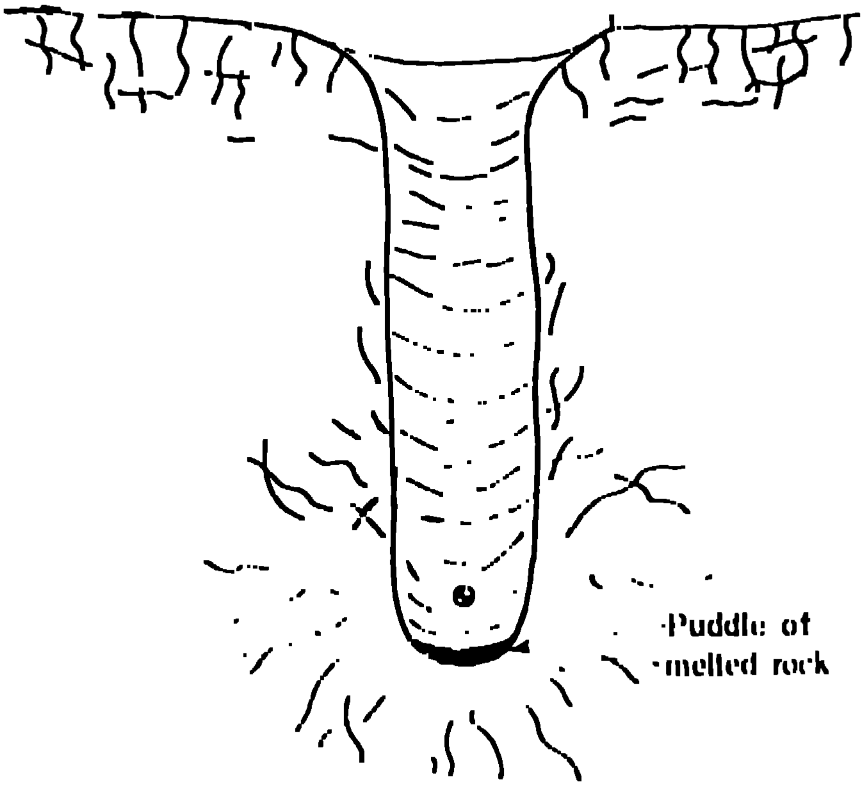
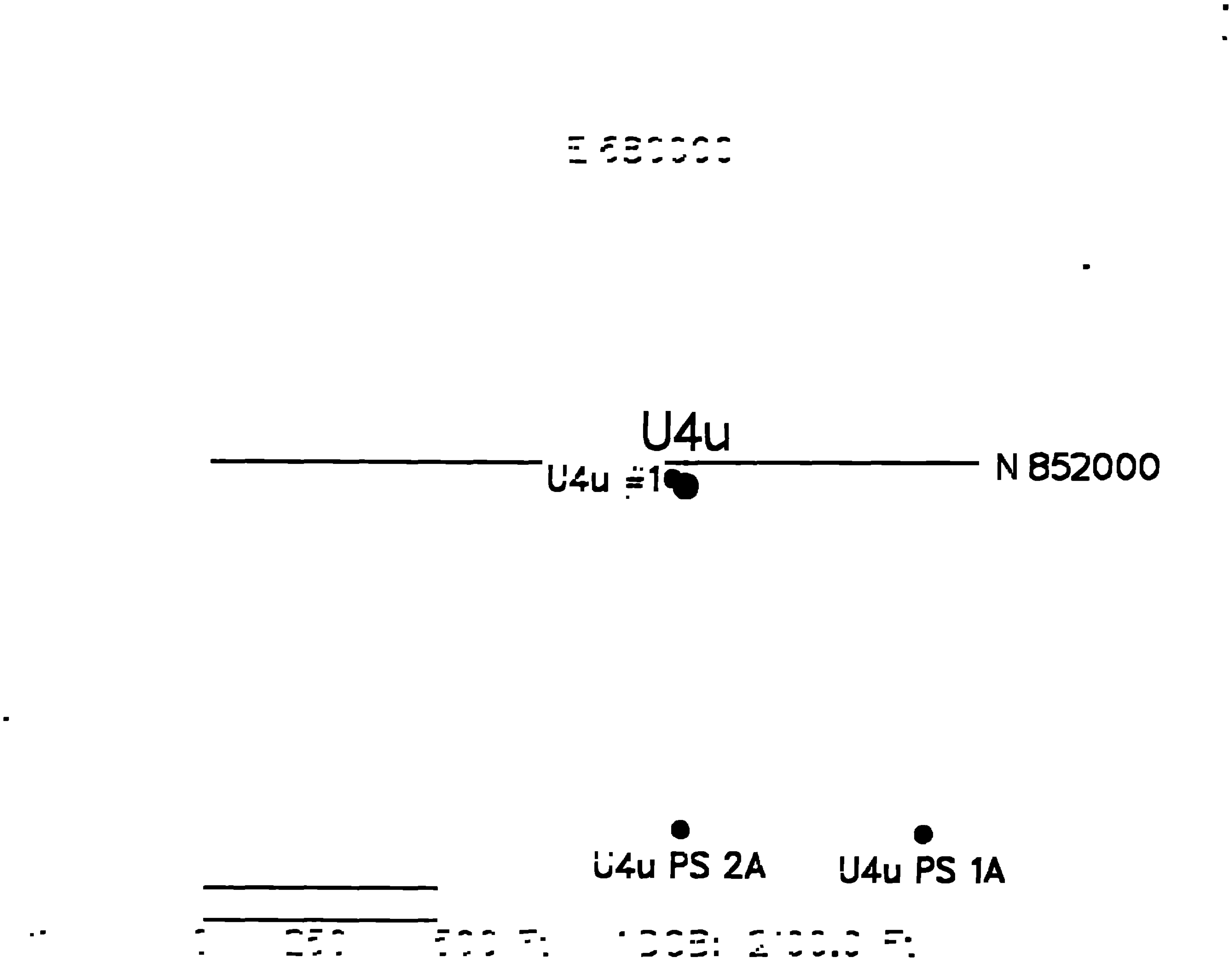
Tbg
Tlu
W.P.
INCHES
OHM-M²/M


Surface expansion
(much exaggerated)
Preshot surface
Surface cracks formed by expansion
Fused rock
Cavity
Shock fractures


Puddle of melted rock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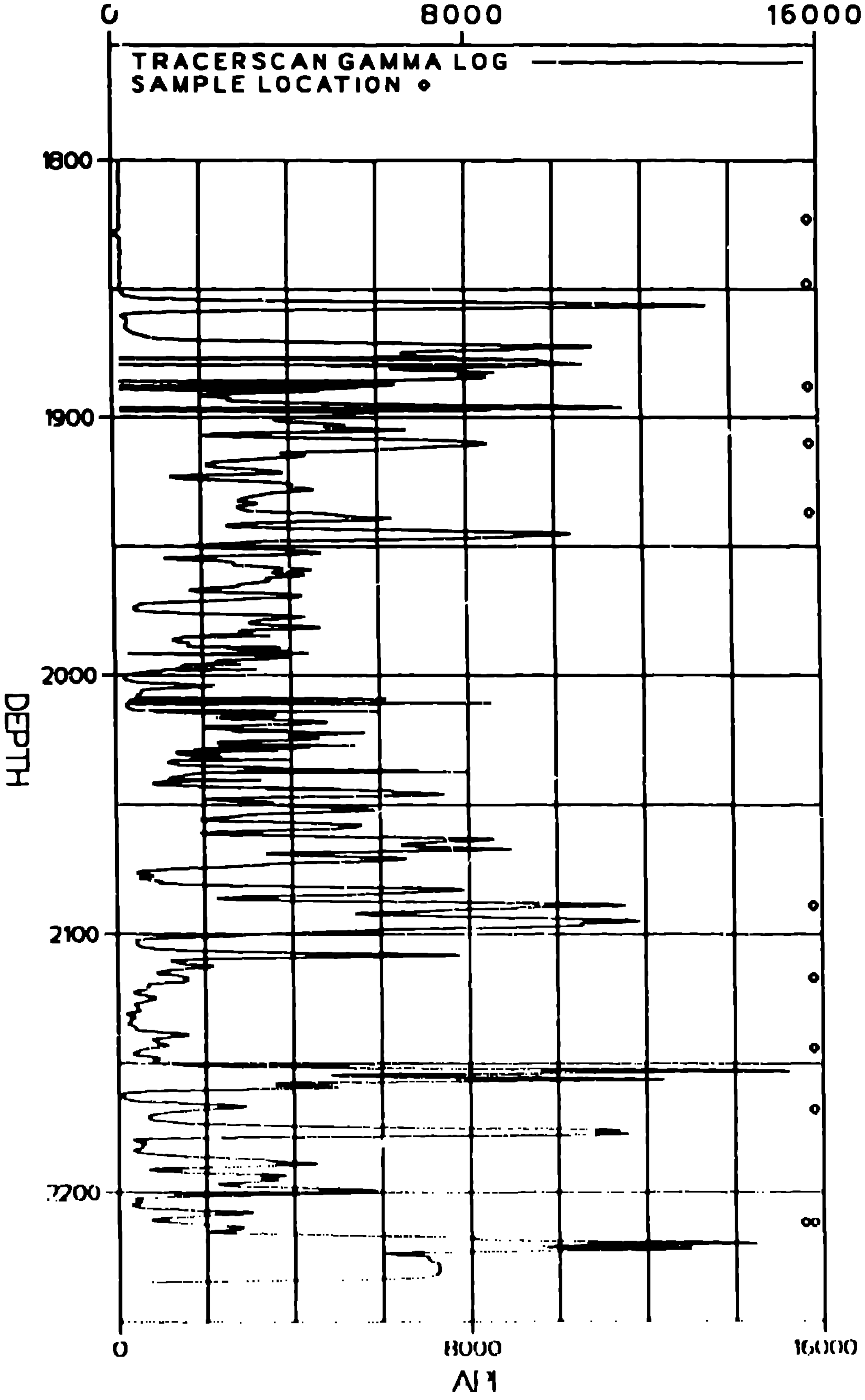
U4u #1
N 852000
U4u PS 2A
U4u PS 1A
0
250
500 Ft

U4U PS2A

TOTAL COUNTS GAMMA



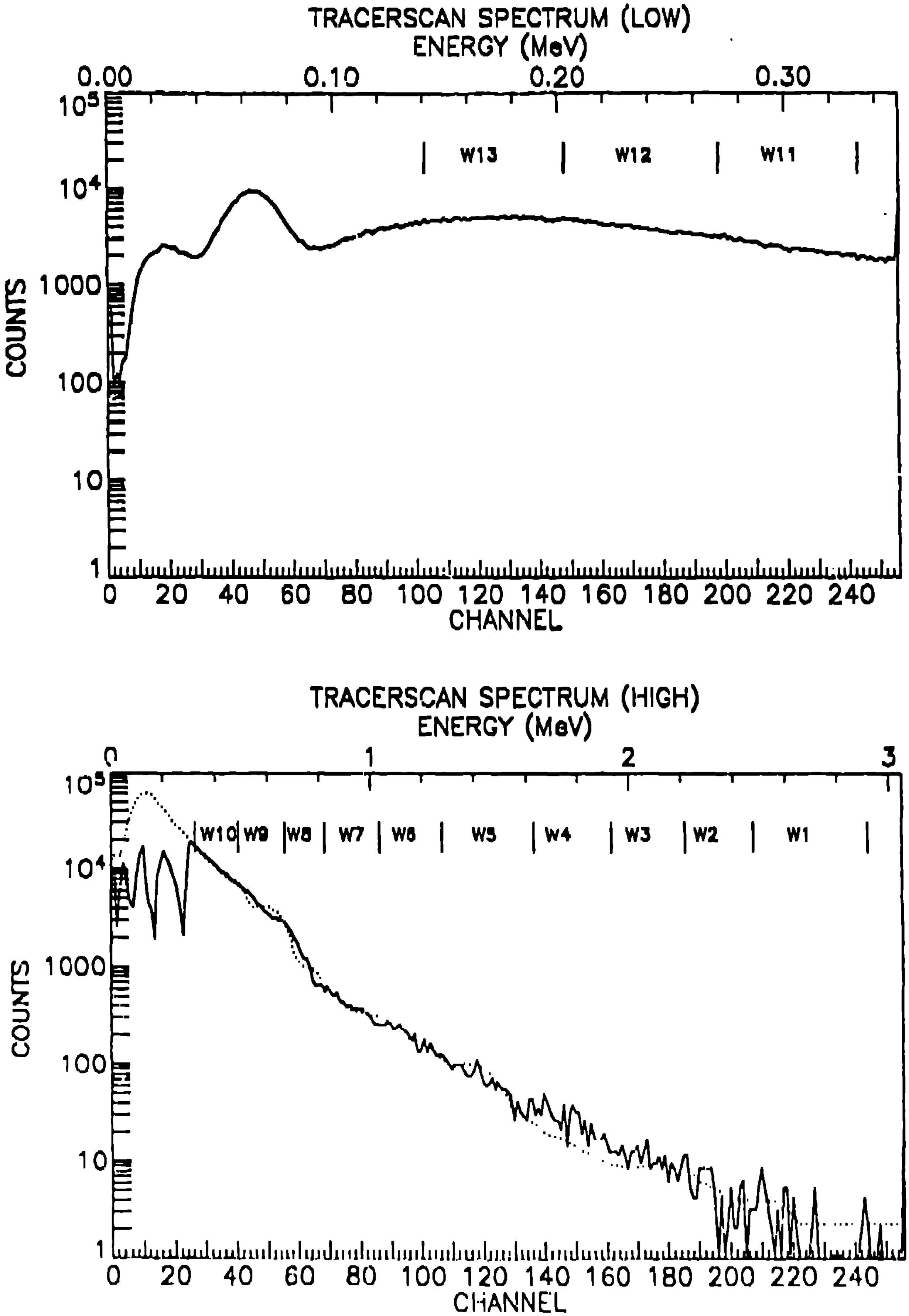
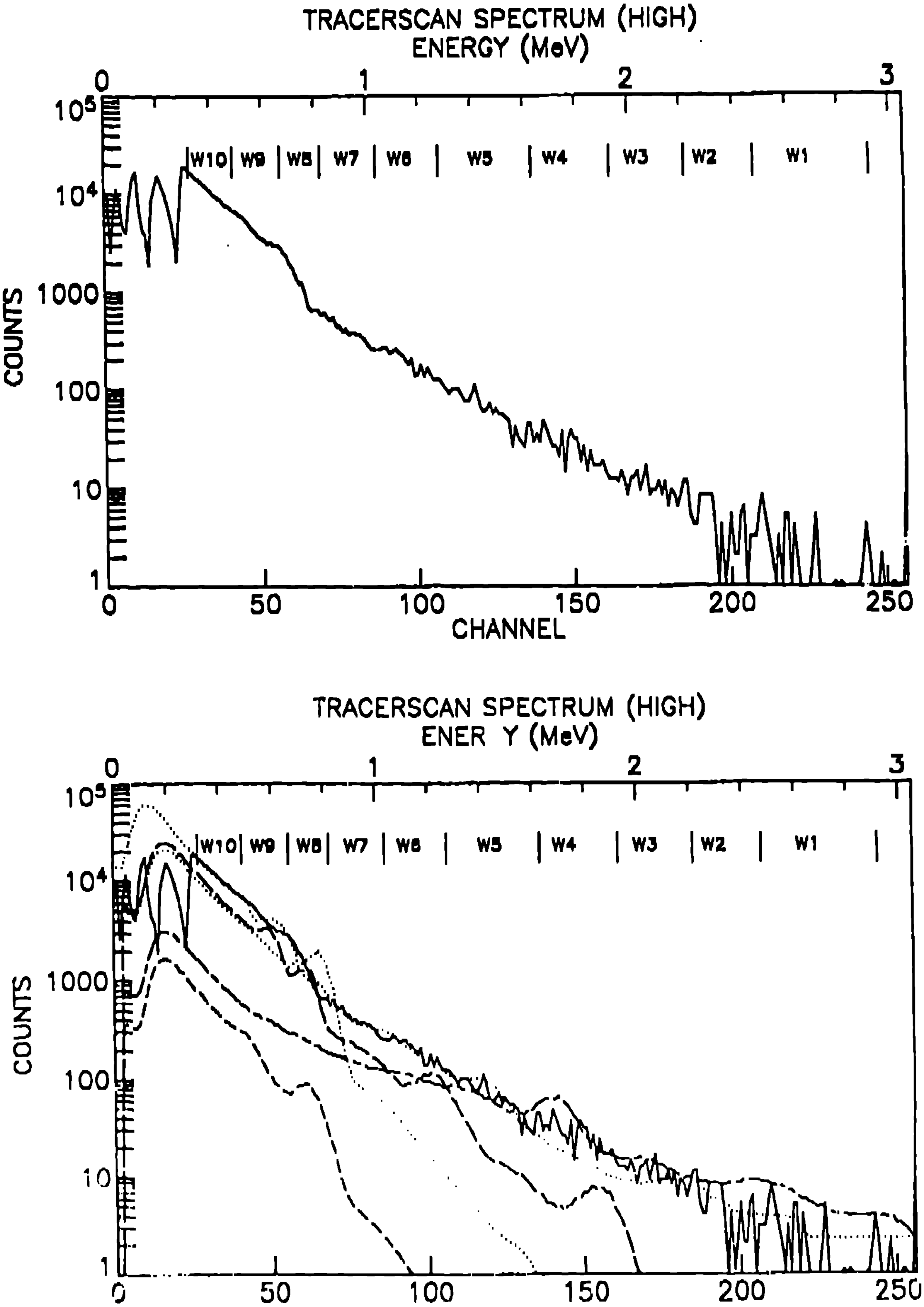

TRACERSCAN SPECTRUM (LOW)
ENERGY (MeV)
0.00
0.10
0.20
0.30
W13
W12
W11
COUNTS
10^5
10^4
1000
100
10
1
0
20
40
60
80
100
120
140
160
180
200
220
240
CHANNEL
TRACERSCAN SPECTRUM (HIGH)
ENERGY (MeV)
0
1
2
3
W10
W9
W8
W7
W6
W5
W4
W3
W2
W1
COUNTS
10^5
10^4
1000
100
10
1
0
20
40
60
80
100
120
140
160
180
200
220
240
CHANNEL

Figure 6



TRACERSCAN SPECTRUM (HIGH)

TRACERSCAN SPECTRUM (HIGH)

Figure 7

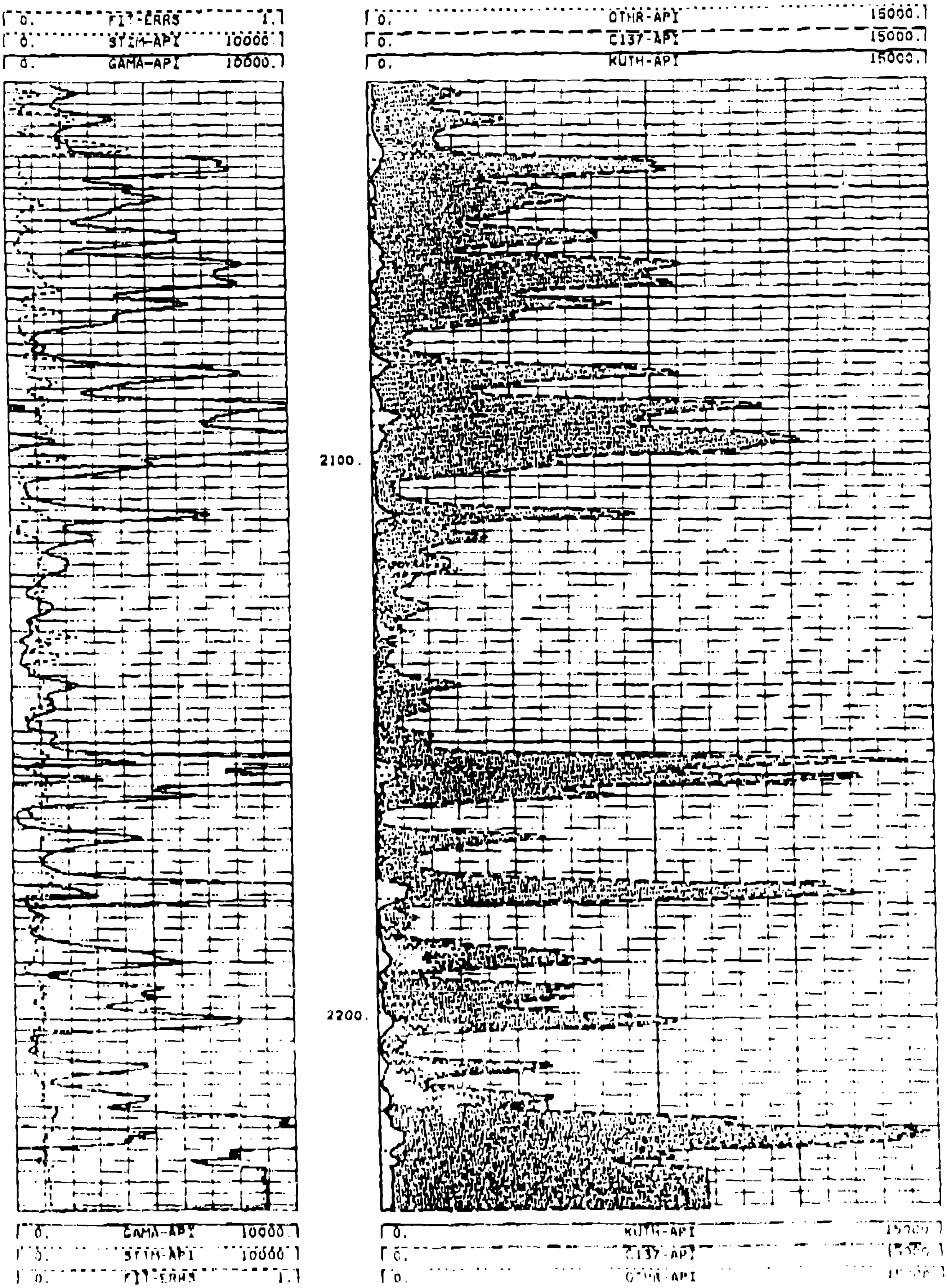


Fig. 8 Repeat Section [illegible] [illegible]