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DENVER, COLORADO 80202
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September 29, 1982

John D. Kinneman
Nuclear Regulatory Commission
Region I
631 Park Avenue
King of Prussia, Pa. 19406

Re: Stepan Chemical Company

Dear Mr. Kinneman:

As promised in my letter of March 22, 1982, to Myu Campbell, enclosed is a report on the radioactive residues in the field west of the Stepan Chemical Company plant in Maywood, New Jersey. The report was prepared by Nuclear Safety Associates, Inc.

Also included in the report is a more complete gamma radiation survey of the plant grounds. Please do not hesitate to call me or Henry Morton, at NSA, should you have any questions.

Sincerely yours,

Richard L. Jacobson

RLJ/dms
Enclosure

SURVEY OF RADIATION AND RADIOACTIVE MATERIALS AT THE MAYWOOD DIVISION OF THE STEPAN CHEMICAL COMPANY

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Characterization of Radioactive Material in the Field West of Stepan Chemical Company..... 2

Nuclear Safety Associates, Inc.
September 29, 1982

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RADIATION SURVEY OF THE STEPAN CHEMICAL COMPANY

Maywood Division
Maywood, New Jersey

Introduction

A comprehensive radiation survey of Stepan Chemical Company's Maywood Division plant has been conducted by Nuclear Safety Associates, Inc. The survey was designed to ascertain the radiological safety of work areas and to describe surface gamma radiation levels on the plant site. This is a report of the findings.

The survey included measurements in the buildings, on the plant grounds, on the thorium burial pits, and in the field at the west end of the site.

Conclusions

No significant alpha radiation was found in radiological surveys of any of the plant buildings. This indicates that the buildings are free of radioactive material contamination.

Gamma radiation exposure rates in all buildings other than Building 76 are within a normal background range. Occupancy in Building 76 is low and it is estimated that employee exposure is increased by less than four percent of the Federal standard applicable to individual members of the public, or about 20 millirem per year as a result of working therein.

Elevated gamma radiation levels were observed in the southwestern portion of the field between Highway 17 and the rail spur, along a dike adjacent the rail spur leading to the plant, in an area of the northwestern quadrant of the field, and along part of the northern fence boundary. The maximum gamma exposure rate observed in the field was 460 uR/hr. That is less than the NRC regulatory limit on permissible levels of radiation in unrestricted areas, 100 mrem in any 7 consecutive days (600 uR/hr continuously).

Elevated gamma radiation levels were also observed on the lawn between Buildings 76 and 78 where thorium processing buildings were previously located. Radiation levels in this area have been addressed previously in Stepan's response to the NRC's Inspection Report No. 40-8610/80-01. It has been estimated that an employee's exposure there will not exceed about 15 millirem per year.

Background

From about 1902 until 1956, Maywood Chemical Works extracted thorium compounds and rare earths from monazite as one of its processes. Stepan Chemical Company acquired the plant and property in 1959, three years after thorium processing ceased, and subsequently cleaned up the thorium waste and buried the thorium residues. Discovery of an area of thorium-bearing residue in the field at the west end of the property has prompted a thorough survey of the entire site to determine radiation levels on the site and to ascertain the radiological safety of the plant.

Survey Description

The purposes of the radiation survey were 1) to locate any surface accumulations of radioactive material on the site, 2) to describe the gamma radiation exposure rate on the site, and 3) to assess whether employees are exposed to radiation or radioactive material in excess of regulatory standards. The interior of buildings, the plant grounds, the field at the west end of the site, and the site perimeter were all surveyed.

Surface Alpha Radiation Survey

The presence of removable alpha radiation emitting material from surfaces in work areas can indicate a potential for occupant exposure by oral intake. In order to evaluate that potential, the interior of buildings were surveyed for removable alpha radiation emitting material.

Surfaces were surveyed for removable alpha emitters by wiping approximately 400 square centimeters of area with a filter paper disc. Each disc was then analyzed for alpha radiation using a Beckman Wide Beta-2 proportional counter.

Gamma Radiation Survey

Gamma radiation intensity on the Maywood Plant site was measured by using a Ludlum Model 12S scintillation survey instrument. Each reading was taken with the instrument held about one meter above ground or above the floor in a building. In Building 3 only, which is atop burial site 3, the gamma measurements, reported in Figure 13, were made with the instrument on the floor.

Calibration. The instrument used for the survey has been calibrated by correlation with independent measurements of gamma exposure rate at the same locations above a land surface source of natural uranium or natural thorium.

Correlations were established with both thermoluminescent dosimeters (TLD) and with pressurized ion chambers (PIC). The results are compared in Appendix A, Figure A1. For the gamma radiation survey on the Maywood Plant site, the calibration was based on the State of Florida PIC above 30 microroentgens per hour (uR/hr) and on combined State of Florida PIC and University of Florida PIC below 30 uR/hr. The calibration is explained further in Appendix A.

a correlation based on a standard reference point (sp?)

Results of Survey

Surface Alpha Radiation Survey

The locations in buildings where surfaces were wipe sampled for removable alpha emitting material are identified in Figures 1 through 13. Unless otherwise identified, each surface alpha sample was taken on the floor of the building. Only 3 of the 44 surface alpha samples exhibited any detectable alpha activity and none of the three exceeded one disintegration per minute per 100 cm^2 of area sampled (dpm/100 cm^2). Thus it can be said that none of the surface alpha samples exhibited any significant alpha activity. This can be recognized by comparison with the NRC recommended limit of 100 dpm/100 cm^2 area on equipment released to the public.

Gamma Radiation Survey

Buildings. Figures 1 through 13 also display gamma radiation exposures rates measured in the buildings at the Maywood Plant. Each value of the exposure rate is shown on the plan view at approximately the same location in the building where it was measured. Gamma exposure rates in all of the buildings other than Building 76 are within a normal range, as is illustrated in Figure 11, which is a histogram of those gamma radiation measurements. The geometric mean of those measurements is 7.4 uR/hour, about the same as the naturally occurring radiation exposure rate in the Maywood area.

Although the exposure rate was somewhat higher in Building 76, a geometric mean of 61 uR/hr, the radiation is apparently coming from ground adjacent the building. Building 76 is a warehouse, usually unoccupied. Even if a person worked therein as much as an hour each day, his annual radiation exposure would be increased by only about 20 millirem, which is but 4 percent of 500 millirem/year, which is the Federal standard applicable to individual members of the public.

Plant Grounds. Gamma radiation measurements of the plant grounds, including measurements atop burial sites 1 and 2 are displayed in Figure 15 at the approximate location where they were measured. Gamma radiation exposure rates around buildings in the natural products area averaged 7.8 uR/hr which compares favorably with the natural background exposure rate in the Maywood area, 6 to 7.5 uR/hr, or with that observed in southern New Jersey.

Gamma exposure rates above the thorium residue burial sites 1 and 2 in the parking lot and the lawn averaged 11 and 18 uR/hr, respectively. Assuming continuous exposure, each of these would be less than one-third of the Federal standard applicable to individual members of the public. No single reading exceeded the standard.

The lawn area adjacent the southeast side of Building 76 where thorium processing facilities were once located was found to have elevated gamma levels. Assuming most exposure there occurs while mowing the grass, a person would receive about 15 millirem/year from doing that job, or 3 percent of the Federal standard. Adjacent the west side of Building 76, gamma levels were somewhat elevated, but the area is seldom visited.

is correct 600 μr/h

Gamma radiation levels along the fence between Buildings 76 and 78 were elevated but all of the readings were less than 600 uR/hr. Continuous exposure at 600 uR/hr would equal 100 mrem in 7 days, the regulatory limit on radiation levels in an unrestricted area.

A small area near the electrical metering building in the southwestern quadrant of the plant exhibited somewhat elevated gamma radiation levels, apparently associated with a small, shallow deposit of residue. Gamma exposure rates at that spot may also be seen on Figure 15.

On the basis of gamma radiation levels observed in buildings and on the plant grounds during this survey, it is very unlikely that any Stepan employee receives as much as 500 millirem/year, the Federal exposure standard appropriate for individual members of the public in public areas, while working at the Maywood Plant.

Field West of Plant. The field at the west end of Stepan's property between the plant grounds, Highway 17, and the Susquehanna and Western Railroad was surveyed for gamma radiation using a Ludlum model 12S survey instrument held about one meter above the ground. The survey is recorded on Figure 15.

To aid in calibrating the survey instrument and to check on the measurements, gamma exposure rates at selected locations were measured by $CaSO_4$(Dy) TLD over a period of about two months. Exposure rates thus measured appear in Figure 16. They are within 3 uR/hr of the survey instrument measurement below about 20 uR/hr and differ by 18% above 20 uR/hr.

Elevated gamma levels were observed in the southwestern portion of the field between Highway 17 and the rail spur, along a dike adjacent the rail spur leading into the plant, in an area in the northwestern quadrant of the field, and along part of the northern fence boundary. The location and general extent of these areas can be seen in Figure 15.

The measurements indicate the gamma exposure rate at one meter above ground in the area between Highway 17 and the rail spur is variable, ranging up to a maximum single observation of 460 uR/hr. The radiation is associated with deposits of thorium bearing residues. In the remainder of the field the maximum reading observed was 250 uR/hr in the

northwestern quadrant of the field associated with thorium bearing residue and debris. Readings did not exceed 200 uR/hr at the fence surrounding the field and in most locations were much lower.

For comparison with these maximum levels, an NRC regulation on permissible levels of radiation in unrestricted areas (10 CFR 20.105 (b)) states:

> "...no licensee shall possess, use, or transfer licensed material in such a manner as to create in any unrestricted area from radioactive material and other sources of radiation in his possession:...radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 100 millirems in any seven consecutive days."

The regulation would not seem to be strictly applicable in that the source of the radiation is not licensed material. It may, however, be useful for comparison. The field is completely fenced with chain-link fencing and is posted. Beyond the fence, there are no residences adjacent the field; it is bordered by a railroad on the north, by a highway on the west, by commercial property on the south and by Stepan's plant on the east. Clearly, the radiation exposure to a member of the public from sources within the field will also be less than the Federal standard of 500 mrem per year. Stepan employees enter the field rather infrequently and because of the absence of activities in the elevated areas of the field, any exposure to employees is expected to be infrequent and at most only to small fractions of the standard of 500 mrem/year.

Accordingly, it is concluded that the levels of gamma radiation found at the Stepan Chemical Company's Maywood Plant do not present radiation exposures to plant employees or members of the public in excess of that permitted by Federal radiation standards.

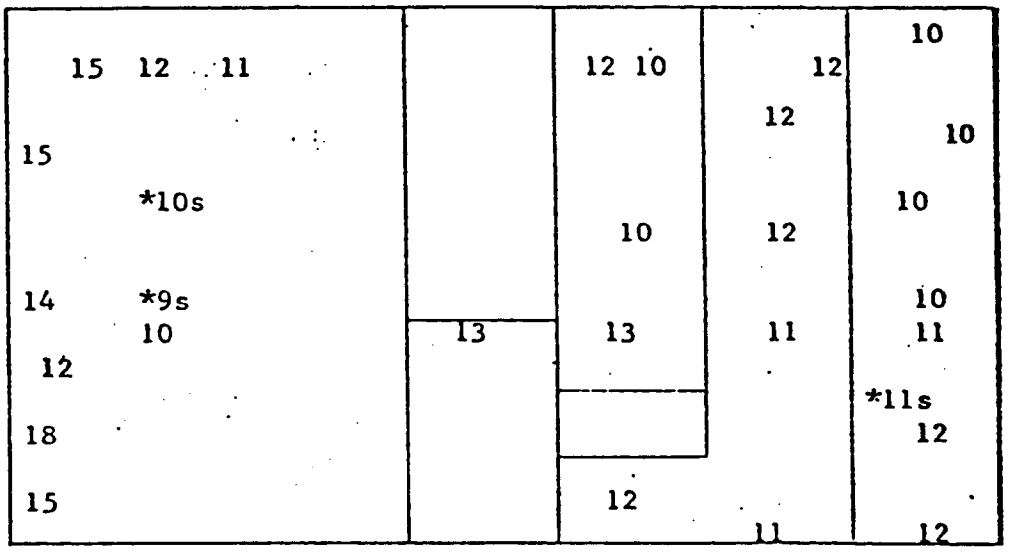

Figure 1. Radiation Survey of Building 78. Numerical values are gamma radiation intensity (μR/hr).
*--S represents the location of a surface alpha sample.

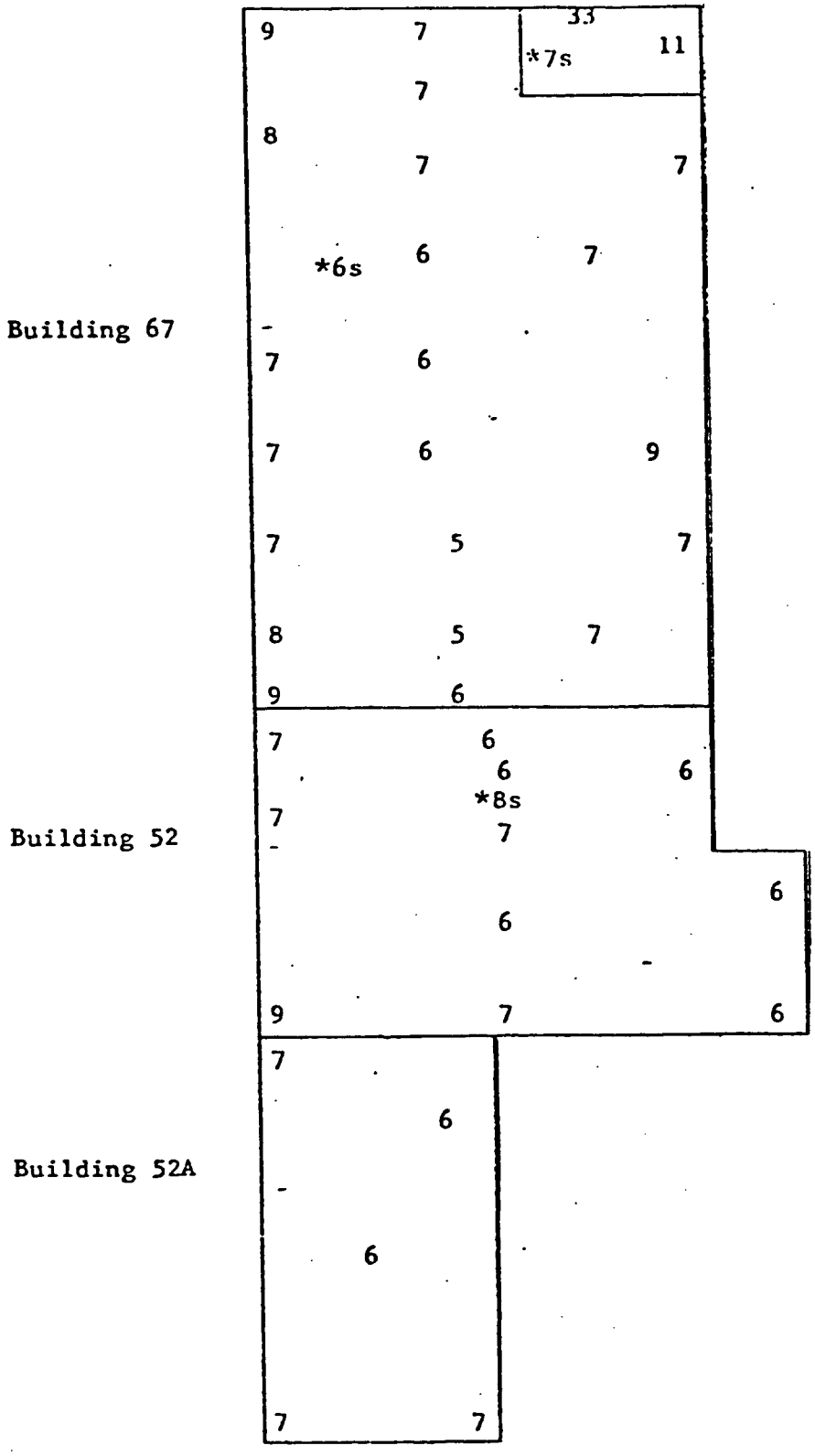

Figure 2. Radiation Survey in Buildings 52, 52A, and 67. Numerical values are gamma radiation intensity (μR/hr) *--S represents the location of a surface alpha sample.

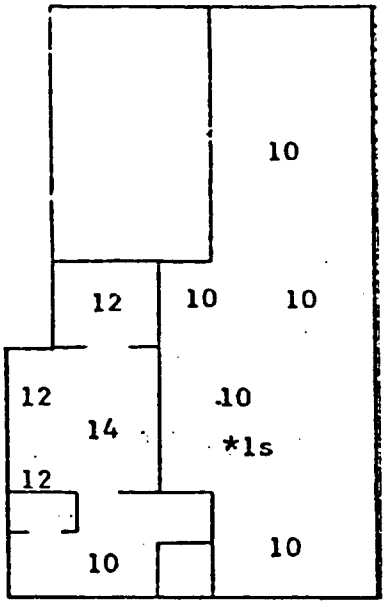

Figure 3. Radiation Survey of Building 20

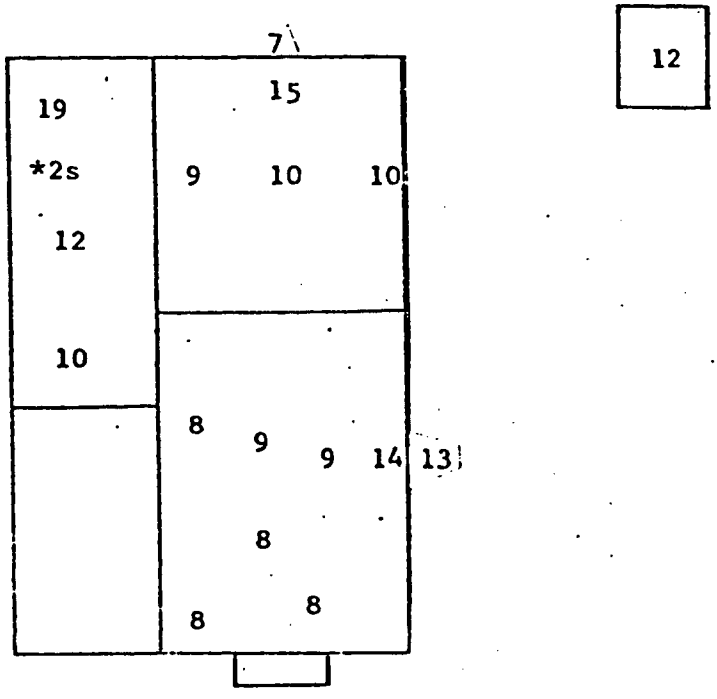

Figure 4. Radiation Survey of Building 1 and Guardhouse. Numerical values are gamma radiation intensity (μR/hr) *--S represents the location of a surface alpha sample.

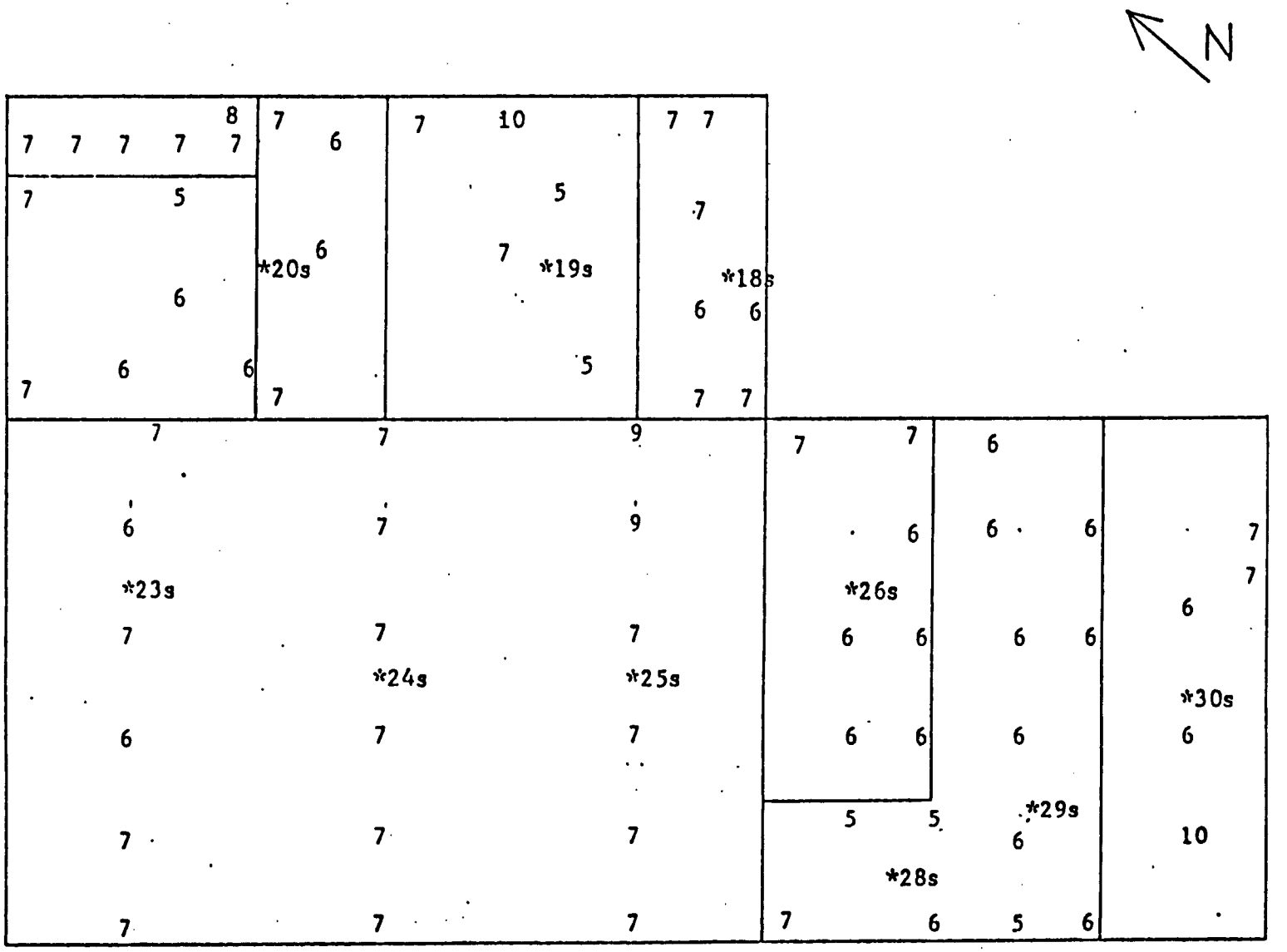

Figure 5. Radiation Survey in Building 13

(*--s represents the location of a surface alpha sample.)

(Other numbers represent the gamma radiation intensity (μR/hr).)

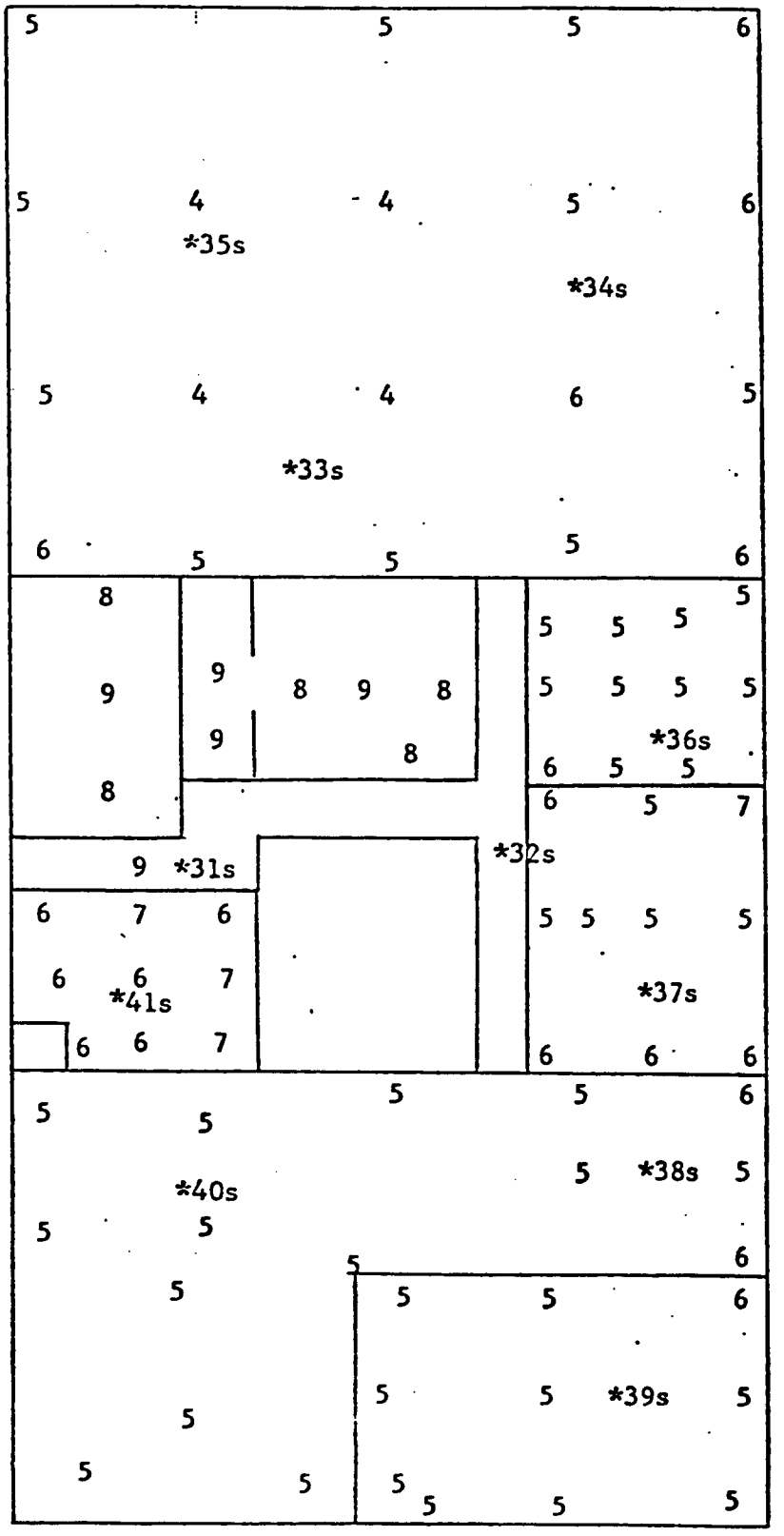

Figure 6. Radiation Survey in Building 2

(*--s represents the location of a surface alpha sample.)

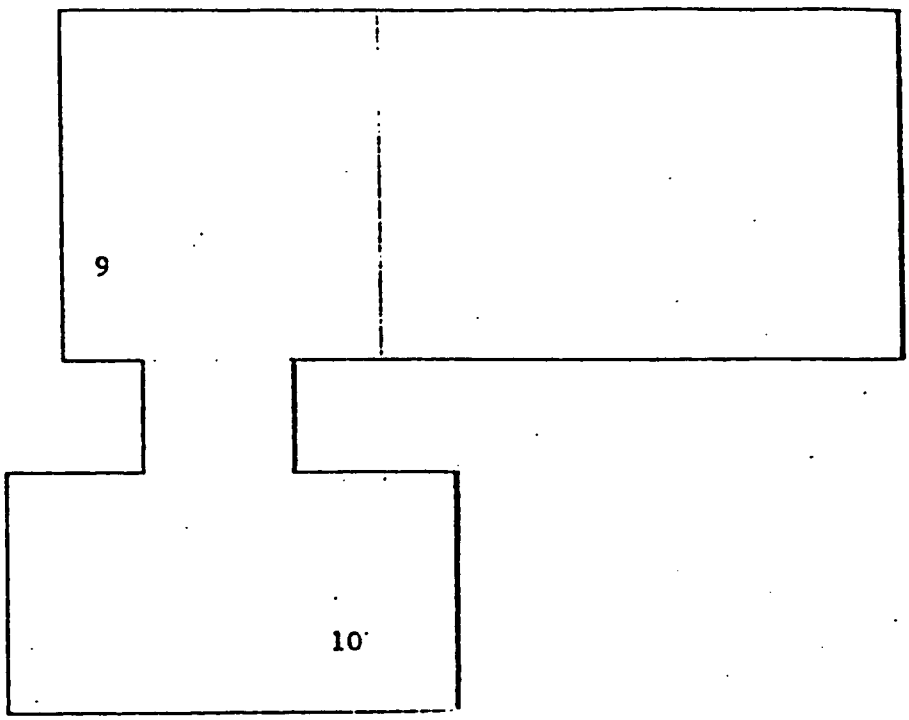

Figure 7. Radiation Survey of Building 15

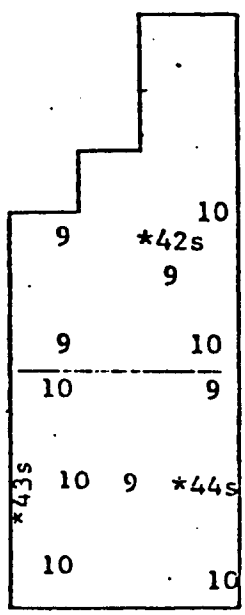

Figure 8. Radiation Survey of Building 14. Numerical values are gamma radiation intensity (μR/hr). *--S represents the location of a surface alpha sample. Alpha sample *43S was taken on the wall.

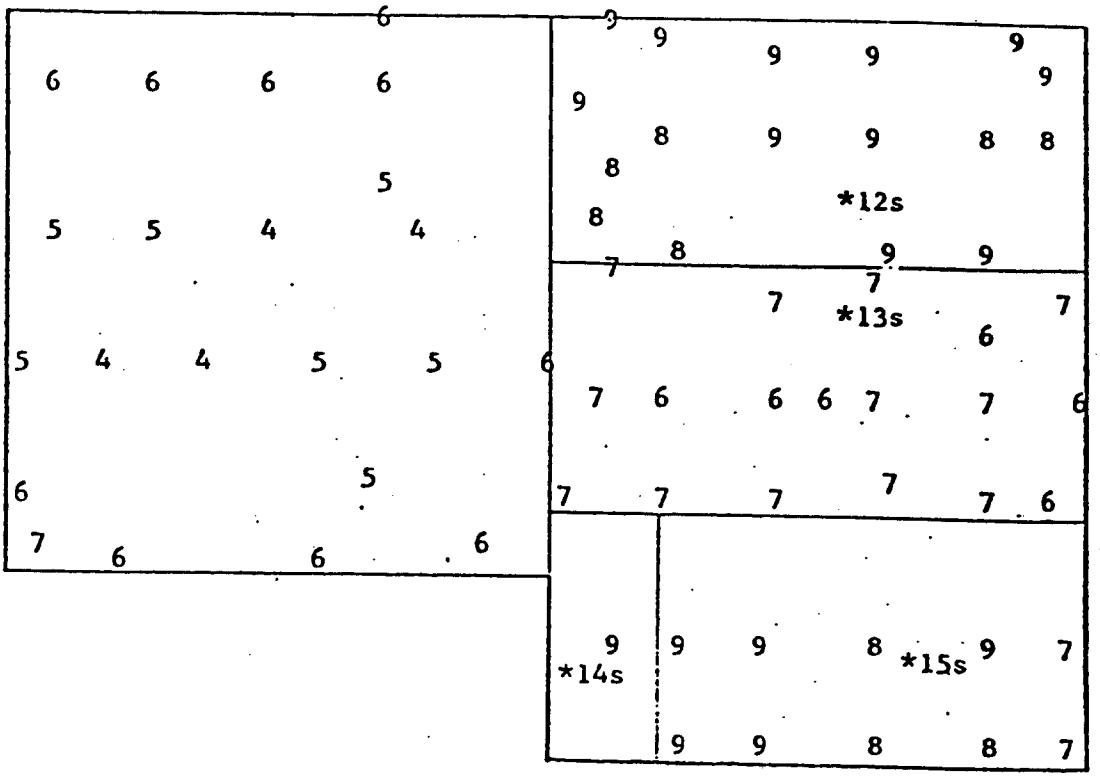

Figure 9. Radiation Survey in Building 10

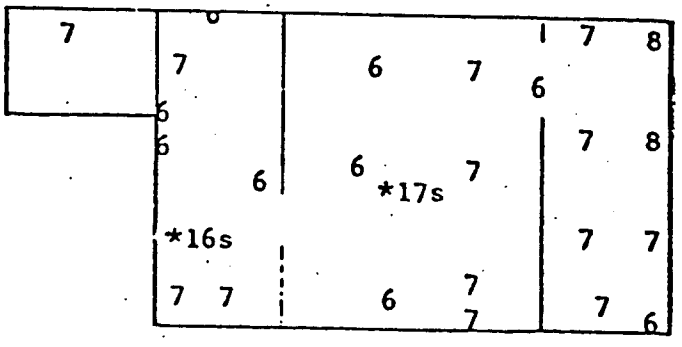

Figure 10. Radiation Survey in Building 10 H. Numerical values are gamma radiation intensity (μR/hr). *--S represents the location of a surface alpha sample.

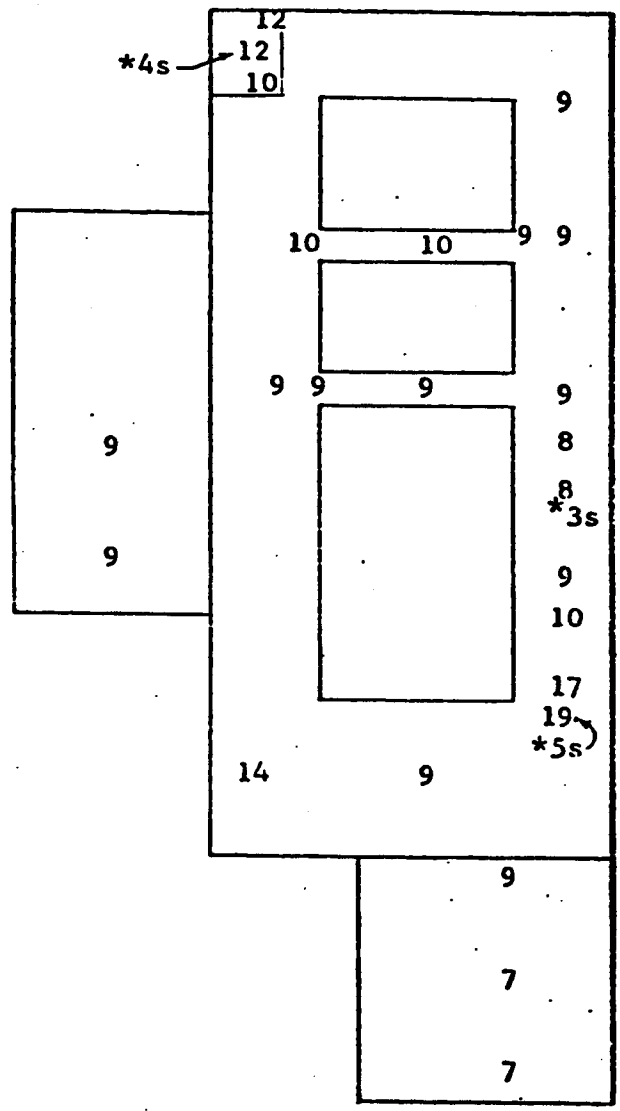

Figure 11. Radiation Survey in Building 4. Numerical values are gamma radiation intensity (μR/hr) *--S represents the location of a surface alpha sample.

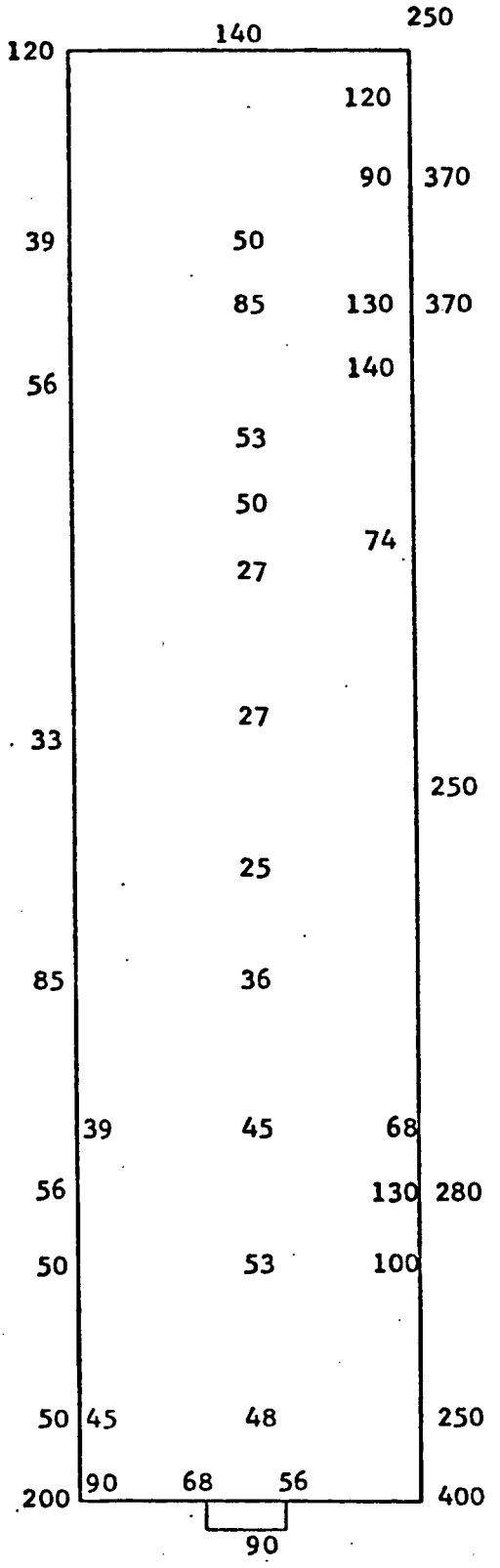

Figure 12. Radiation Survey in Building 76

Numerical values represent gamma radiation intensity (μR/hr).

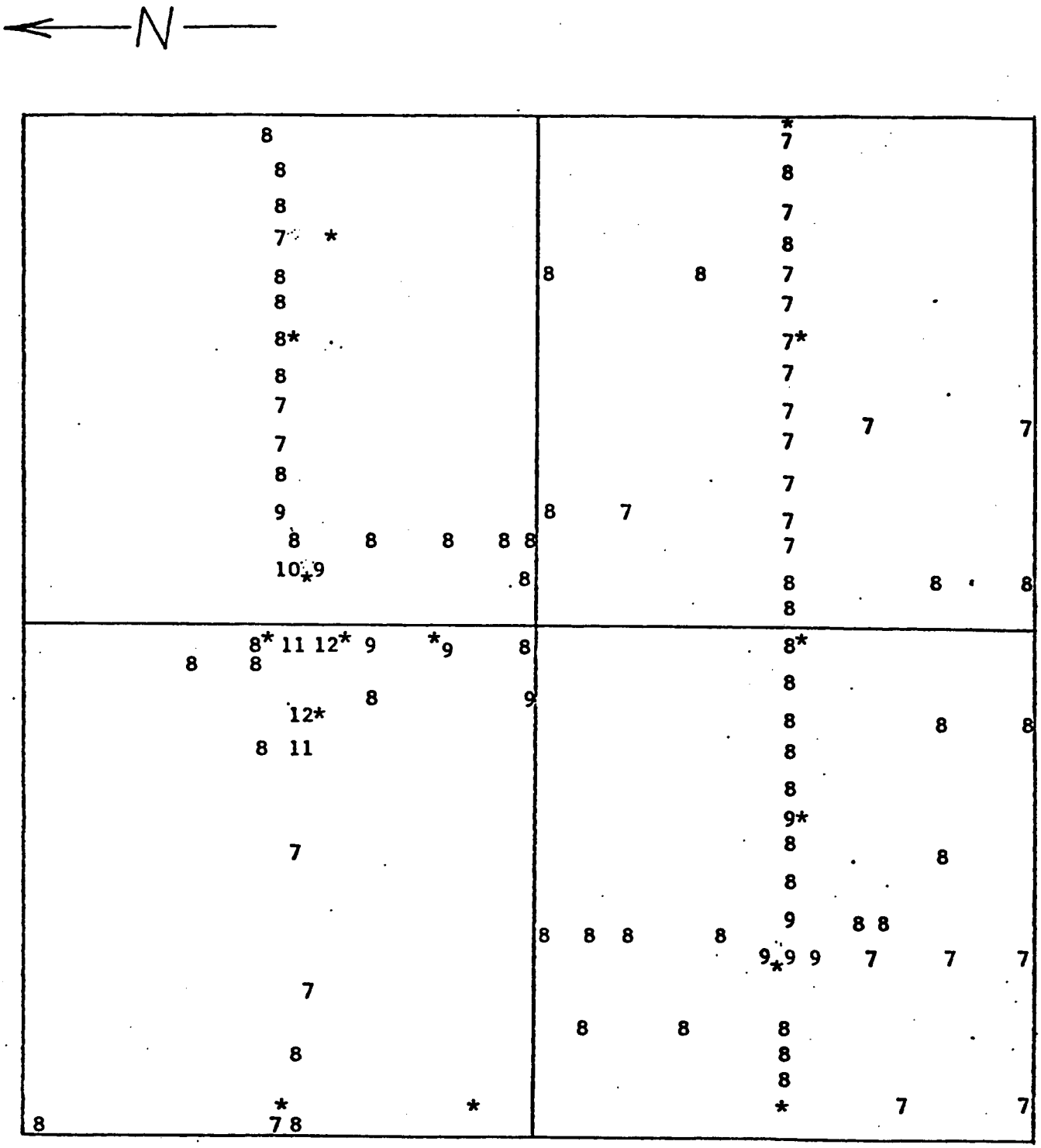

Figure 13. Gamma Radiation Survey in Building 3
Numerical Values represent gamma intensity (μR/hr). The * represents the location of a surface alpha sample.

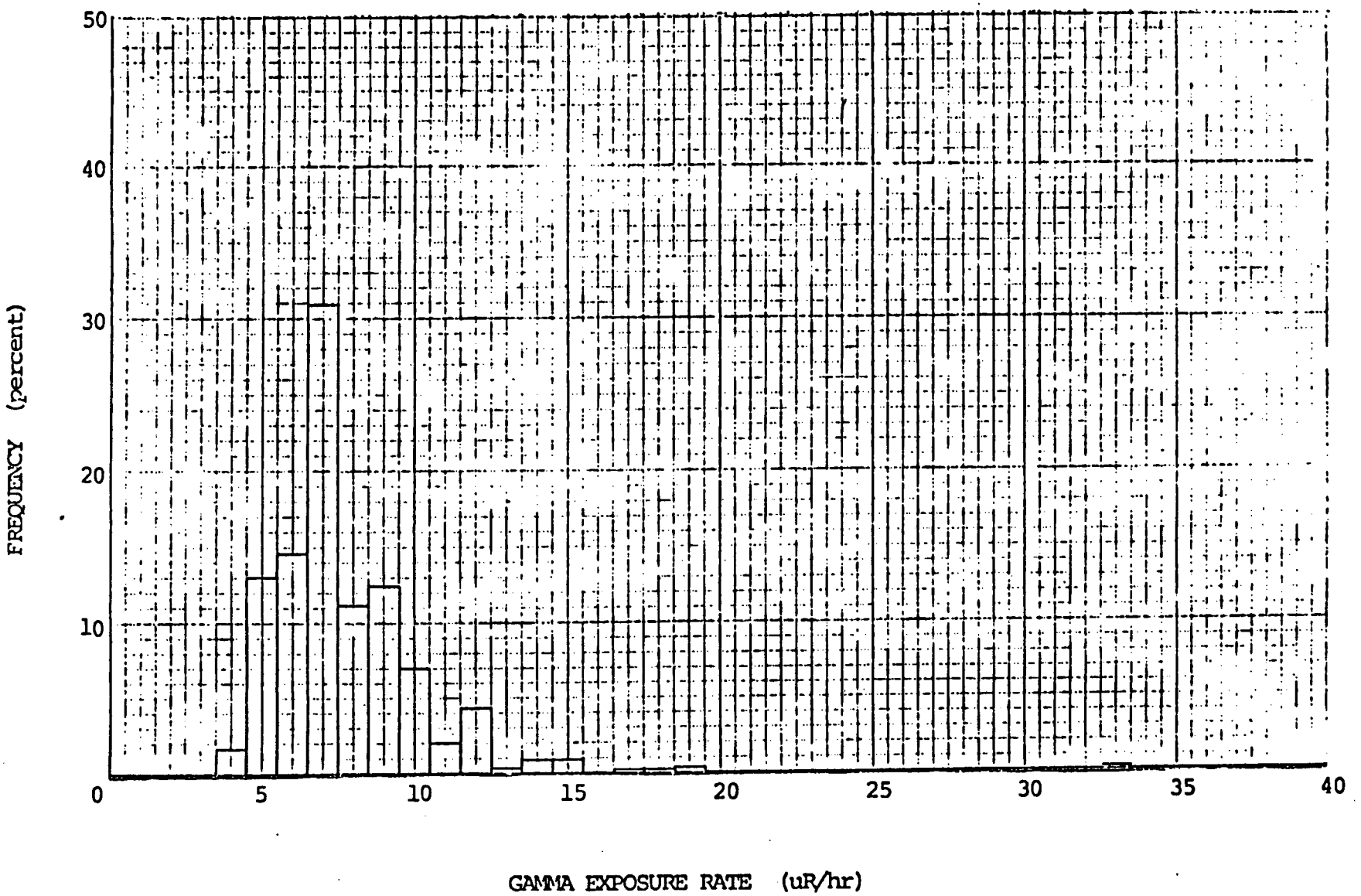

Figure 14 Histogram of Gamma Radiation Measured in Maywood Plant Buildings

Building 76 not included.

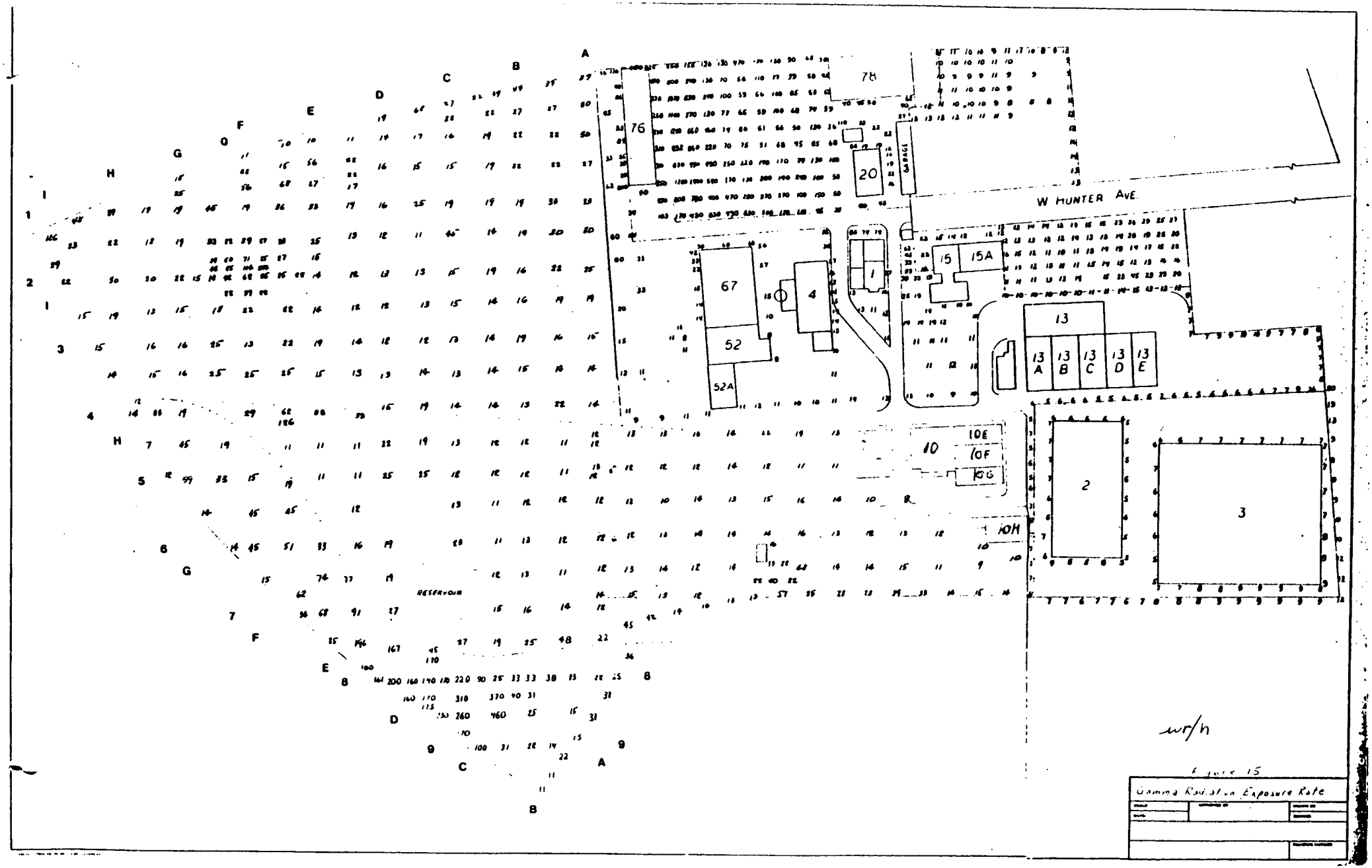

Figure 15

Gamma Radiation Exposure Rate

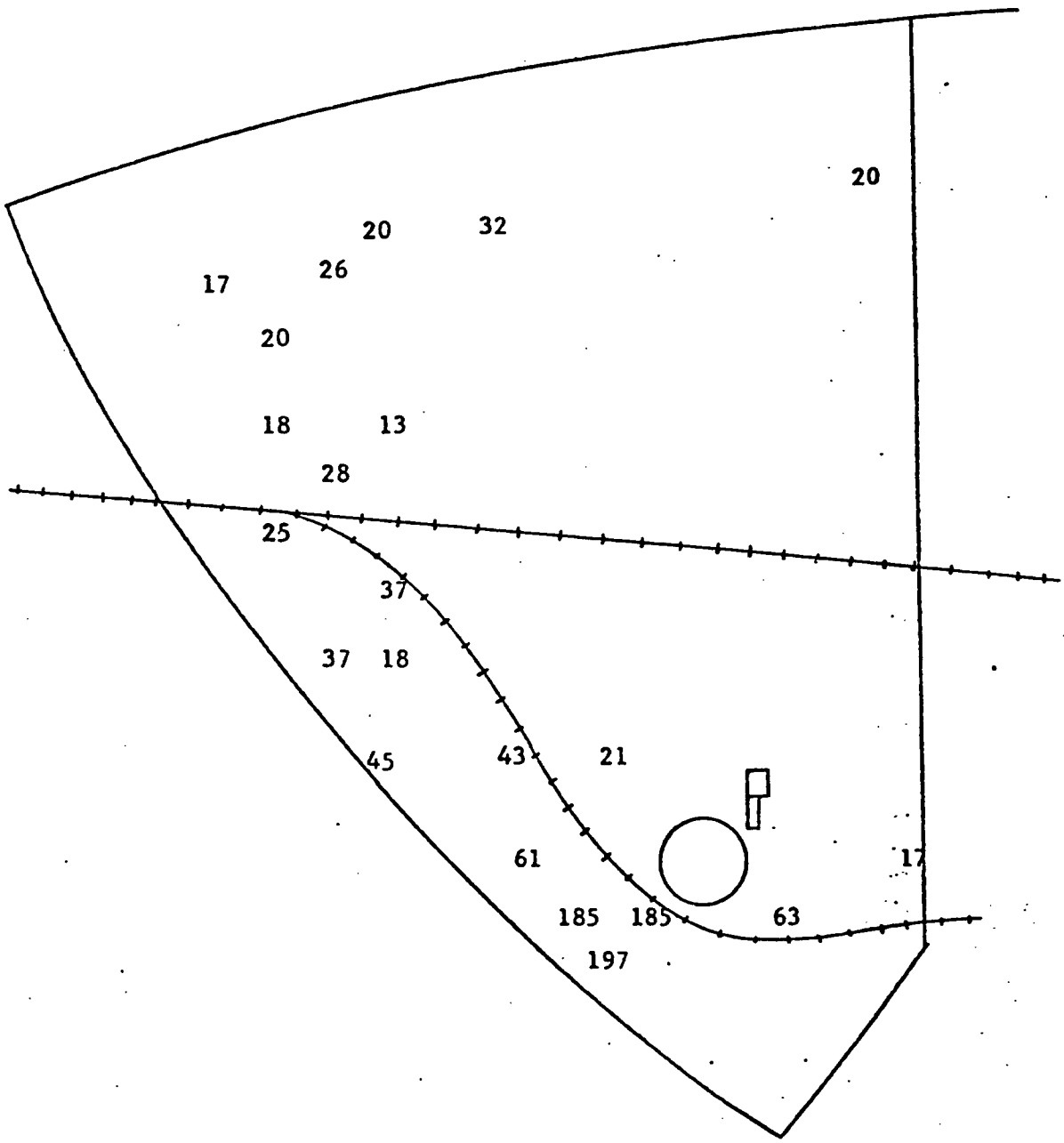

Figure 16. Gamma Radiation Exposure Rate in the Field Measured by Thermoluminescent Dosimeters. Units: microRoentgen/hour

APPENDIX A

Ludlum 12S Gamma Scintillation Survey Instrument Calibration

A Ludlum 12S gamma scintillation survey instrument was used to measure the gamma exposure rate above a land source of natural thorium series and, to a minor extent, natural uranium series radionuclides. It was calibrated by comparison with $CaSO_4$ thermoluminescent dosimeter (TLD) measurements made above the same land and with pressurized ion chamber (PIC) measurements made above land containing natural uranium series radionuclides. Each calibration point was obtained by making a measurement with the survey instrument and with a TLD or PIC at the same location about one meter above ground.

A set of 21 TLD and instrument readings were made above land by Nuclear Safety Associates and the TLD exposure interpreted by Teledyne Isotopes. The TLD were deployed approximately two months and instrument readings were taken when the TLD were retrieved. The land contained natural thorium series and a minor amount of natural uranium series radionuclides.

A separate set of 24 readings was assembled from TLD readings made by the NRC and by a survey instrument reading made by NSA at each of the TLD locations.

Two separate comparisons of the Ludlum survey instrument and a PIC were made above land sources of natural uranium series radionuclides in Florida. In one case, a set of 15 measurements were made at the University of Florida. In the second case, the State of Florida Radiological Health Services compared six survey instruments of the same model including the one of interest, with a PIC at 7 locations.

Each PIC was initially calibrated by its manufacturer, Reuter Stokes, with a radioactive source traceable to the National Bureau of Standards. The State's PIC has been recalibrated annually with an NBS secondary standard.

The resulting best fit correlation curves describing the four comparisons appear in Figure A1. Each comparison is best represented by a two component linear fit. The TLD curves were generally higher than the PIC curves. Differences in the curves may be related to slight differences in energy dependent response between TLD and PIC, in gamma spectra from land sources of natural thorium and natural uranium, or other related factors.

Even so, the NSA TLD curve, made with $CaSO_4$(Dy) TLD over the thorium bearing land of interest would indicate an exposure rate just 18% above the State of Florida PIC curve. This correlation would seem to be acceptable agreement for the intended field survey.

Differences in TLD and PIC response may be seen in Figure A2. The energy dependence of Teledyne $CaSO_4$(Dy) TLD and Reuter Stokes PIC are compared by normalizing energy response curves to unity at the energy level of one million electron volts (1 Mev). The energy response curves were provided by Teledyne Isotopes and Reuter Stokes, Inc. respectively. The response is about the same between 0.1 and 1 Mev. Below 0.1 Mev, the TLD is more responsive than the PIC. Although no data were reported above 1 Mev for the TLD, its energy response above 1 Mev should be about the same as it is at 1 Mev. Overall, the TLD should indicate a slightly higher exposure rate than the PIC when exposed to natural radiation from the ground.

The gamma radiation spectra of both the uranium series and the thorium series are complex, include a broad energy band to about 2.5 Mev, and are similar when measured above a distributed land source of the radioactive material. The similarity is evident in Figure A-3 which applies closely to the dosimetry conditions of interest. In Figure A-3, the integral exposure rate spectra at one meter above land containing uranium series and thorium series radionuclides respectively[a] are seen

a H. Beck and G. dePlanque, 1968, The Radiation Field in Air Due to Distributed Gamma Ray Sources in the Ground, HASL-195, May 1968.

to be similar. Either spectrum should be adequate for calibrating an instrument for surveying land under conditions similar to the calibration. Moreover, calibrating a field survey instrument under conditions similar to its intended use (ie, above a land source of either natural uranium series or thorium series radioactivity) is preferrable to calibration with a monoenergetic or even multienergy point source in air.

A calibration curve to be used with the Ludlum 12S survey instrument when measuring the gamma exposure rate about one meter above a distributed land source of thorium series and/or uranium series radioactivity was selected from the curves in Figure A1. The calibration of the Ludlum 12S survey instrument below 30 uR/hr is based on combined State and University of Florida PIC measurements, and above 30 uR/hr on the State of Florida PIC comparison. The reasons for the choice are:

1. a PIC overresponds less at low energies than TLD;
2. the State of Florida has experience in calibrating the same model instrument to measure land sources of radiation;
3. the State and the University PIC calibrations differ by less than 2 uR/hr when the exposure rate is less than 30 uR/hr;
4. the PIC were calibrated with NBS traceable sources; and
5. the survey instrument and PIC measurements of the land sources were made at the same time (ie, same day and under identical conditions).

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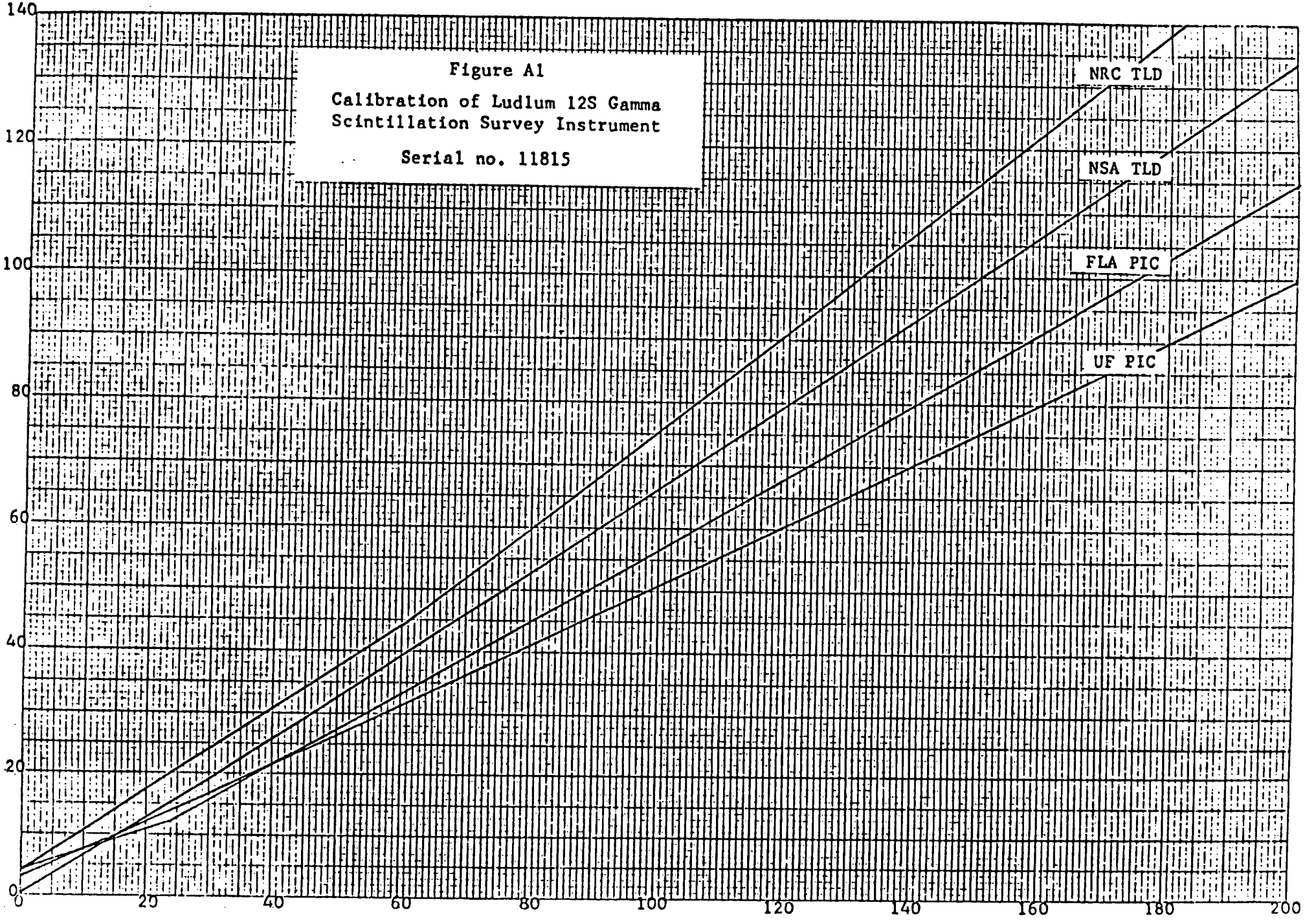


Figure A1

Calibration of Ludlum 12S Gamma Scintillation Survey Instrument

Serial no. 11815

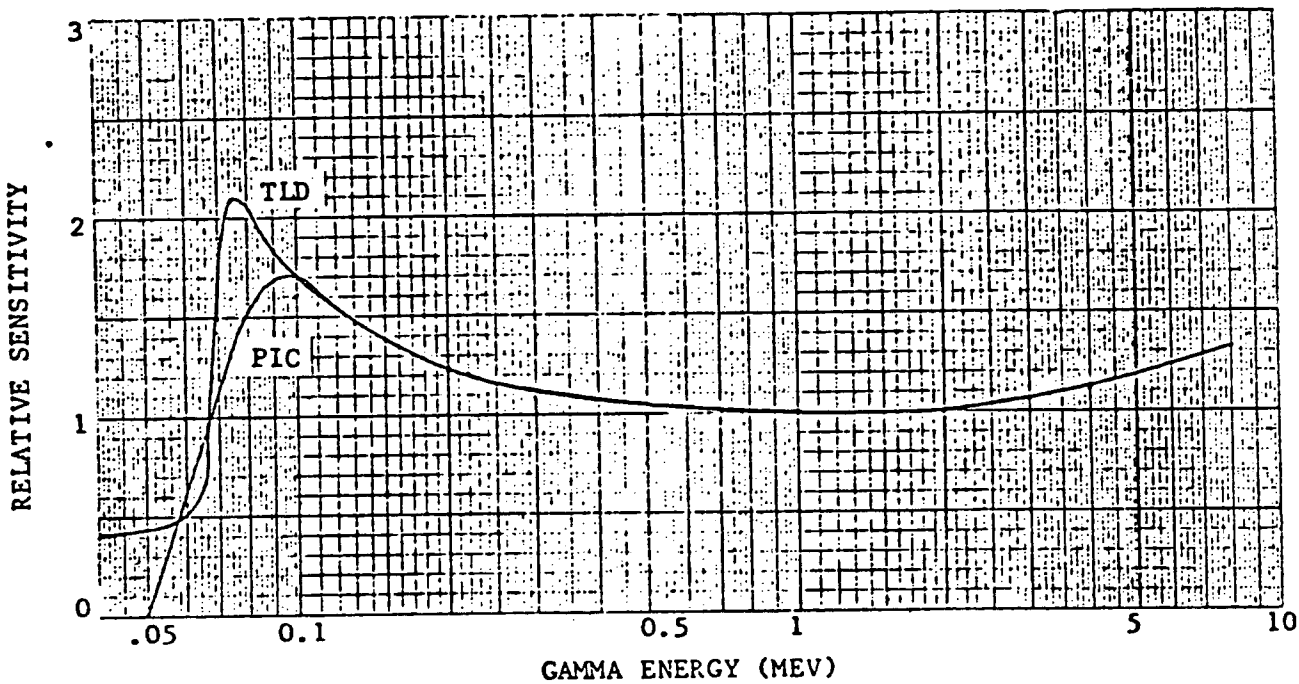


Figure A2. Relative Sensitivity of $CaSO_4(Dy)$ Thermoluminescent Dosimeter and Pressurized Ion Chamber.

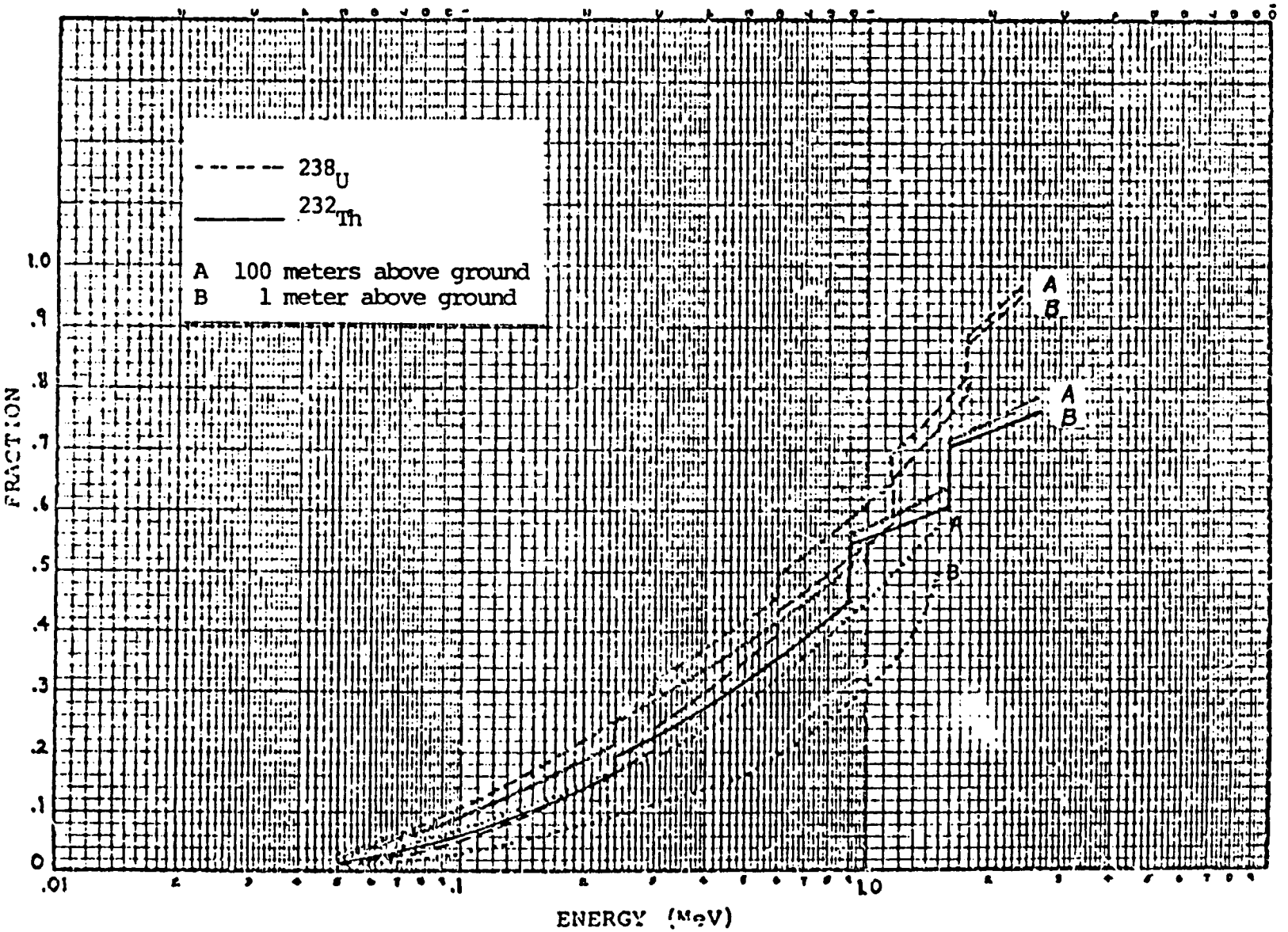


Figure A3. Integral exposure rate spectra (fraction of the total exposure rate due to gamma-rays of energy less than E) for the natural emitters ^{40}K, ^{238}U, and ^{232}Th, at 1 and 100 meters for uniformly distributed sources.

Figure A 3.

CHARACTERIZATION OF RADIOACTIVE MATERIAL IN THE FIELD WEST OF STEPAN CHEMICAL COMPANY

Maywood, New Jersey

Discovery of naturally occurring radioactive material in the field at the west end of Stepan Chemical Company's Maywood Division property has prompted an interest in its origin, nature and extent. Thorium was extracted from monazite in the adjacent chemical plant beginning about 1902 and extending until 1956. During the 1940s, monazite ore was also processed for the extraction of rare earths. The radioactive material in the field is speculated to be residue from that monazite processing. Gamma spectrum analyses indicate that it contains natural thorium series and a lesser amount of natural uranium series radionuclides.

A series of measurements has been conducted to characterize the radioactive material in the field. This report describes the results of the survey.

An adequate description of radioactive material in the field includes the spectrum of radionuclides, their location, and concentration. The spectrum, or relative concentration distribution of these nuclides has been established by analyses of material samples from the field. A gamma radiation survey above ground helped to locate near surface deposits of the radioactive material. Its location and concentration was then be defined by in-situ measurements and to a lesser extent by measurement of material samples collected in the field.

Survey Grid

To aid in describing sampling and measurement locations in the field, a grid was established by a land surveyor and survey stakes were placed on a 100-foot square grid over the field. This grid, identified in Figure 1, was used as a reference for the in-situ radioactive material survey and the gamma radiation survey.

Gamma Radiation Above Ground

Gamma radiation measurements above ground helped to locate near surface deposits of radioactive material. To aid in locating thorium

residue deposits in the field, a survey of the gamma radiation exposure rate has been performed with a sensitive gamma scintillation survey instrument. Readings were made one meter above ground on a regular grid over the field and along the boundary fence. The results are reported in the first section of this survey, Table 1, supra.

Gamma Spectrum Analyses of Soil Samples

The concentrations of gamma emitting nuclides in soil samples can be determined by multi-channel gamma spectrum analysis (MCA). Some soil samples have been collected in the field and analyzed in this manner. In the field survey, MCA analysis of core samples was used primarily to determine the radionuclide distribution and to be an independent comparison with in-situ single-channel gamma spectrum analyzer (SCA) measurements.

The sampling for MCA analysis was done by augering a four-inch diameter hole in the ground with a flight auger to the depth of interest and driving a split-spoon sampler beyond that depth, by a hand-held core barrel auger, or by scraping a sample from the sidewall of the hole at the depth of interest. Usually, a sample was collected from a six-inch or one-foot increment of depth in the ground.

MCA analysis of soil samples from the field was done by Dr. W. E. Bolch (U. Fla.) to identify the concentration of thorium and uranium series radionuclides. Key radionuclide concentrations in samples from the field which were analyzed in this manner are listed in Table 1. Most of the thorium concentrations measured by MCA analysis of core samples agreed well with the in-situ SCA measurements.

In-situ Measurement of Soil Radioactivity

In-situ measurement using an NaI scintillation detector coupled to an SCA is a practical way to survey land to determine the location and concentration of naturally radioactive material in the ground. The calibration and capability of the instrument and the survey method used in the field survey are described in Appendix A.

Locations in the field and on the plant site which were examined by in-situ SCA analysis for radioactivity in the soil are identified in Figure 1. The Th-232 concentration measured as a function of depth in the ground at each location is included in Appendix B in graphical form.

Discussion of Measurements. Overall, the measured radioactivity concentrations in the field, the physical appearance of core samples, above ground gamma exposure rates, and the physical appearance of the ground surface all contribute to interpreting the survey. Together, they point to identifiable deposits of thorium-bearing residues in the field.

One deposit of thorium-bearing residue lies in the southern part of the field, bounded by the fence adjacent Highway 17 on the southwest, a railspur on its northeast side and apparent dikes on its northeast and southeast ends. An approximate outline of the area appears in Figure 1. Thorium-232 concentrations near the surface ranged from about 170 to 700 picocuries per gram (pCi/g). They diminished rapidly to about 5 pCi/g or less within 4 to 6 feet below the surface. The uniformity of the deposit over the area, the concentration gradient with depth, and the apparent boundaries of the deposit suggest it was a settling area. Graphs in Appendix B of measurements at location (7 + 75, C + 50) and at location (8, C + 79) are typical of measurements associated with that area.

About 30 feet to the northwest of the first deposit mentioned, between the fence adjacent Highway 17 and the same rail spur begins another apparent settling area. The measurements indicate some thorium, about 10 to 80 pCi/g, near the surface in the southeastern end of that area. Thorium concentrations in the interior of the area are generally low. A layer of material with elevated thorium concentration, ie, about 40 to 230 pCi/g, about 2 feet thick occurs at a depth of about 8 to 12 feet deep in this area. Measurement locations which illustrate the observed activity concentrations in this area are at (5, F), (6, E + 50), and (5 + 60, E + 200).

Another apparent settling area, bounded on its north and west sides by the rail spurs and on its east and south sides by dikes is indicated in Figure 1. Most of the residue in this area is less than 5 pCi Th-232/g.

However, a layer about a foot thick and containing about 10 to 60 pCi Th-232/g occurs about 9 to 11 feet deep. This profile can be seen in thorium concentration graphs for locations (5, E), (5 + 12, D + 33), and (6, D).

In the field north of the rail track leading into the plant, an area approximately within the bounds of grid points (2,A), (2,D), (4,D), and (4,A) is essentially free of thorium. At most other locations examined in that area, thorium was observed at some depth. With exceptions, the deepest thorium deposit, or layer, observed in the northern half of the field, trends from about 3 to 7 feet near the northeastern side to 12 to 14 feet deep near the western side. With a few exceptions, the deepest thorium deposition observed in this part of the field was less than 80 pCi/g. Other lesser radioactive or non-radioactive residues, construction debris, and earth fill have been deposited atop the material in the same area.

In one area of the northern half of the field materials deposited nearer or at the surface also contain measurable thorium. Notably, the area in the vicinity of grid points (1,E), (1,F), (2,E), and (2,F) has thorium deposited near the surface to a depth of about six feet. The maximum thorium-232 concentration observed in all but one location in this vicinity was less than 200 pCi/g. At 3 1/2 feet deep at location (1,E), however, a peak concentration of 3000 pCi Th-232/g was recorded.

In the northeastern corner of the field, an area bounded generally by grid line 1, grid line C, the fence along the northern boundary, and Building 76, has irregularly distributed thorium concentrations within 6 to 8 feet of the surface. Thorium sludge was once retained in a pile surrounded by earthen dikes in approximately the same area, but the pile has since been removed and the ground covered with earth fill. Peak thorium-232 concentrations ranging from about 10 to 2000 pCi/g were observed between about 2 and 8 feet deep in this area.

The remaining area surveyed for the presence of thorium lies between Buildings 76 and 78. Thorium was once refined in buildings situated in that area. The process buildings have been demolished, the debris removed, the area graded and seeded with grass by Stepan and surveyed and released for unrestricted use by the NRC. Because elevated gamma

radiation levels have been measured, particularly in the southwestern part of that area, thorium concentrations in the ground were also measured in this survey.

Figure 2 explains the grid used to identify the location of measurements made between Buildings 76 and 78. Thorium concentrations measured in-situ in that area are recorded in graphs in Appendix B. The presence of building debris, especially brick and tile, in the ground impeded augering holes for in-situ measurements in the area.

Thorium concentrations measured in the ground between Buildings 76 and 78 tended to exceed those measured in the field west of the plant. Peak thorium-232 concentrations of a few thousand picocuries per gram were measured within about 4 feet of the surface. More thorium-bearing material appears to be accumulated along the western and southern sides of the field than toward Building 78 on the northeast side.

Table 1

Radioactivity Concentration in Selected Soil Samples

Sample			Radioactivity Concentration			
Location (grid)		Depth (ft)	Th-232	U-238 (pCi/g)	Ra-226	K-40
1	D	3.25 - 3.75	0.2	<1.	0.45	2
1	F	1.75 - 2.25	0.1	<1.	0.4	
2	F+50	1.75 - 2.25	0.2	< 1.	0.35	
5	E	1.50 - 2.	0.15	< 1.	0.3	2.7
5	E	4.75 - 5.25	0.7	0.8	0.5	
5	F	2.75 - 3.25	0.45	<1.	0.4	1.7
6	E	2.75 - 3.25	0.35	<1.	0.9	
6	E+50	1.75 - 2.25	0.4	<1.	1.1	1.2
8	C	2.75 - 3.25	64.5		2.45	
8	C	5.75 - 6.25	0.9		0.6	8.5
8	C+79	1. - 1.25	235.		7.9	
8+10	B+10	2.75 - 3.25	1.3	< 1.	0.8	10.5
0+50	C	6. - 7.	0.3	0.9	0.9	ND
3	G+20	12. -13.	0.3	2.1	0.5	ND
1	E	8. - 9.	0.8	1.7	0.6	7.7
6	C+82	5. - 6.	7.3	2.0	0.9	7.6
1	E+50	5. - 6.	16.9	5.3	5.2	ND
1+50	H	5. - 6.	0.1	0.7	0.5	ND
0+18	D	1. - 2.	2.1	3.1	0.97	7.6
6	E+50	11. -12.	170.	71.	12.	ND
6+22	E+70	5. - 6.	103.	25.	31.	ND
6+30	E	7. - 7.	0.3	0.83	0.75	2.7
8+40	B+24	3. - 4.	1.	1.3	0.92	9.1

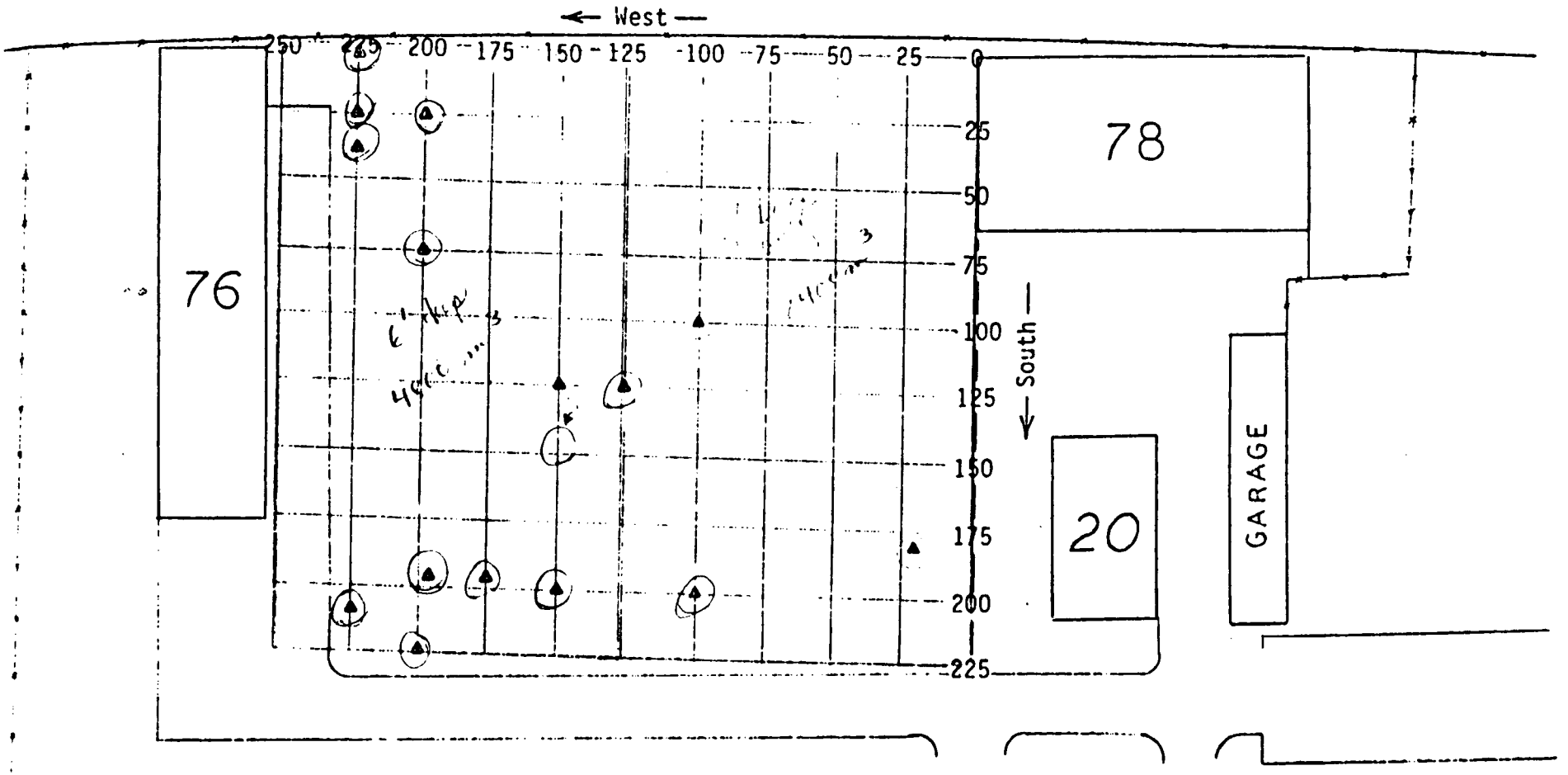


Figure 2. Coordinates for Survey Locations Between Building 76 and 78
Key: W125 S75 = 125 ft west and
75 ft south of origin at Building 78

2-4
4-6

Appendix A

In-situ Thorium Measurement Method

Removing a core sample and analyzing it by multi-channel gamma spectrum analysis is a good method of measuring soil radioactivity concentration, but it is also slow and expensive. Large land areas can be surveyed in less time and with less expense by in-situ gamma spectrum analysis. In-situ measurement is also able to analyze a larger sample than is practical in core sampling and laboratory analysis. Whereas MCA Ge(Li) rely on controlled conditions and relatively long counting time to achieve precise measurements, in-situ measurement using an NaI detector takes advantage of a more sensitive detector immersed in a much larger sample to achieve precision.

In-situ radioactivity concentration measurement is accomplished by lowering a gamma scintillation detector into a borehole in the ground. Coupled with a single channel gamma analyzer (SCA), the gamma intensity associated with a key radionuclide is measured in-situ, its concentration determined, and the concentration of other radionuclides inferred from the distribution observed in representative core samples analyzed by multichannel gamma spectrum analysis (MCA).

At Maywood, the radioactive source of interest is residue from processing monazite ore. It contains thorium series radionuclides and a lesser amount of uranium series radionuclides. The thorium series radionuclides should be in secular equilibrium since the residue is more than 25 years old, unless radon-220 diffuses away. In moist soil at the site, radon diffusion is not likely to be significant. The minor constituent in residue, the uranium series, may not be in equilibrium however, because several uranium progeny have long decay times relative to the time elapsed since the ore was chemically processed.

Actinium-228, the second decay product of thorium-232, was selected as the indicator radionuclide to measure in-situ since neither thorium-232 nor radium-228, its first decay product, emits a detectable gamma ray. However, actinium-228 emits easily detected gamma rays and is almost certain to be present in secular equilibrium with thorium-232 in the material in the field. The progeny of actinium-228 have relatively short decay times; all have less than two year half-lives. Thus, unless radon-220 diffuses away, actinium progeny would also be in equilibrium.

The relative concentration of the uranium series nuclides to thorium series nuclides in the residue can be determined by MCA analysis of representative residue samples from the field.

The instrument used to perform the in-situ thorium survey was an NaI scintillation detector coupled to a single channel gamma spectrum analyzer. To make a measurement, the detector was suspended stationary in a borehole about four inches in diameter. A timed, integral count of the 911-kev gamma rays from actinium-228 detected was recorded by the SCA. The derived counting rate was interpreted as a radioactivity concentration by referring to a calibration curve established for the instrument and detector.

For the survey of residues in the field on Stepan's property, the calibration was done empirically by correlation with MCA analysis of samples of soil-residue mixtures. Seven mixtures ranging from 0.25 to 2300 pCi thorium-232/g were sampled and analyzed by MCA. About 70 liters of a mixture was put into a drum and a three inch diameter hole made to the center to simulate field source conditions. The SCA detector was inserted into the center of each calibration drum and a timed, integral count of the 911-kev actinium gamma radiation was recorded. The correlation between the thorium concentration in the calibration standards measured by MCA analysis and by the SCA counting rate is excellent over three orders of magnitude in concentration. Whereas MCA Ge(Li) rely on controlled conditions and relatively long counting time to achieve precise measurements, in-situ measurement using an NaI detector takes advantage of a more sensitive detector immersed in a much larger sample to achieve precision.

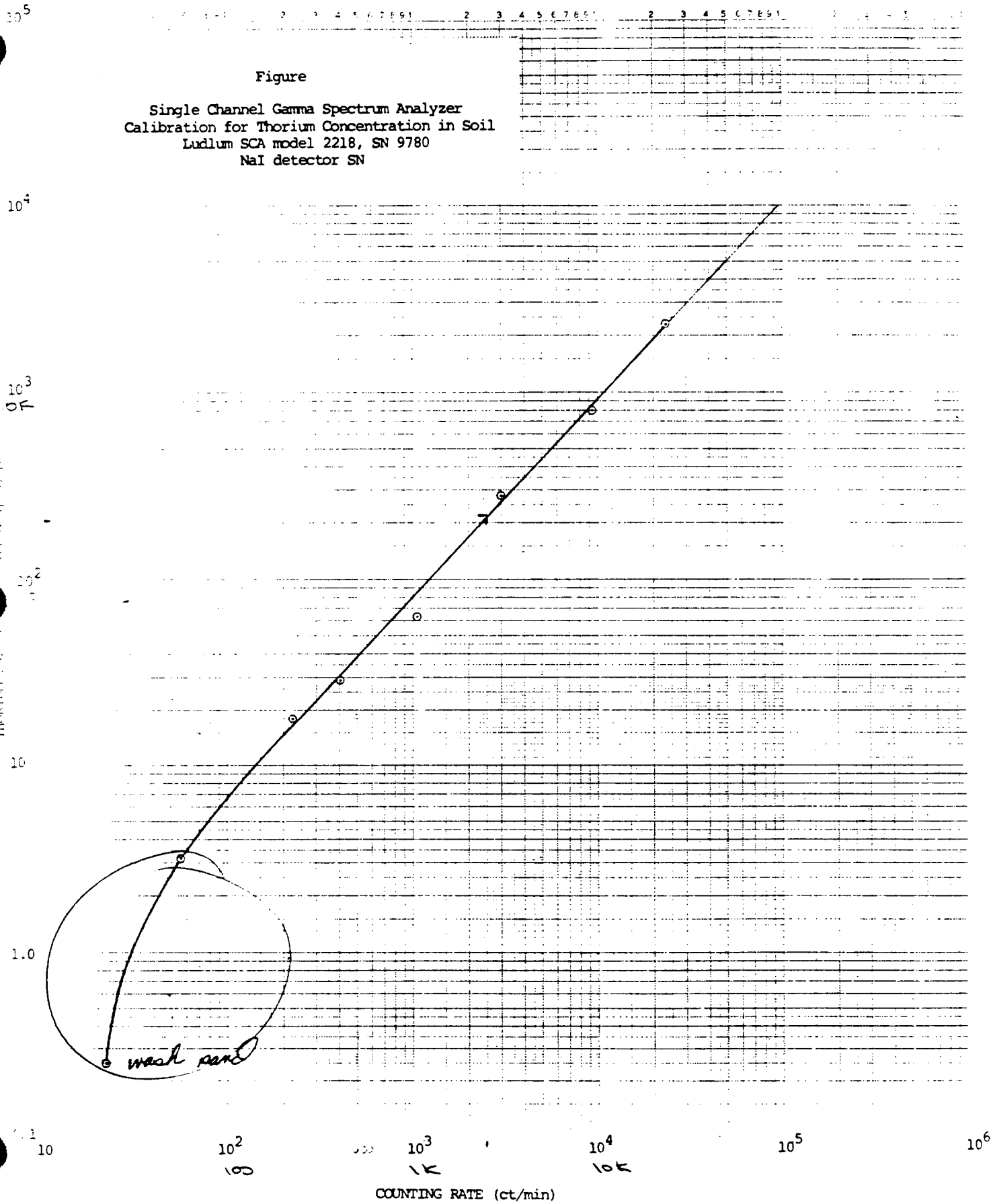
In field conditions where soil radioactivity may not be uniform, the correlation between activity concentration measured in-situ by SCA and measured in a core sample from the same location by MCA may not be as high as exhibited under calibration conditions. The main reason, simply stated, is that the same sample is not analyzed. The thorium bearing material being examined is not uniform usually: the thorium concentration may vary significantly within a fraction of a foot. Uncertainty in determining the depth from which a core sample was extracted and uncertainty in locating the detector for a in-situ measurement at the same depth, combined, seem to have the most effect on the correlation. Otherwise, the volume of material analyzed by the SCA in-situ is many times larger than the volume of core sample analyzed by MCA. For the characterization of radioactive material in the field, averaging over the larger volume as measured in-situ by SCA would seem to provide a more representative measurement of radioactivity concentrations than the analysis of a small sample by MCA.

Figure A1 illustrates the correlation between MCA analysis of core samples extracted from the ground manually and SCA analysis at the center of the sampling depth of each core. To make these measurements, an area of residue was core sampled in six-inch or one-foot sections and each section was analyzed by MCA in an offsite laboratory. In-situ measurements were made in the core holes with the detector positioned at the depth corresponding to the center of each core section. The field conditions for most of these in-situ measurements were demanding in that there was a strong thorium concentration gradient with depth. Nevertheless, the comparison is quite good (realizing that the samples analyzed were not exactly identical.) In-situ measurements at three inches depth or less display a low bias since the detector was incompletely surrounded by soil. Otherwise, there is no apparent bias between the two methods of measurement.

In order to insure repeatability and accuracy during the survey, the calibration drums were kept and used throughout the survey to check and maintain the in-situ instrument calibration.

Figure

Single Channel Gamma Spectrum Analyzer
Calibration for Thorium Concentration in Soil
Ludlum SCA model 2218, SN 9780
NaI detector SN



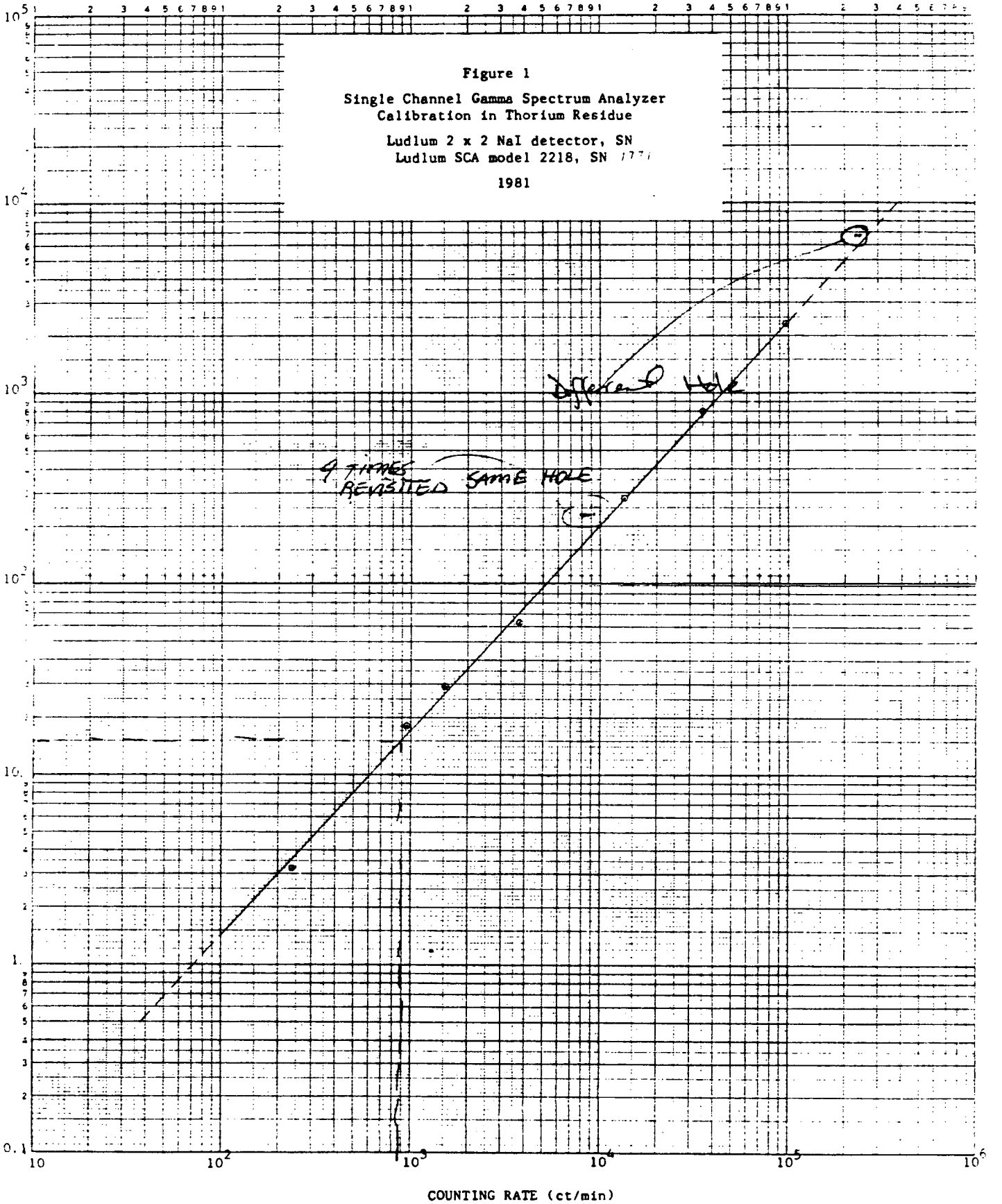


Figure 1

Single Channel Gamma Spectrum Analyzer Calibration in Thorium Residue

Ludlum 2 x 2 NaI detector, SN
Ludlum SCA model 2218, SN 1771

1981

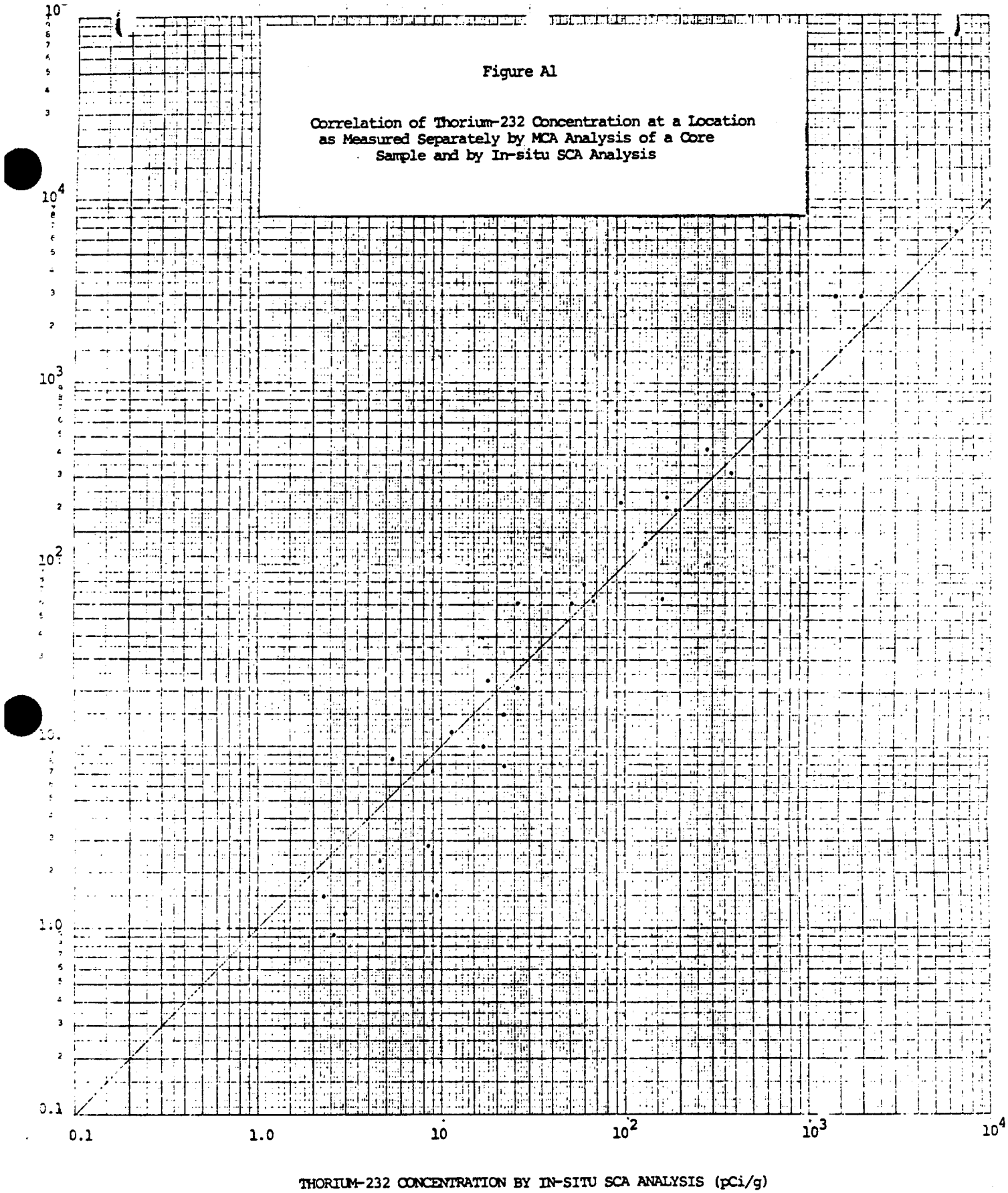
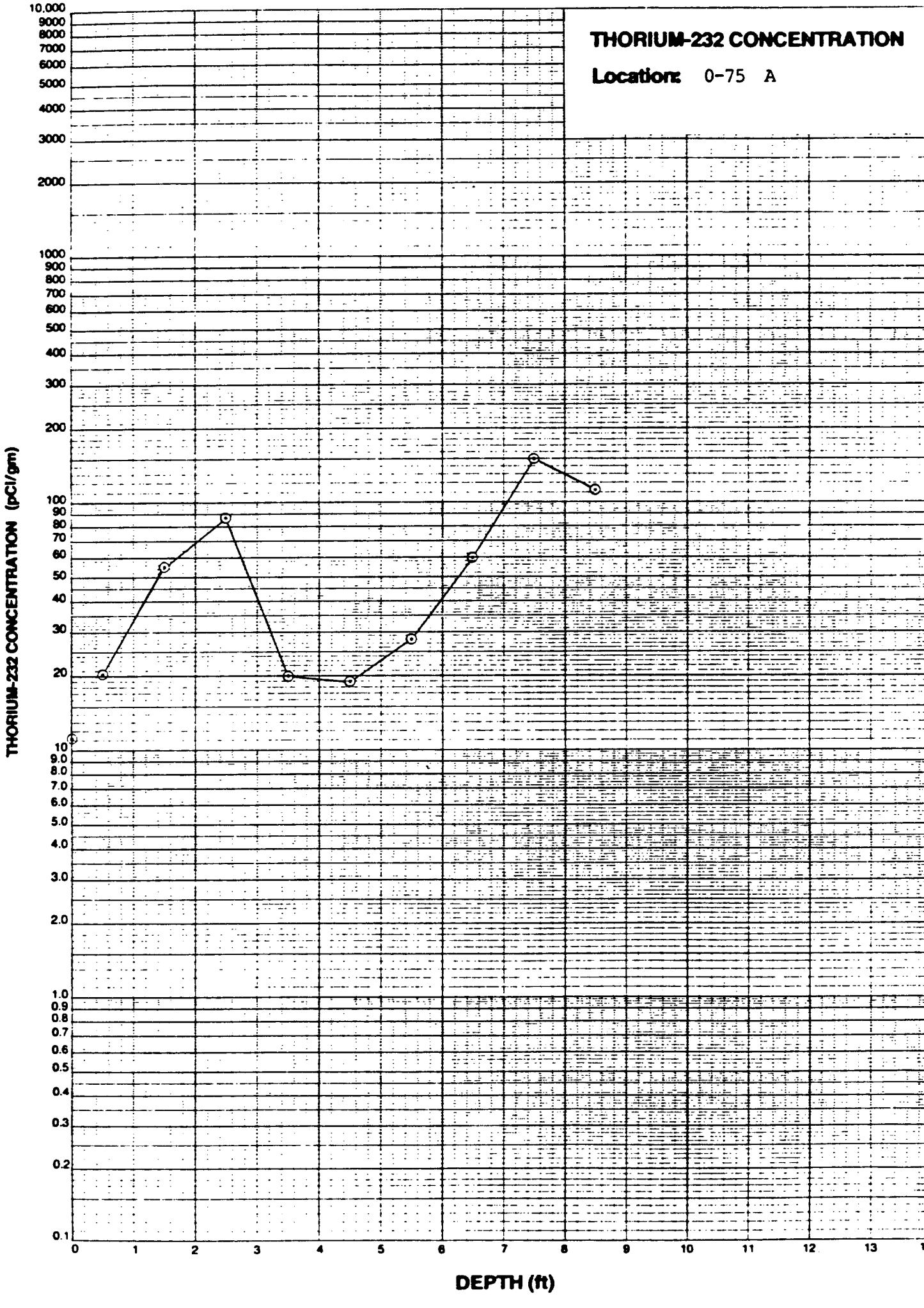
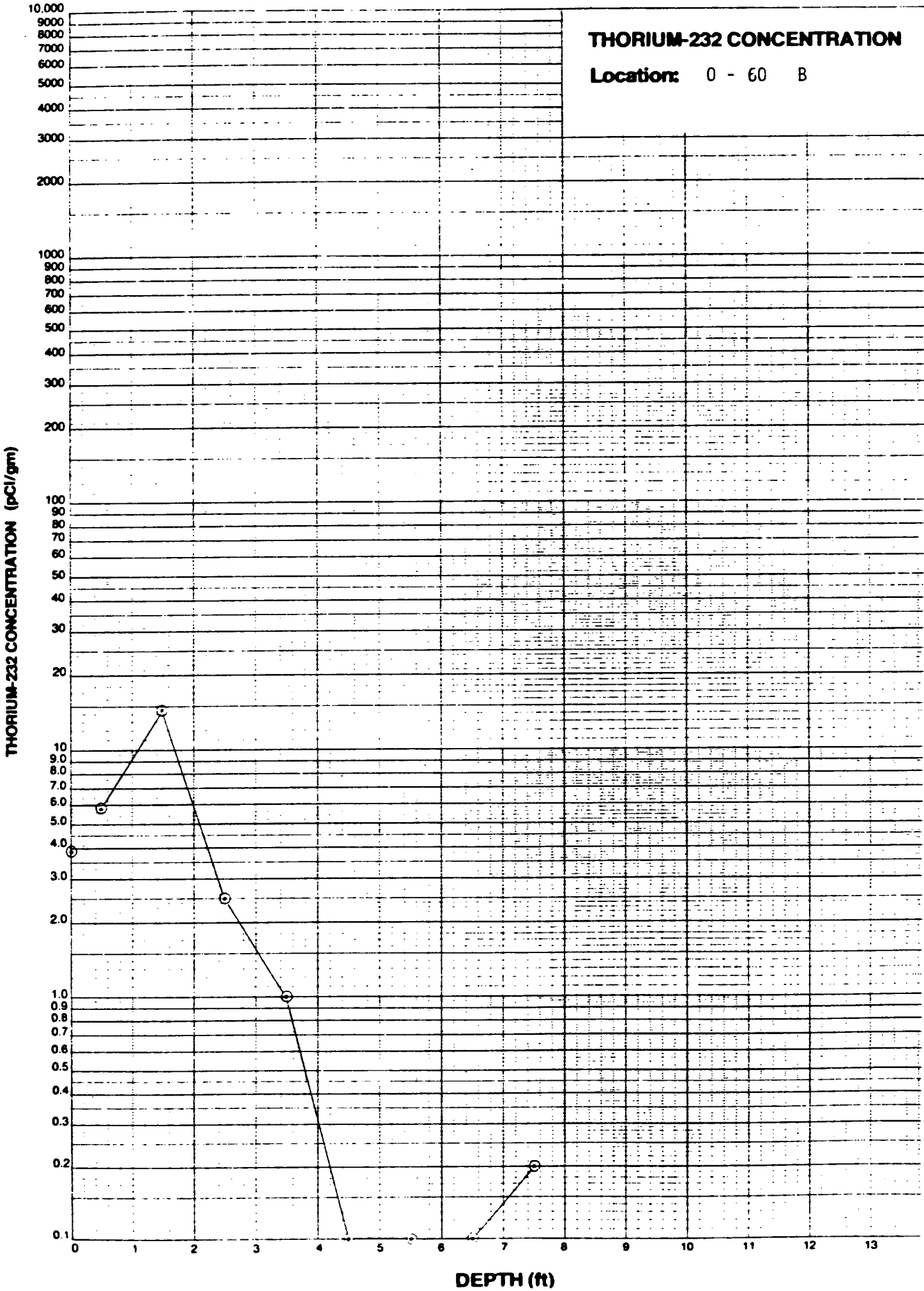


Figure A1
Correlation of Thorium-232 Concentration at a Location as Measured Separately by MCA Analysis of a Core Sample and by In-situ SCA Analysis
10^4
10^3
10^2
10.
1.0
0.1
0.1
1.0
10
10^2
10^3
10^4
THORIUM-232 CONCENTRATION BY IN-SITU SCA ANALYSIS (pCi/g)

APPENDIX B

Thorium-232 Concentrations in the Field West of Stepan Chemical Company


THORIUM-232 CONCENTRATION
Location: 0-75 A
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13


THORIUM-232 CONCENTRATION
Location: 0 - 60 B
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)

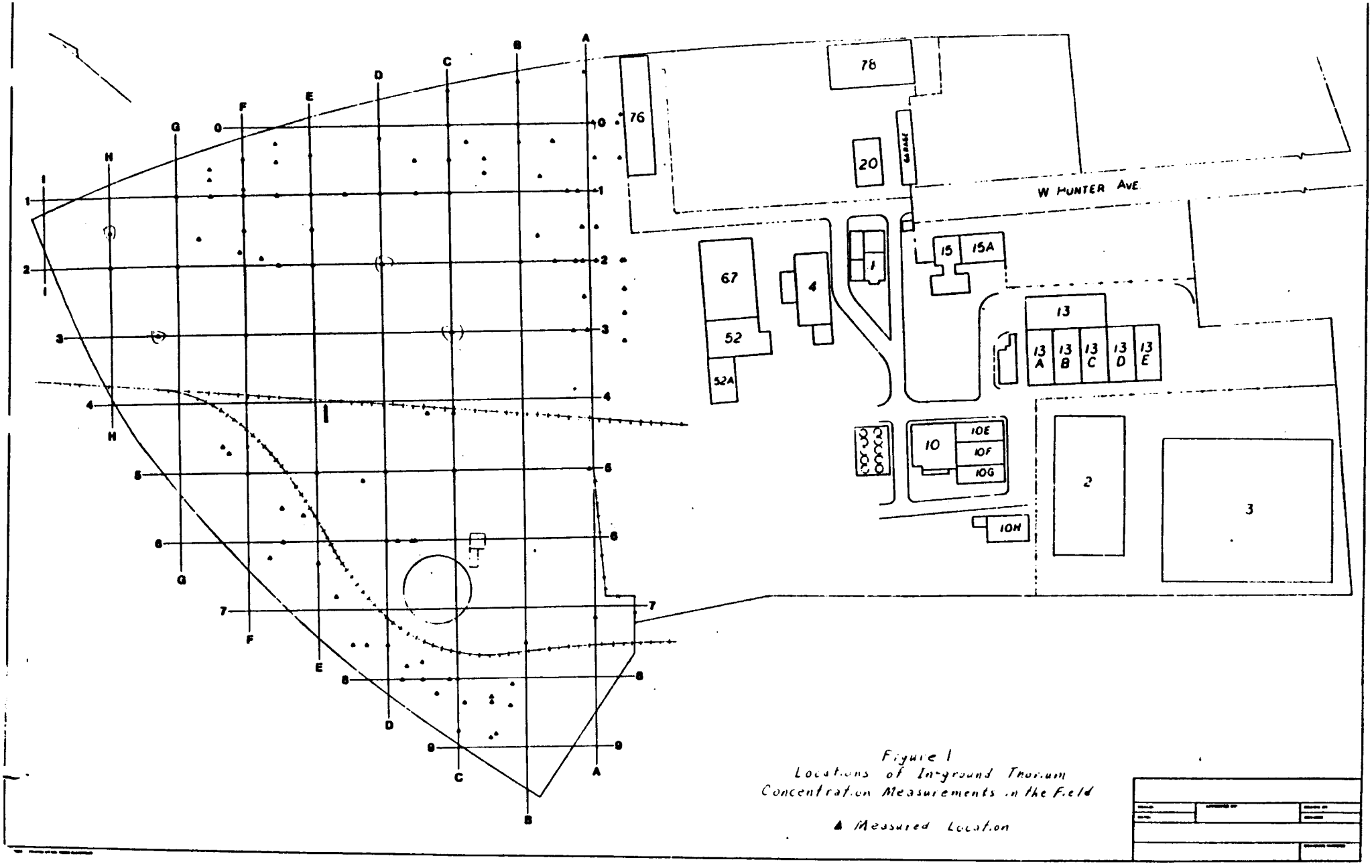
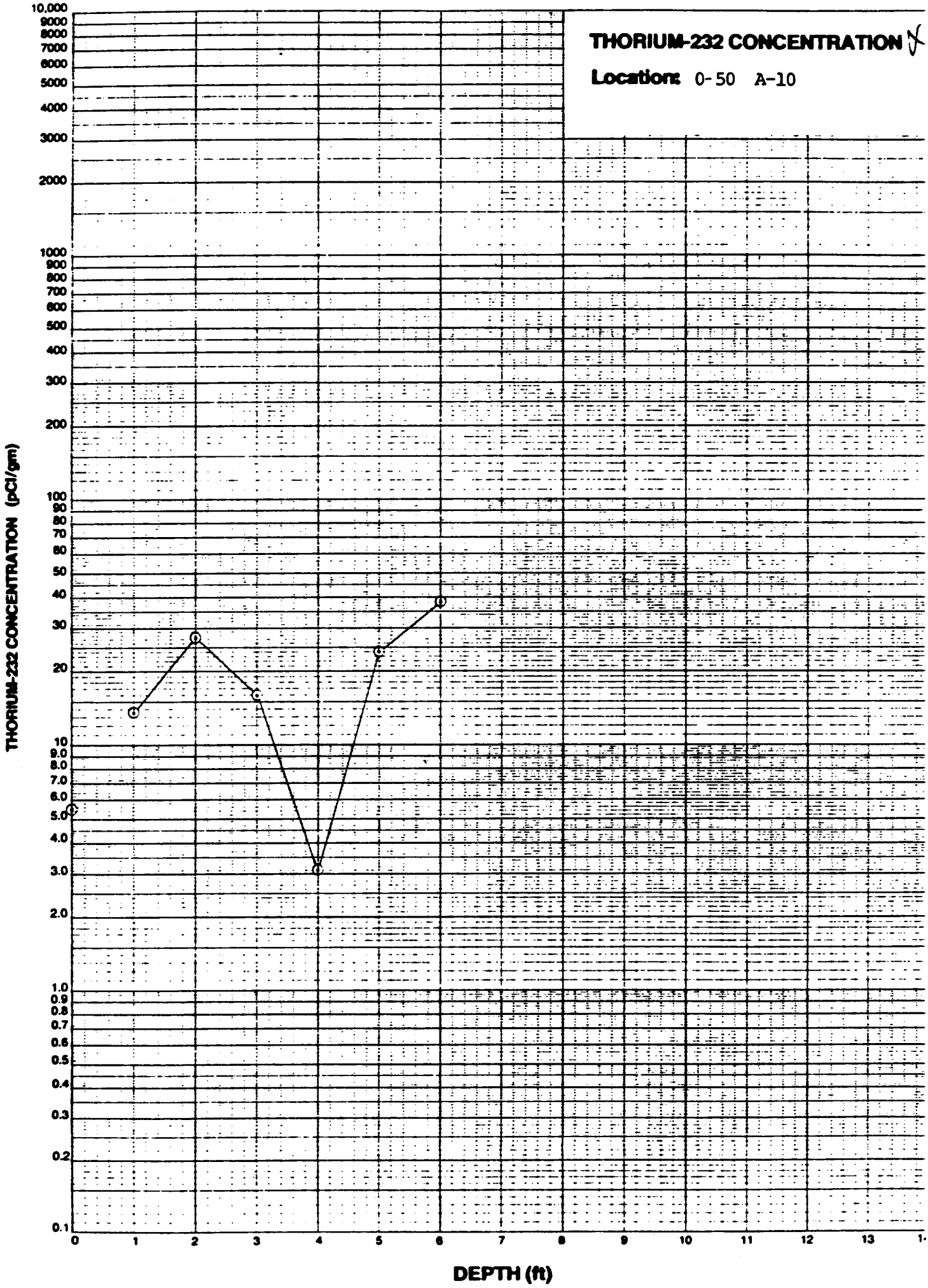
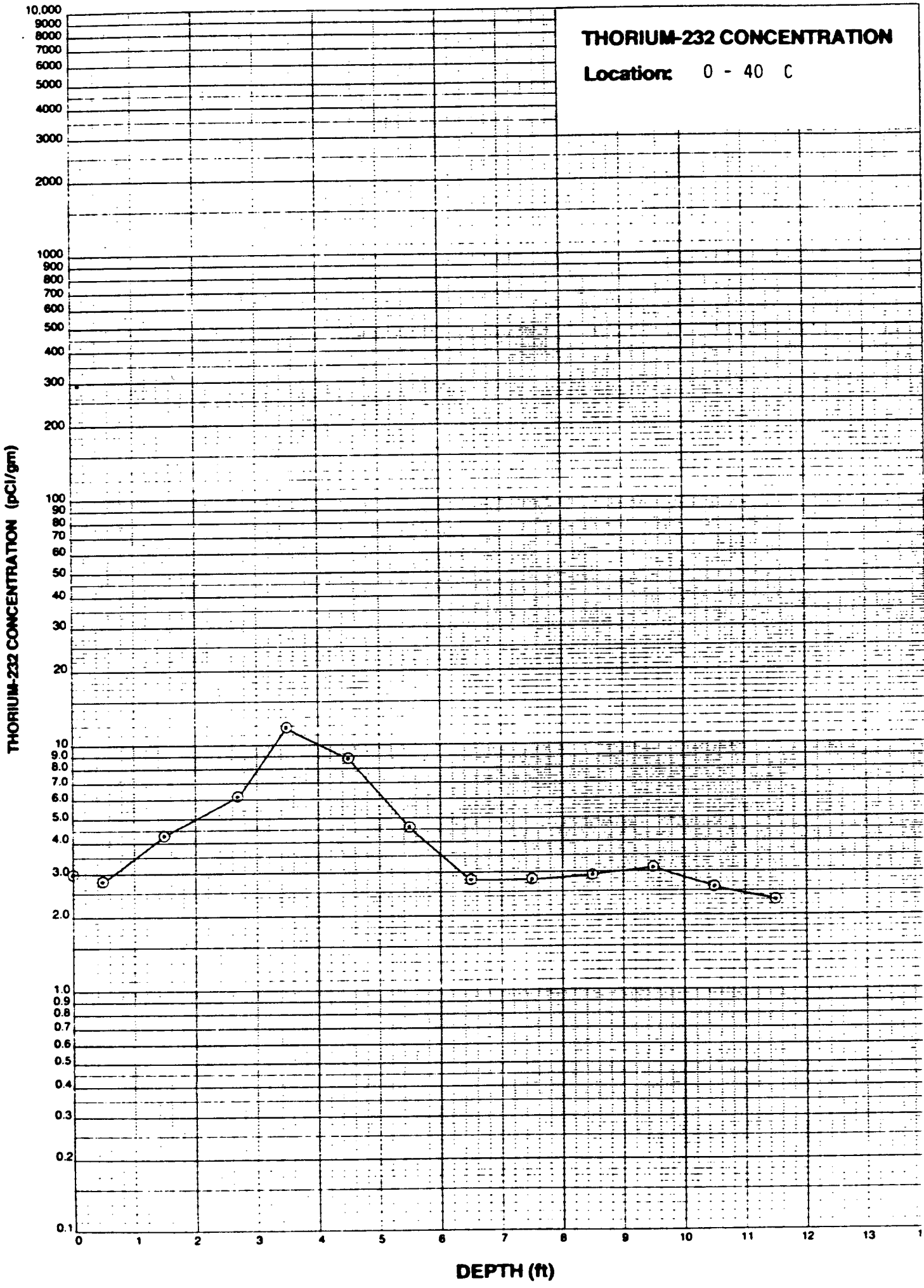
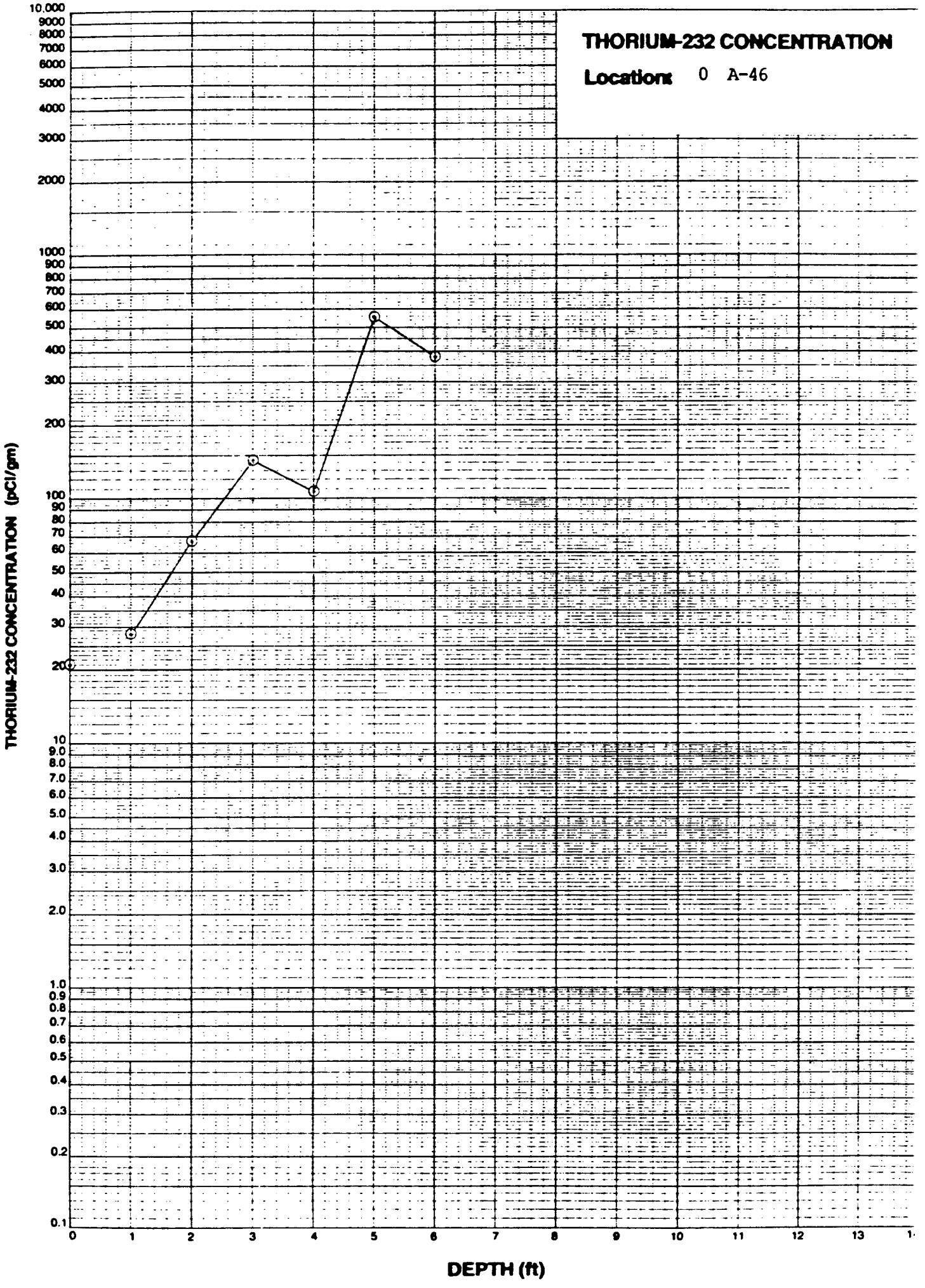


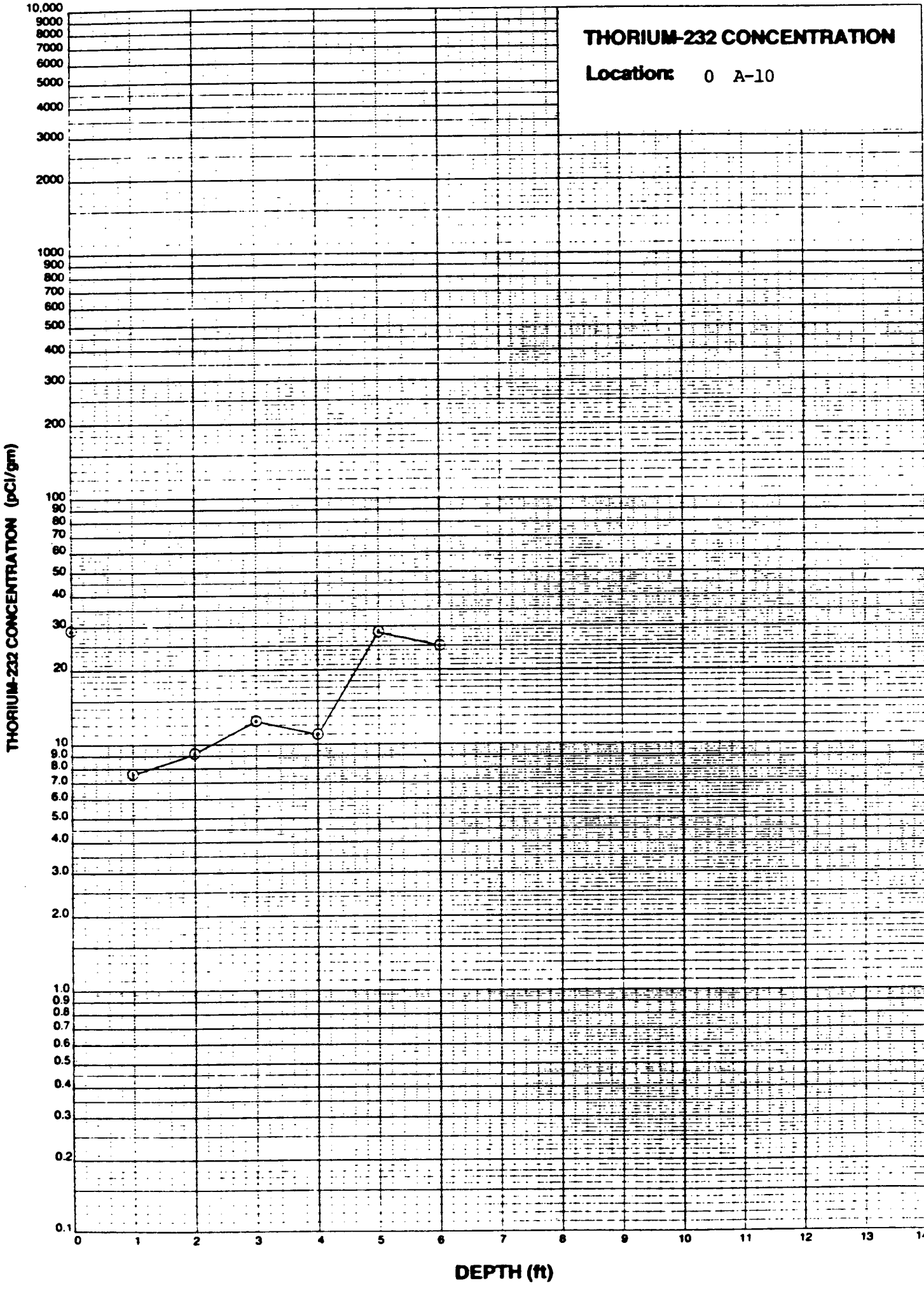
Figure 1
Locations of In-ground Thorium
Concentration Measurements in the Field

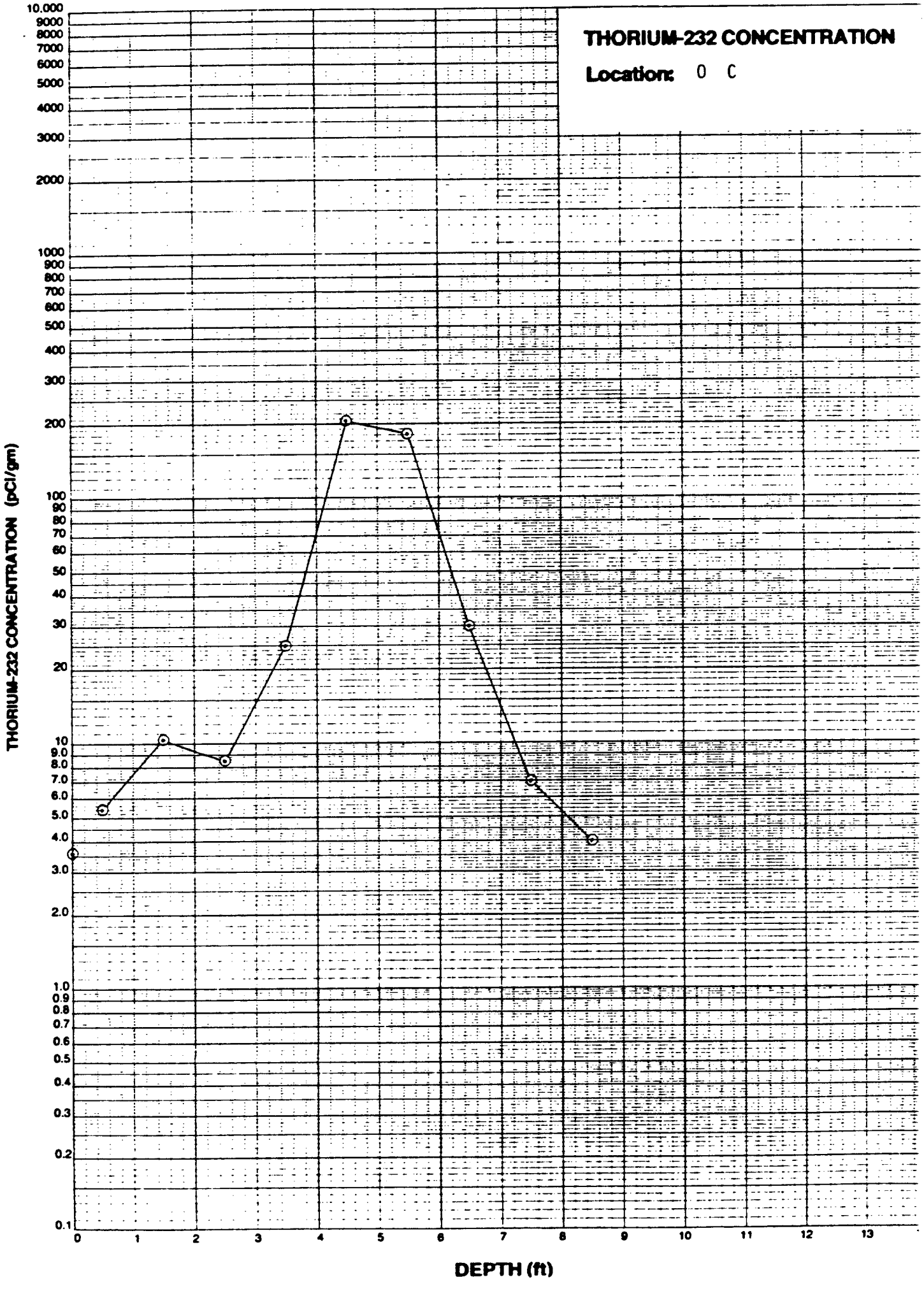
▲ Measured Location

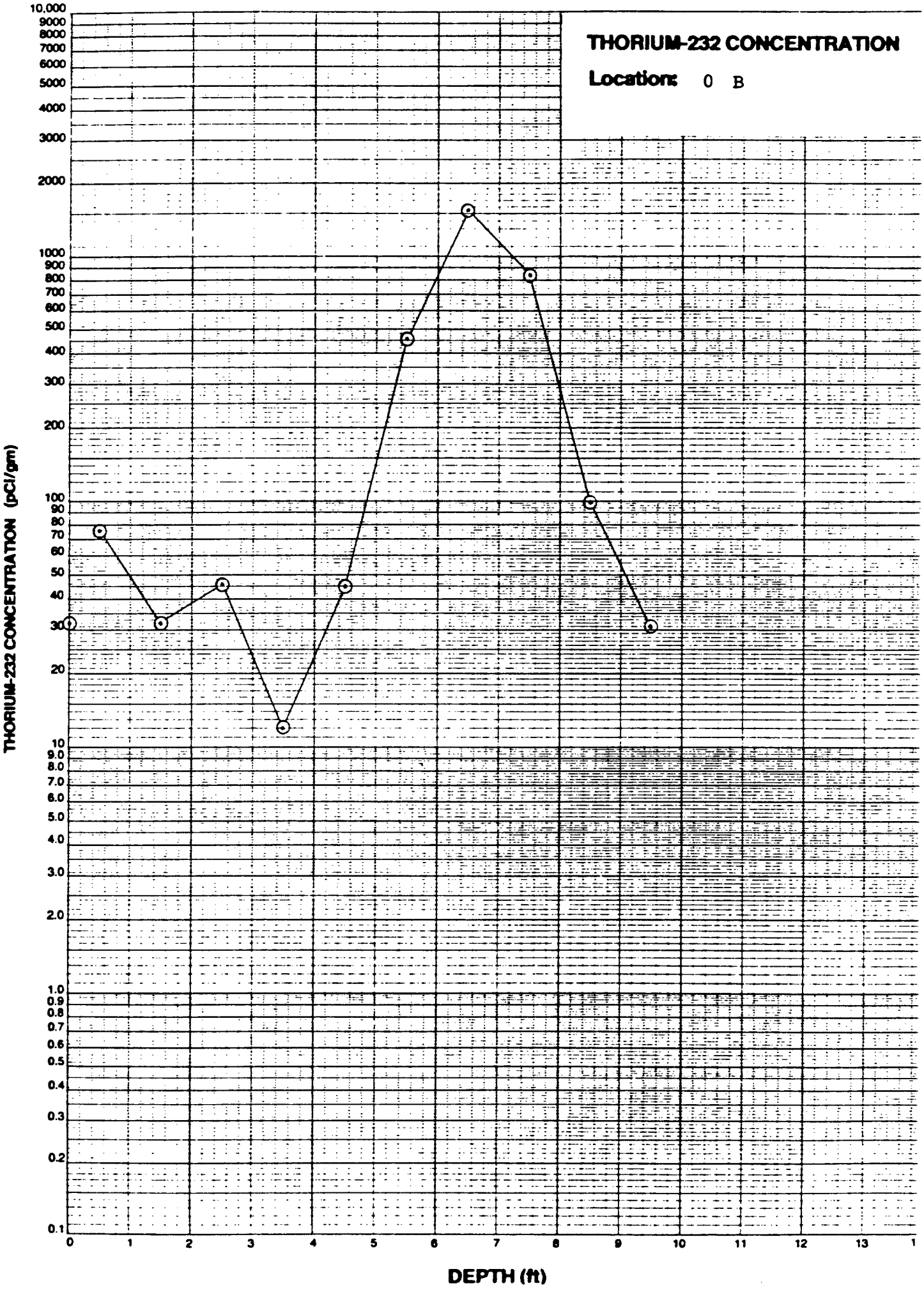

THORIUM-232 CONCENTRATION
Location: 0-50 A-10
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0 - 40 C
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0 A-46
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0 A-10
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0 C
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0 B
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
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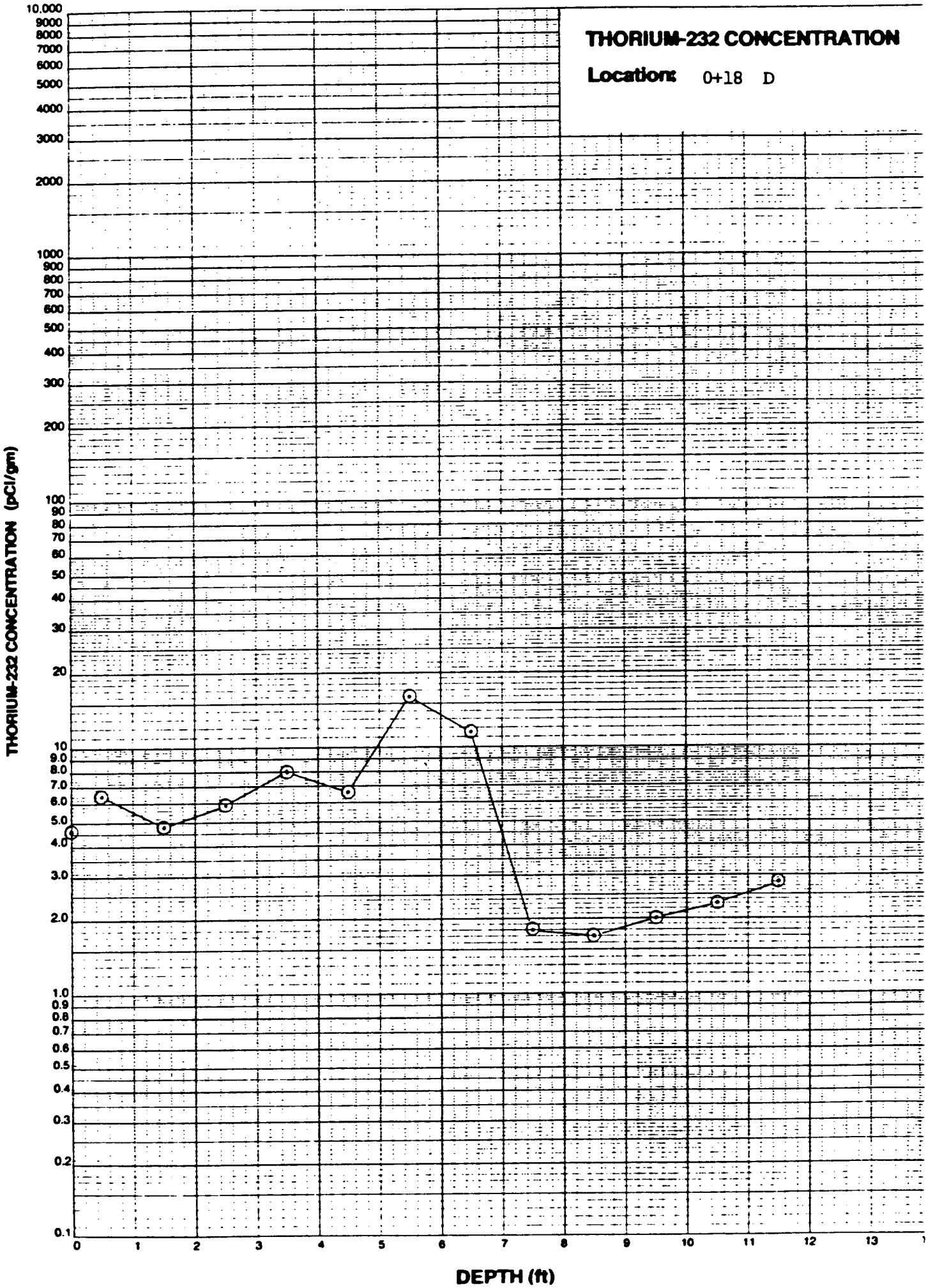
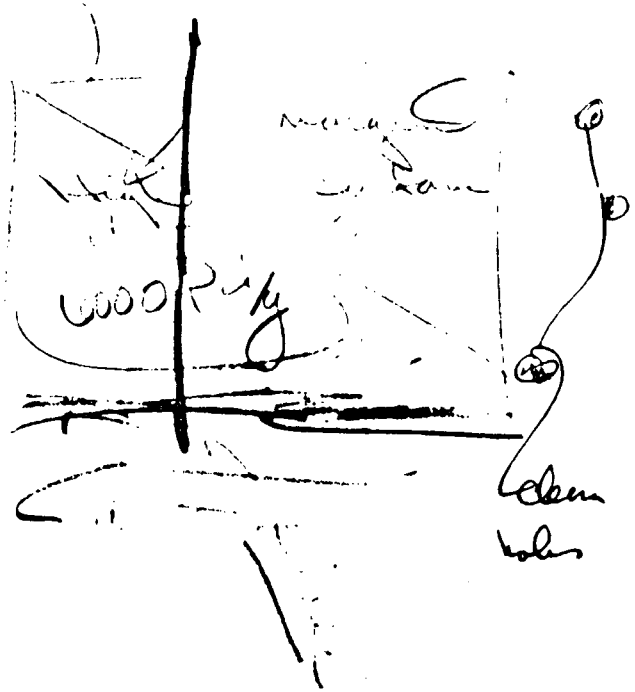
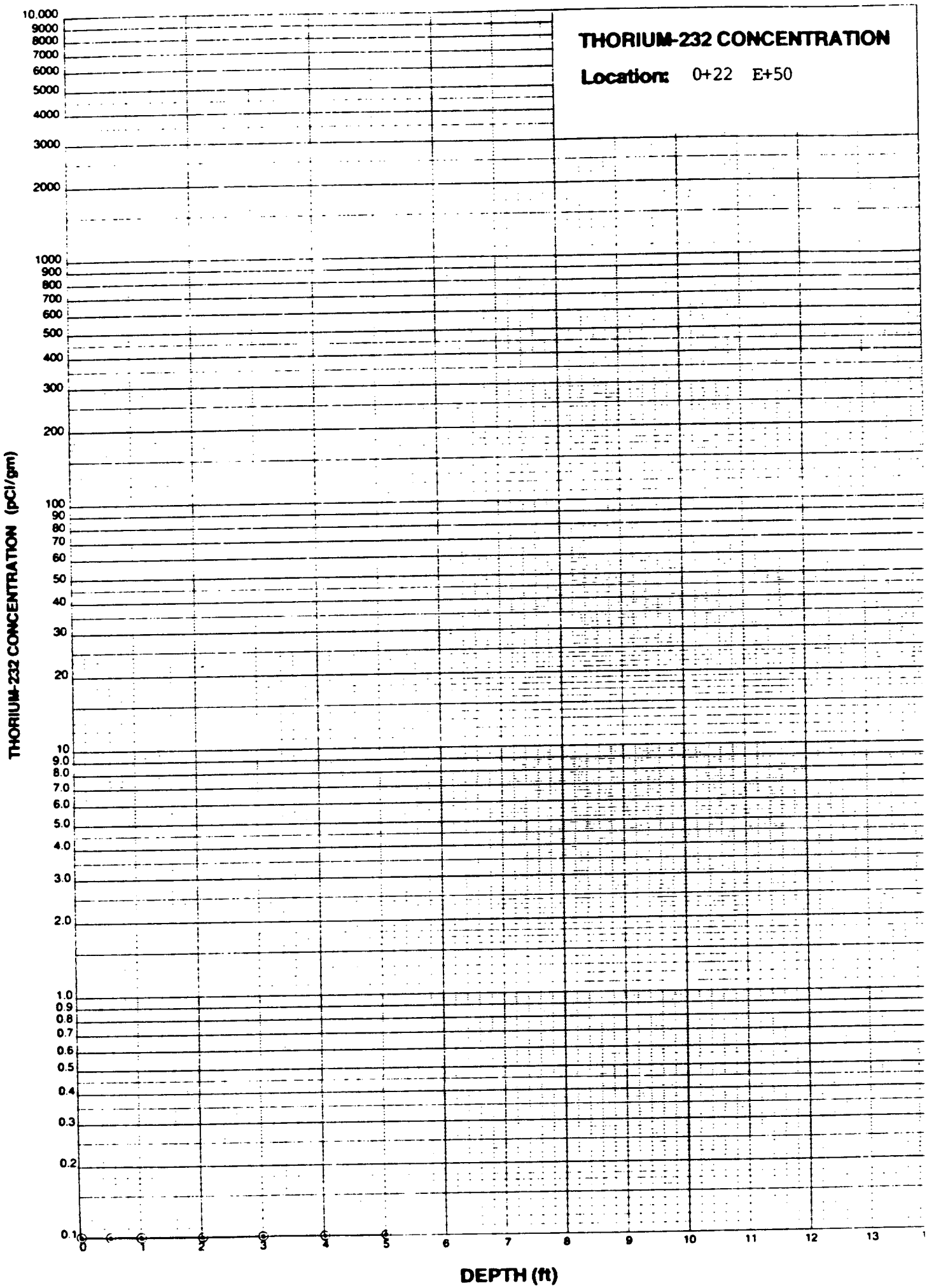
7
8
9
10
11
12
13


THORIUM-232 CONCENTRATION
Location: 0+18 D
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)



1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]


THORIUM-232 CONCENTRATION
Location: 0+22 E+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
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0
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2
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4
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8
9
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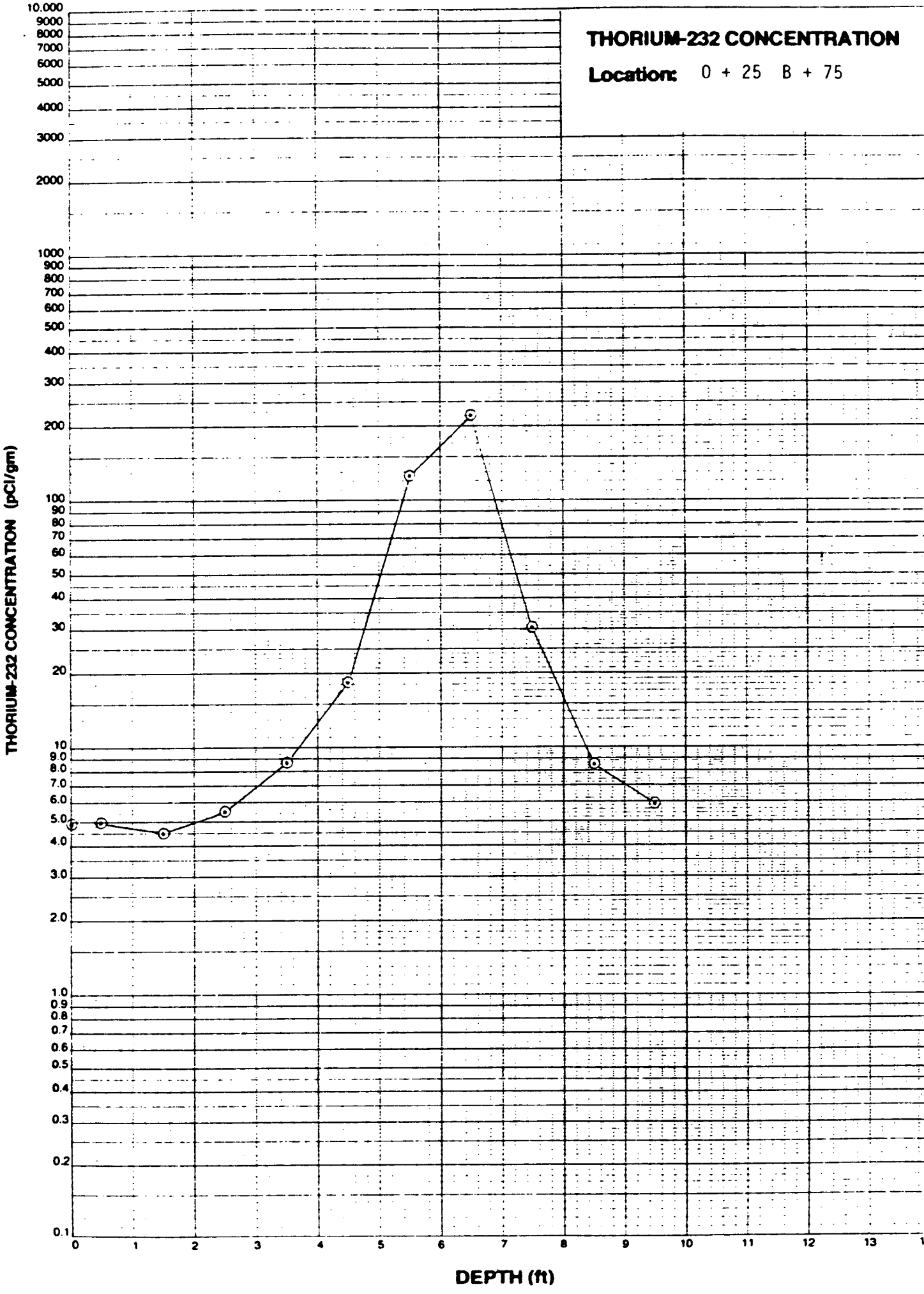
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0 + 25 B + 75
THORIUM-232 CONCENTRATION (pCi/gm)
10.000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
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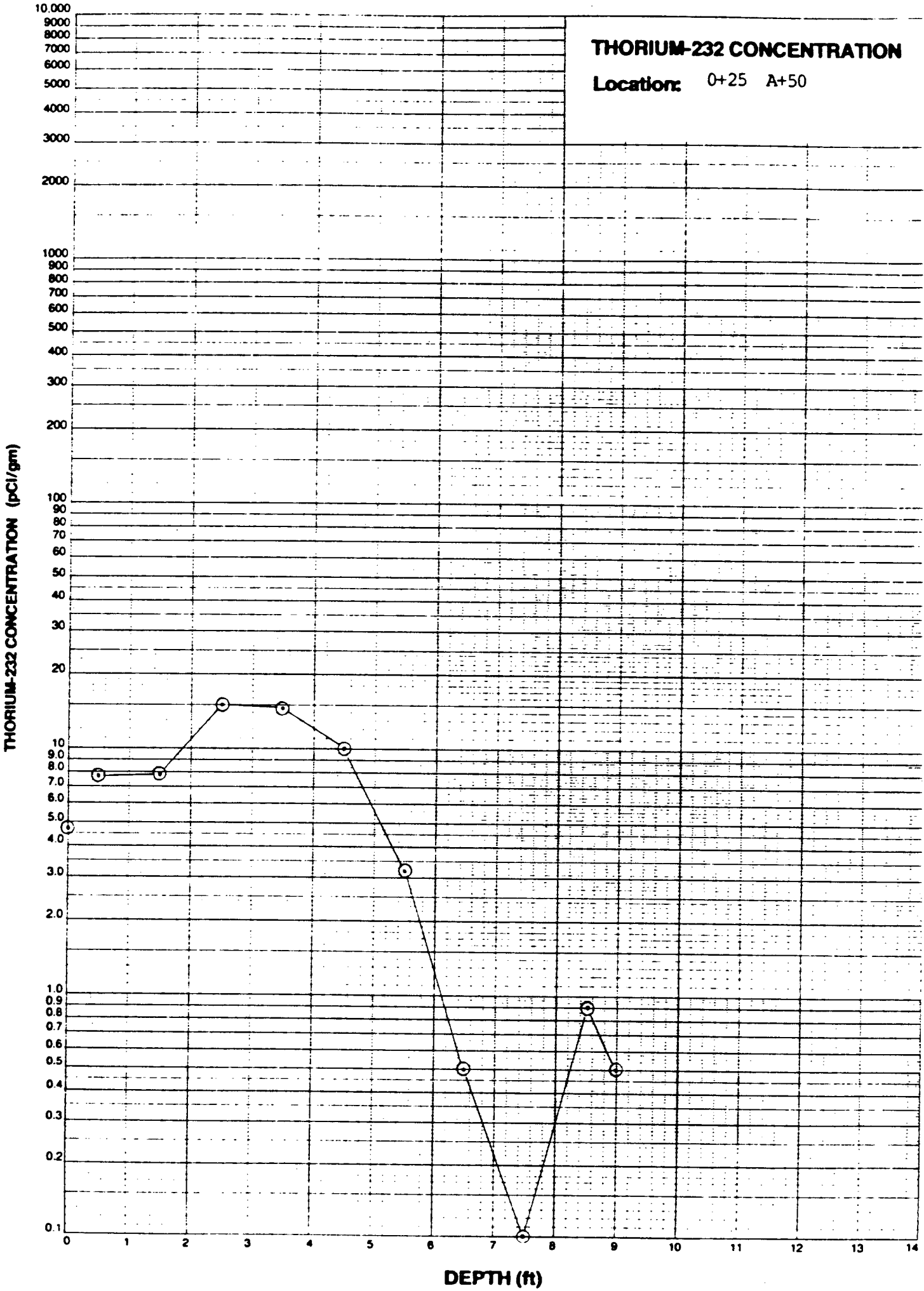
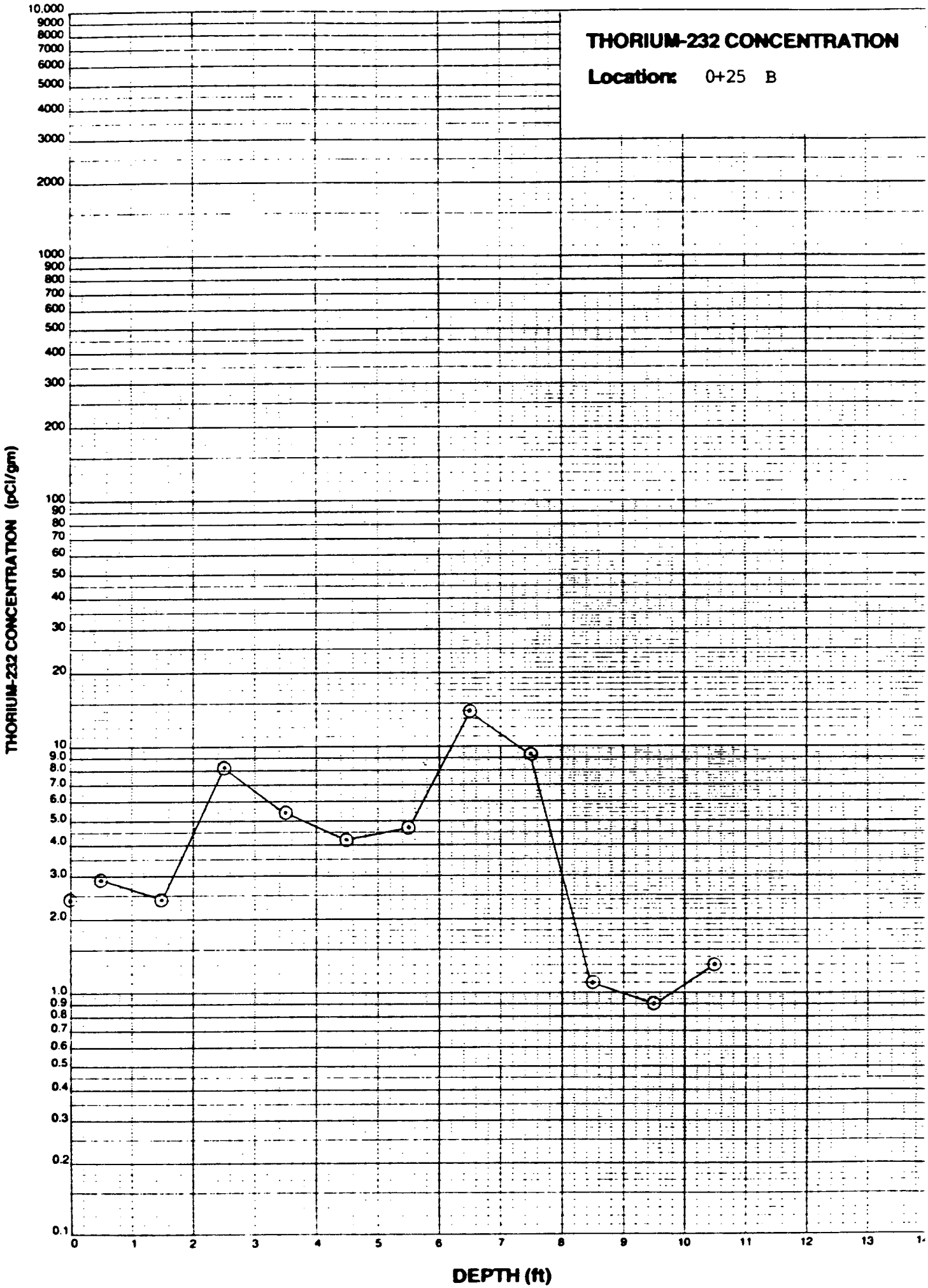
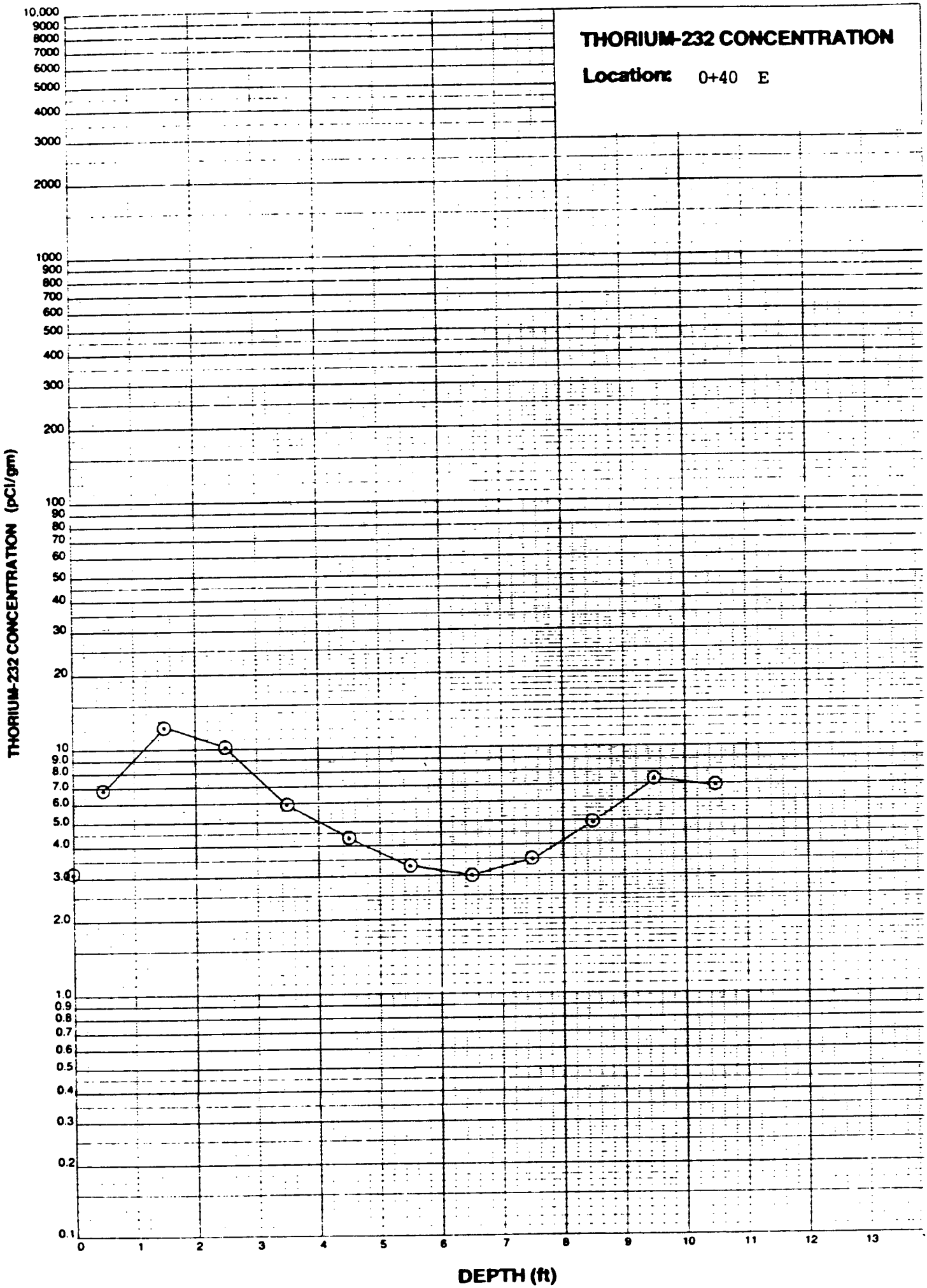
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+25 A+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+25 B
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+40 E
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
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9
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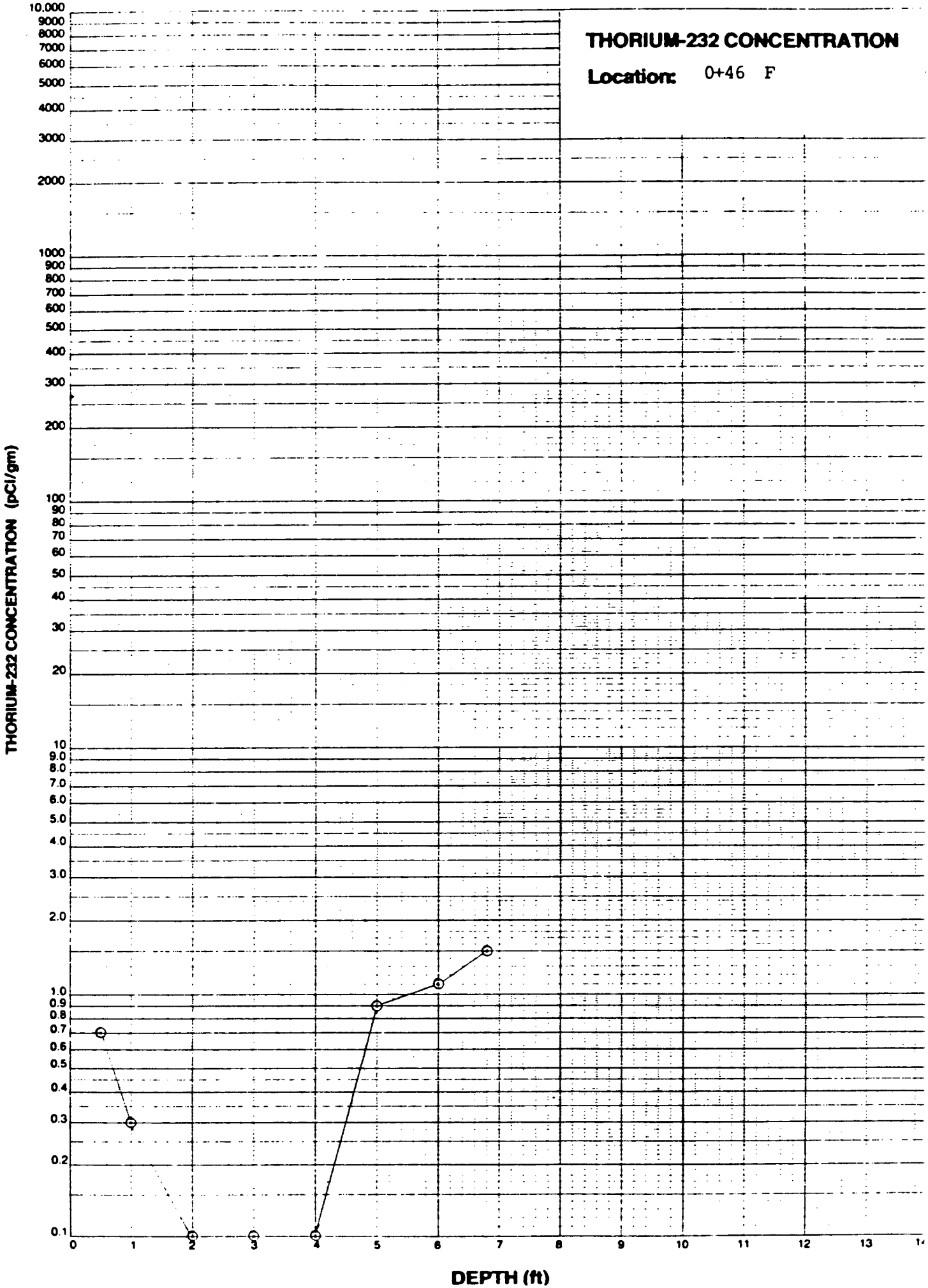
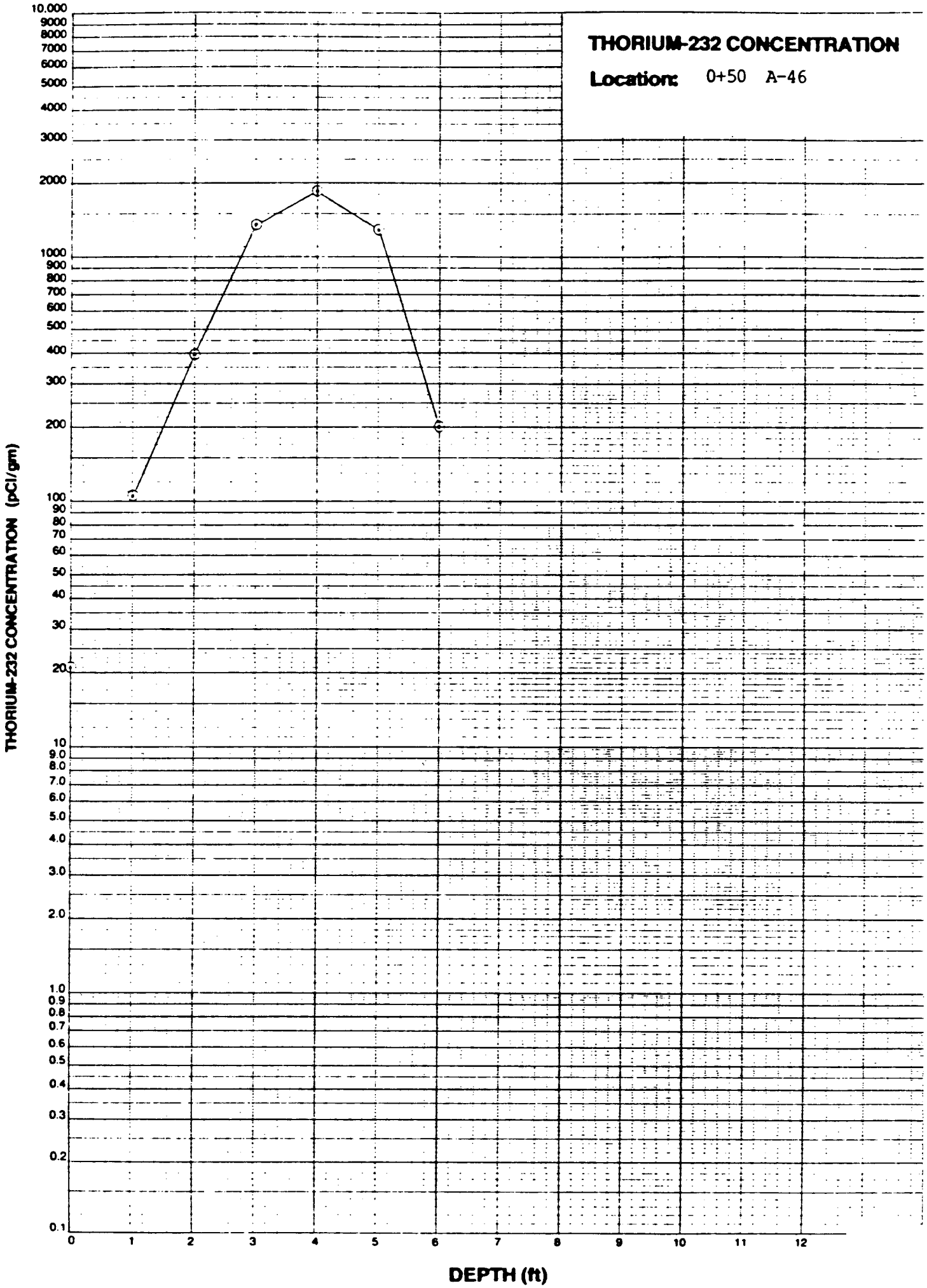
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+46 F
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+50 A-46
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
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400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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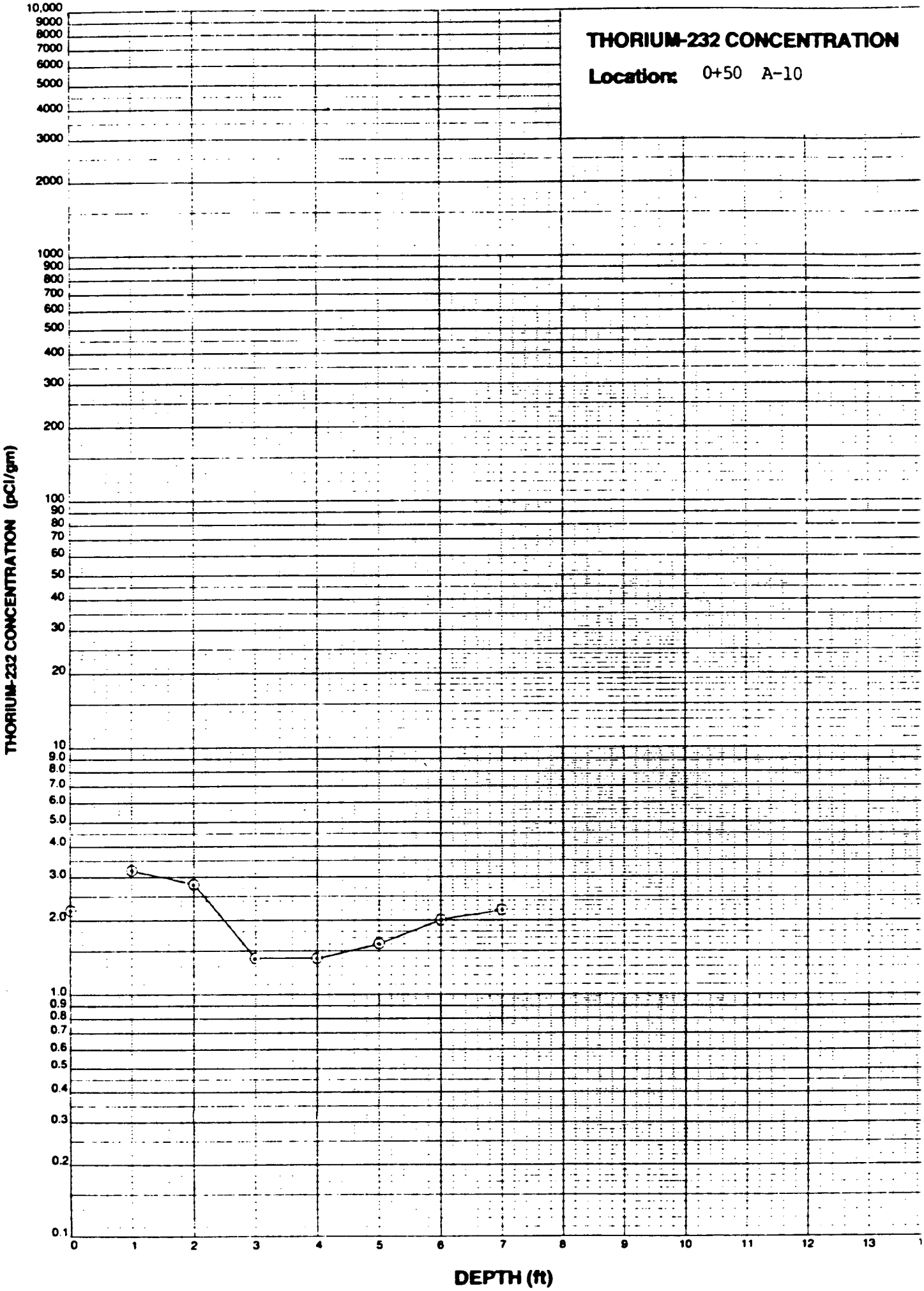
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+50 A-10
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
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40
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20
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9.0
8.0
7.0
6.0
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4.0
3.0
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0.7
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1
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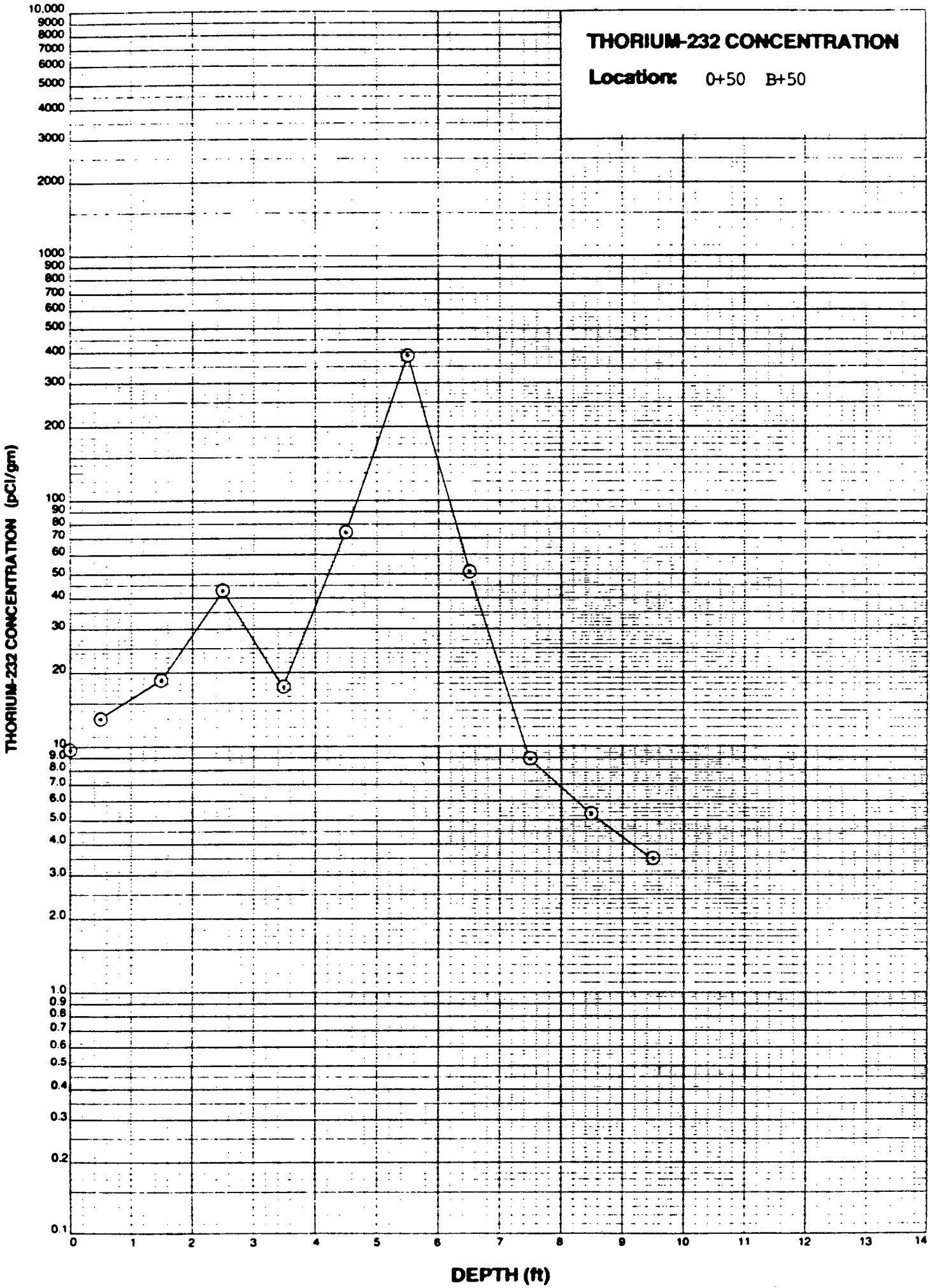
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+50 B+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
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8.0
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11
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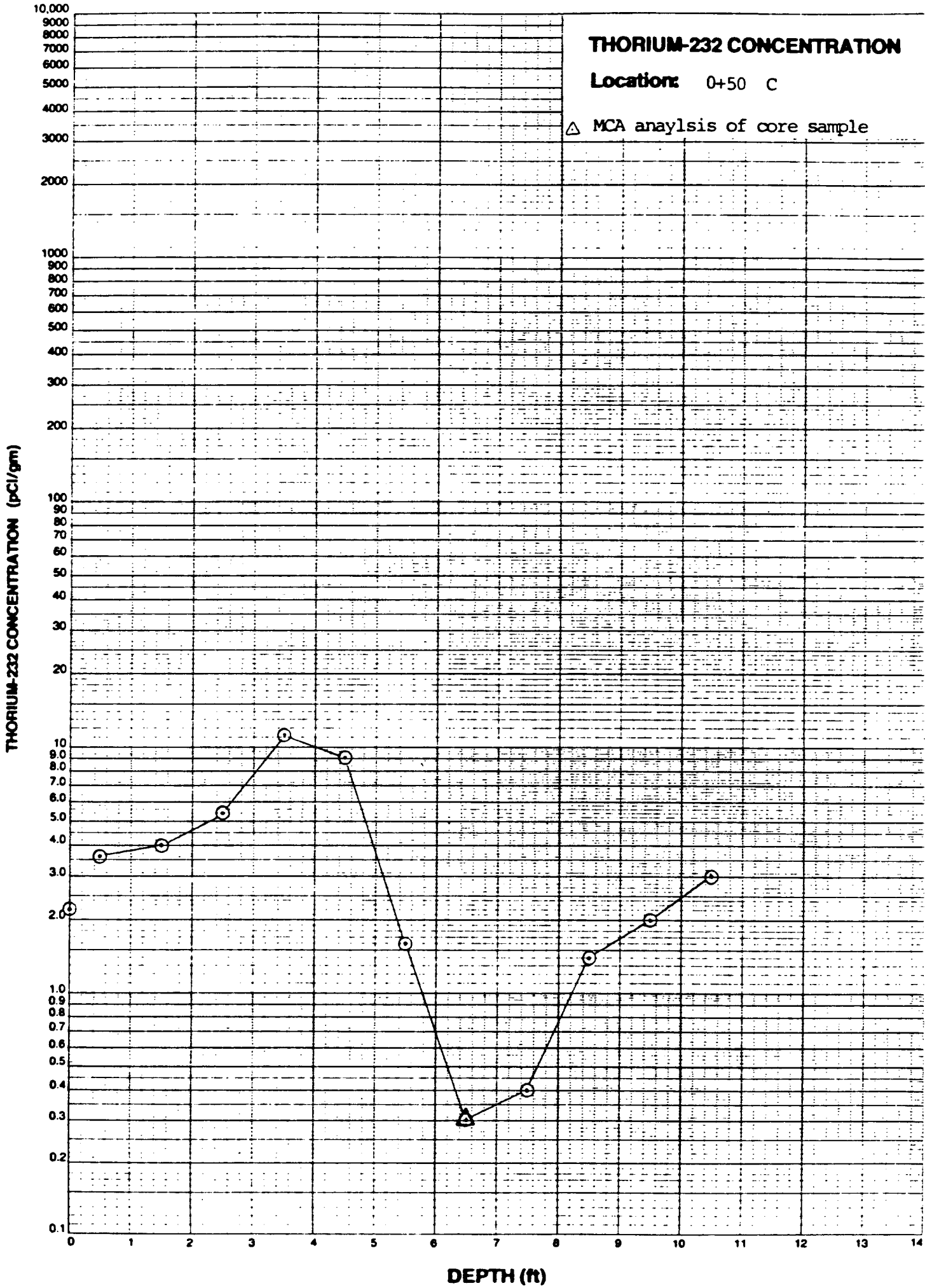
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+50 C
△ MCA anaylsis of core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
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5000
4000
3000
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1000
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9.0
8.0
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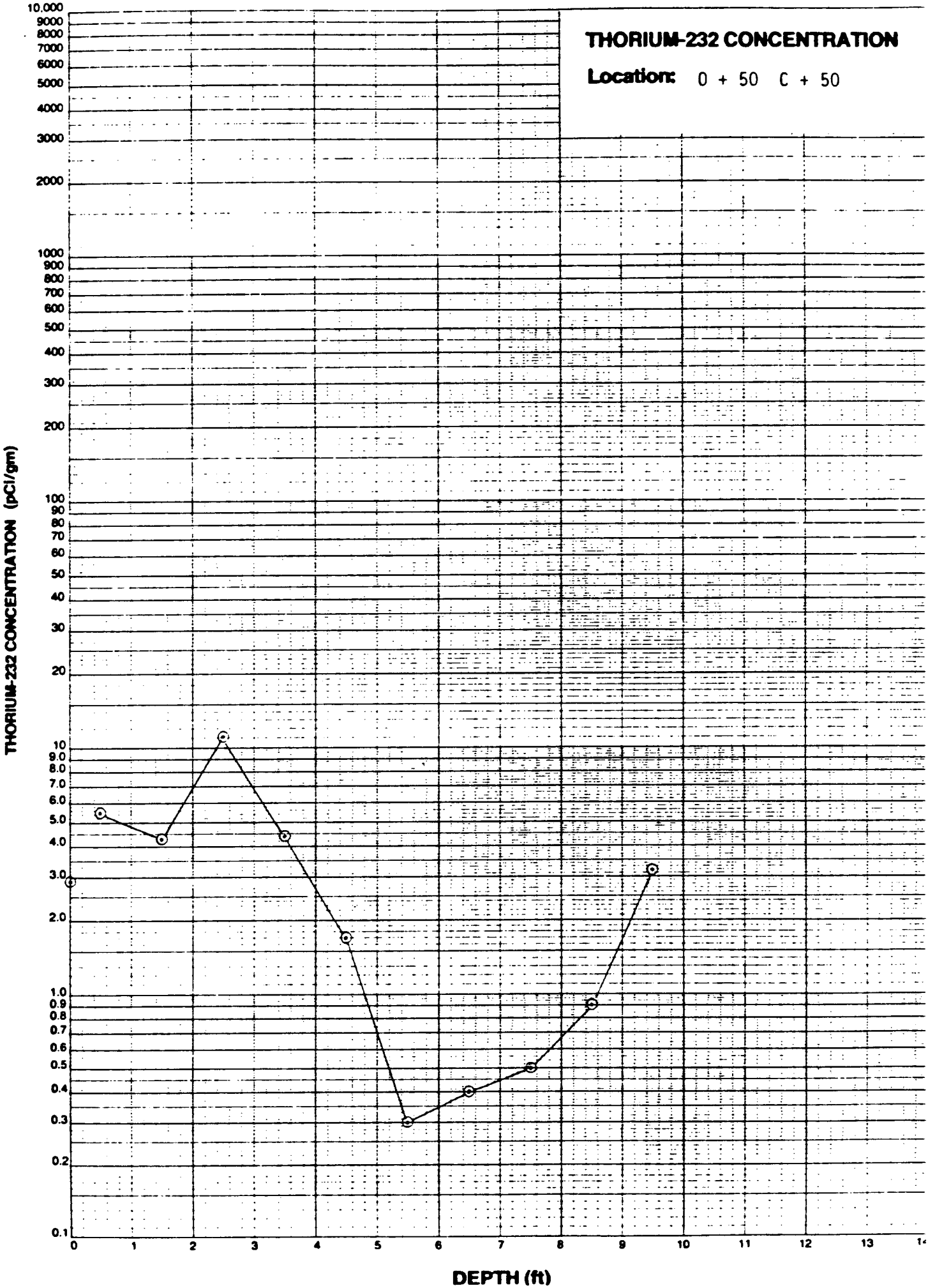
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0 + 50 C + 50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
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9.0
8.0
7.0
6.0
5.0
4.0
3.0
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1.0
0.9
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0.5
0.4
0.3
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0.1
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9
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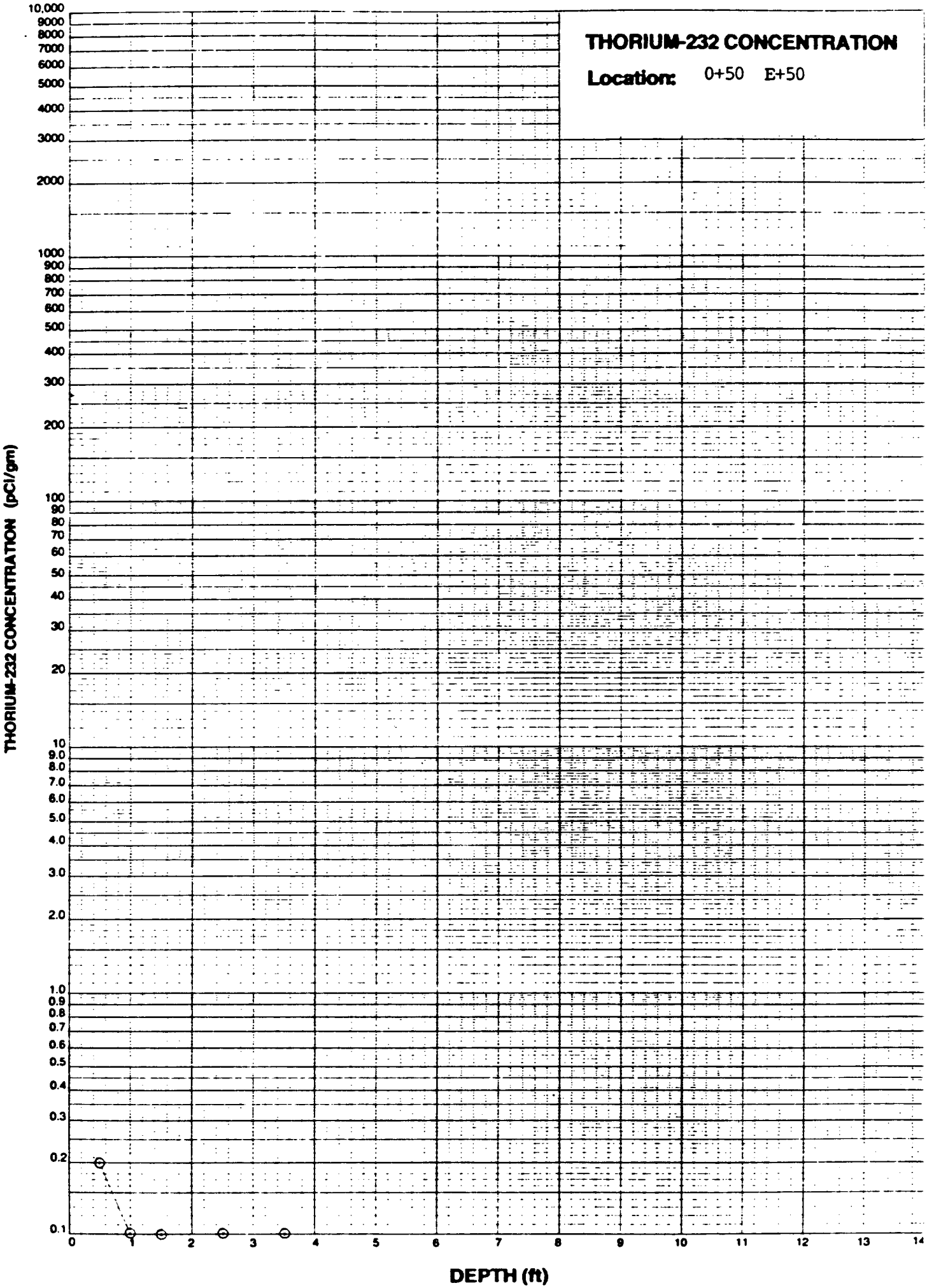
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+50 E+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
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400
300
200
100
90
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9.0
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6.0
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3.0
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1.0
0.9
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0.7
0.6
0.5
0.4
0.3
0.2
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4
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6
7
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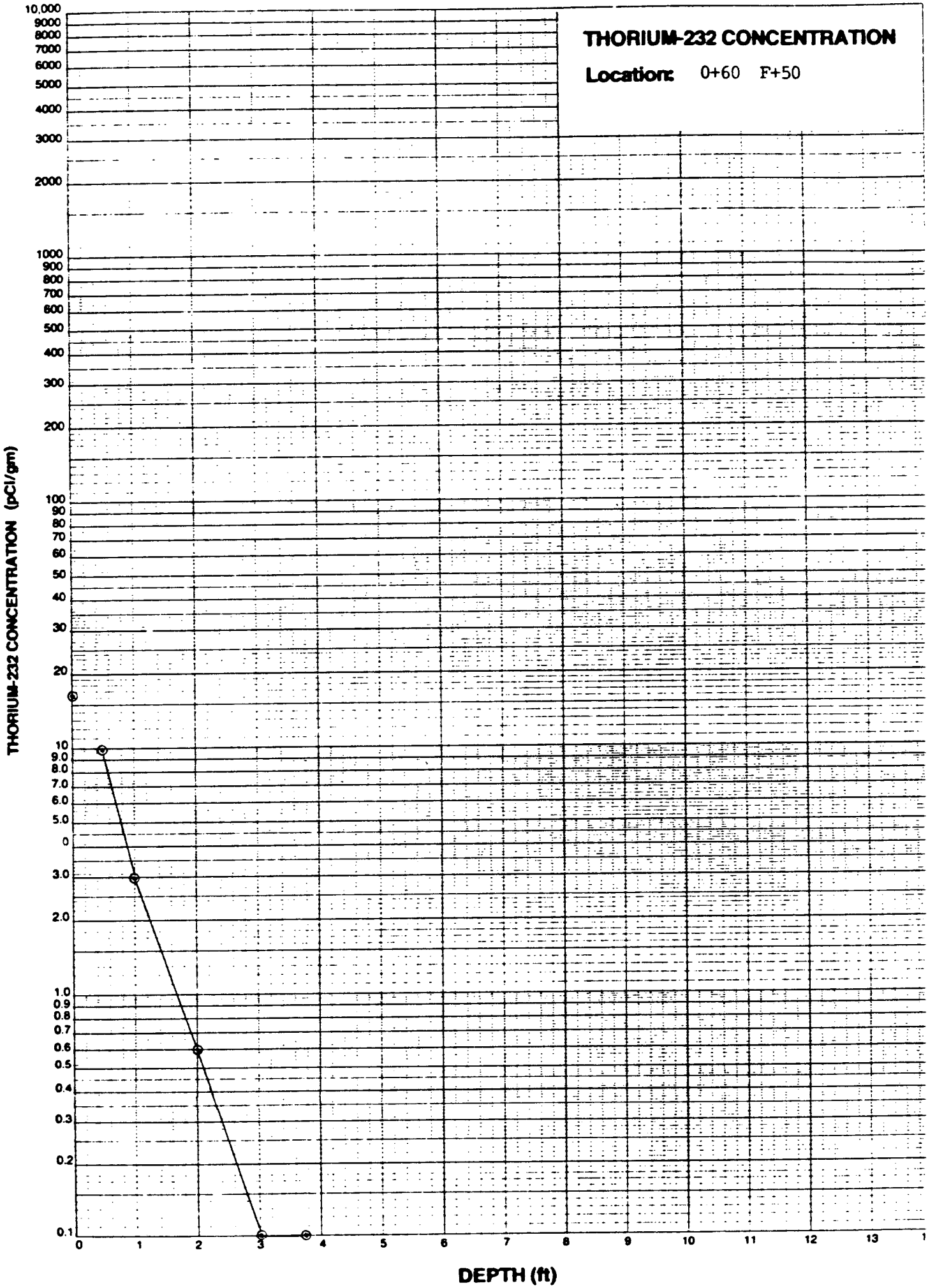
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+60 F+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
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3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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0.1
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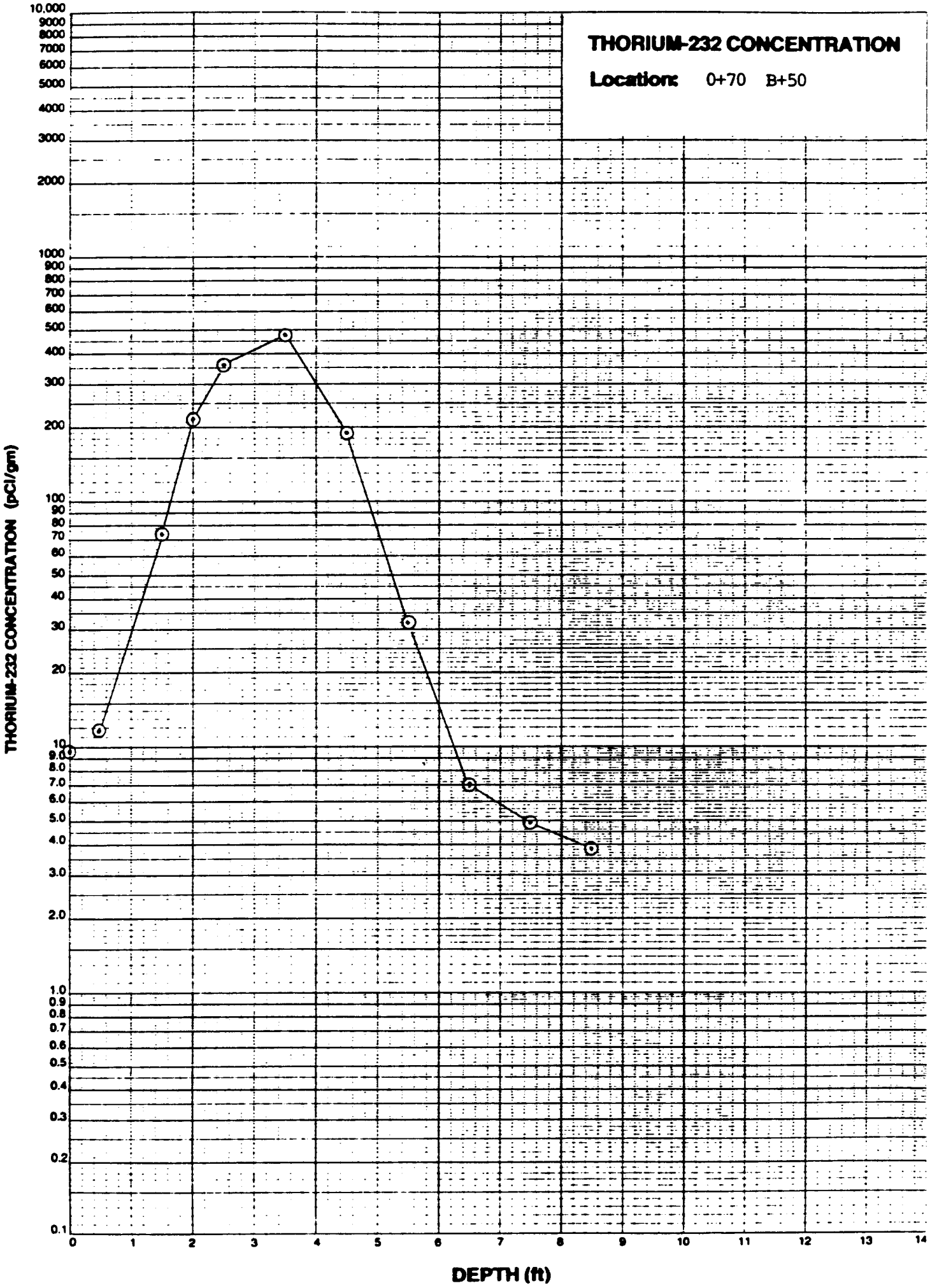
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+70 B+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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10
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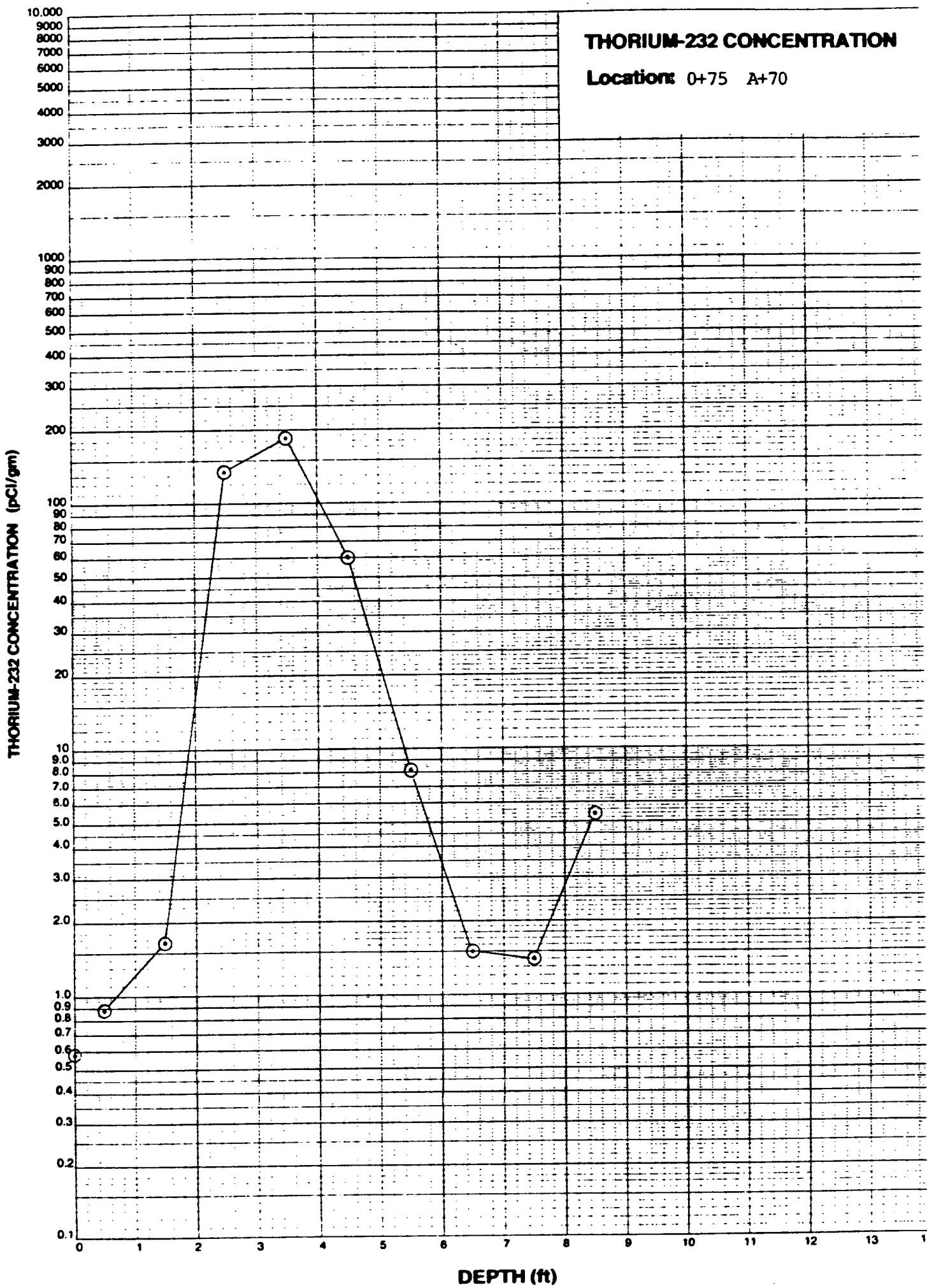
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+75 A+70
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
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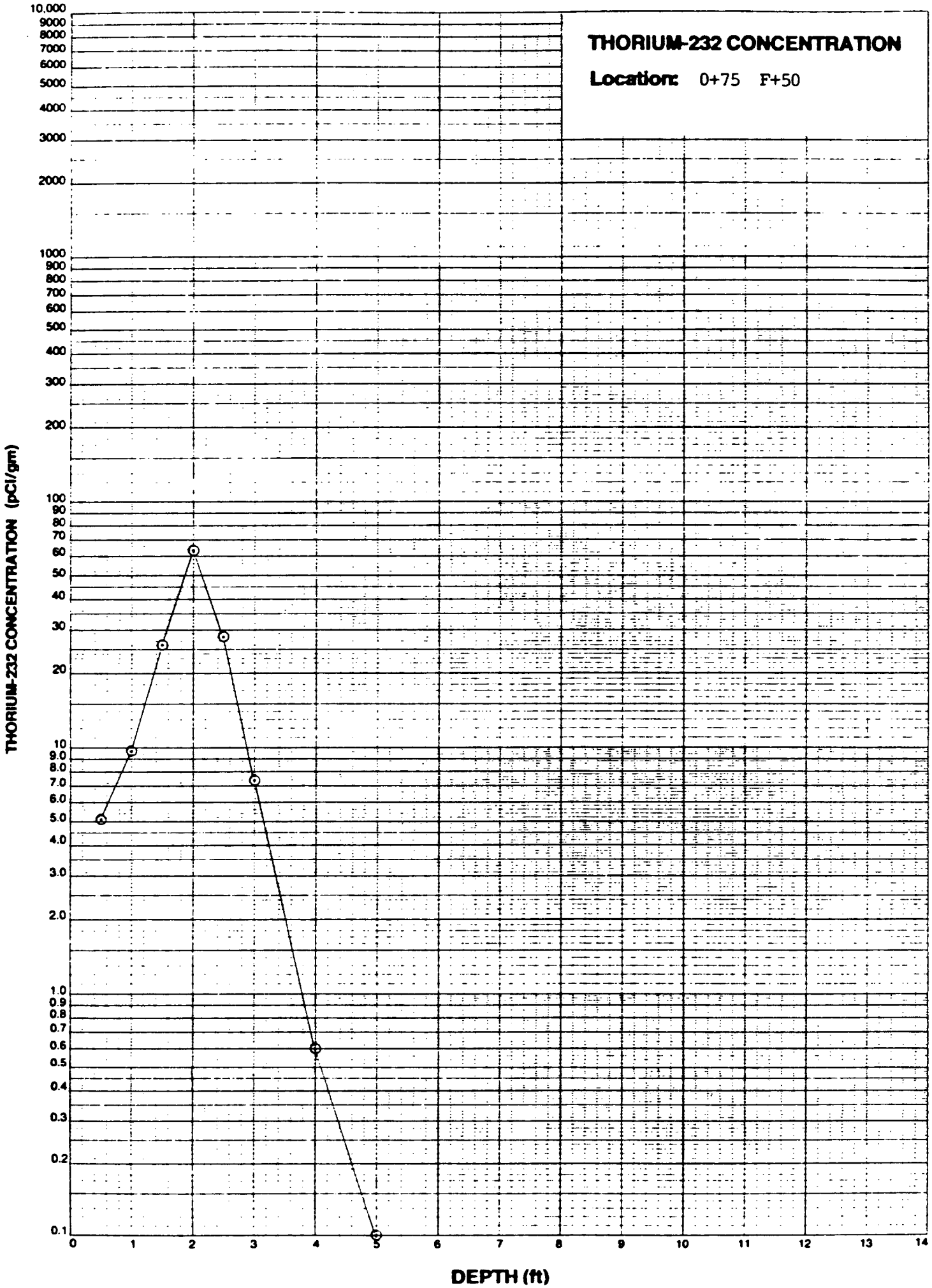
THORIUM-232 CONCENTRATION
Location: 0+75 F+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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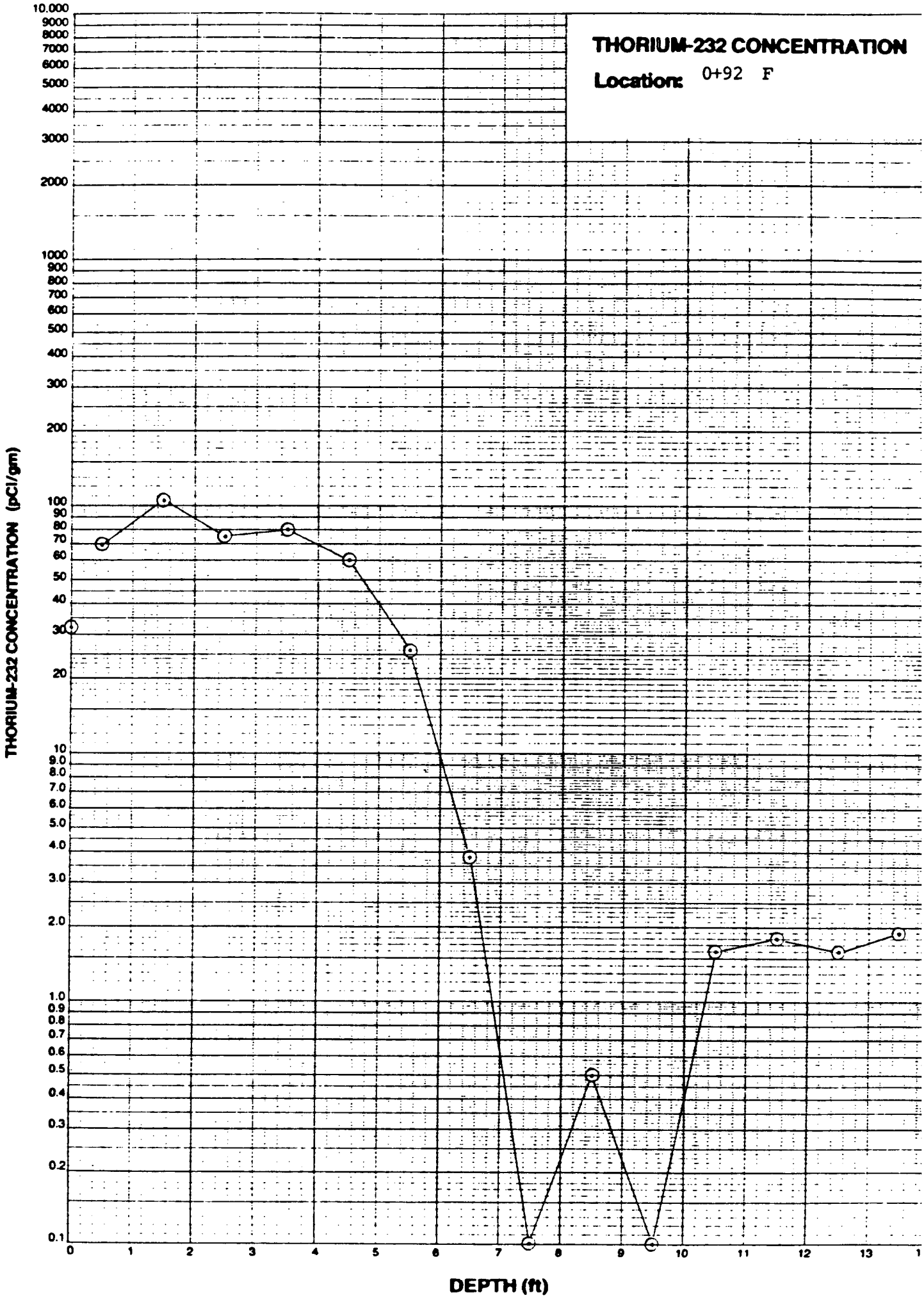
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 0+92 F
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
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9.0
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7.0
6.0
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4.0
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2.0
1.0
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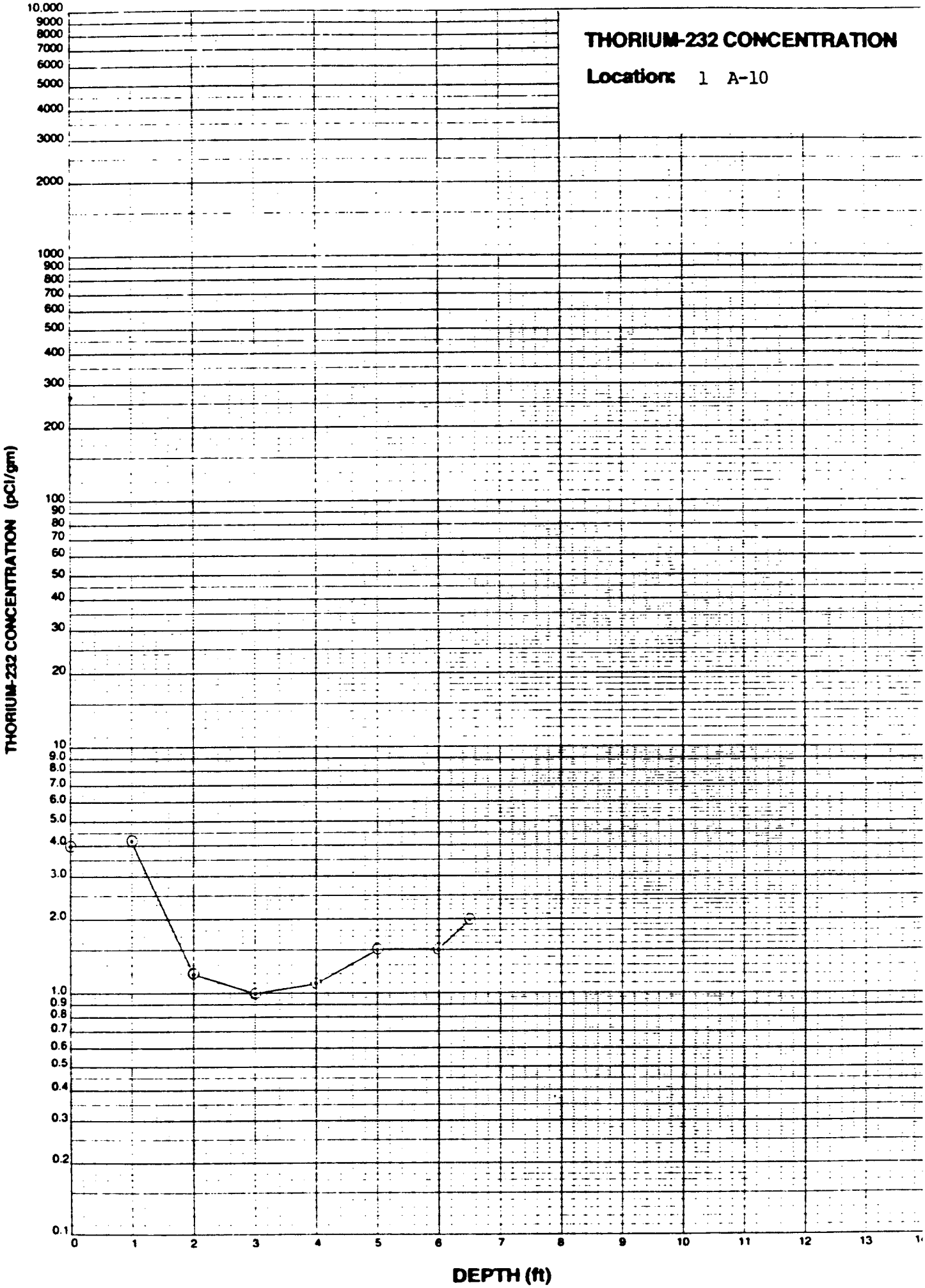
THORIUM-232 CONCENTRATION
Location: 1 A-10
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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4
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6
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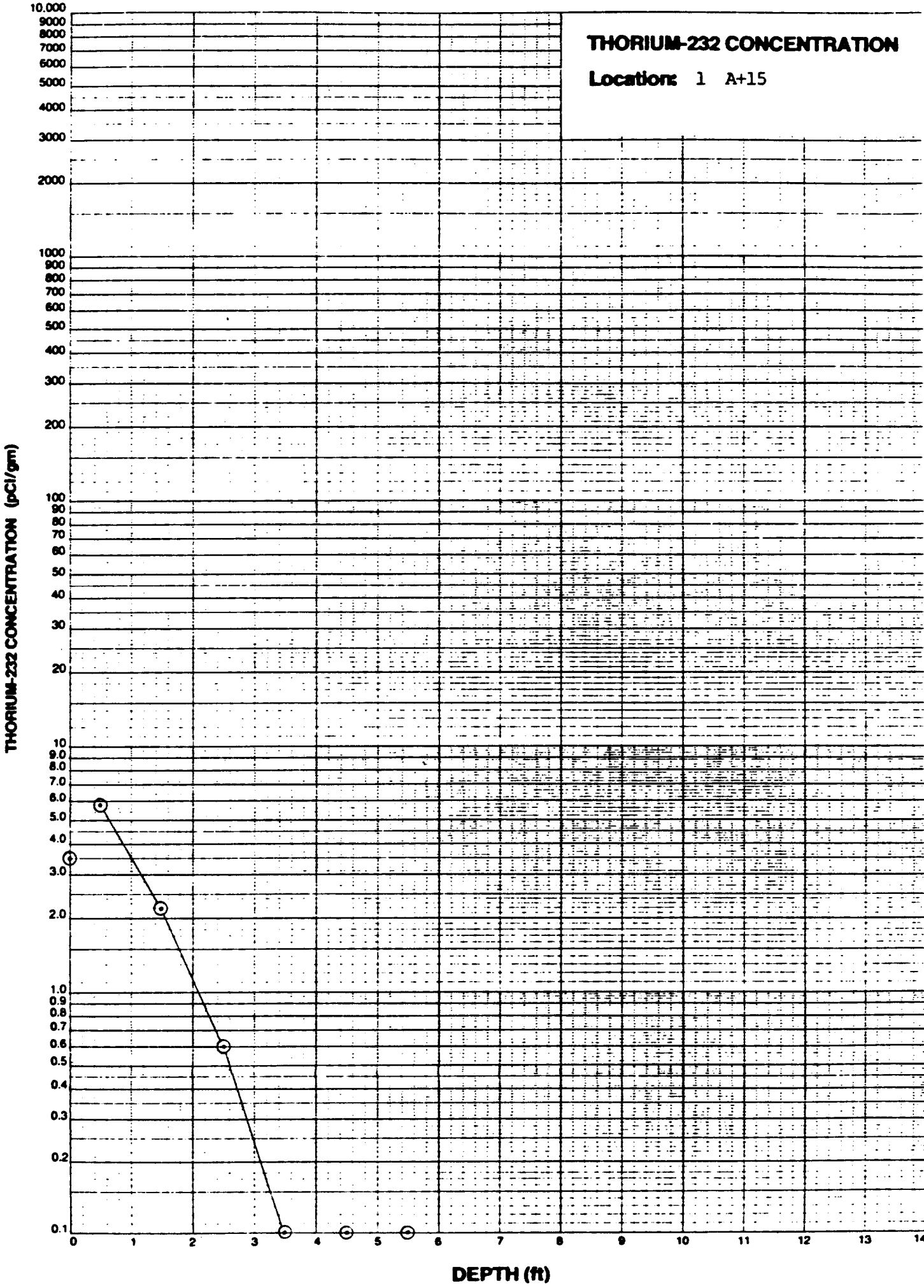
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 A+15
THORIUM-232 CONCENTRATION (pCi/gm)
10.000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
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4
5
6
7
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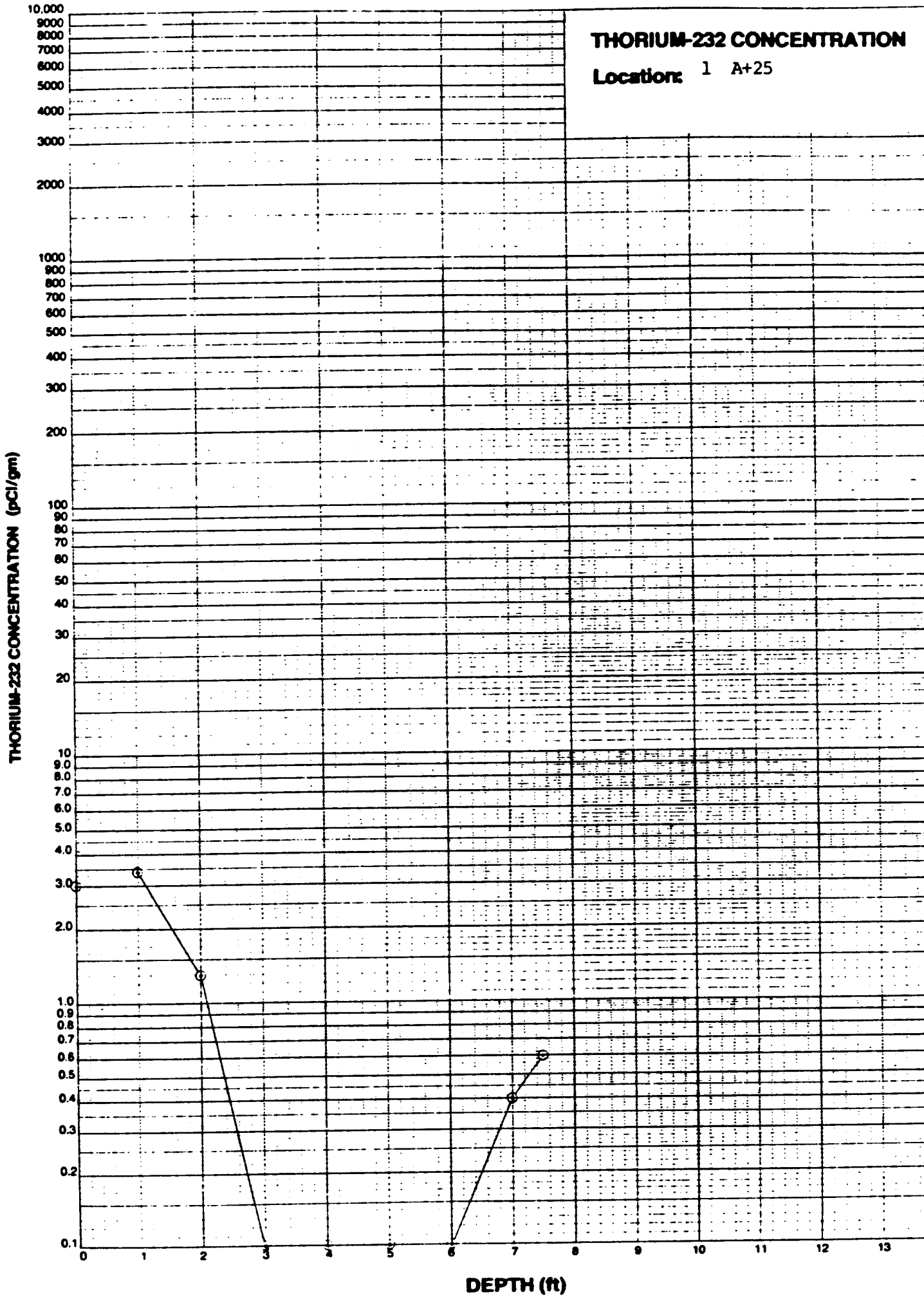
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 A+25
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
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700
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500
400
300
200
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90
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9.0
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
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0
1
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5
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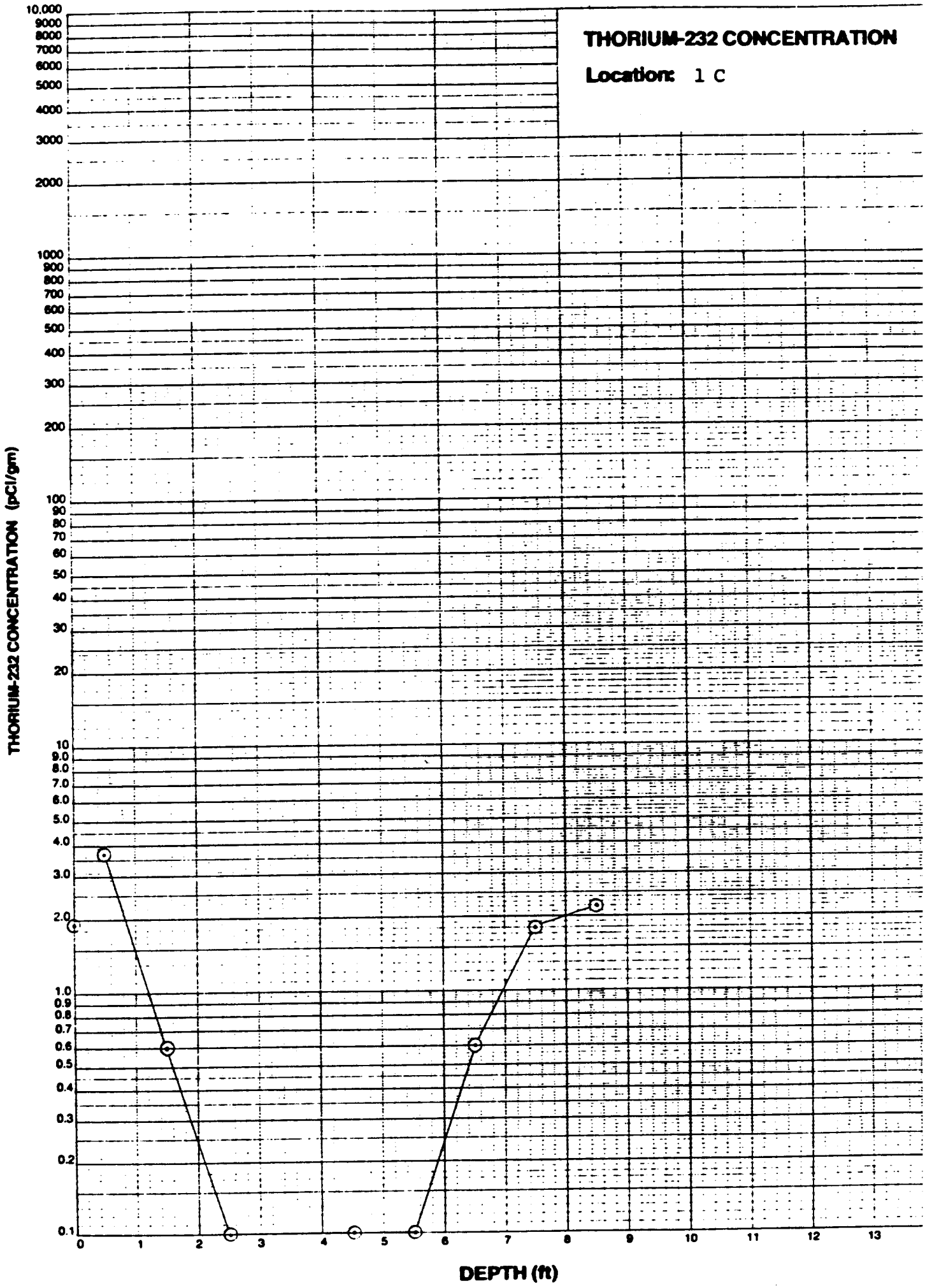
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 C
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
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4000
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2000
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50
40
30
20
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9.0
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7.0
6.0
5.0
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3.0
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
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0.1
0
1
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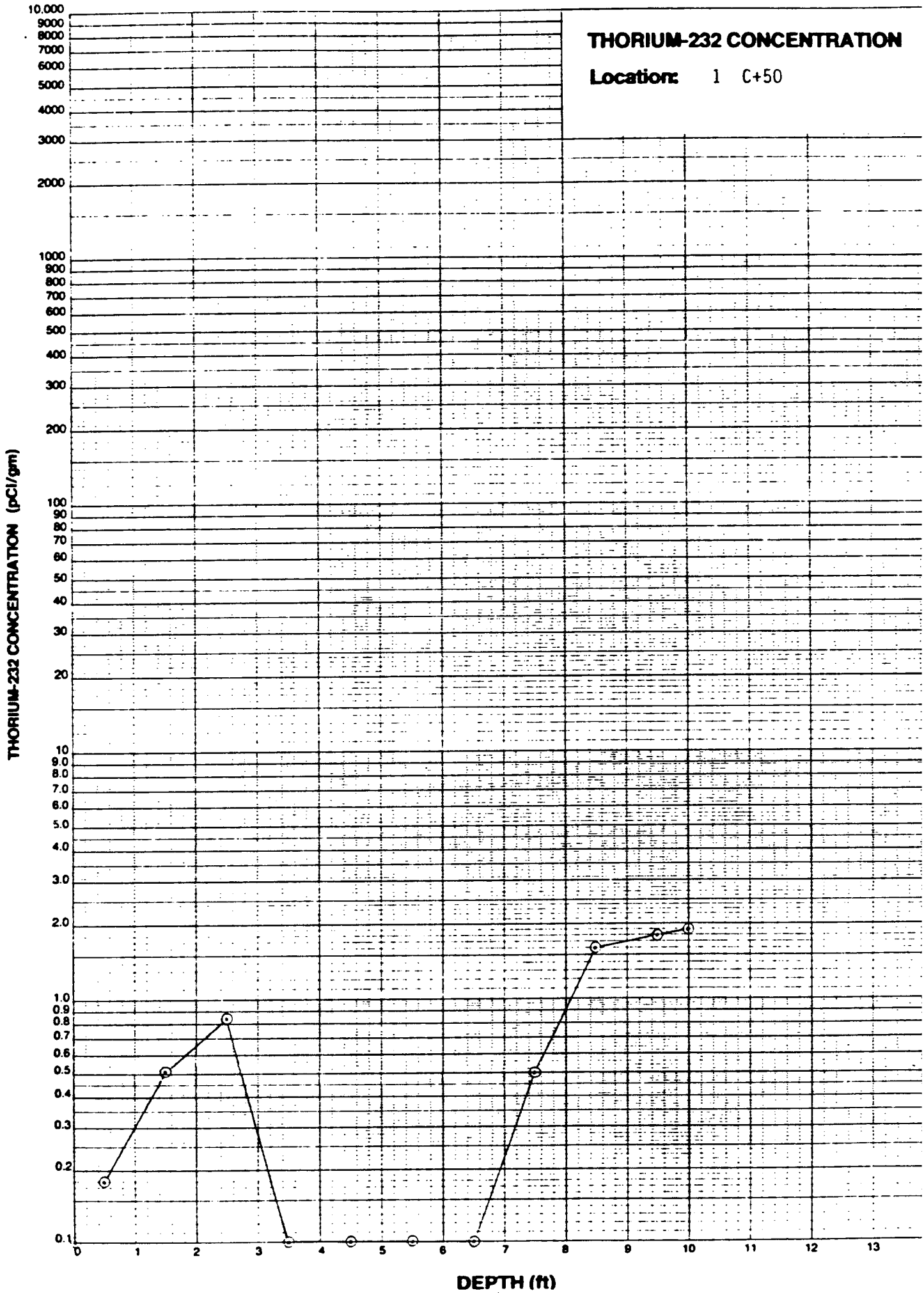
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 C+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
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700
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300
200
100
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9.0
8.0
7.0
6.0
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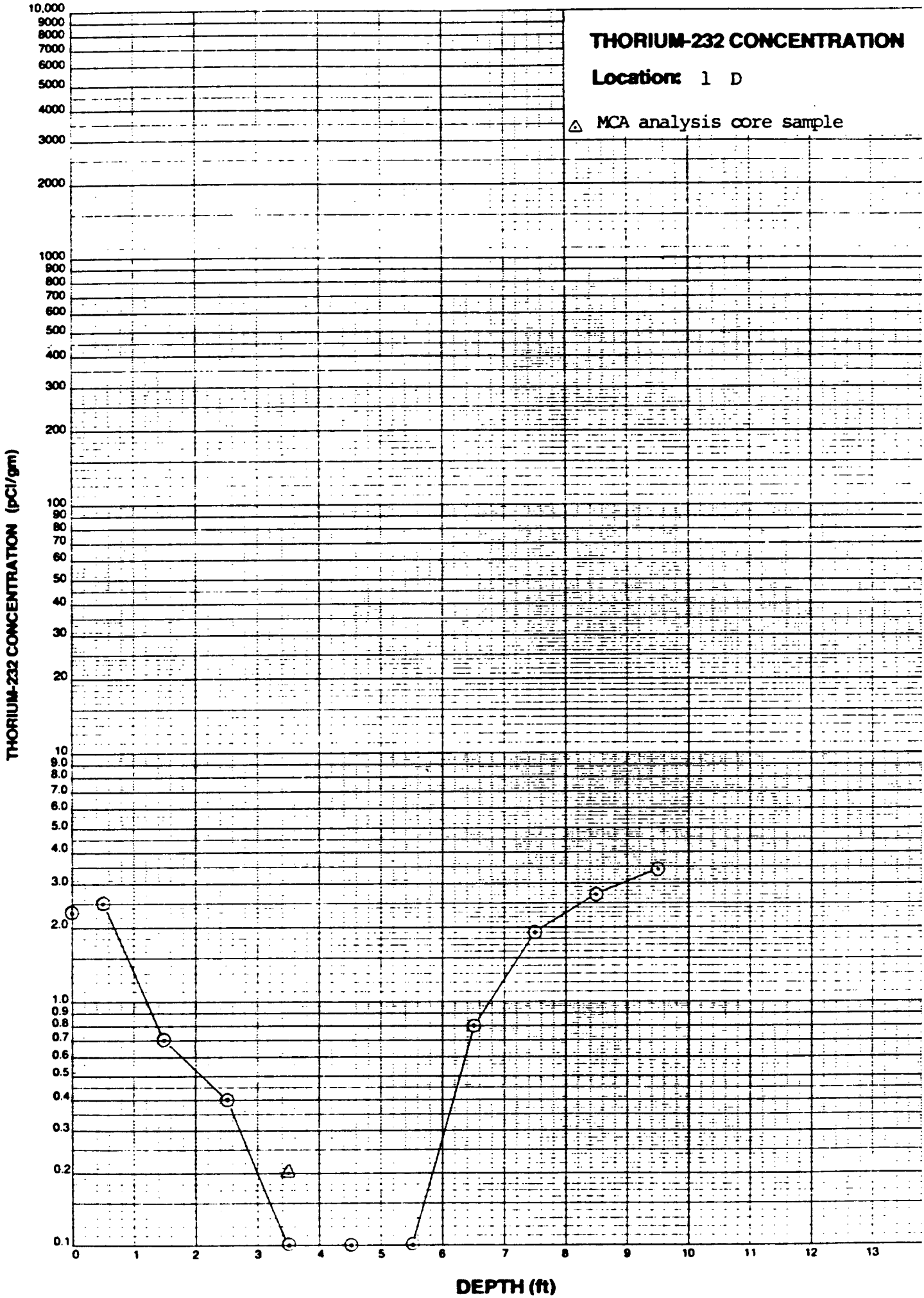
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 D
MCA analysis core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
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9.0
8.0
7.0
6.0
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4.0
3.0
2.0
1.0
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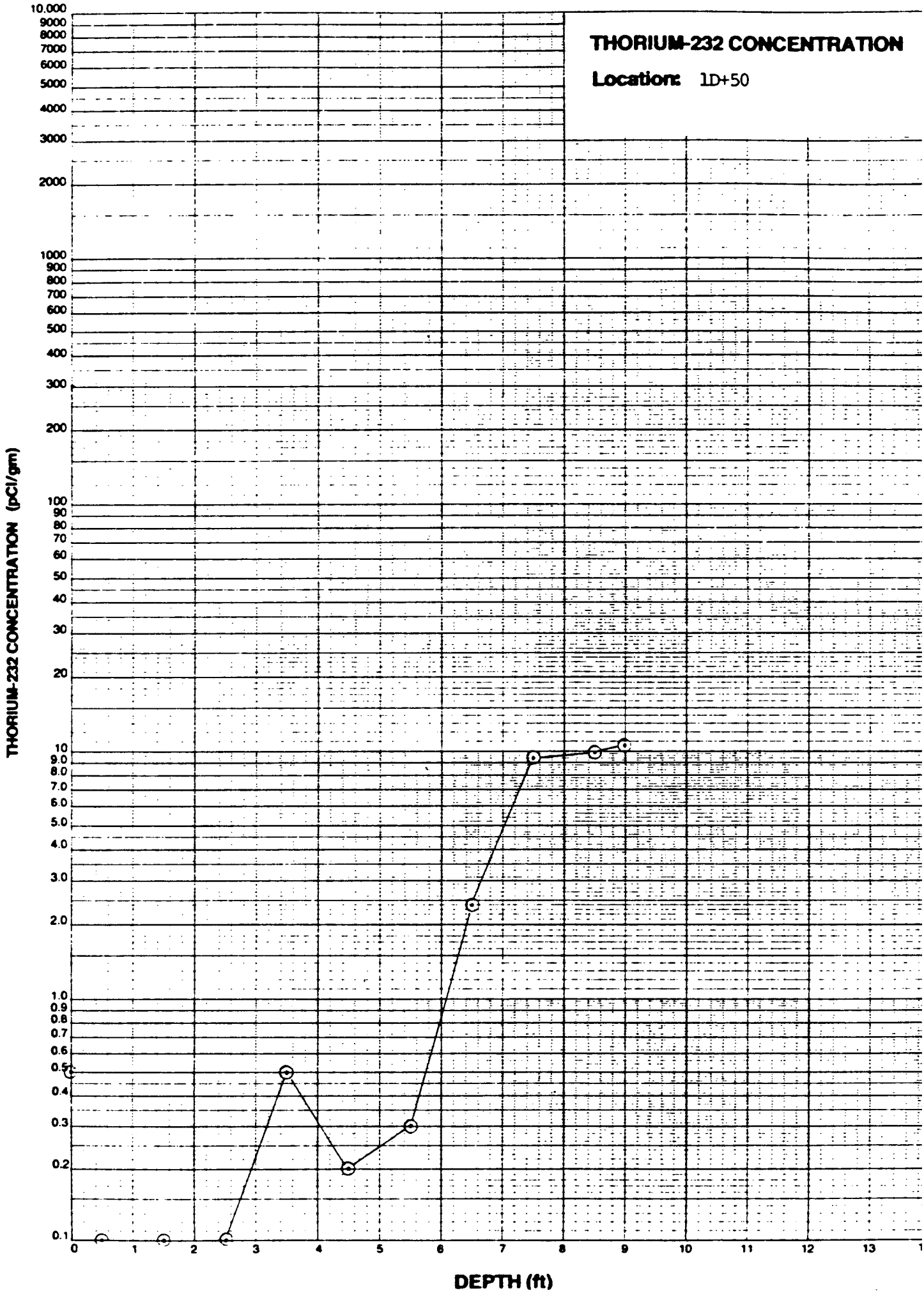
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1D+50
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
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5000
4000
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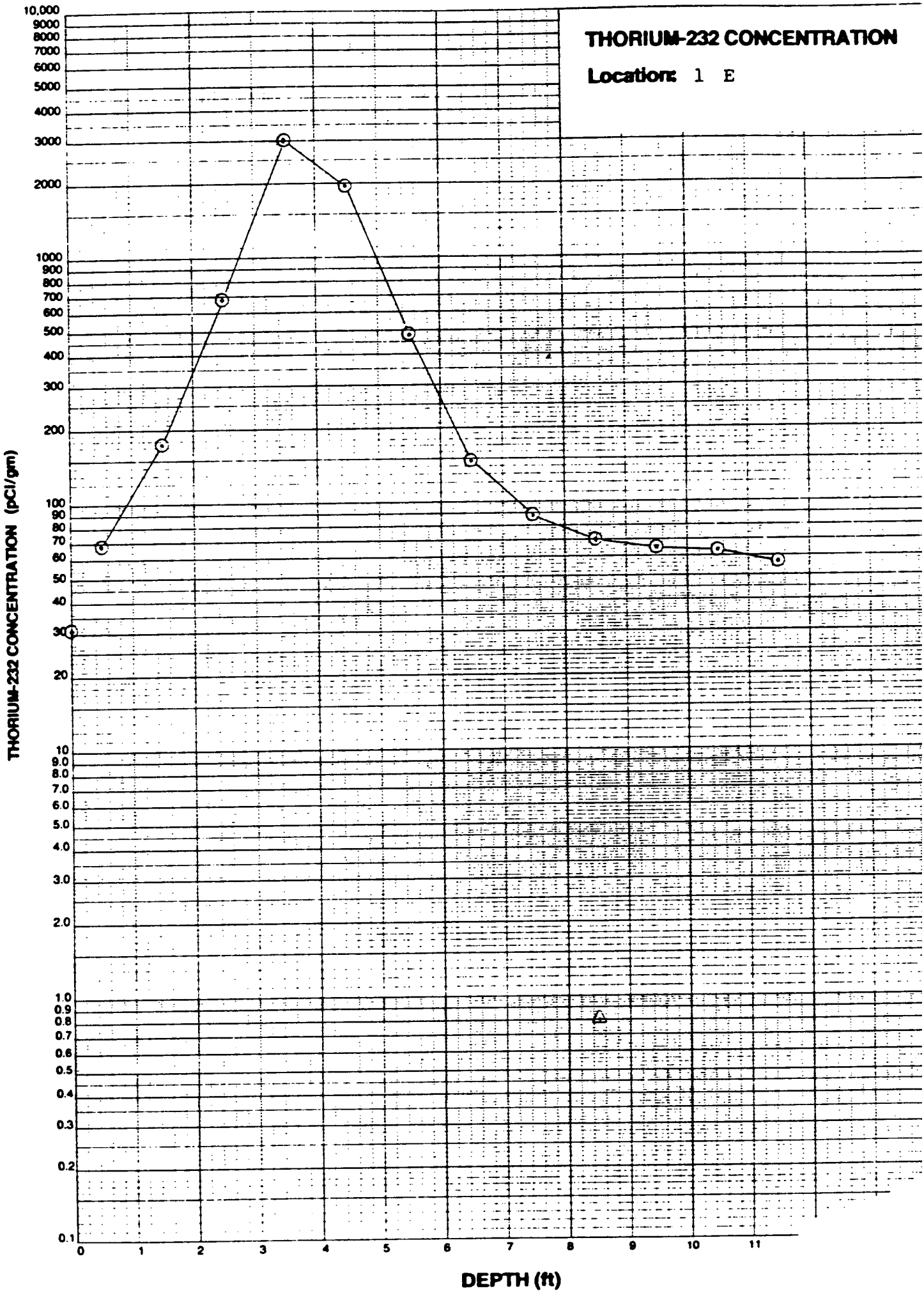
THORIUM-232 CONCENTRATION
Location: 1 E
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
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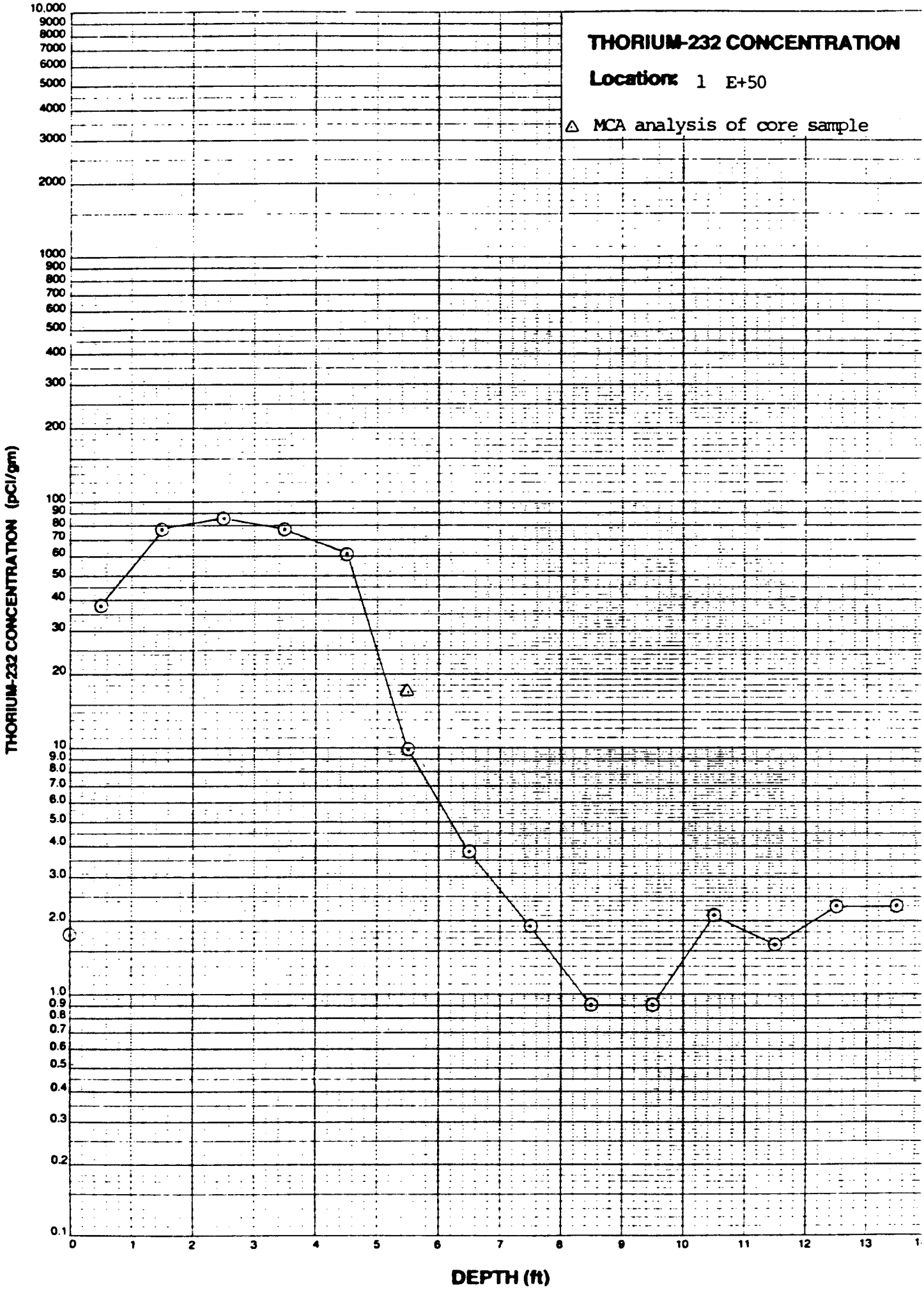
11
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 E+50
△ MCA analysis of core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
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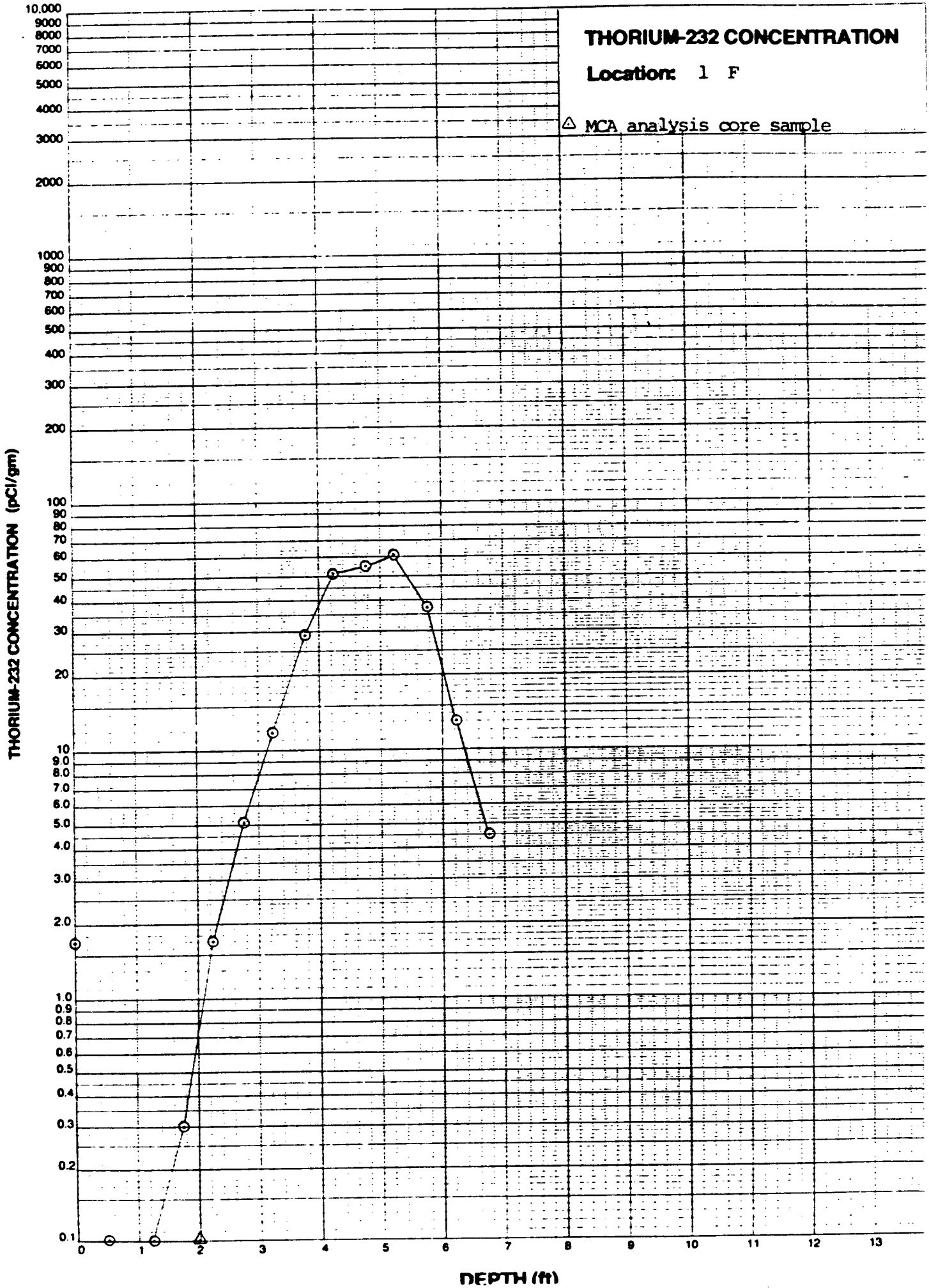
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 F
△ MCA analysis core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
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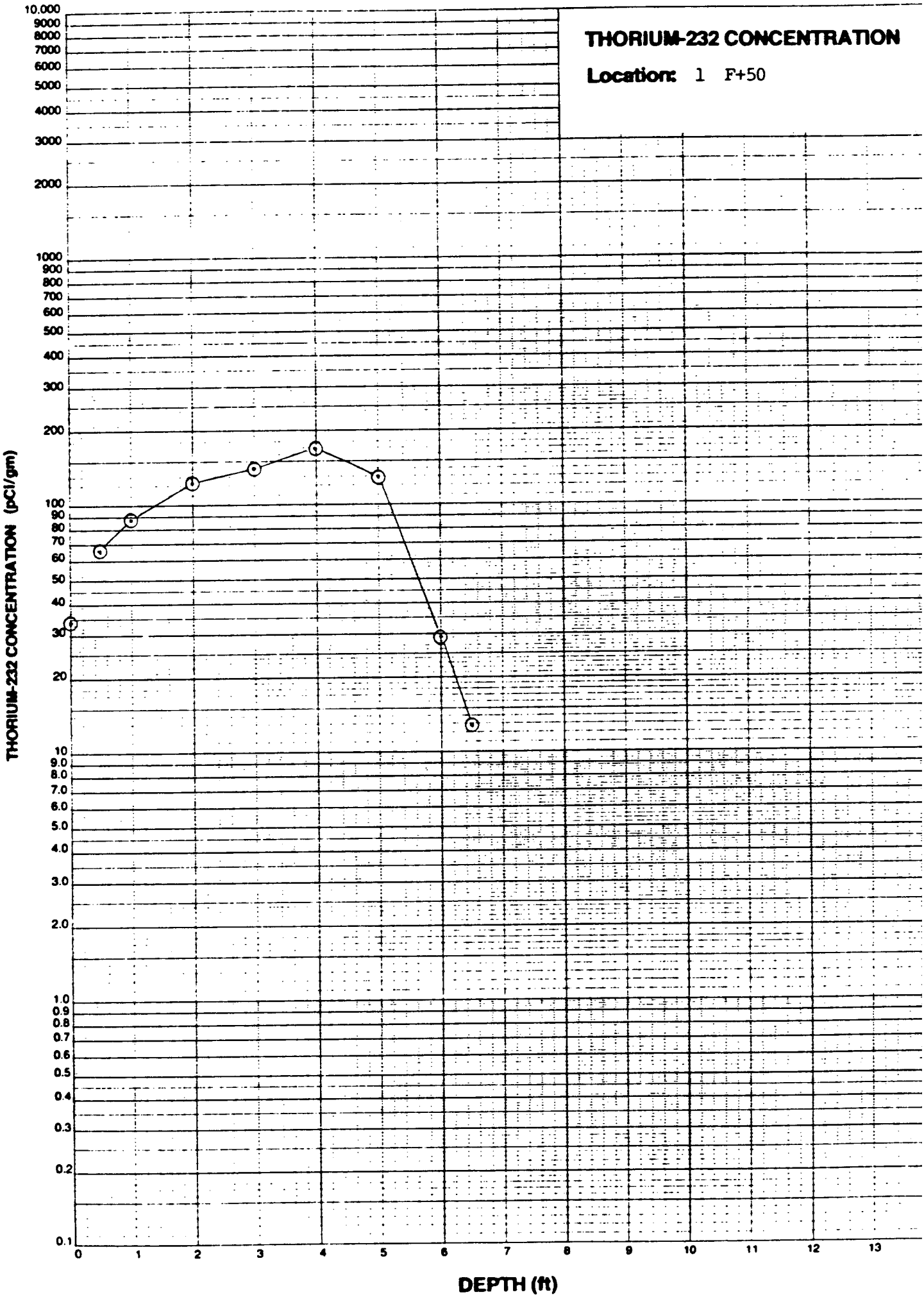
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 F+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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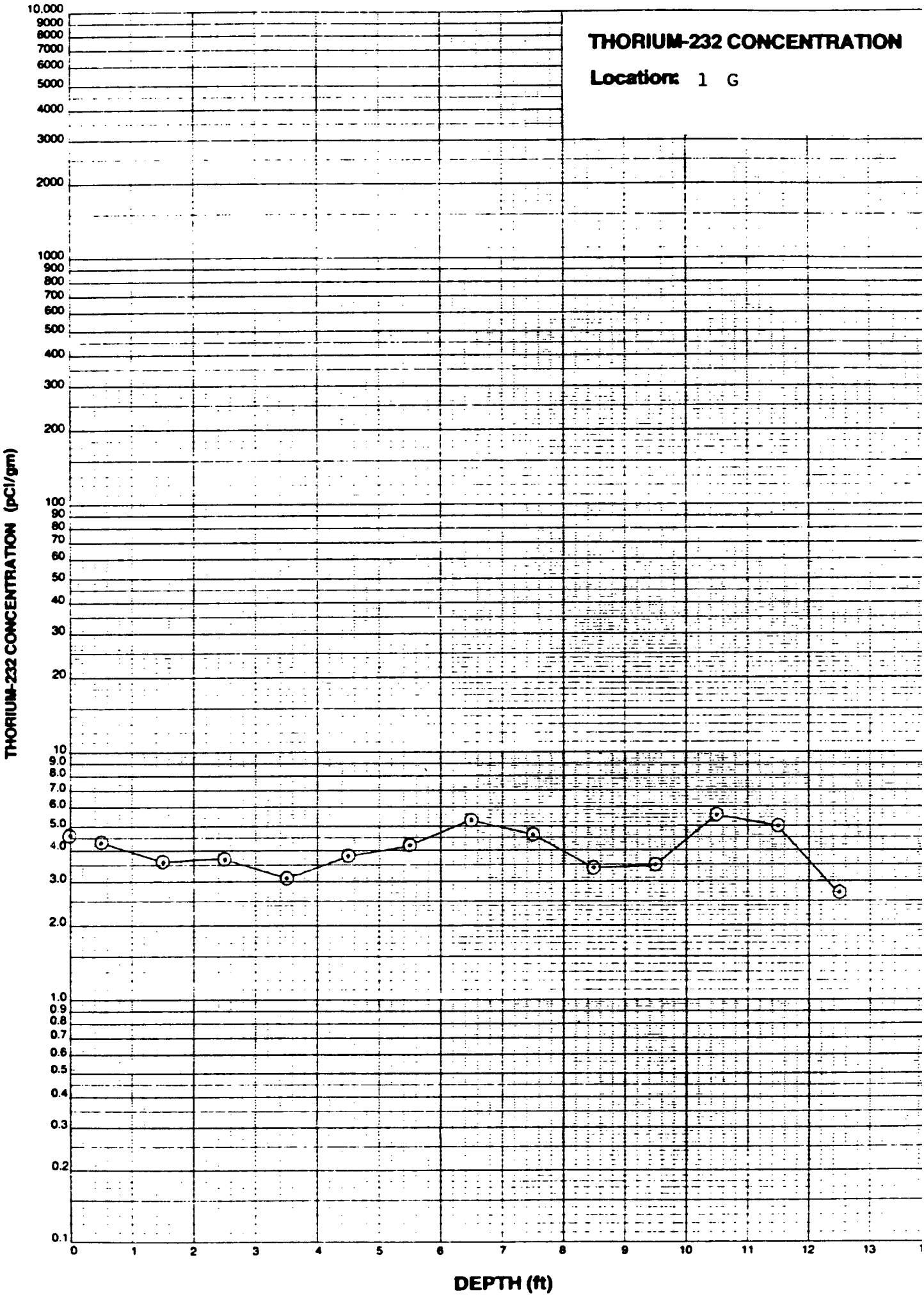
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1 G
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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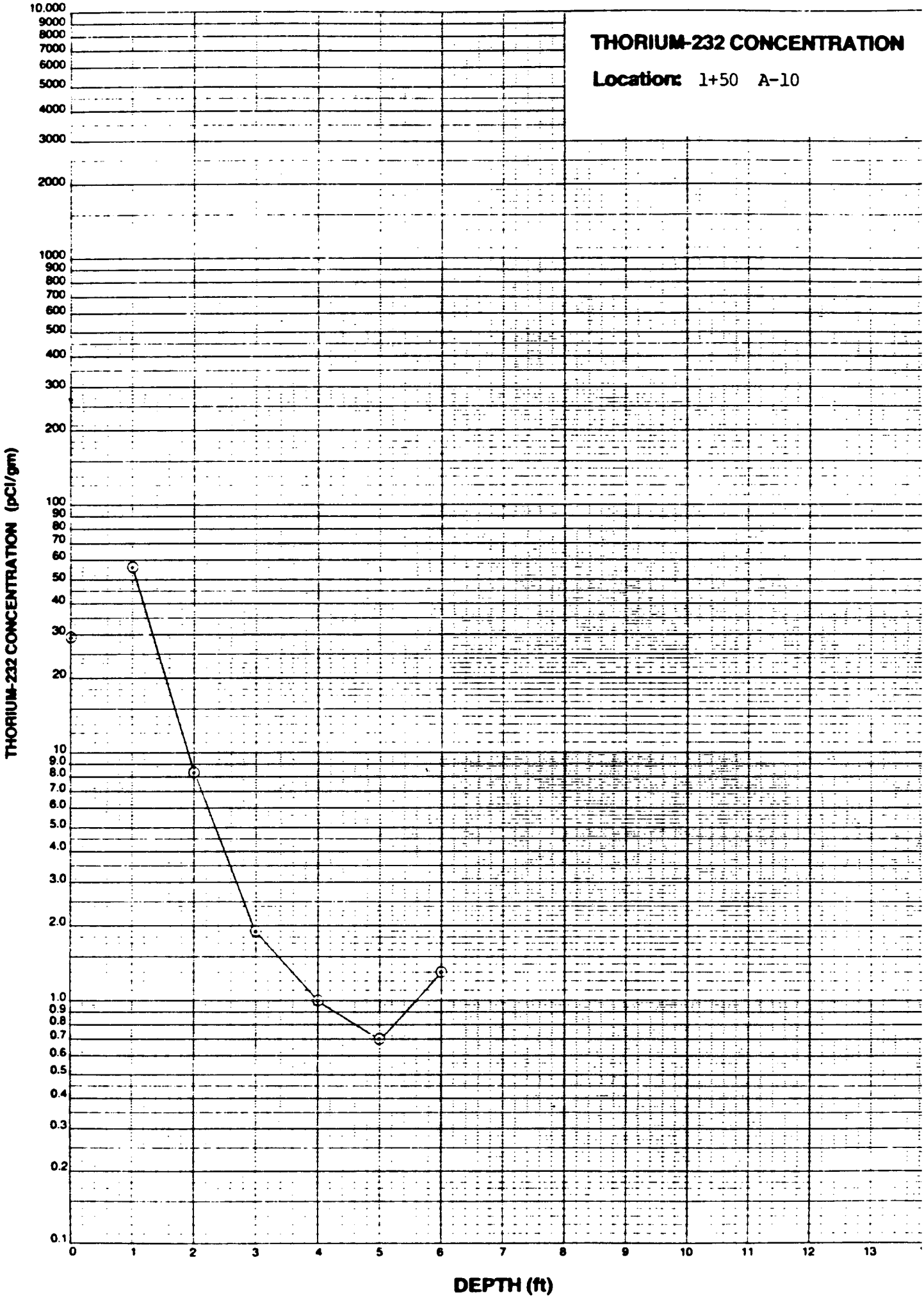
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+50 A-10
THORIUM-232 CONCENTRATION (pCi/gm)
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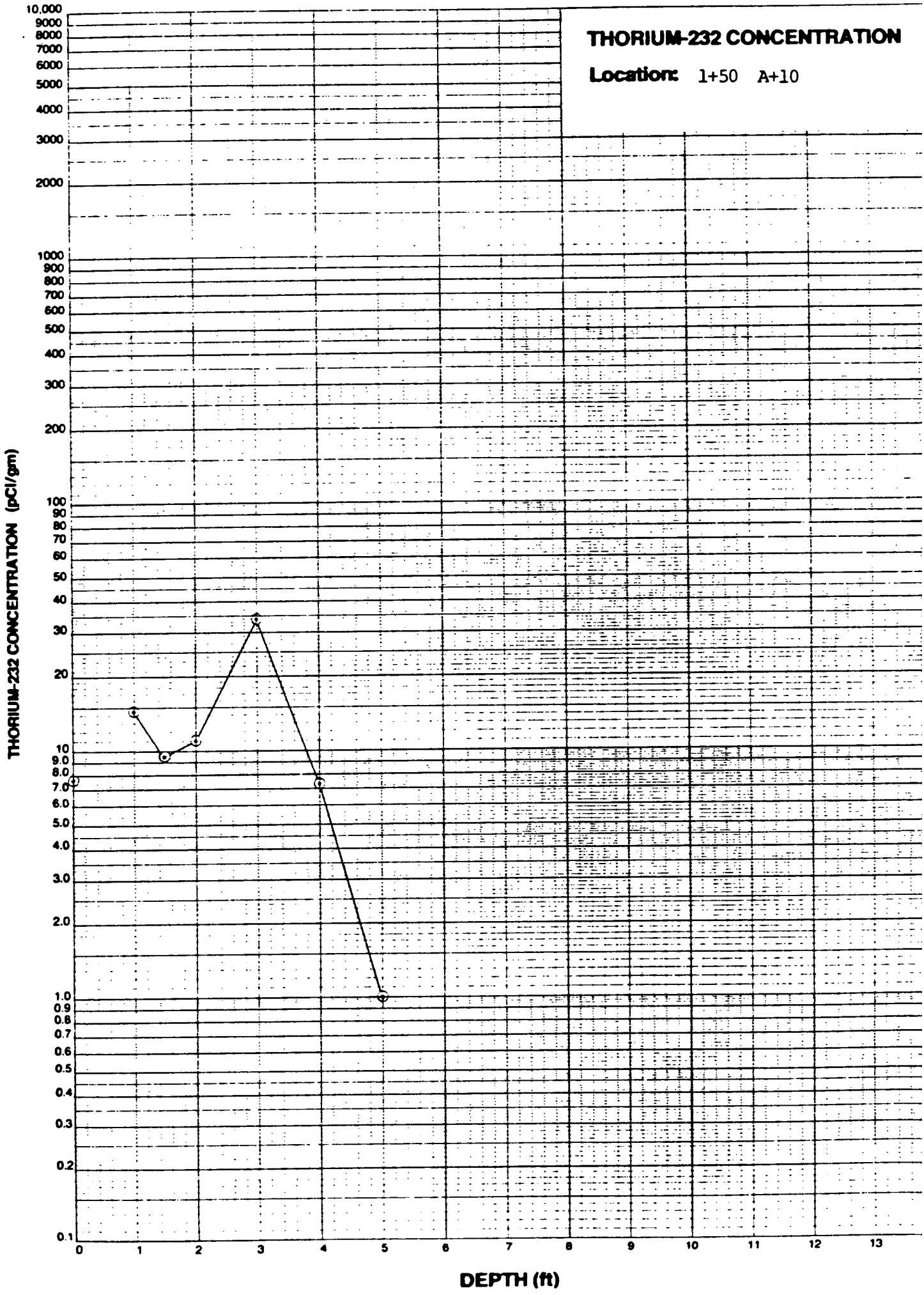
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+50 A+10
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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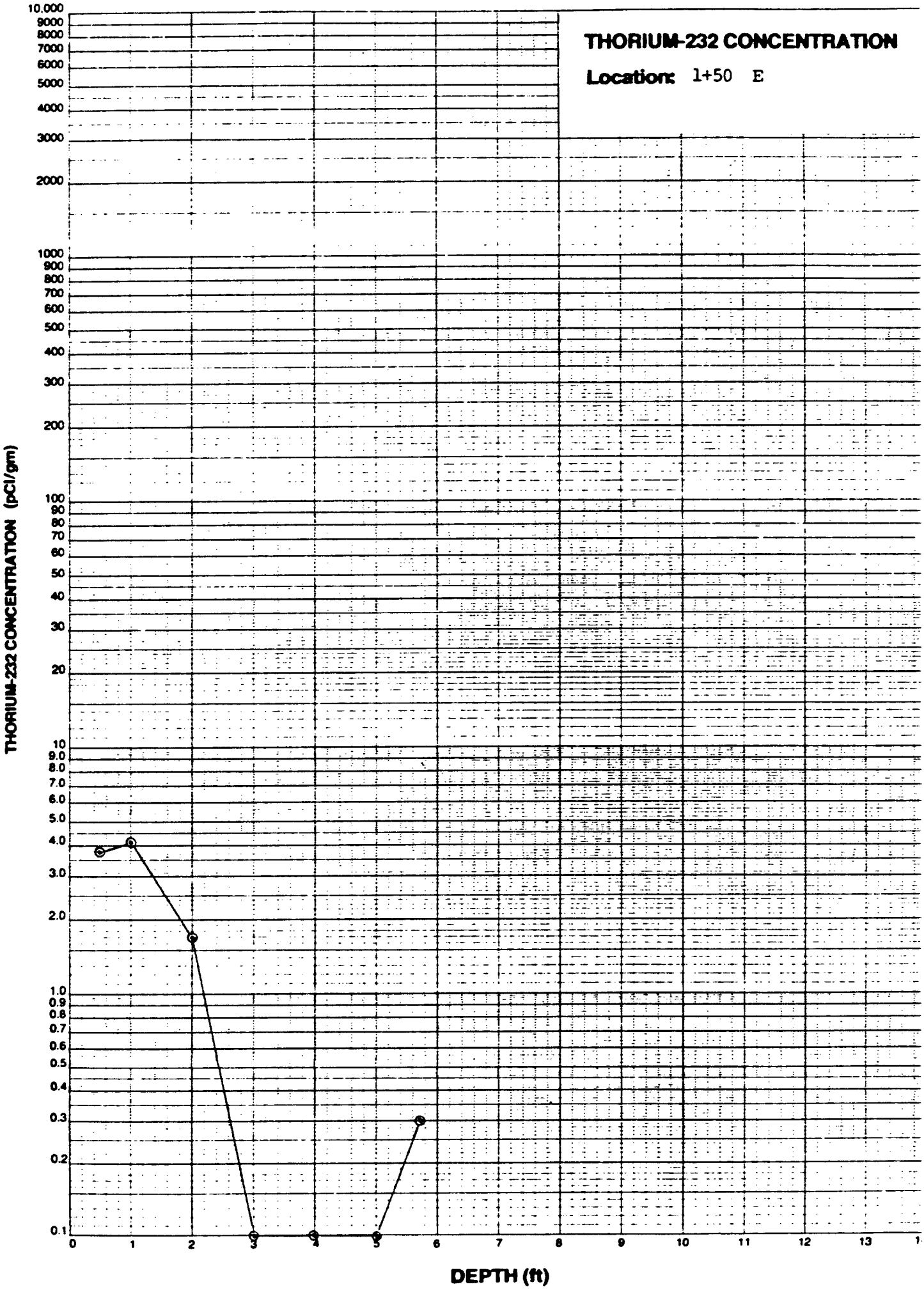
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+50 E
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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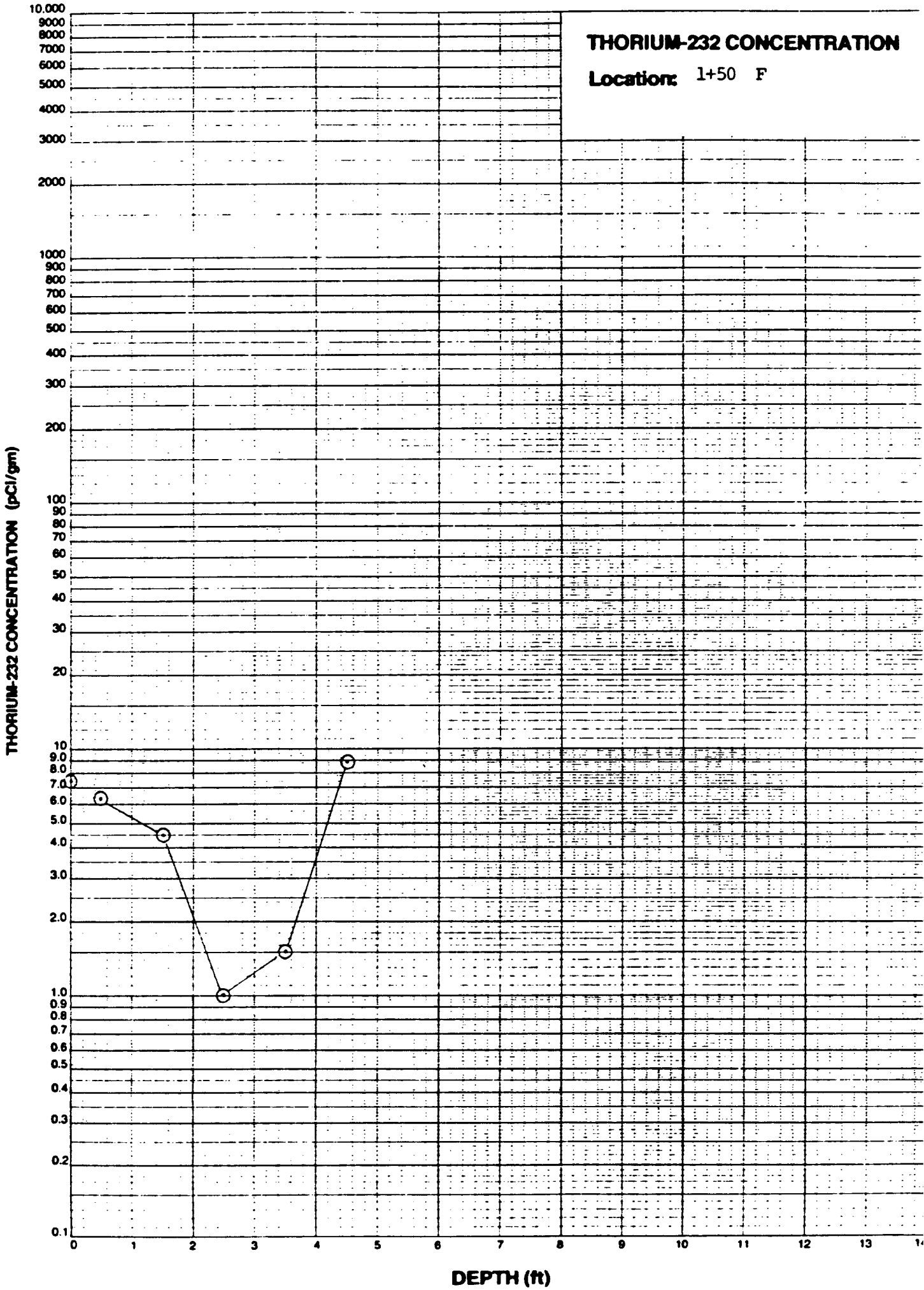
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+50 F
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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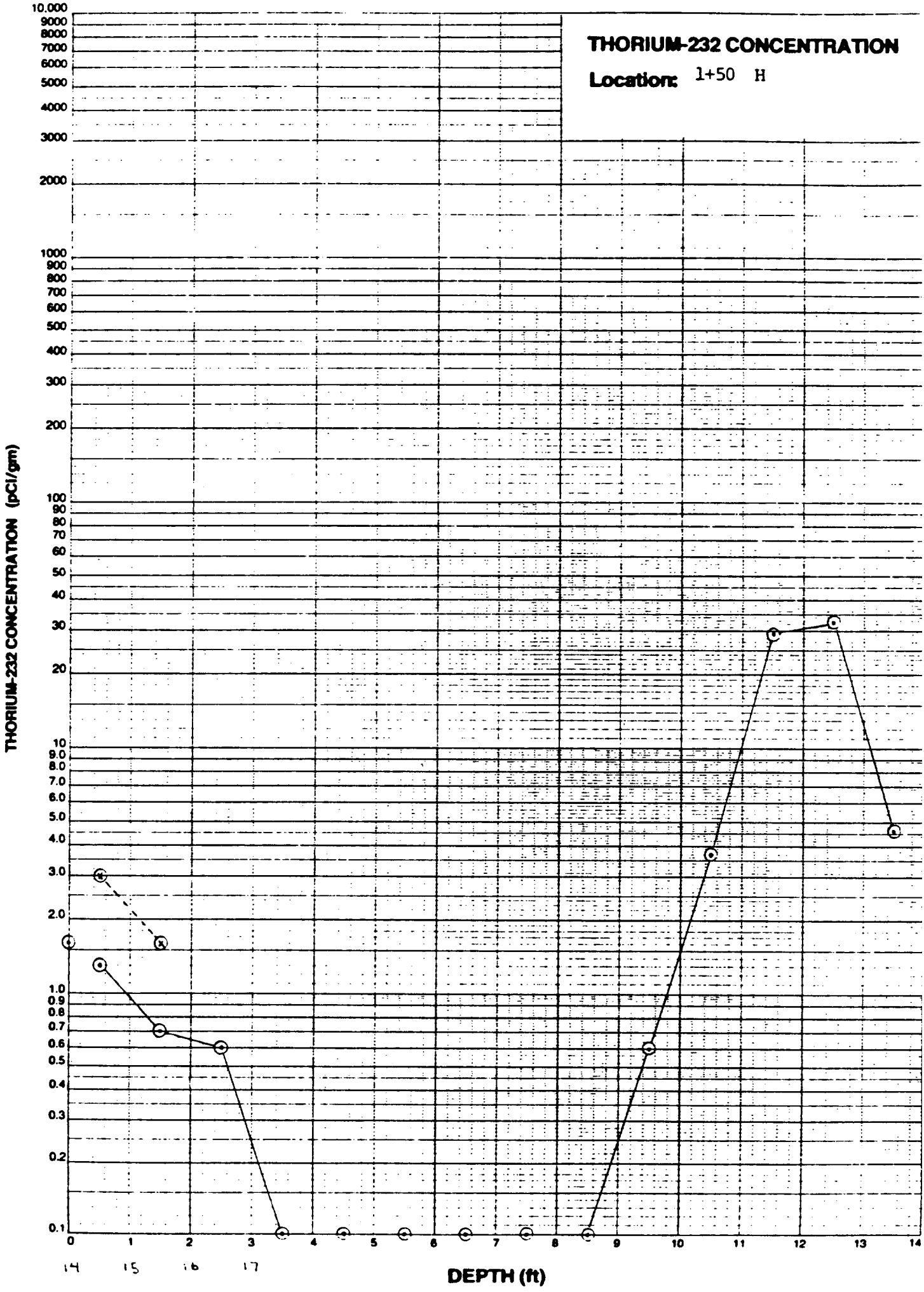
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+50 H
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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9.0
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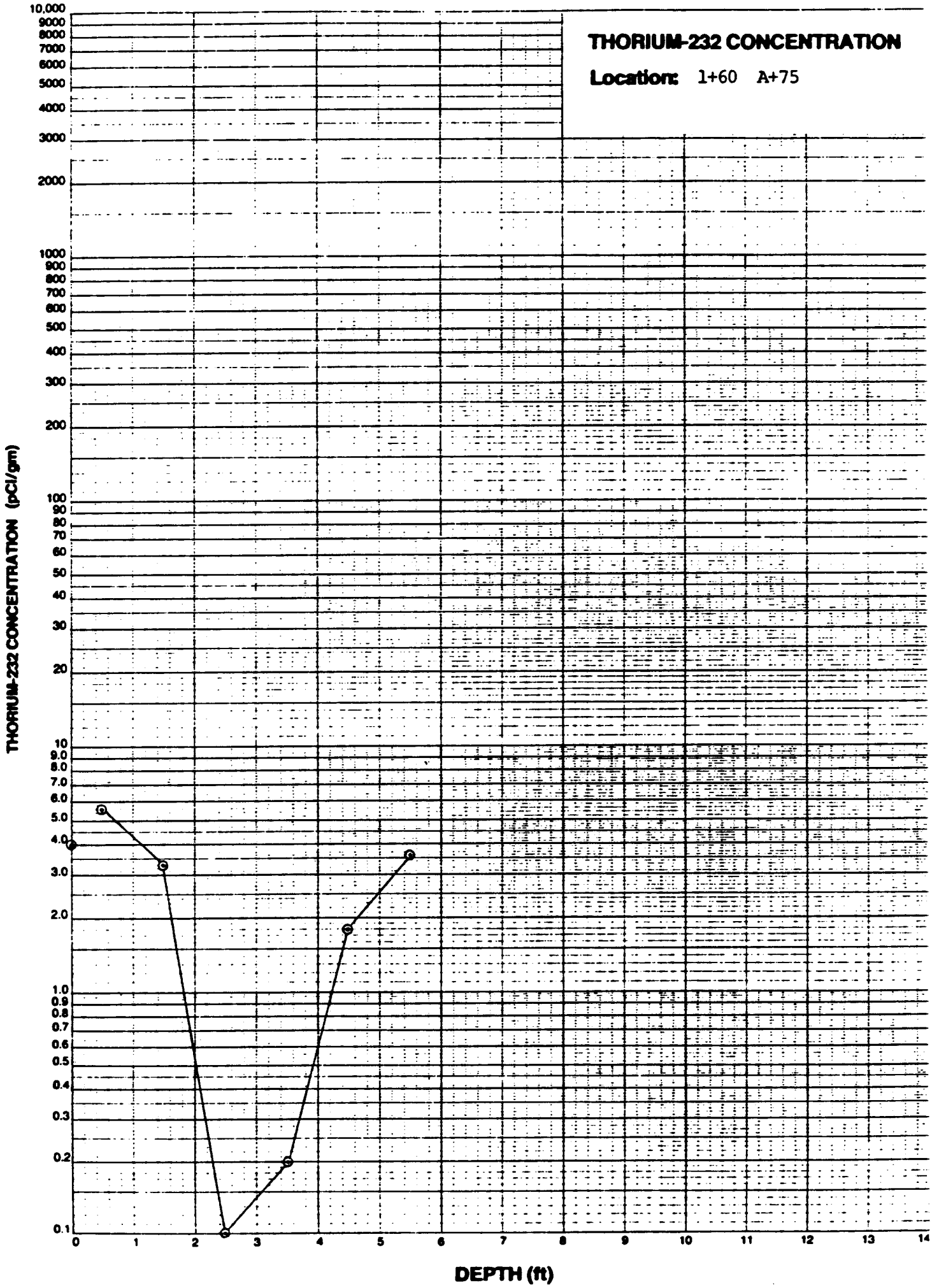
15
16
17
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+60 A+75
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
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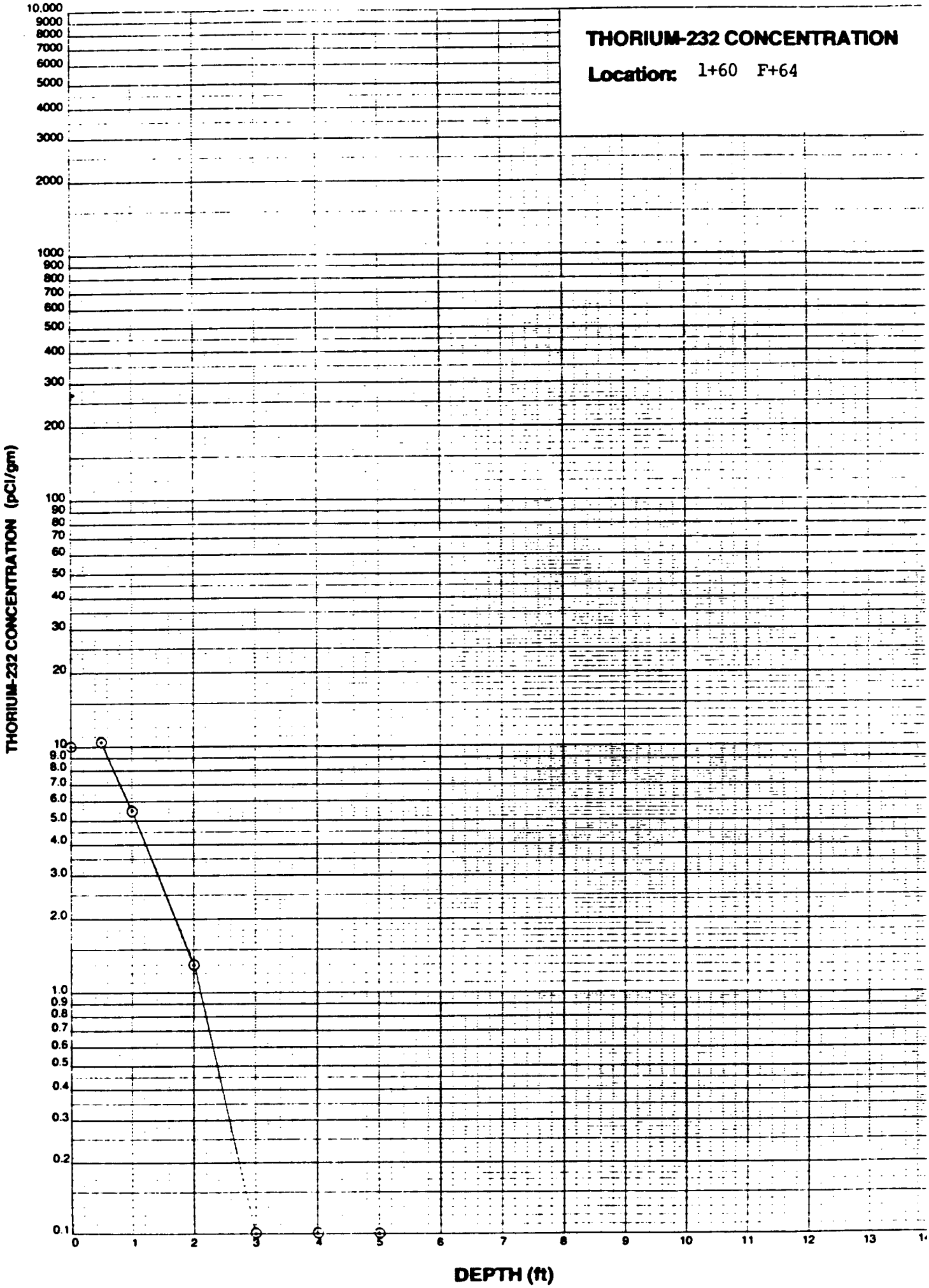
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+60 F+64
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
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0.3
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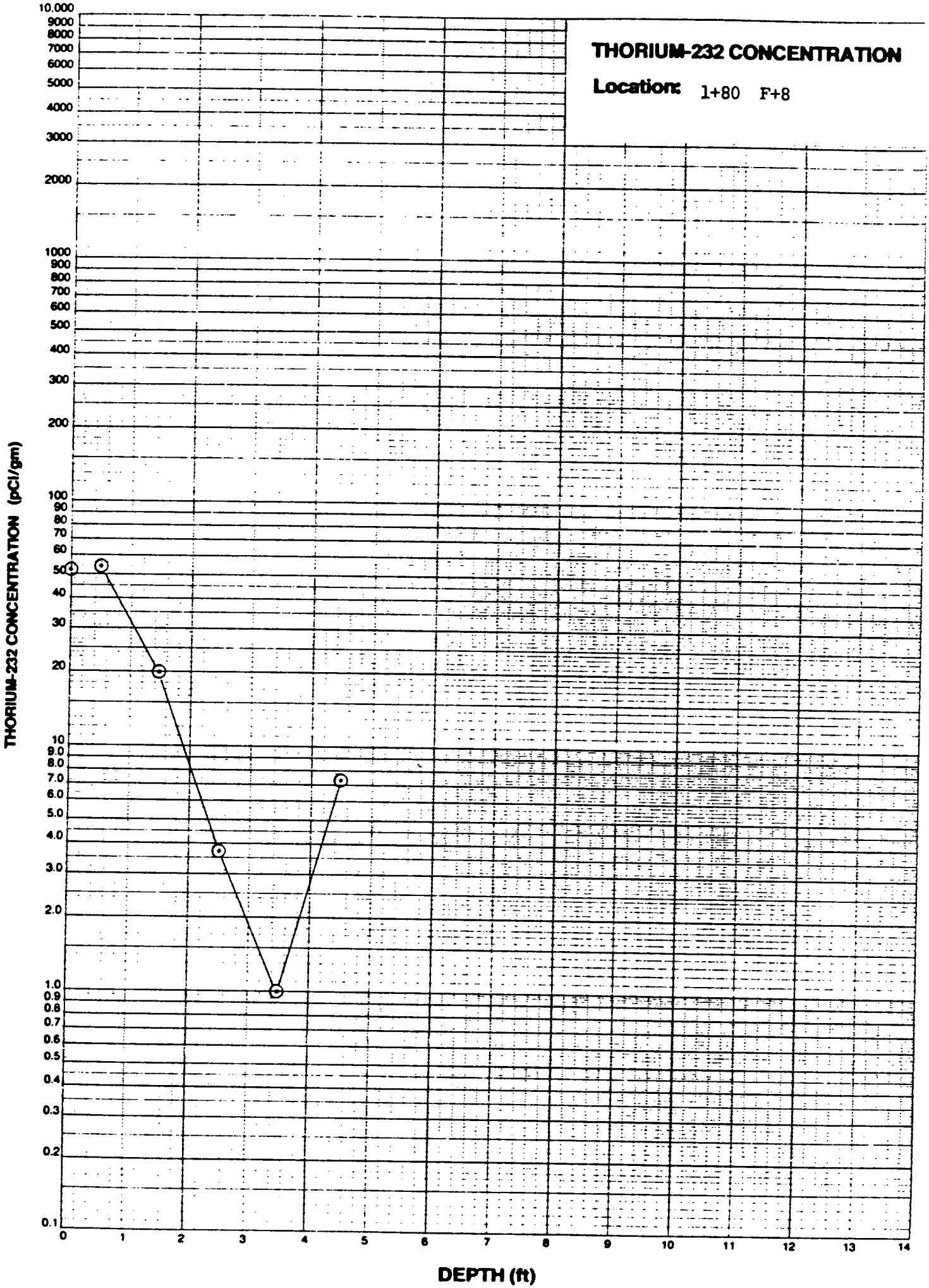
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+80 F+8
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
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100
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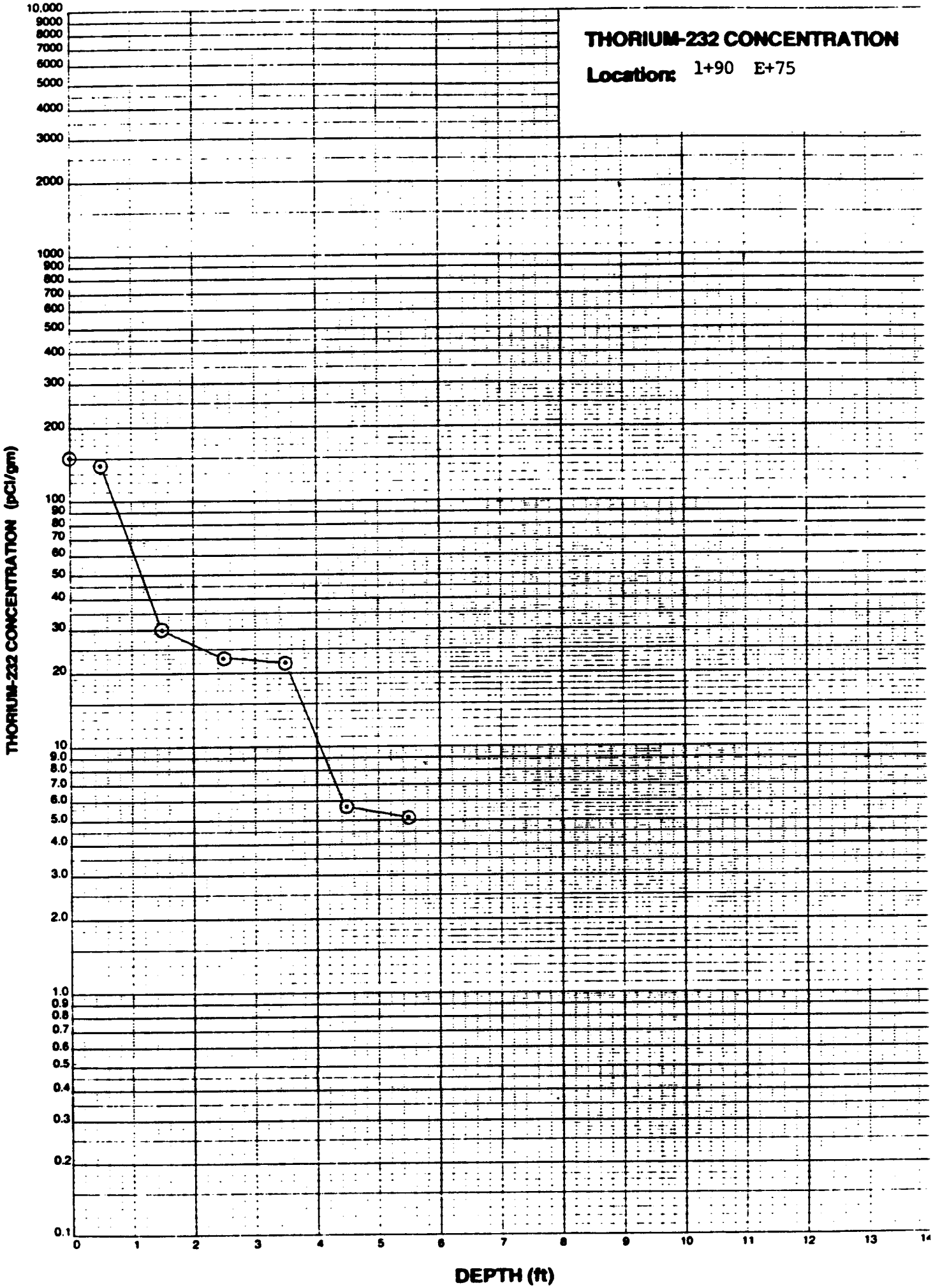
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 1+90 E+75
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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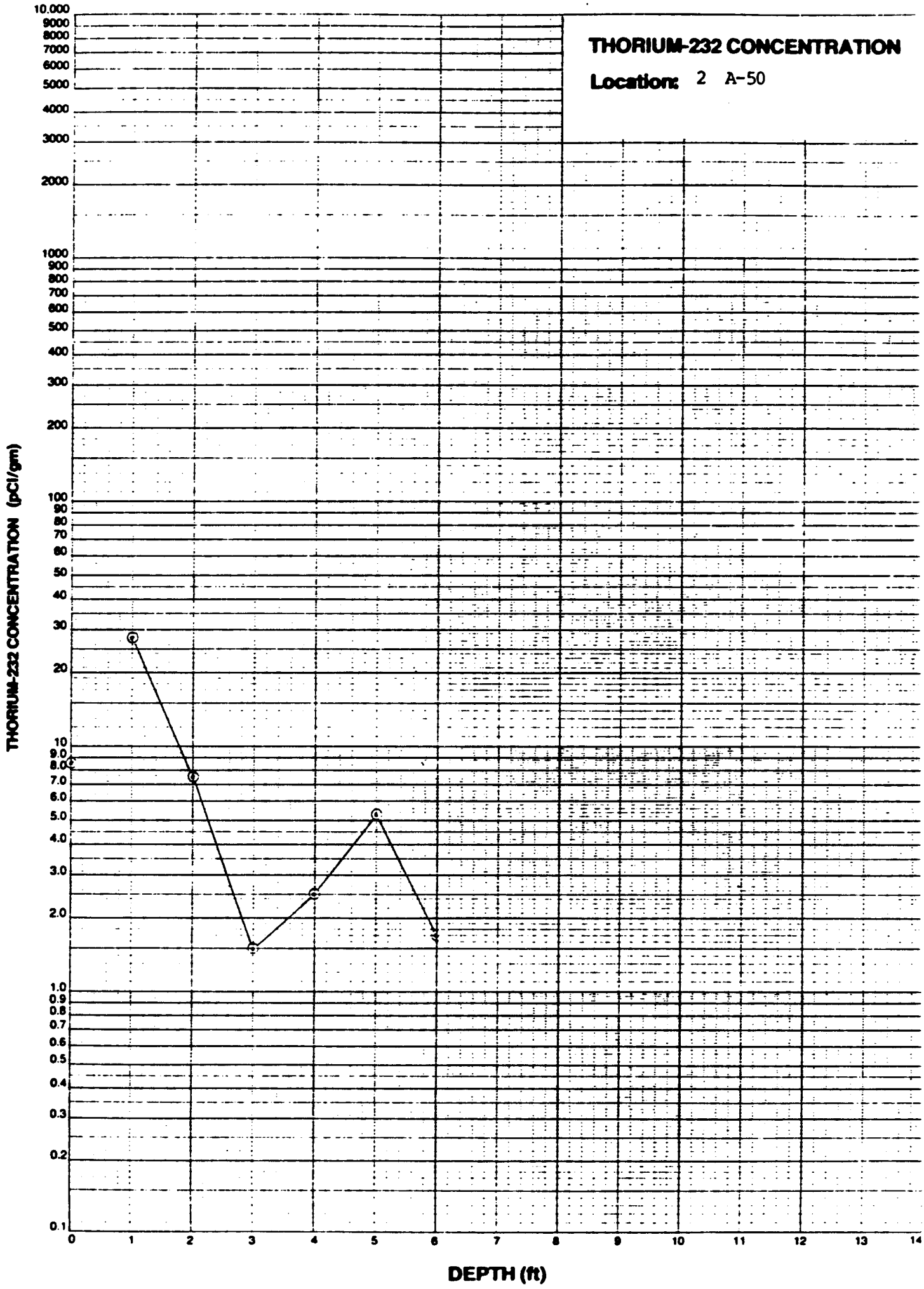
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 A-50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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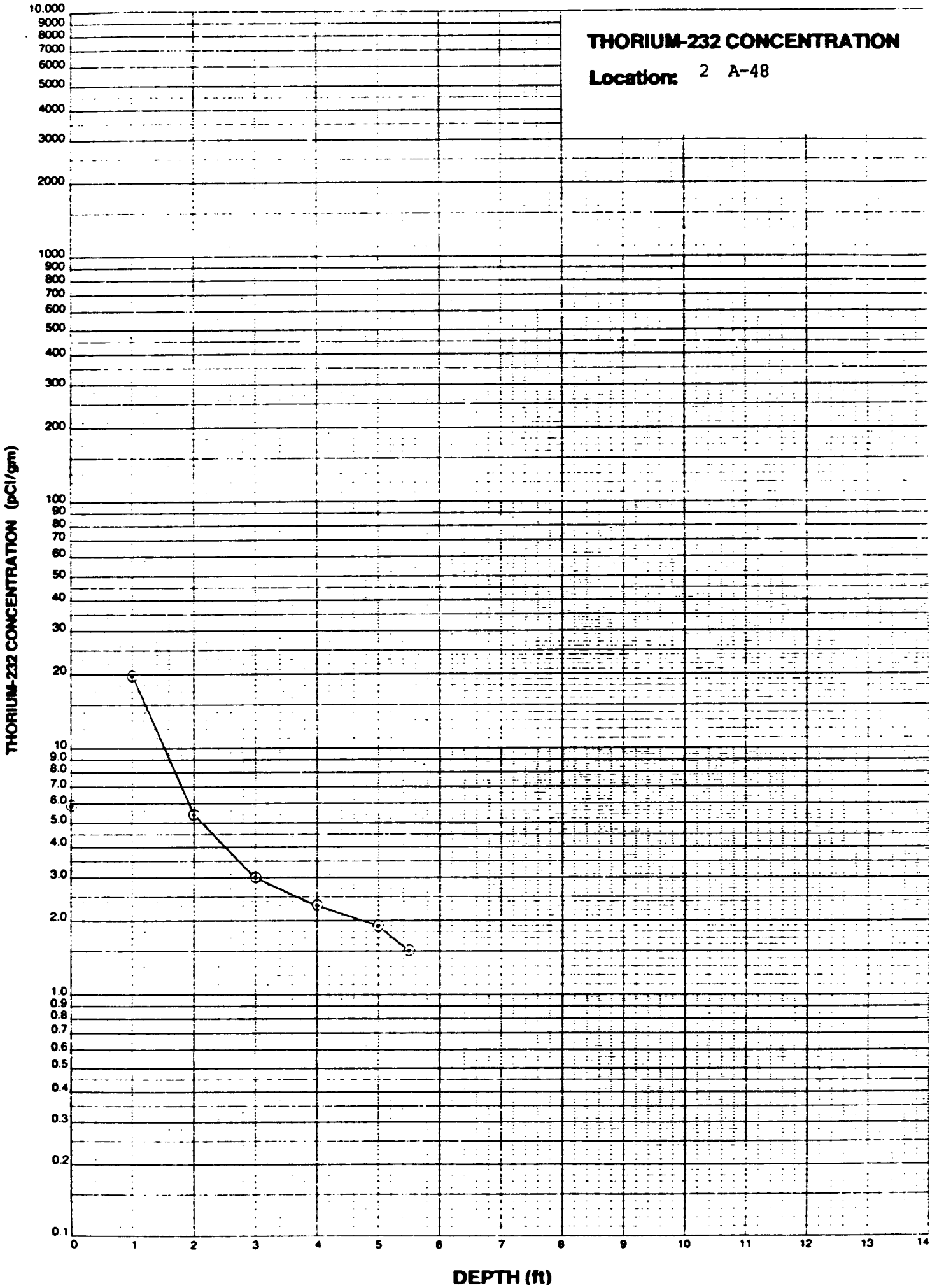
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 A-48
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
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6000
5000
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0.4
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9
10
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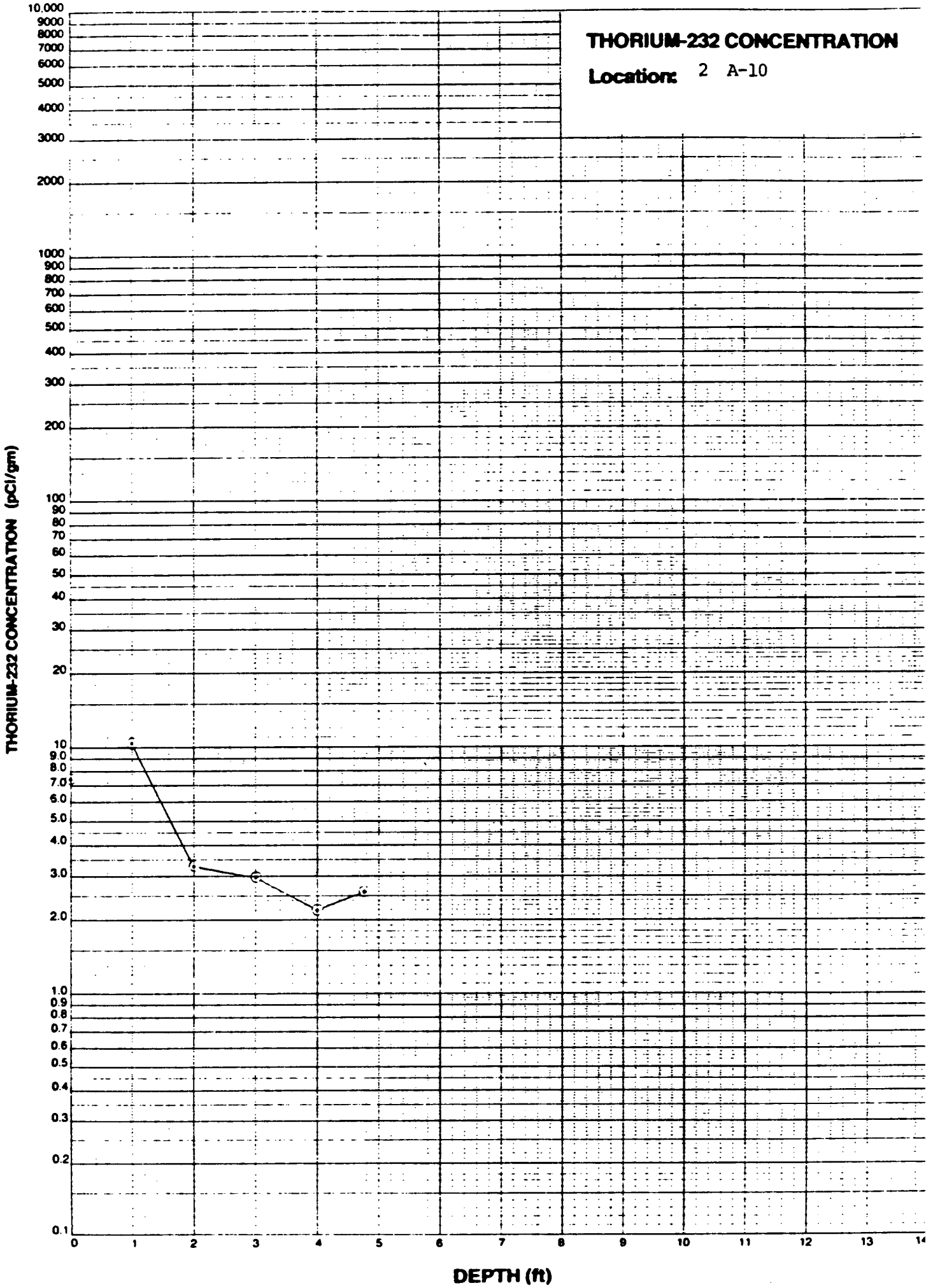
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 A-10
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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6000
5000
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10
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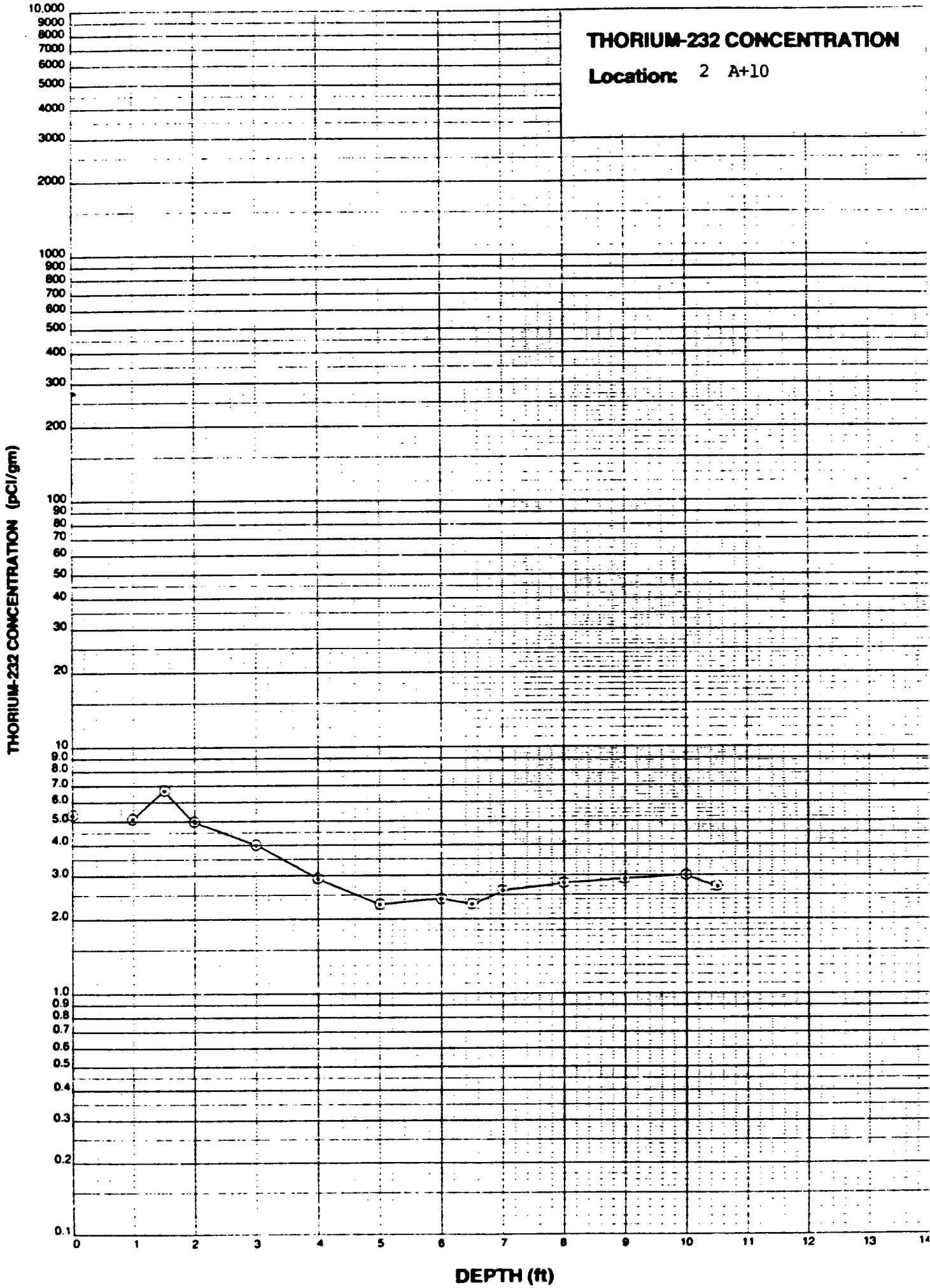
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 A+10
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
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600
500
400
300
200
100
90
80
70
60
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30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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6
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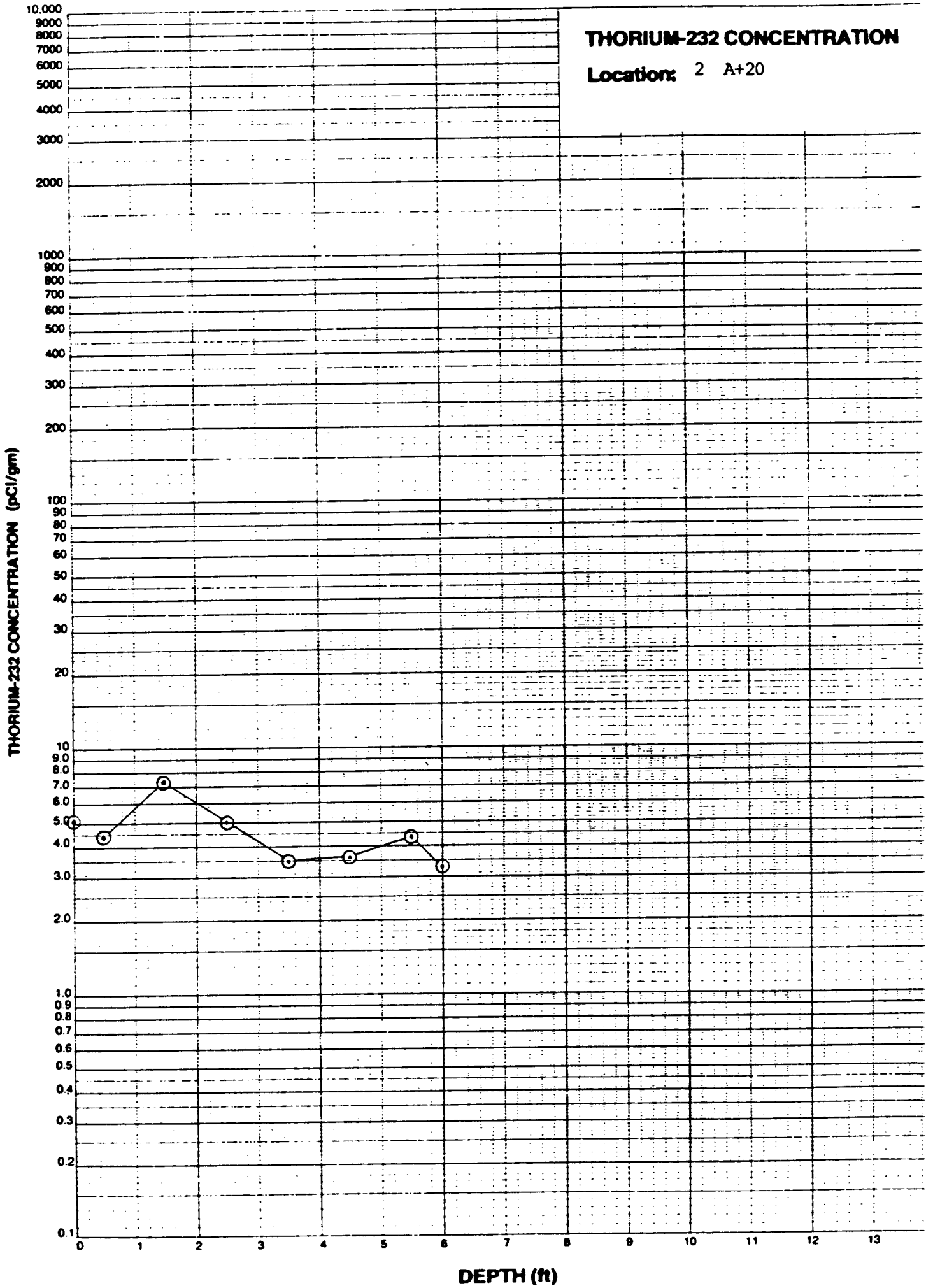
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 A+20
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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0.1
0
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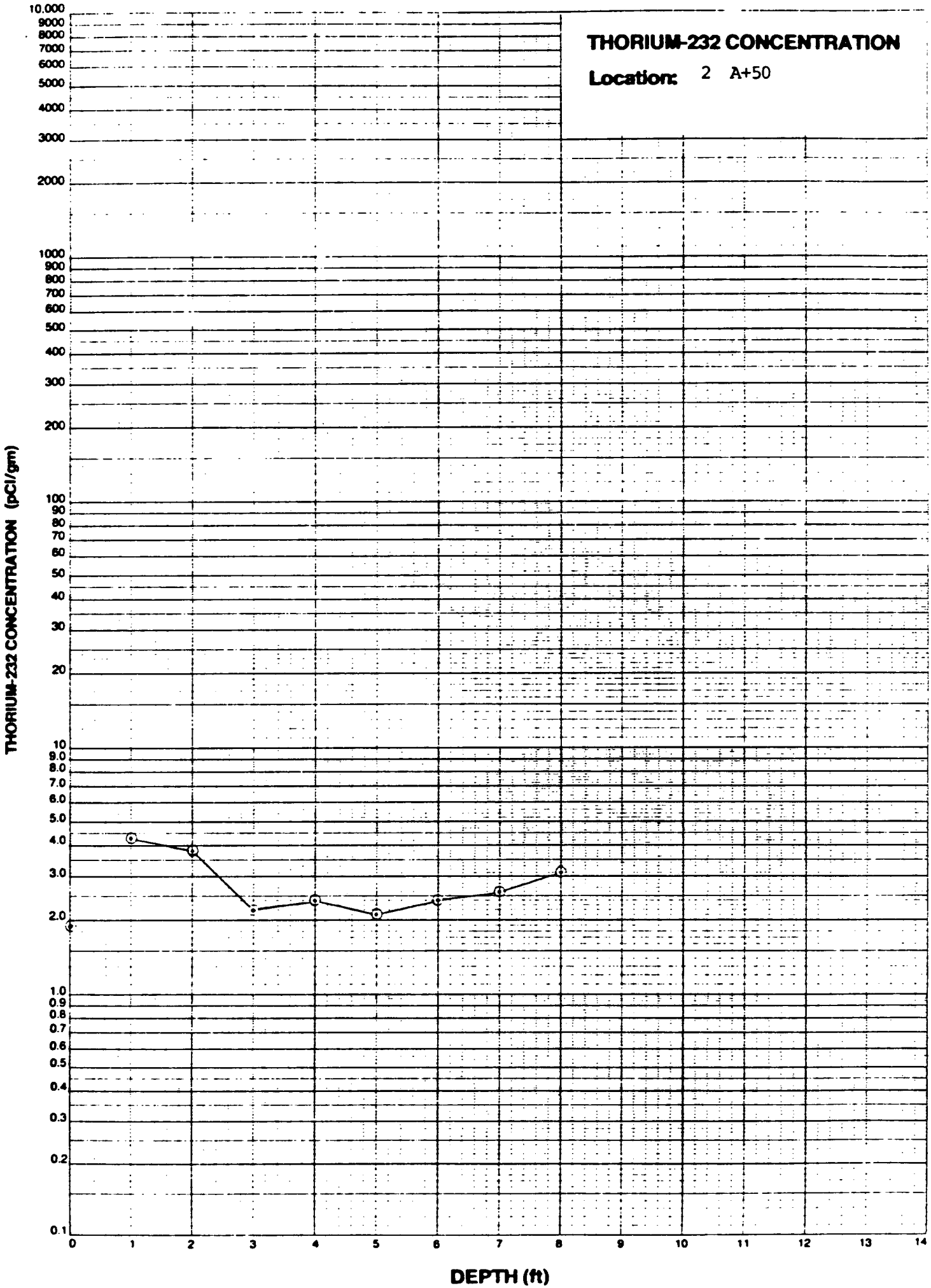
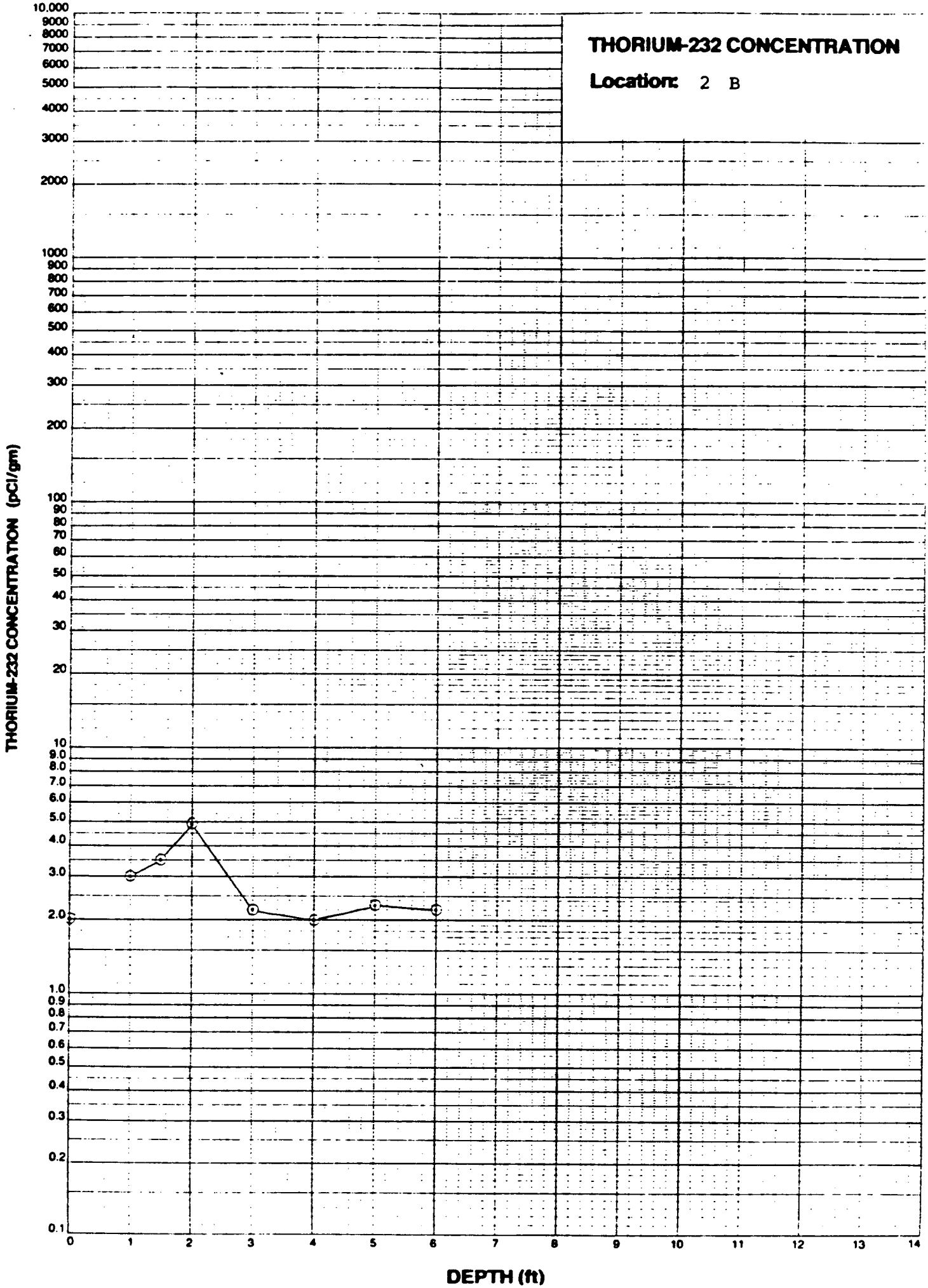
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 A+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 B
THORIUM-232 CONCENTRATION (pCi/gm)
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9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
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3
4
5
6
7
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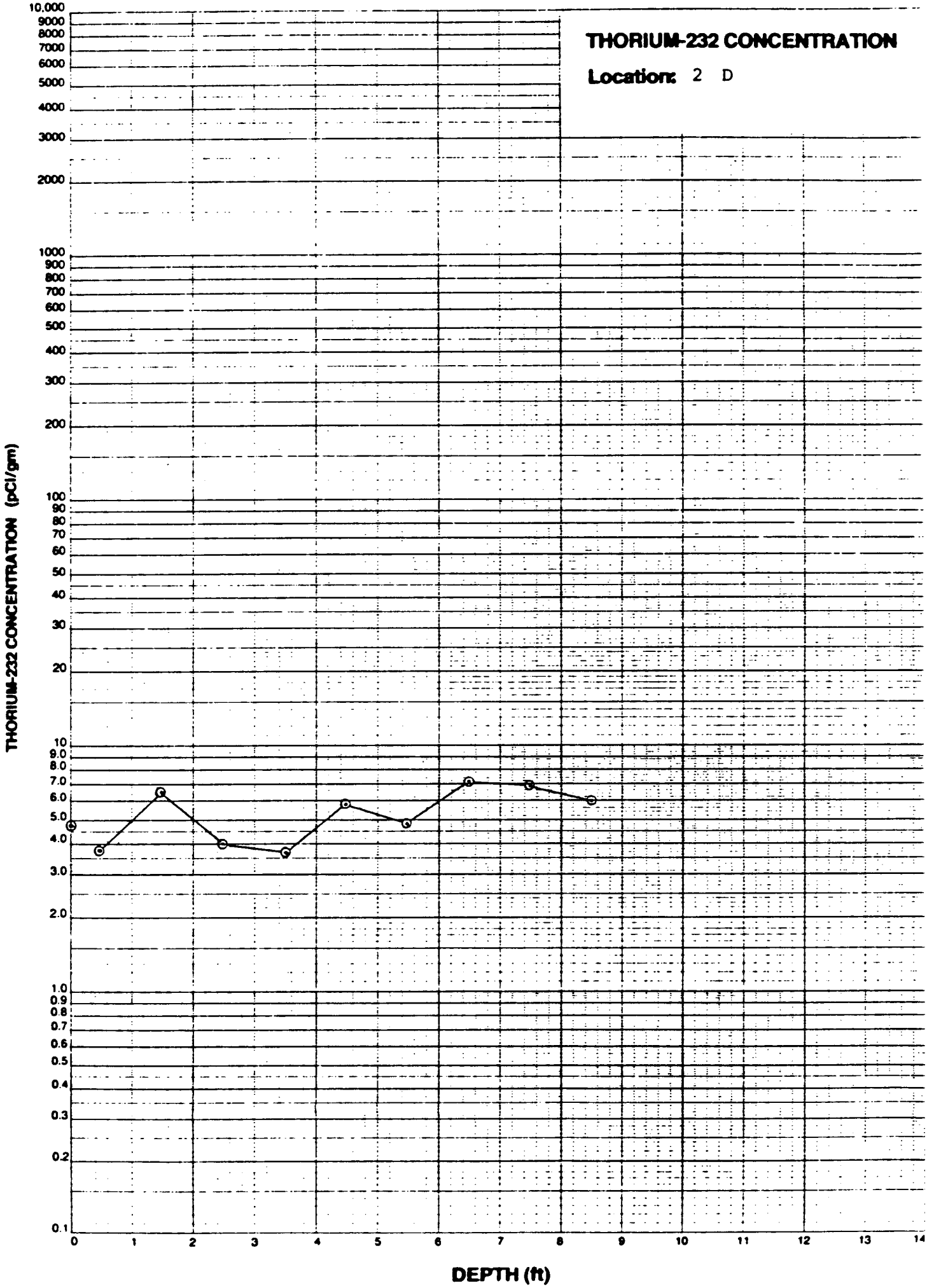
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 D
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
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40
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9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
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0.4
0.3
0.2
0.1
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1
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6
7
8
9
10
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12
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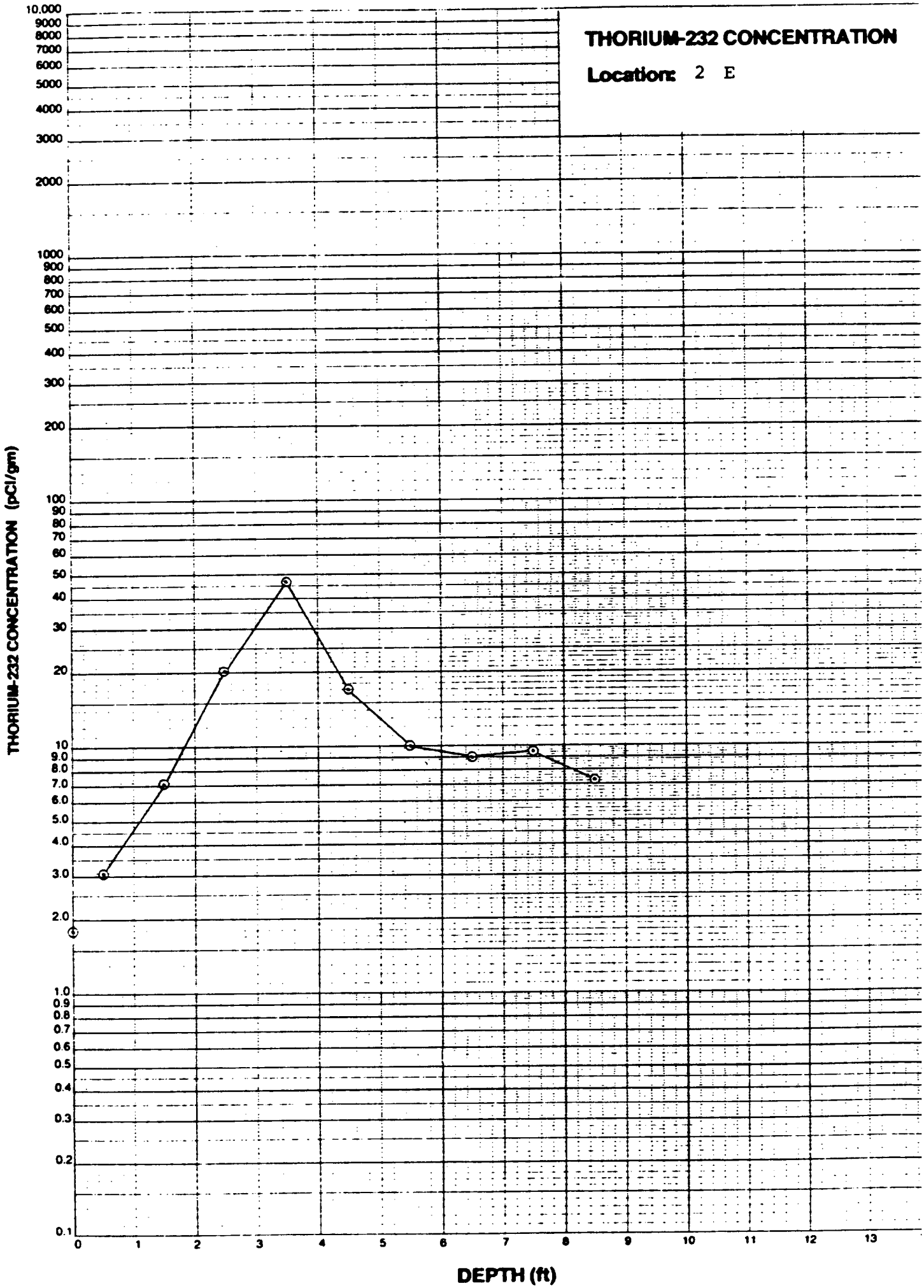
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 E
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
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1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
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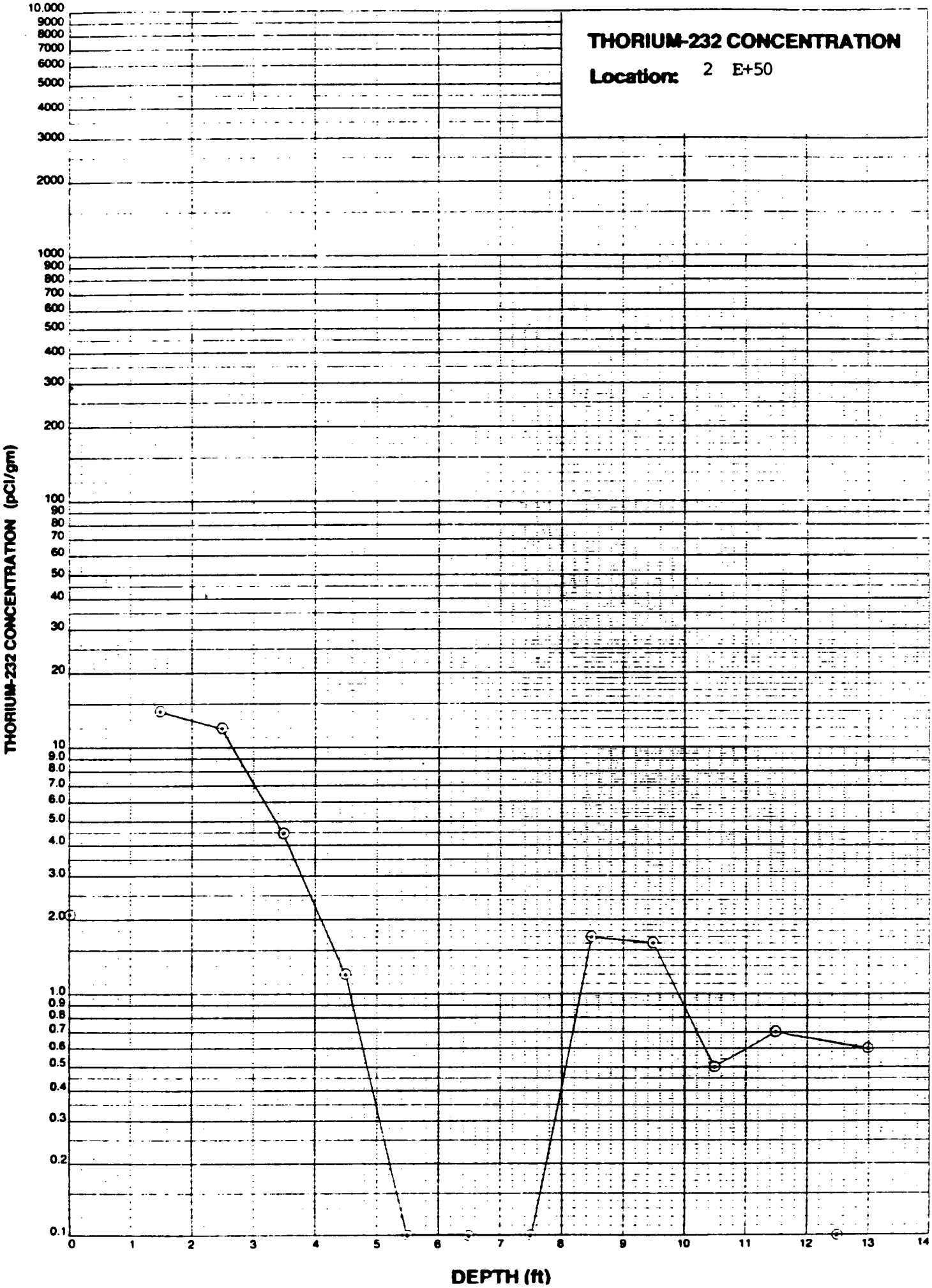
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 E+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
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6.0
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0.1
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1
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9
10
11
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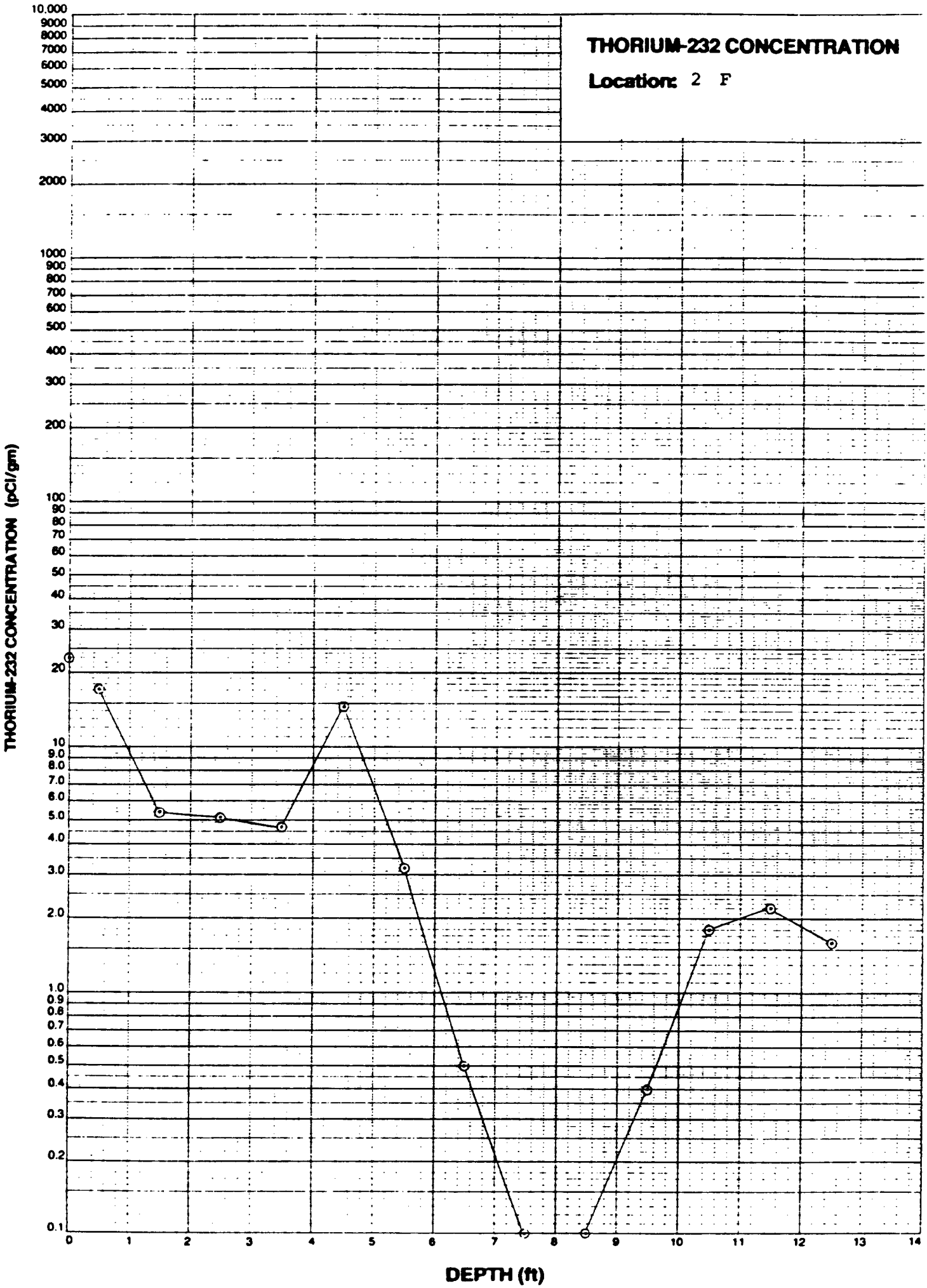
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 F
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
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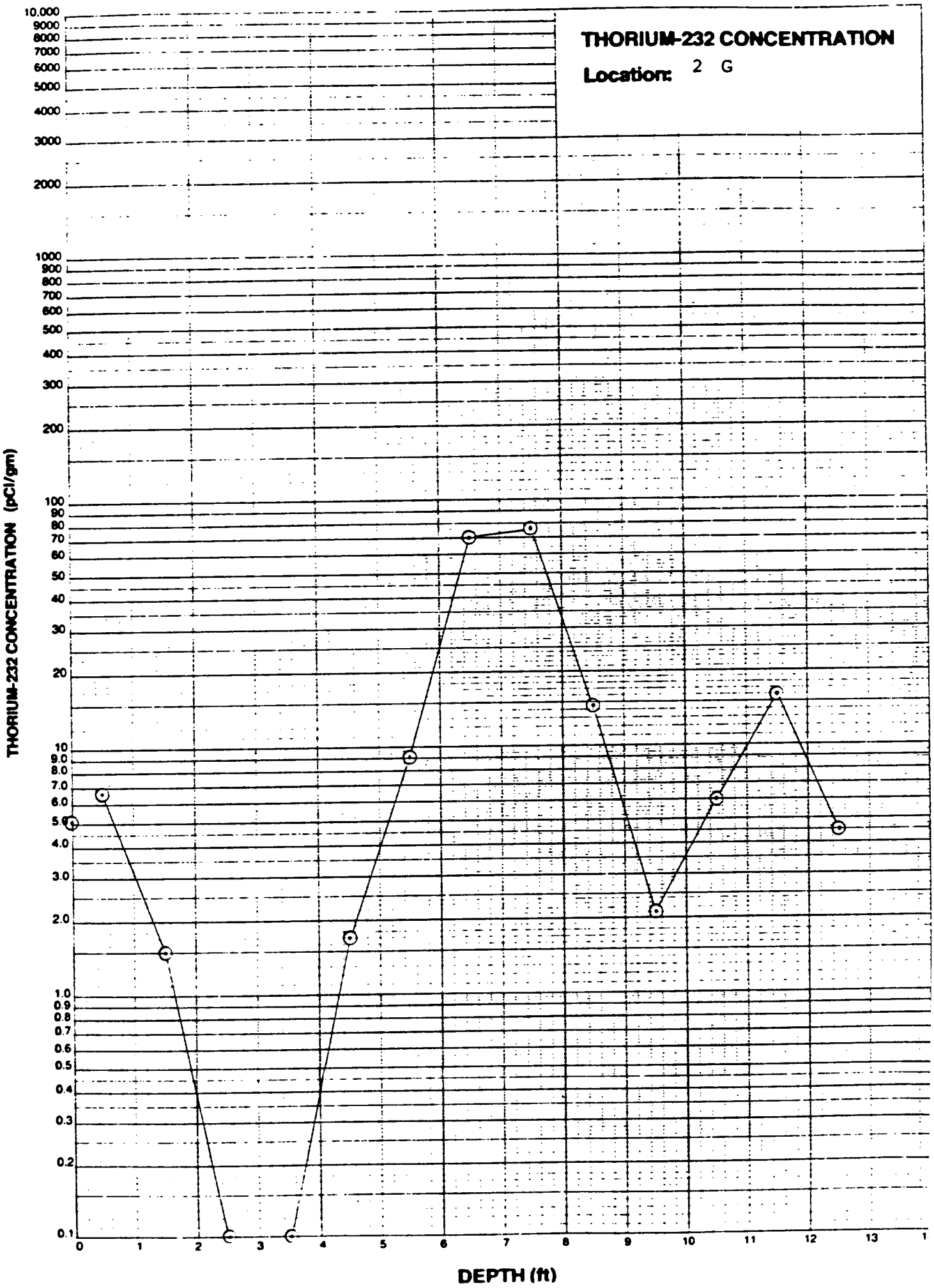
THORIUM-232 CONCENTRATION
Location: 2 G
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
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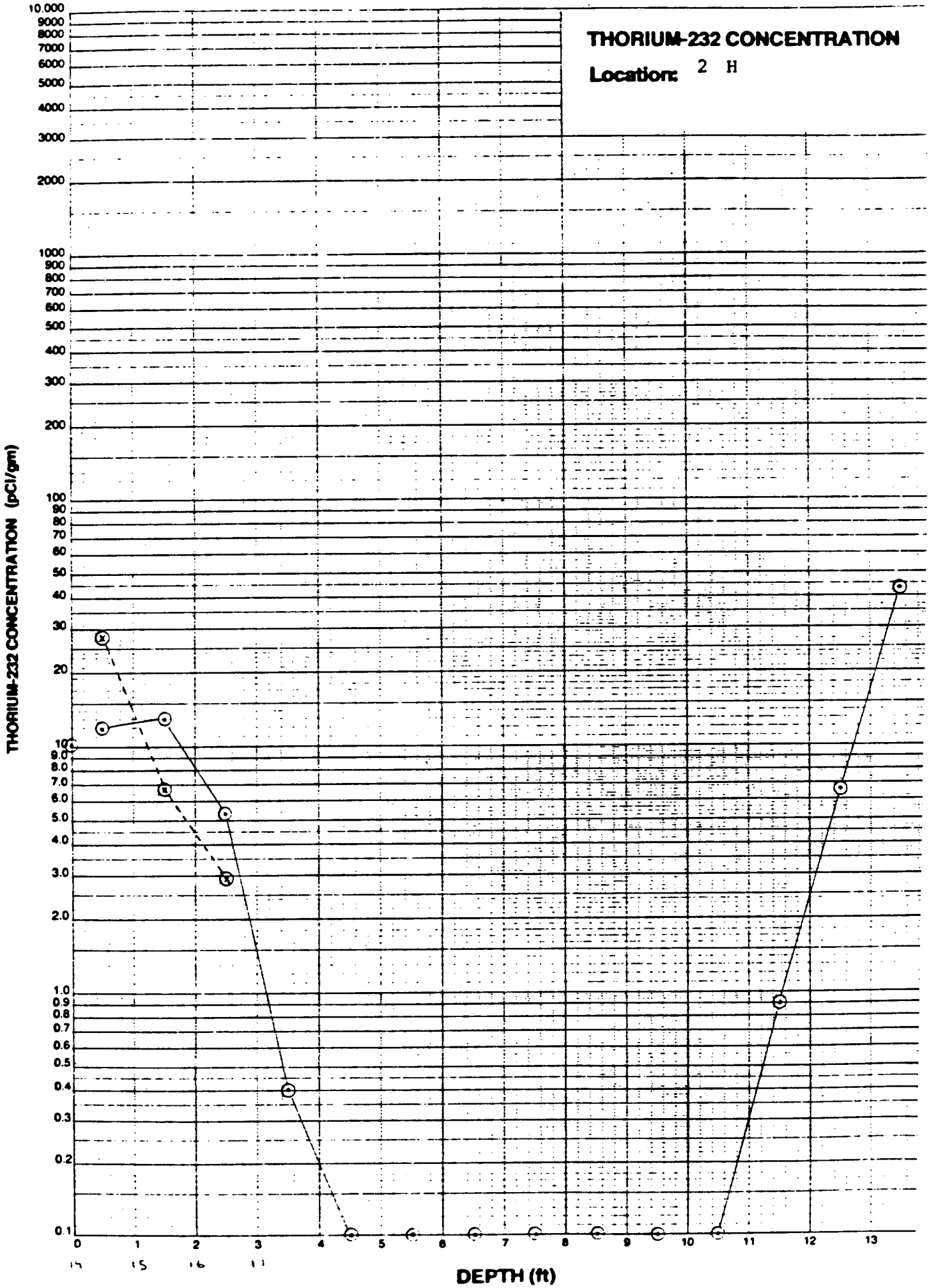
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2 H
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
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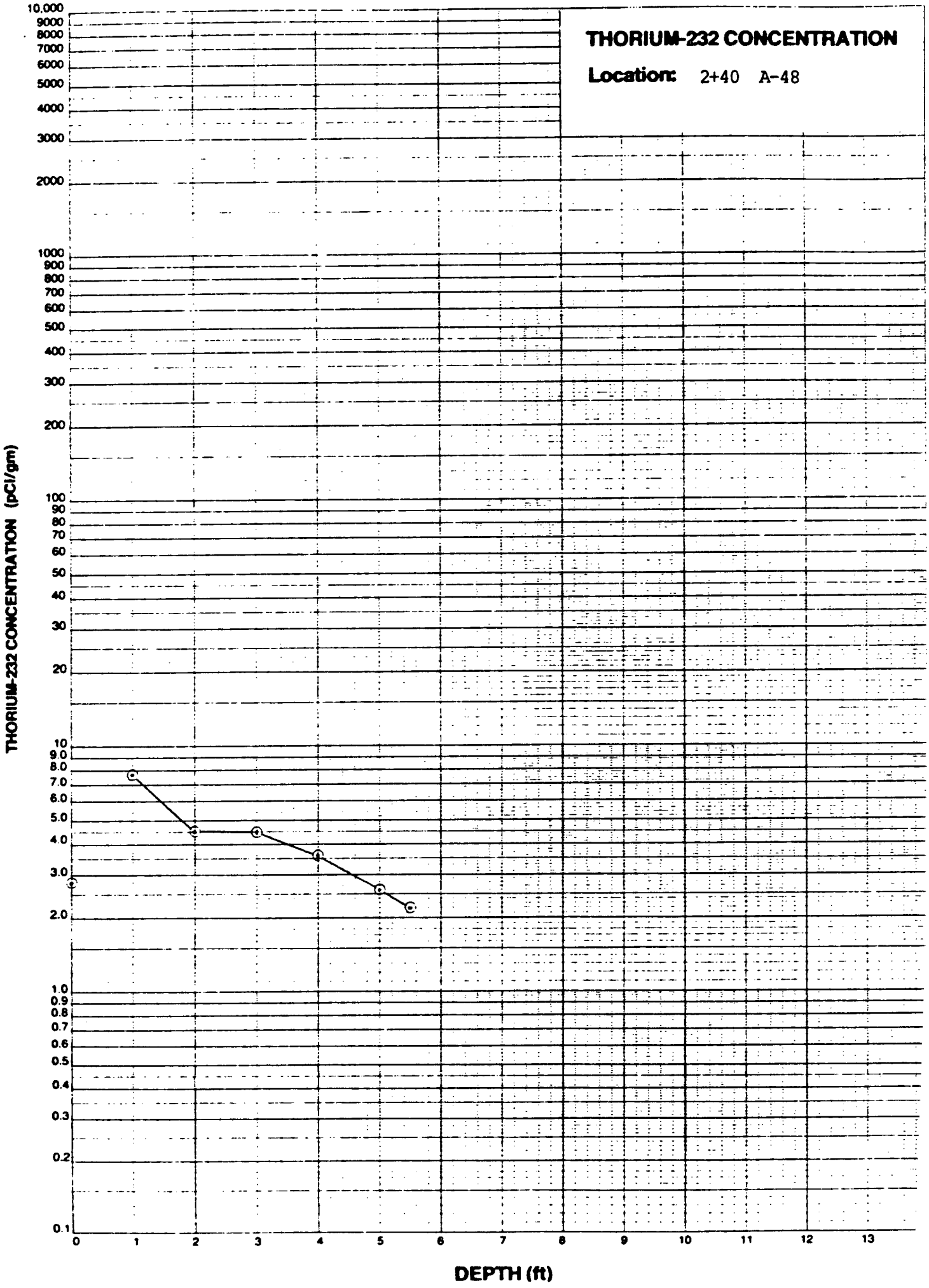
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2+40 A-48
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
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9.0
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1
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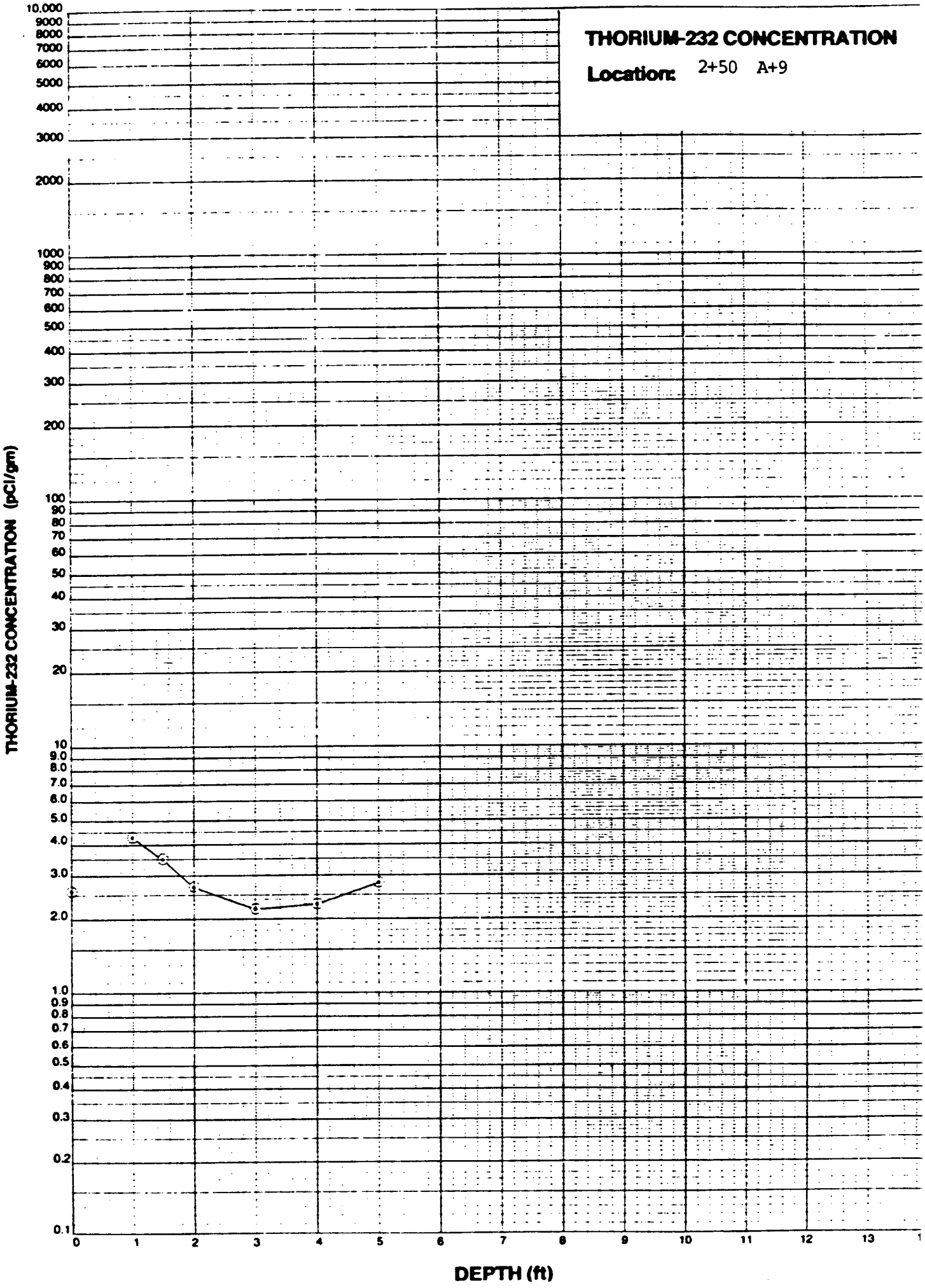
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2+50 A+9
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
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9.0
8.0
7.0
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0.8
0.7
0.6
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0.4
0.3
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0.1
0
1
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5
6
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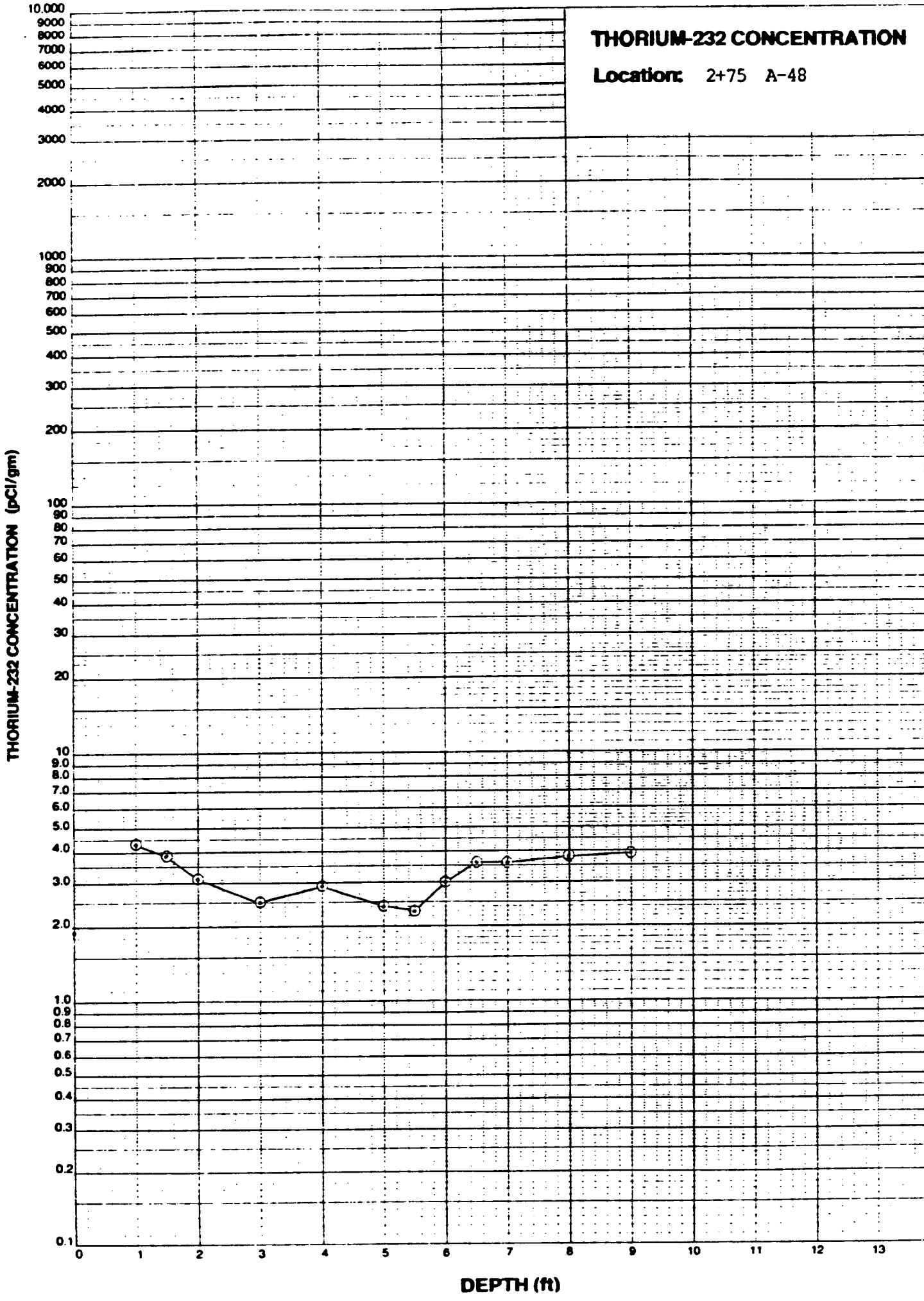
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 2+75 A-48
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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0
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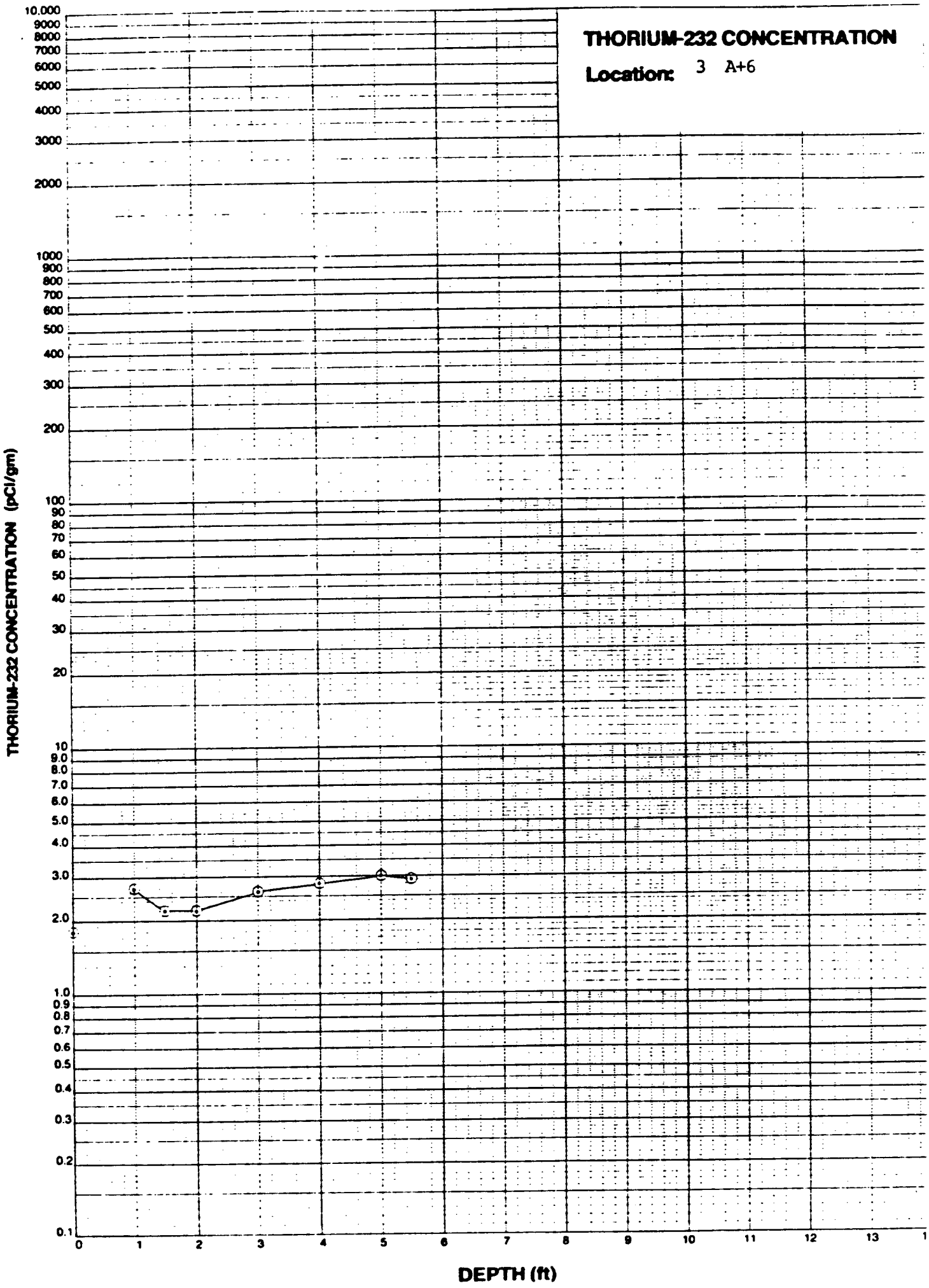
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 3 A+6
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
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100
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80
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60
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20
10
9.0
8.0
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5.0
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0.7
0.6
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0.4
0.3
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0
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2
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4
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6
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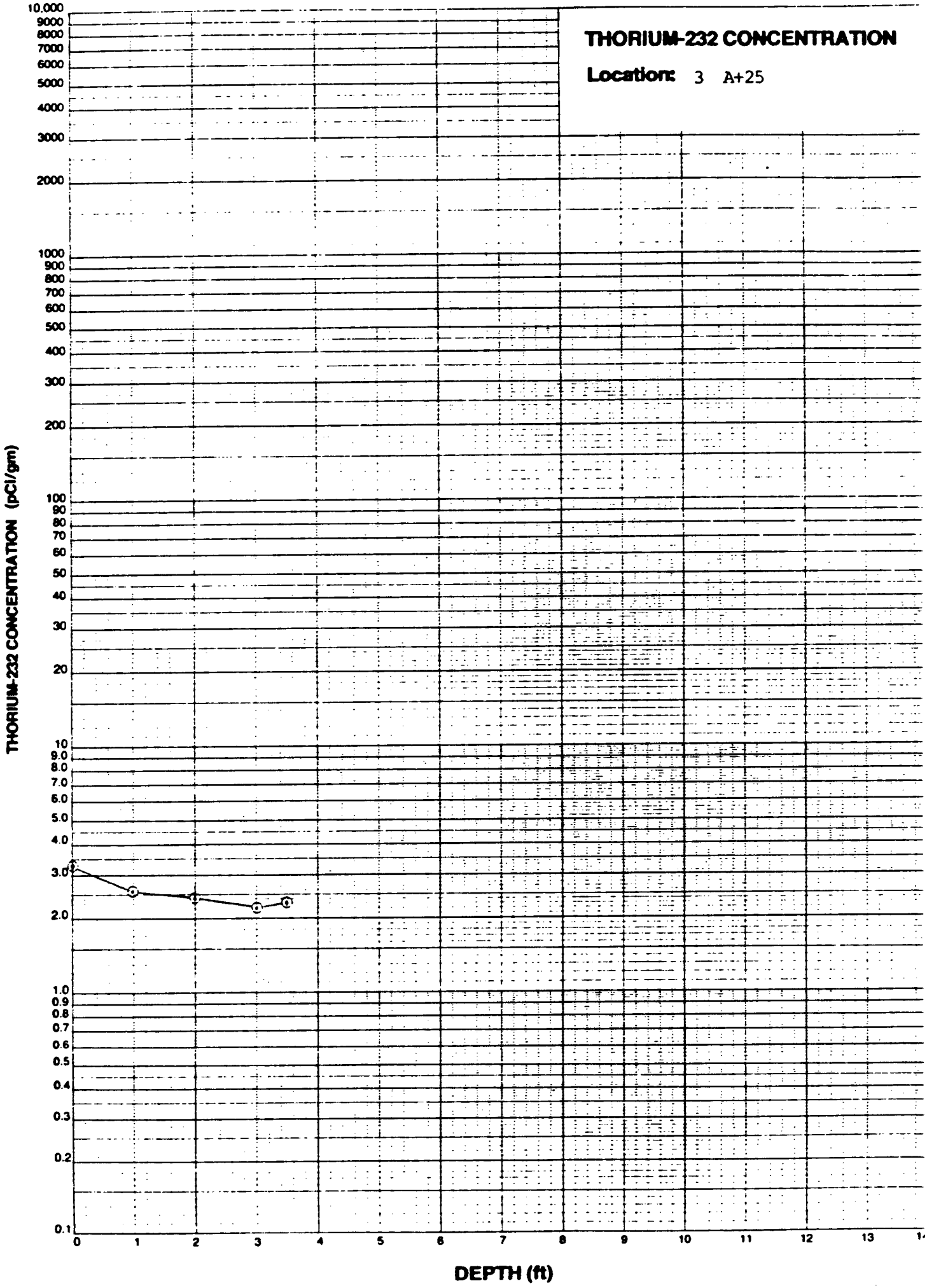
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 3 A+25
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
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800
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400
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100
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20
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9.0
8.0
7.0
6.0
5.0
4.0
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1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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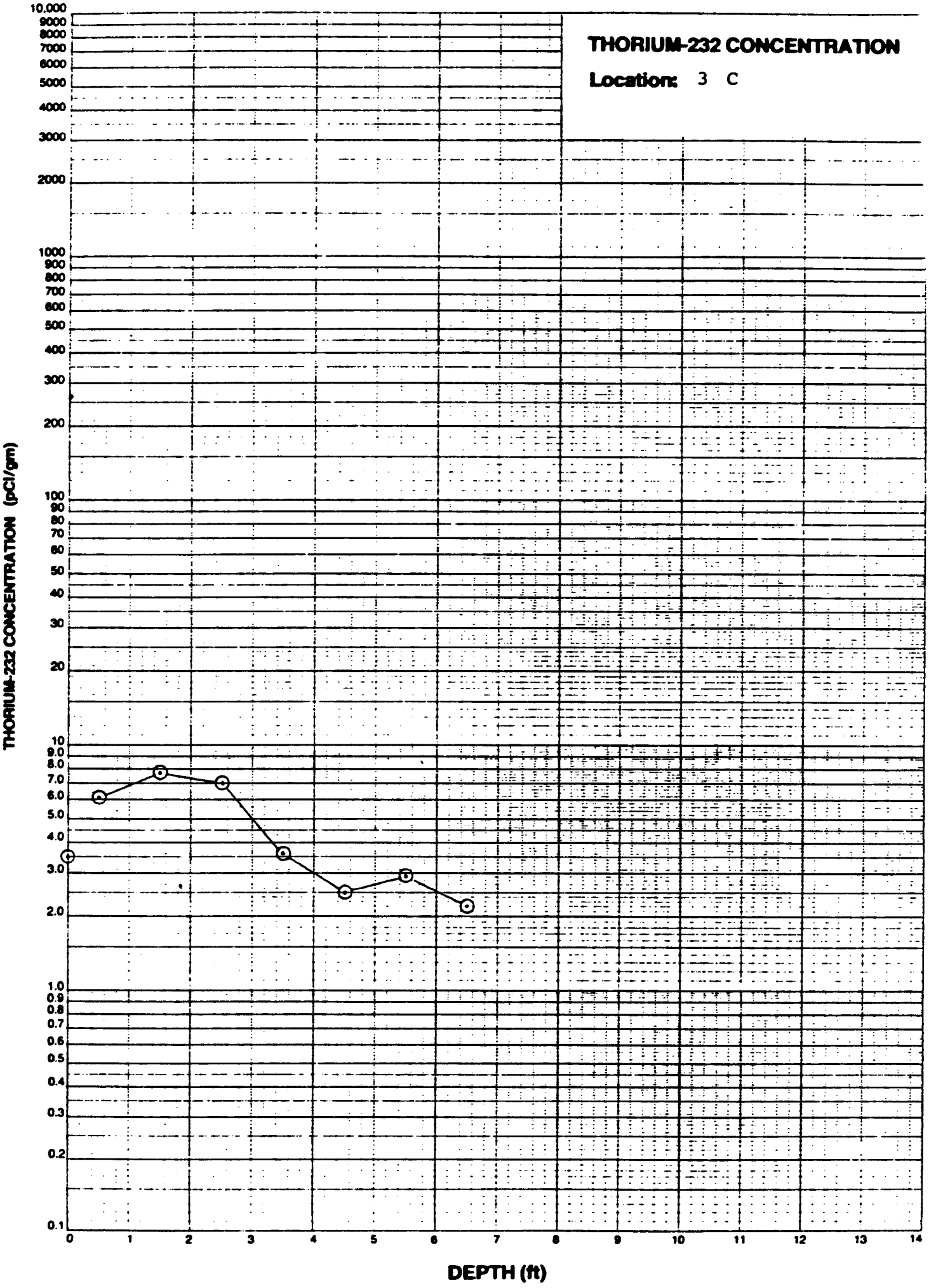
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 3 C
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
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900
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9.0
8.0
7.0
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
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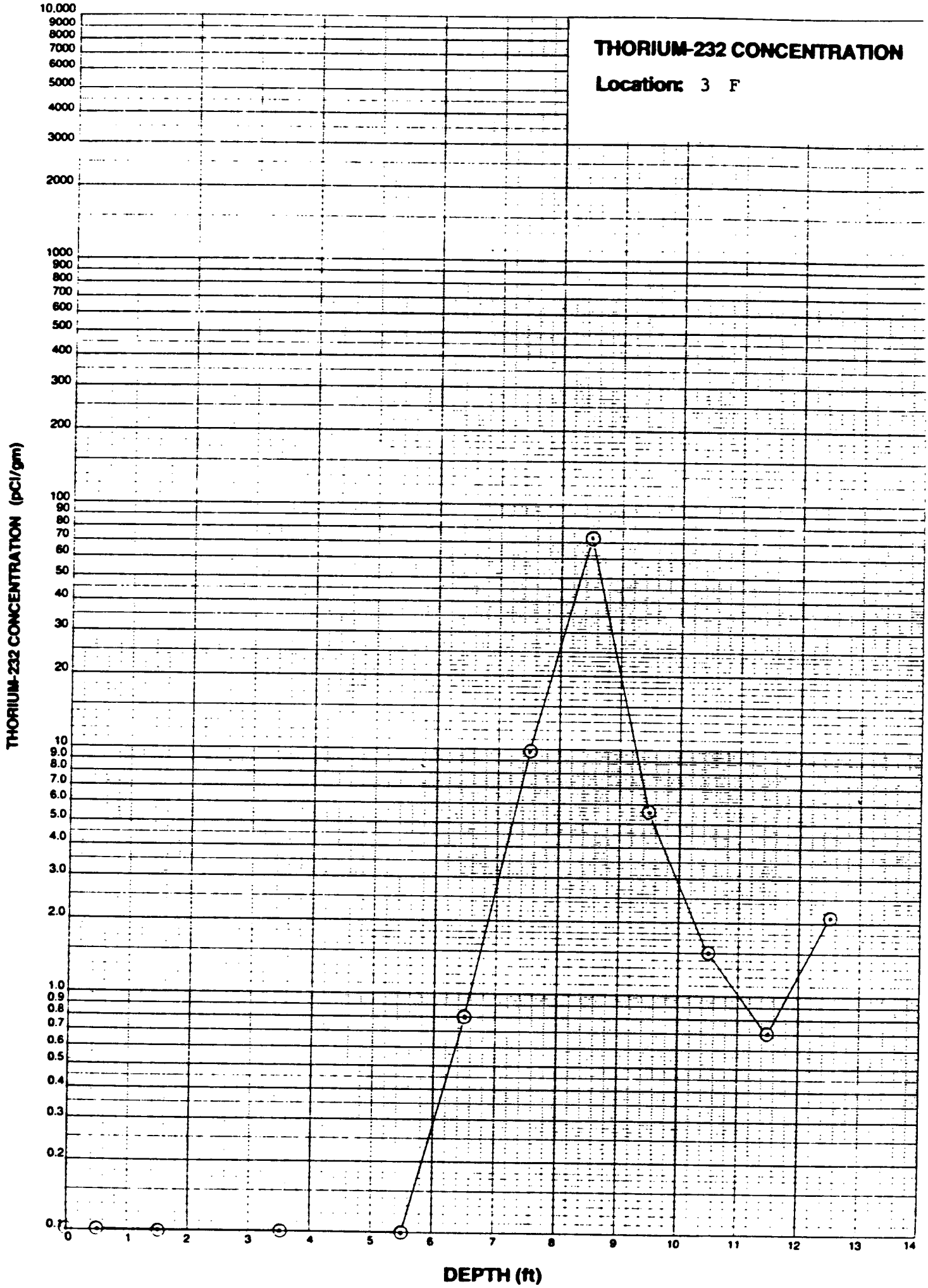
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 3 F
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
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9.0
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0.4
0.3
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6
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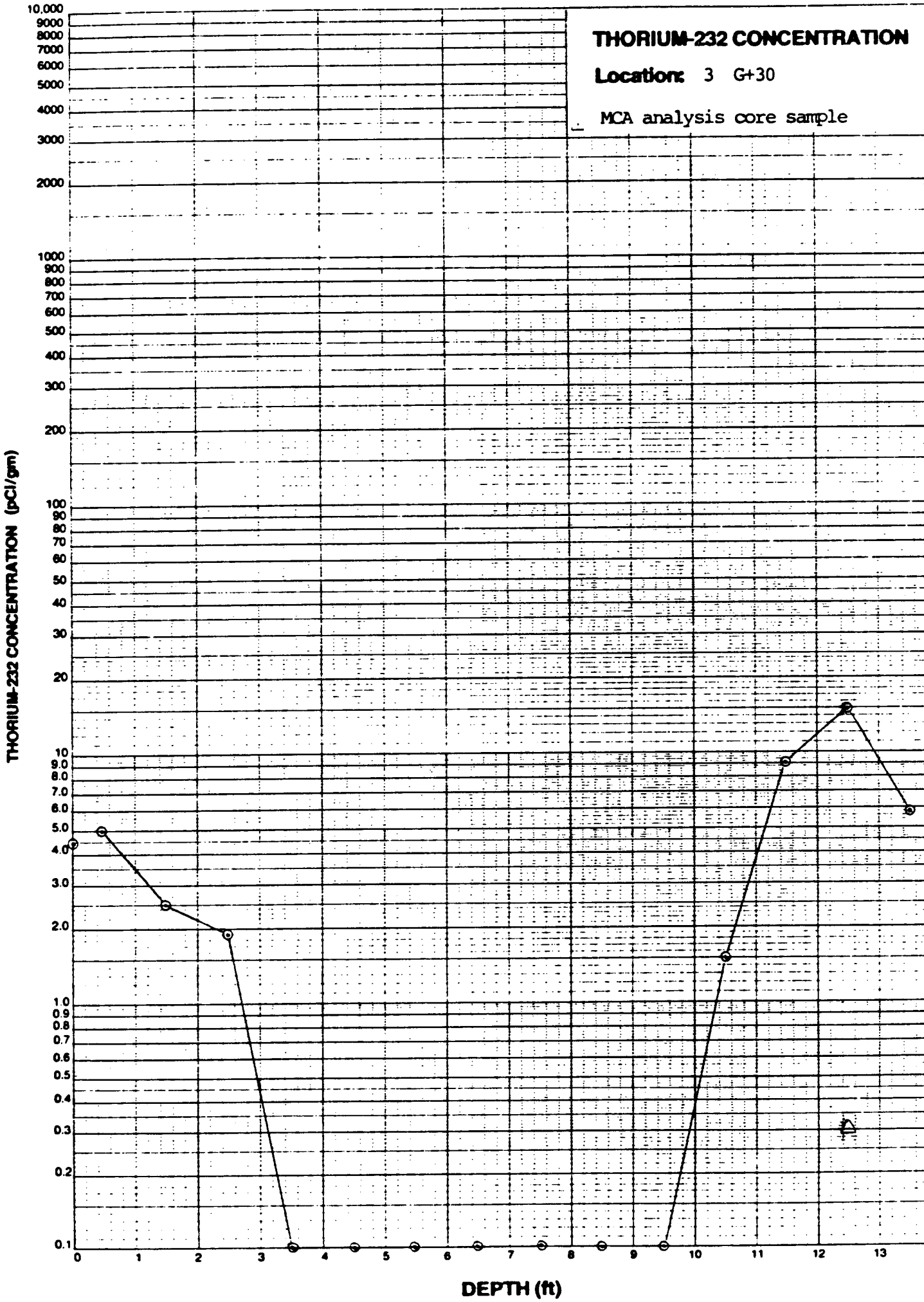
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 3 G+30
MCA analysis core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
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5000
4000
3000
2000
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6.0
5.0
4.0
3.0
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0.7
0.6
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0.4
0.3
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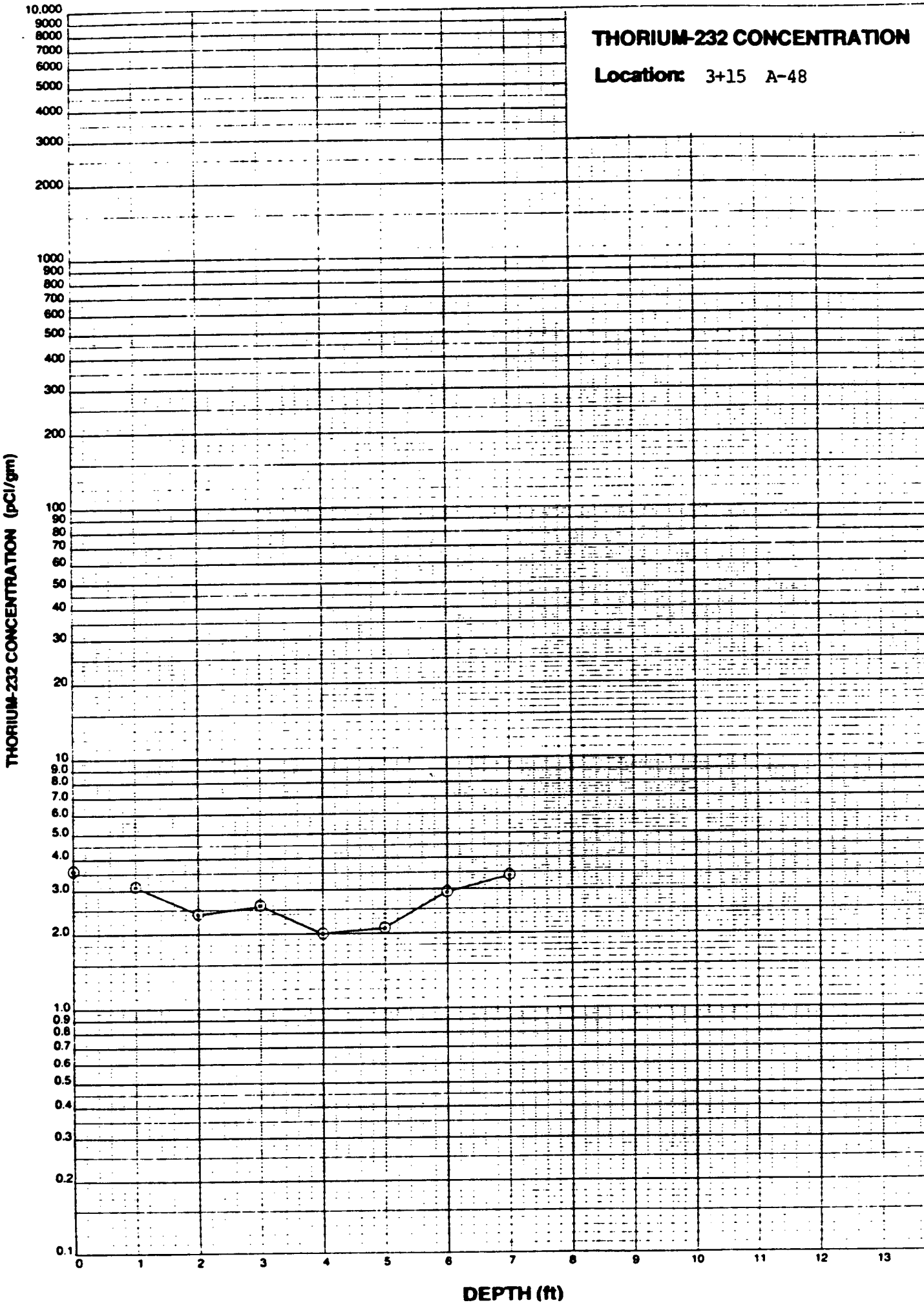
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 3+15 A-48
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
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1.0
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0.5
0.4
0.3
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1
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9
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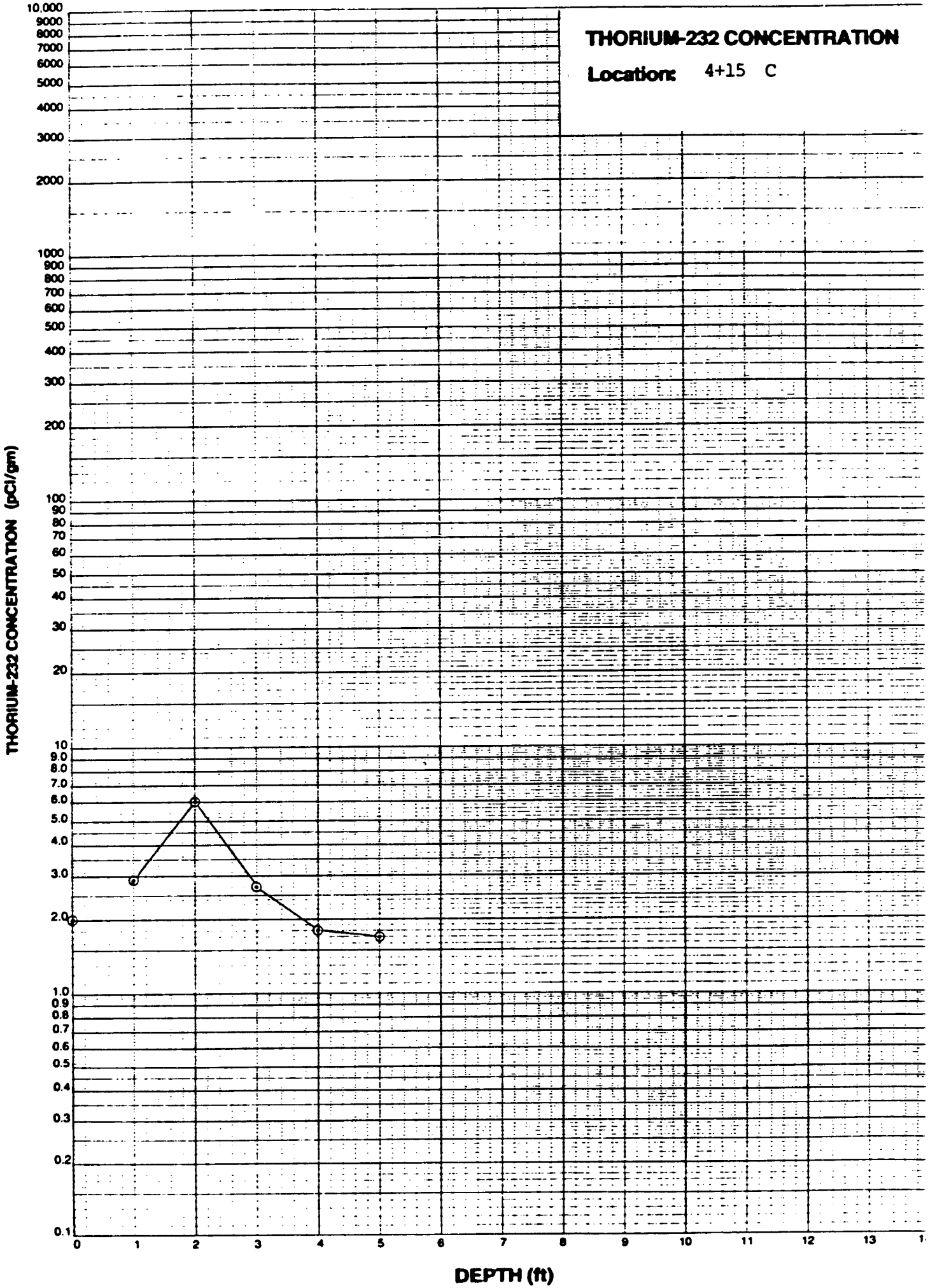
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+15 C
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
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400
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200
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9.0
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6.0
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4.0
3.0
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0.4
0.3
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1
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9
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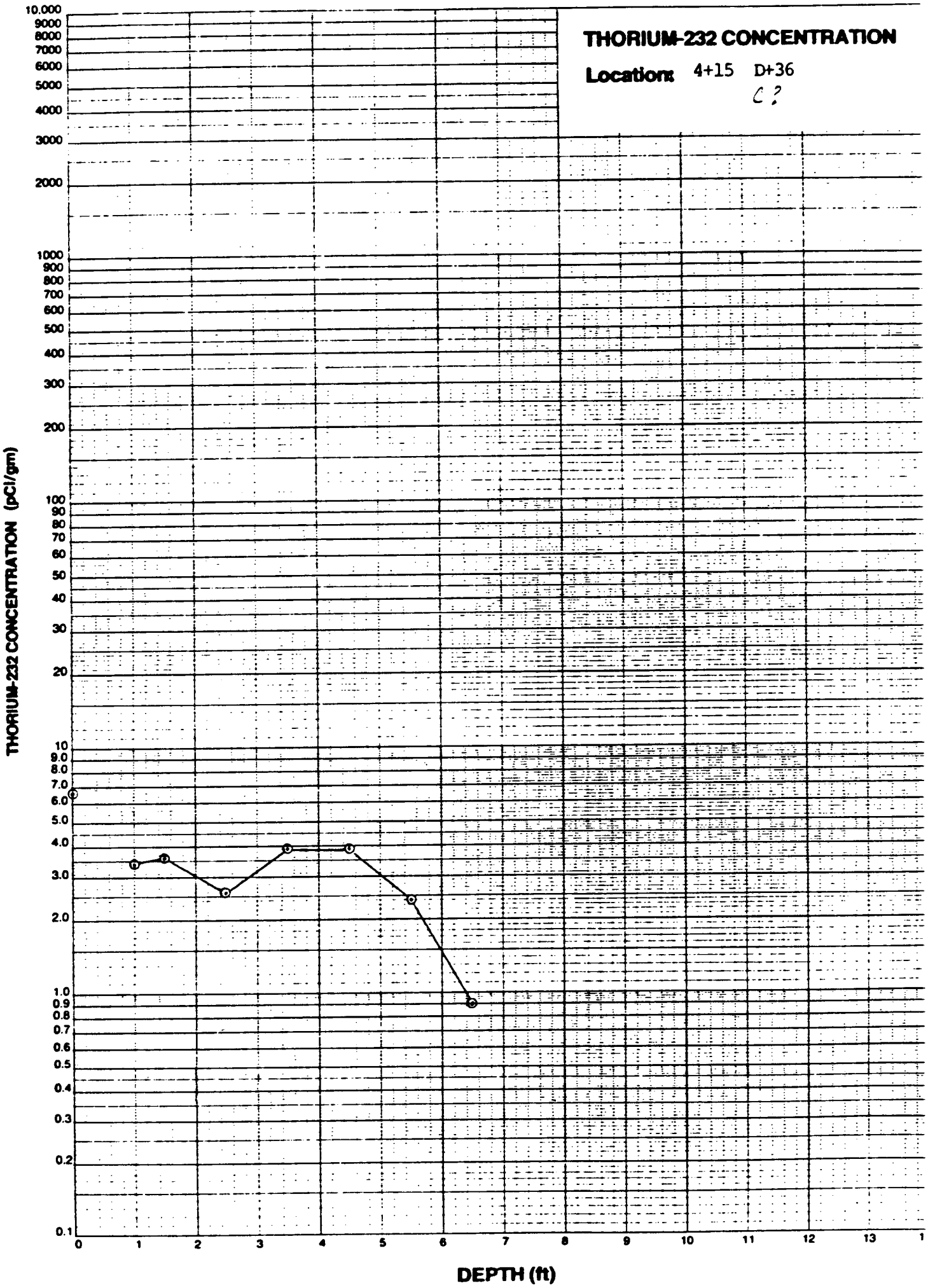
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+15 D+36
C?
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
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0.4
0.3
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4
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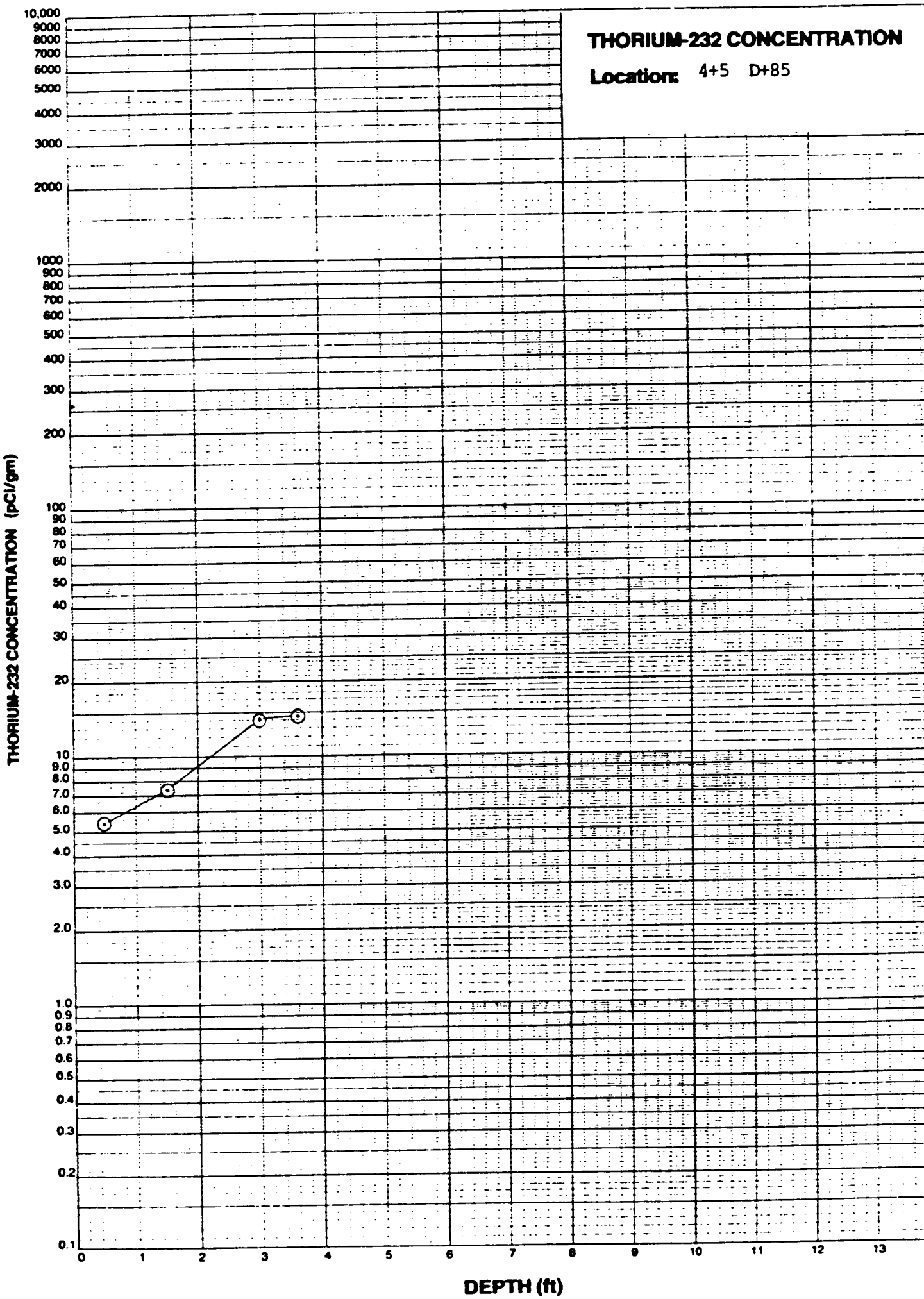
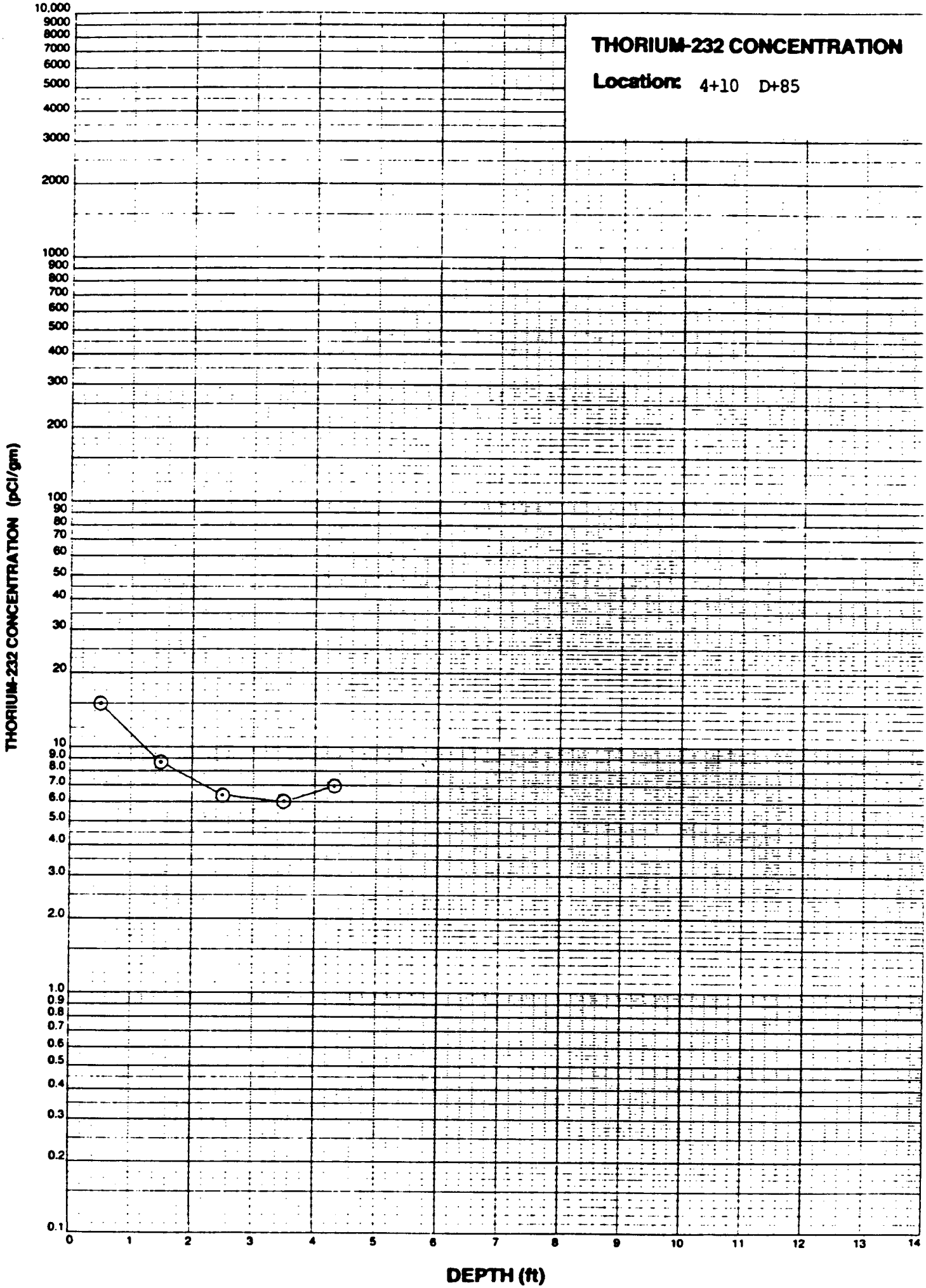
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+5 D+85
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+10 D+85
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
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70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
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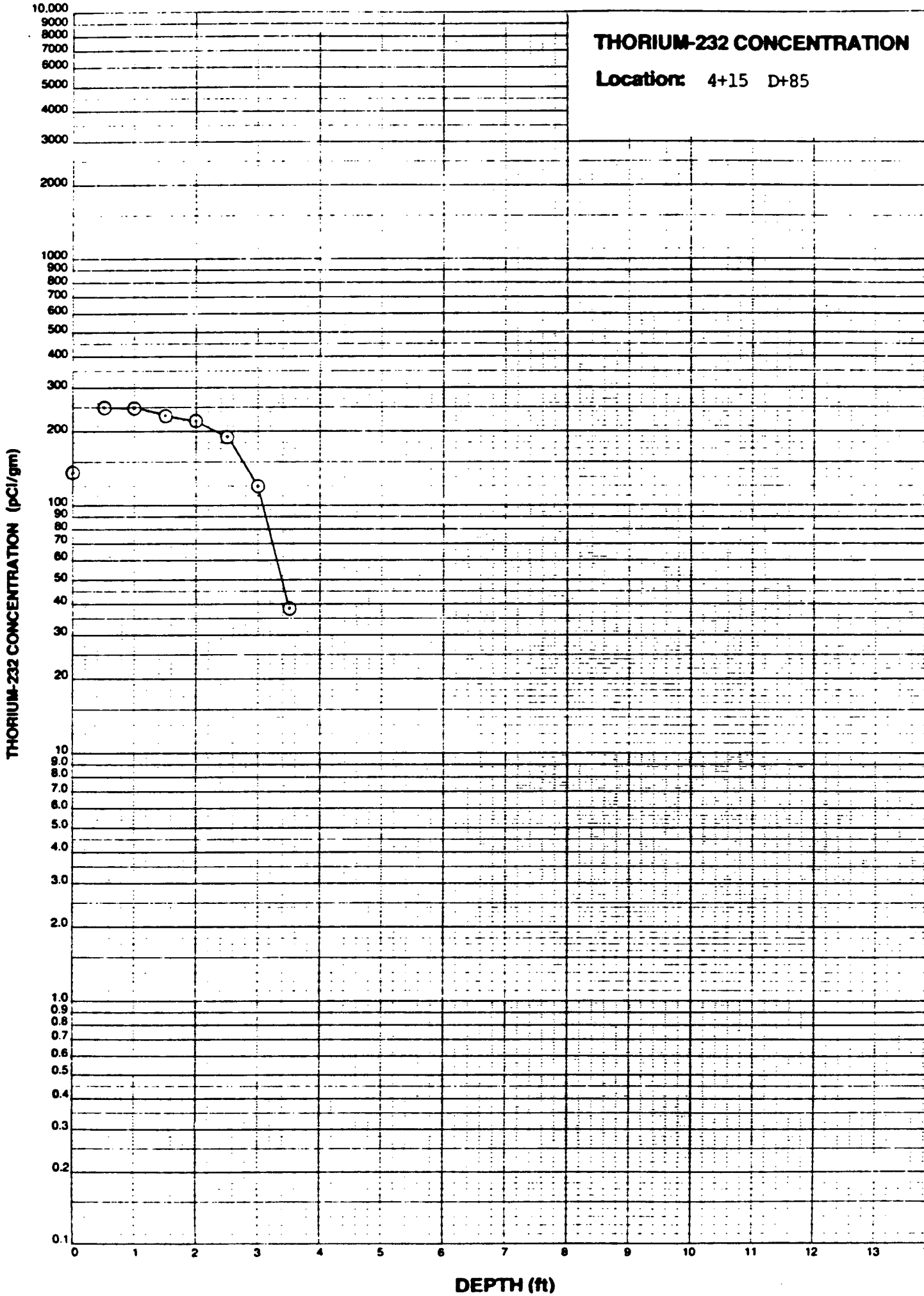
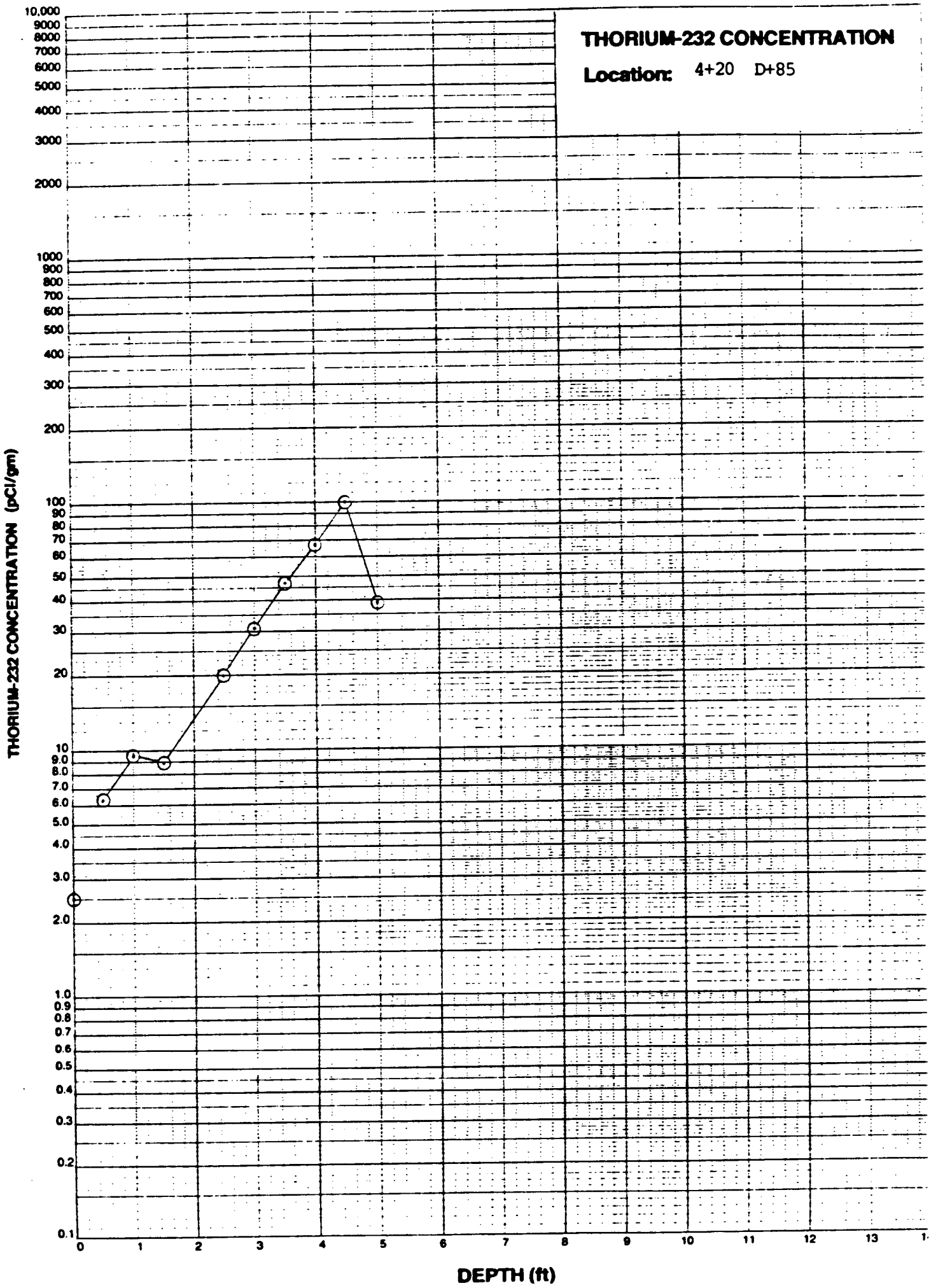
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+15 D+85
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+20 D+85
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
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50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
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0.7
0.6
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0.3
0.2
0.1
0
1
2
3
4
5
6
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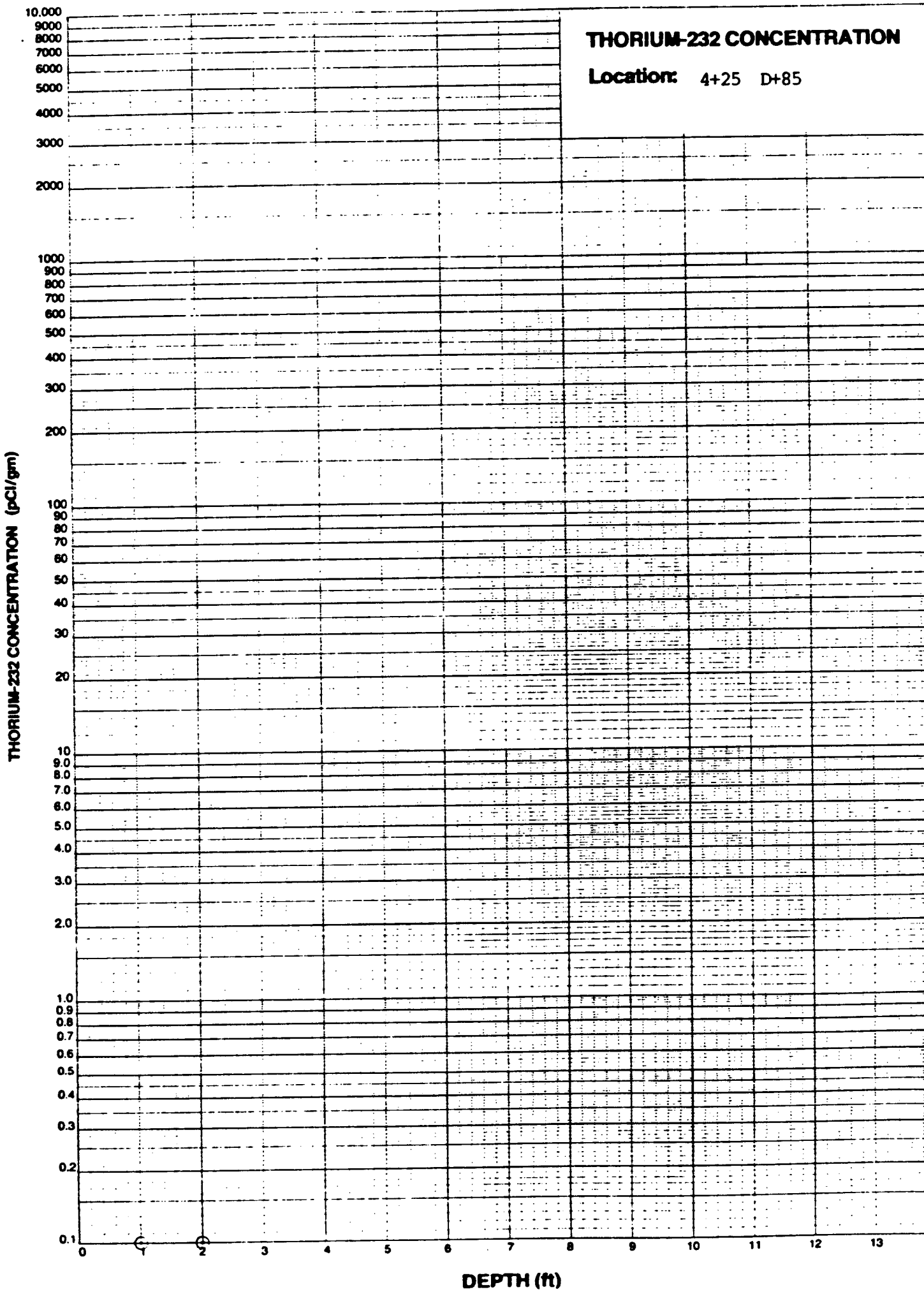
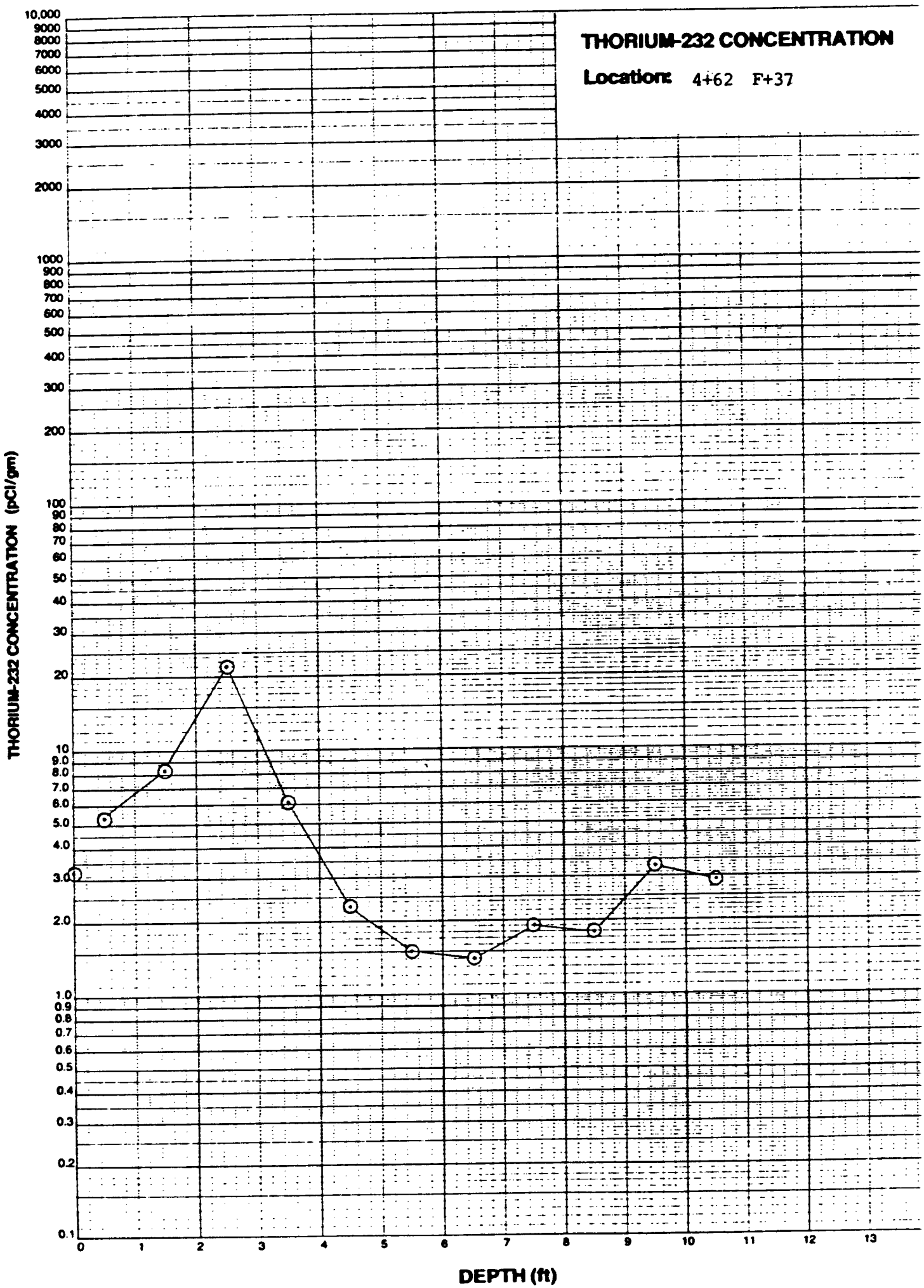
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+25 D+85
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+62 F+37
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
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800
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400
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40
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20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
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0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
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4
5
6
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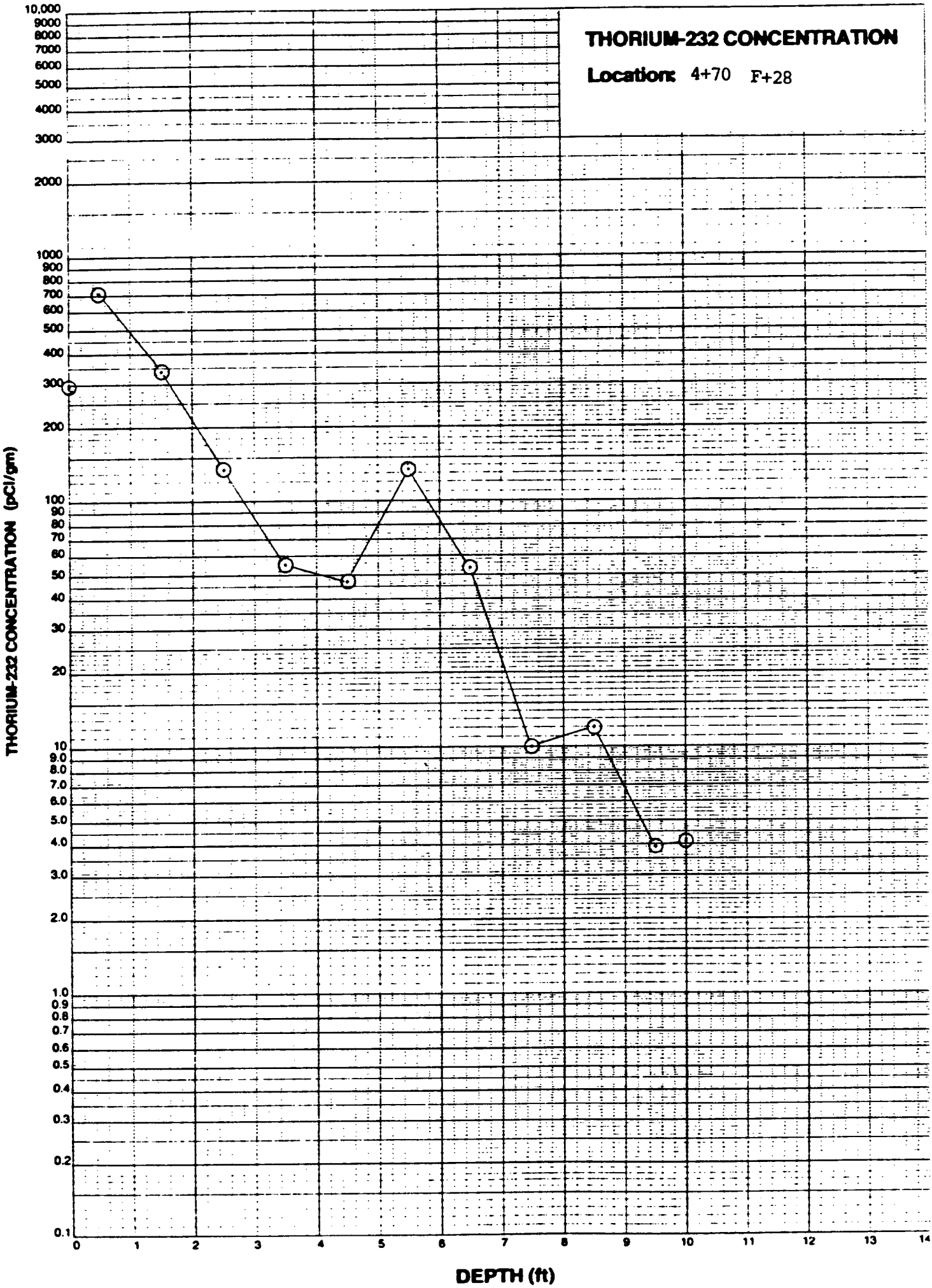
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 4+70 F+28
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
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600
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100
90
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9.0
8.0
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0.1
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1
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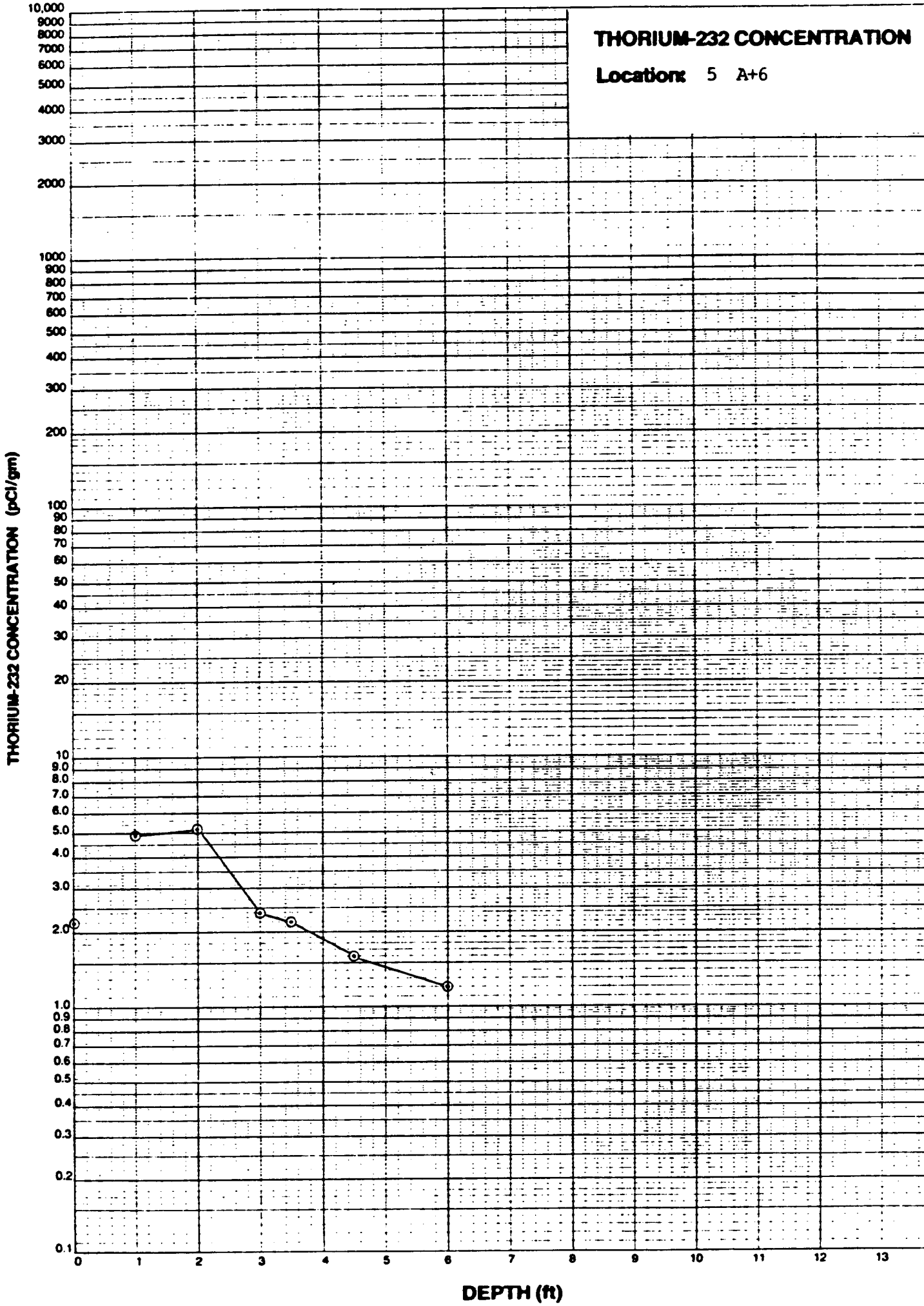
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5 A+6
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
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1000
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9.0
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0.5
0.4
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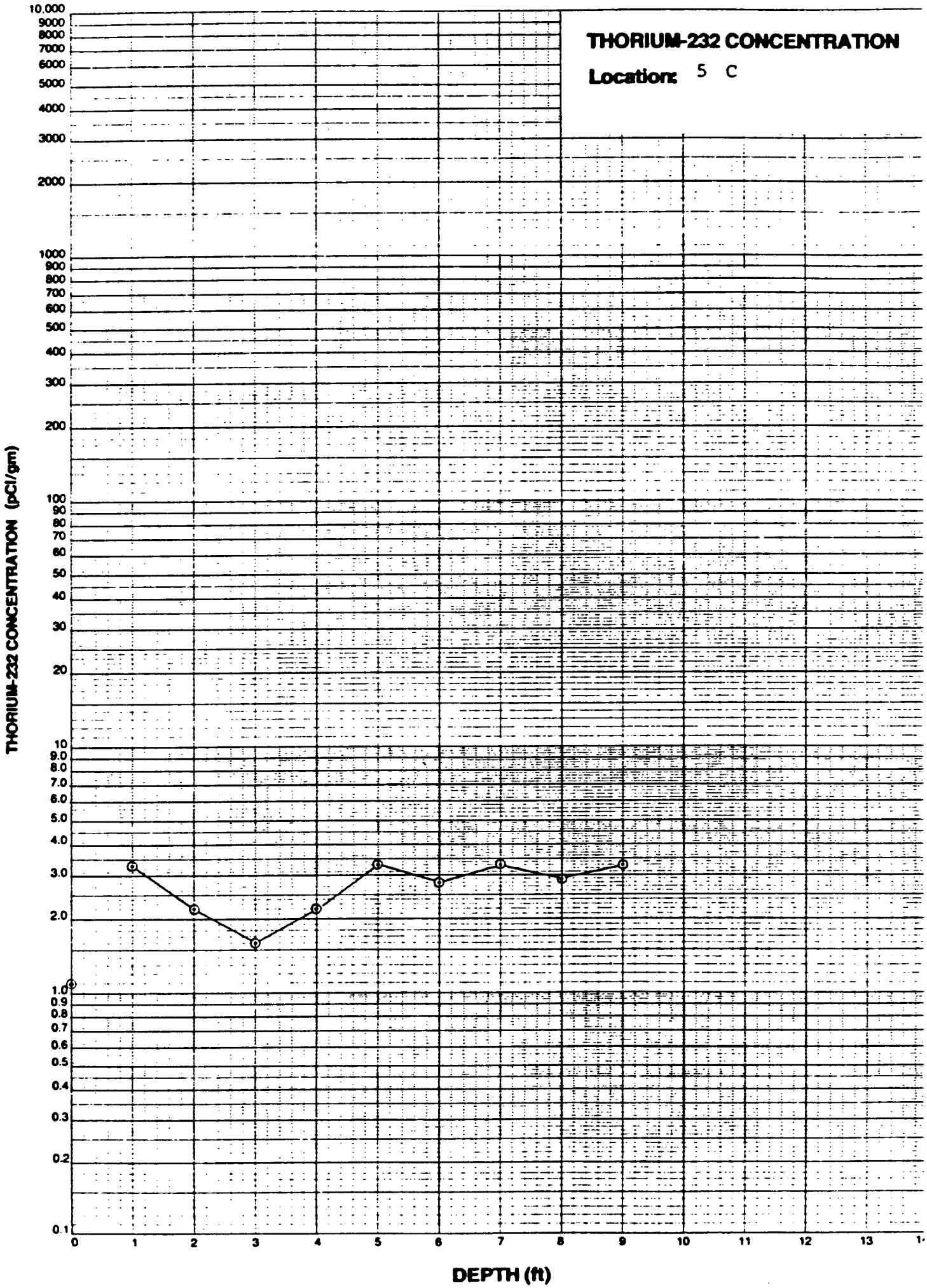
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5 C
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
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0.6
0.5
0.4
0.3
0.2
0.1
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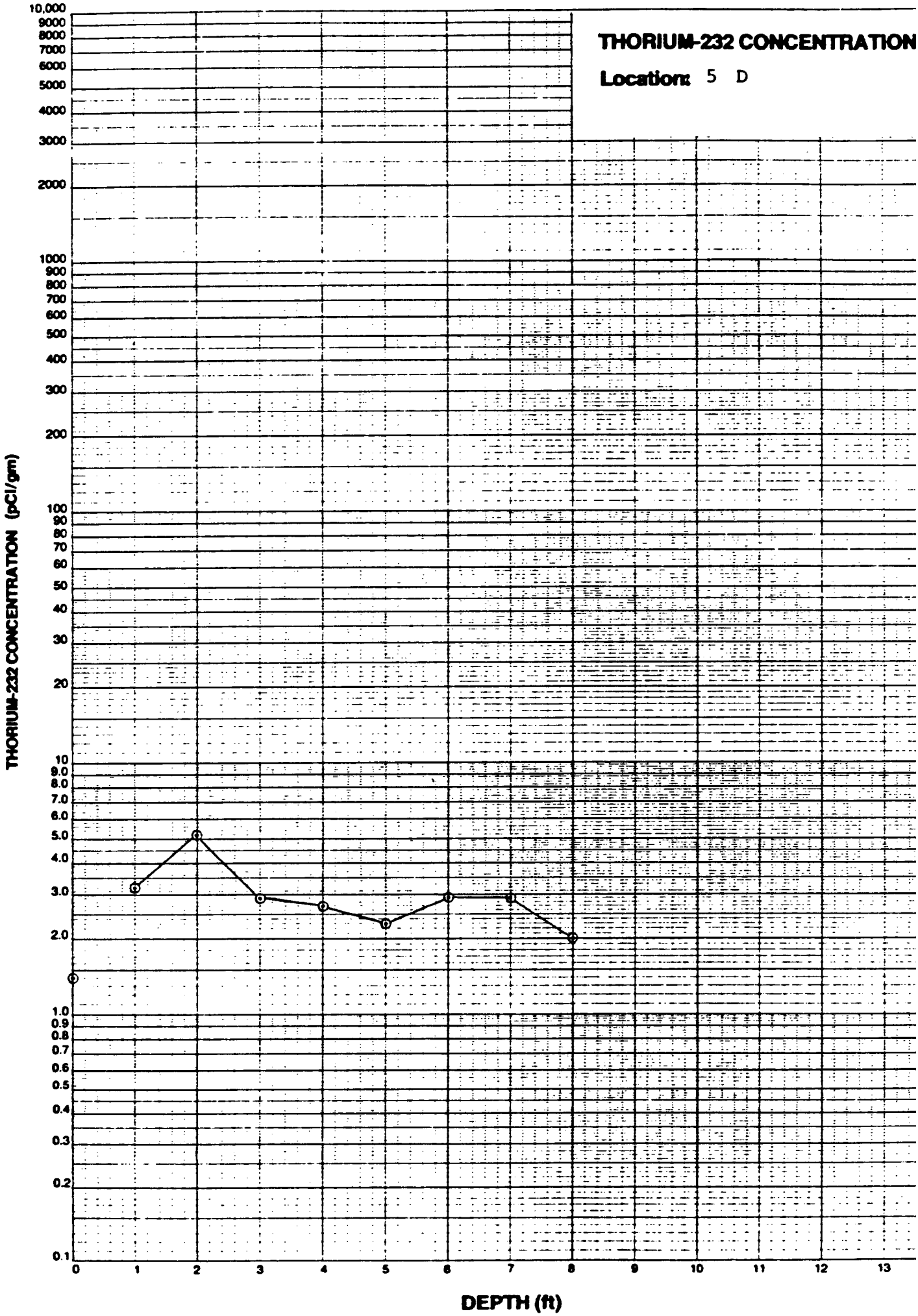
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5 D
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
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500
400
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200
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0.5
0.4
0.3
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9
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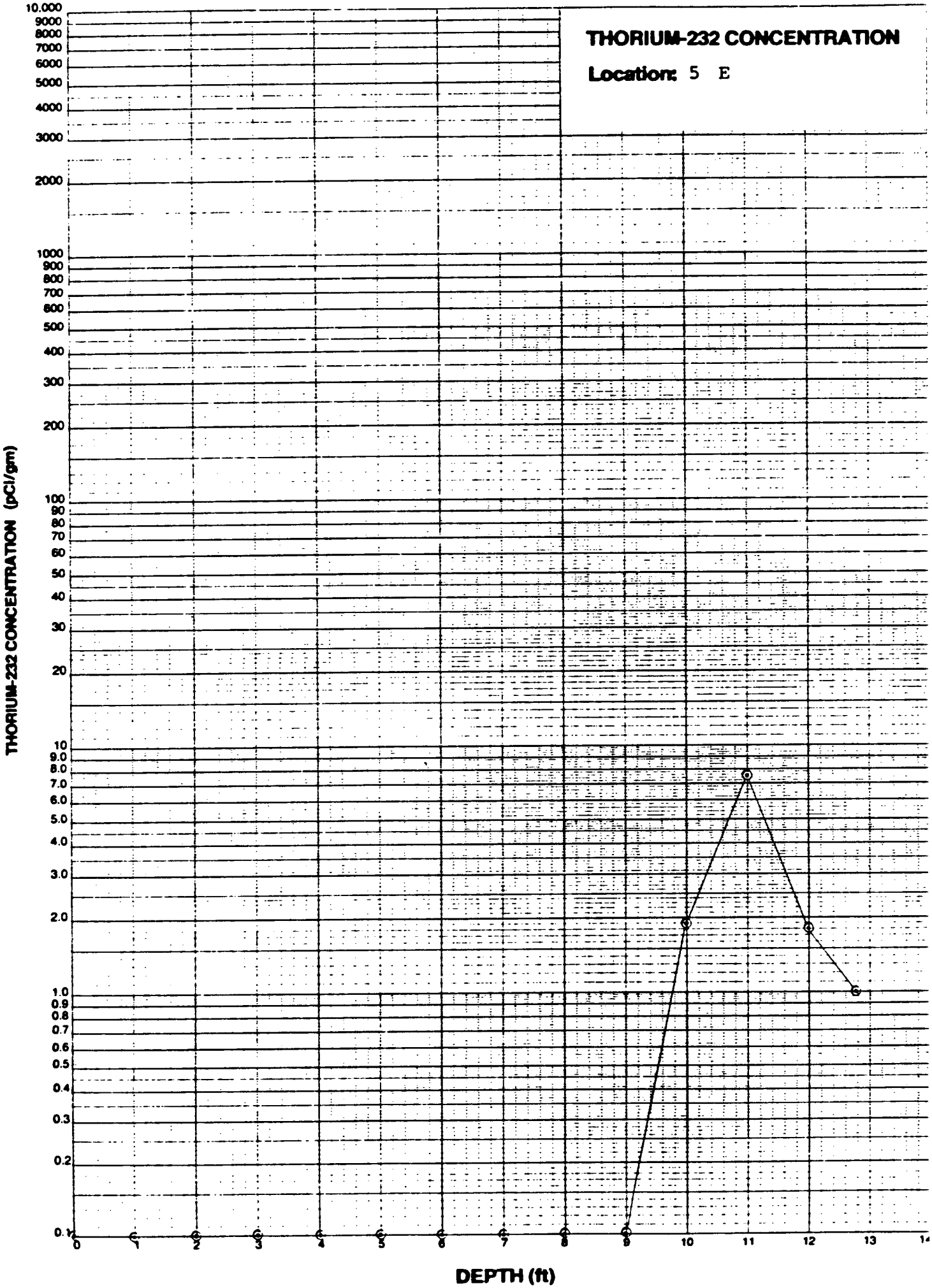
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5 E
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
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500
400
300
200
100
90
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40
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10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
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6
7
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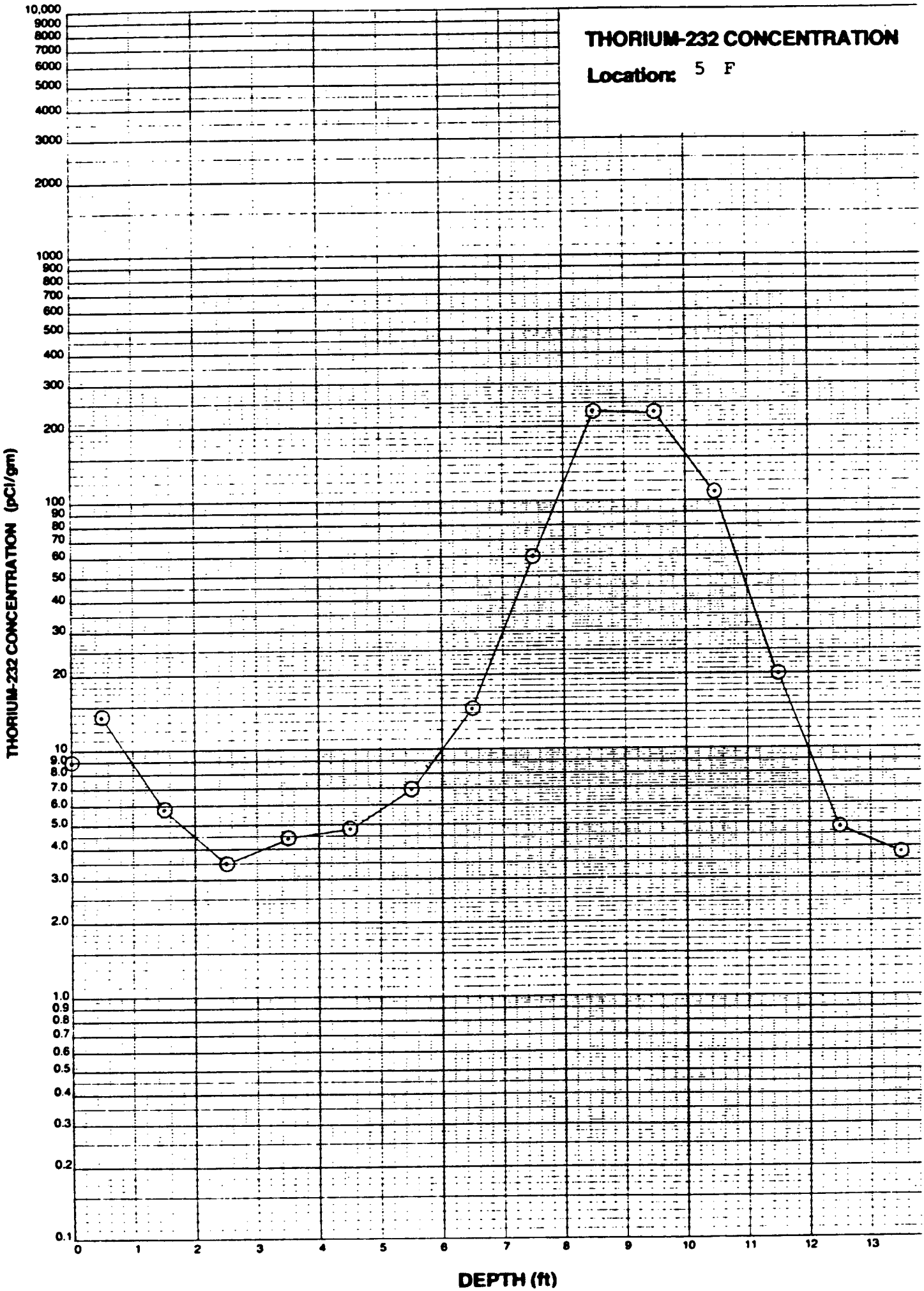
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5 F
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
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0.7
0.6
0.5
0.4
0.3
0.2
0.1
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1
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3
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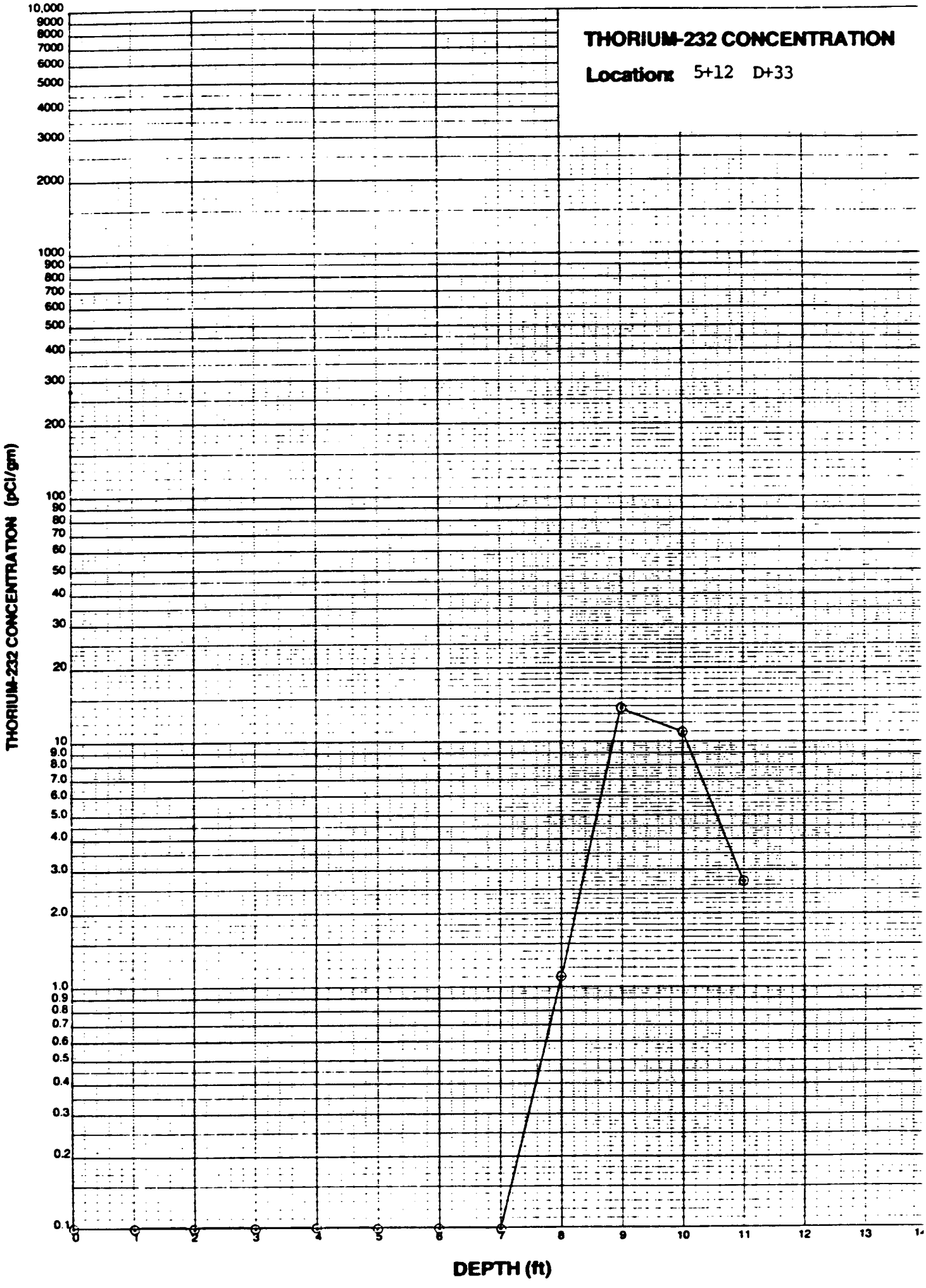
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5+12 D+33
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
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70
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50
40
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20
10
9.0
8.0
7.0
6.0
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4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
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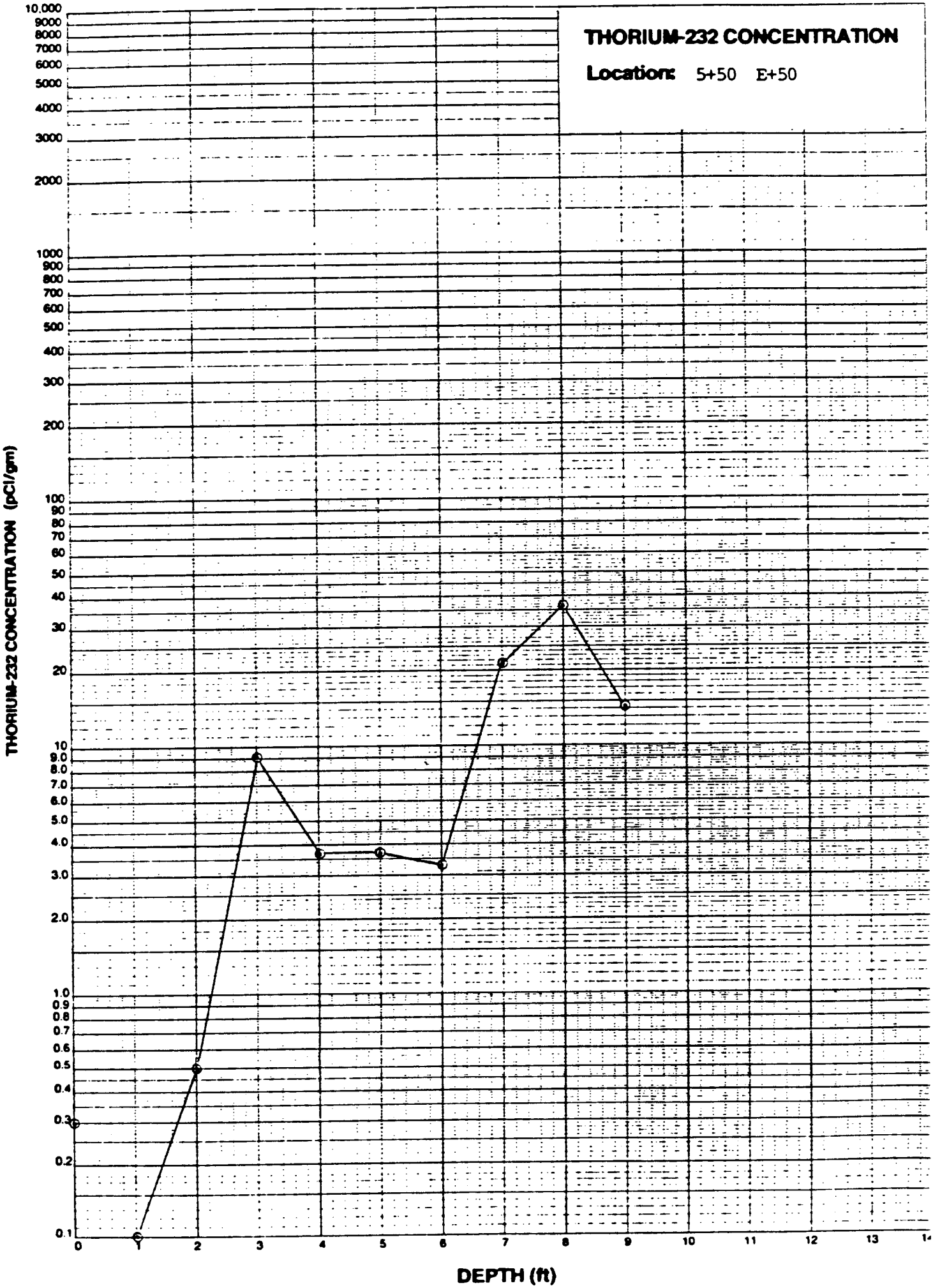
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5+50 E+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
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40
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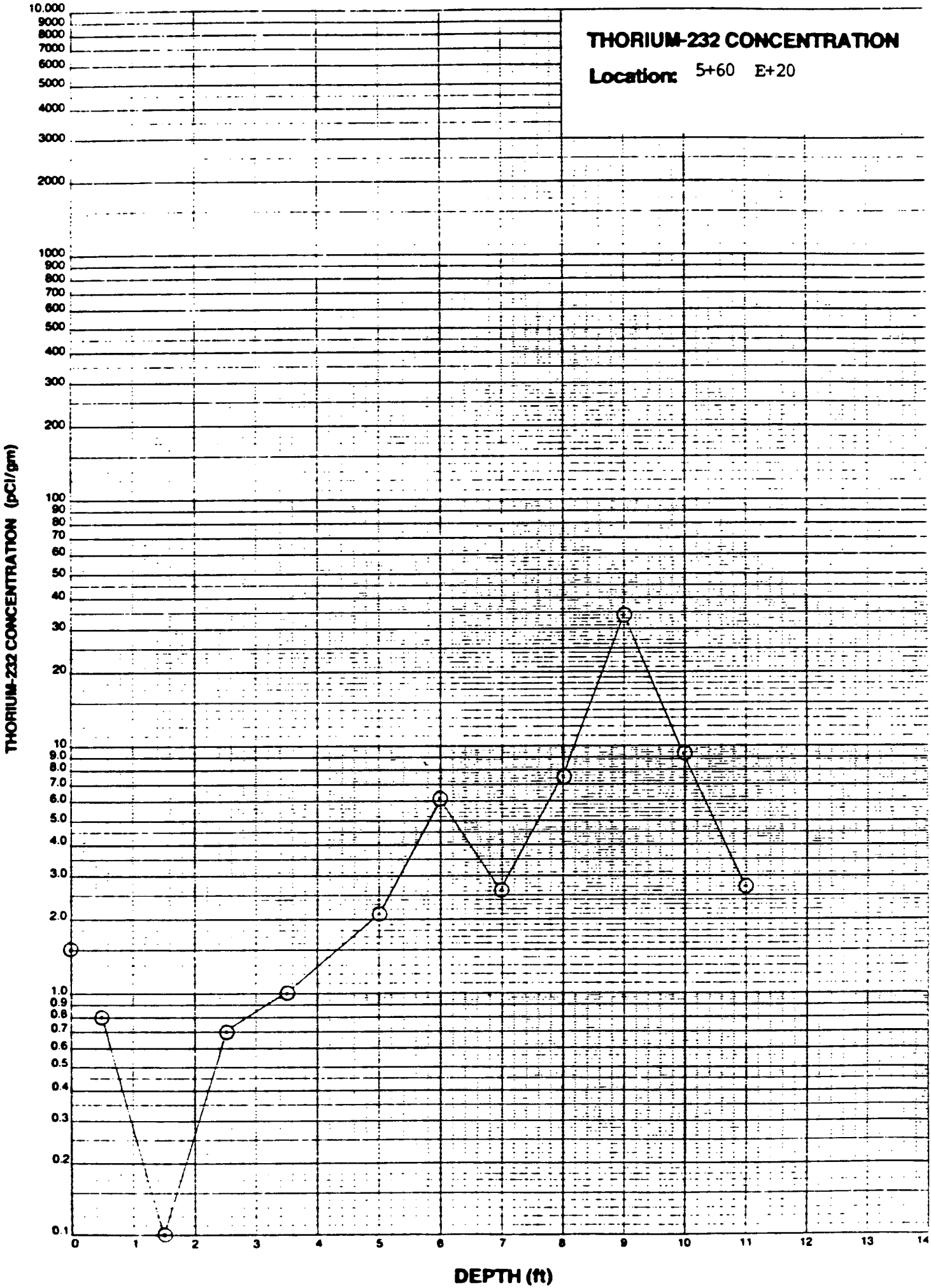
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 5+60 E+20
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
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50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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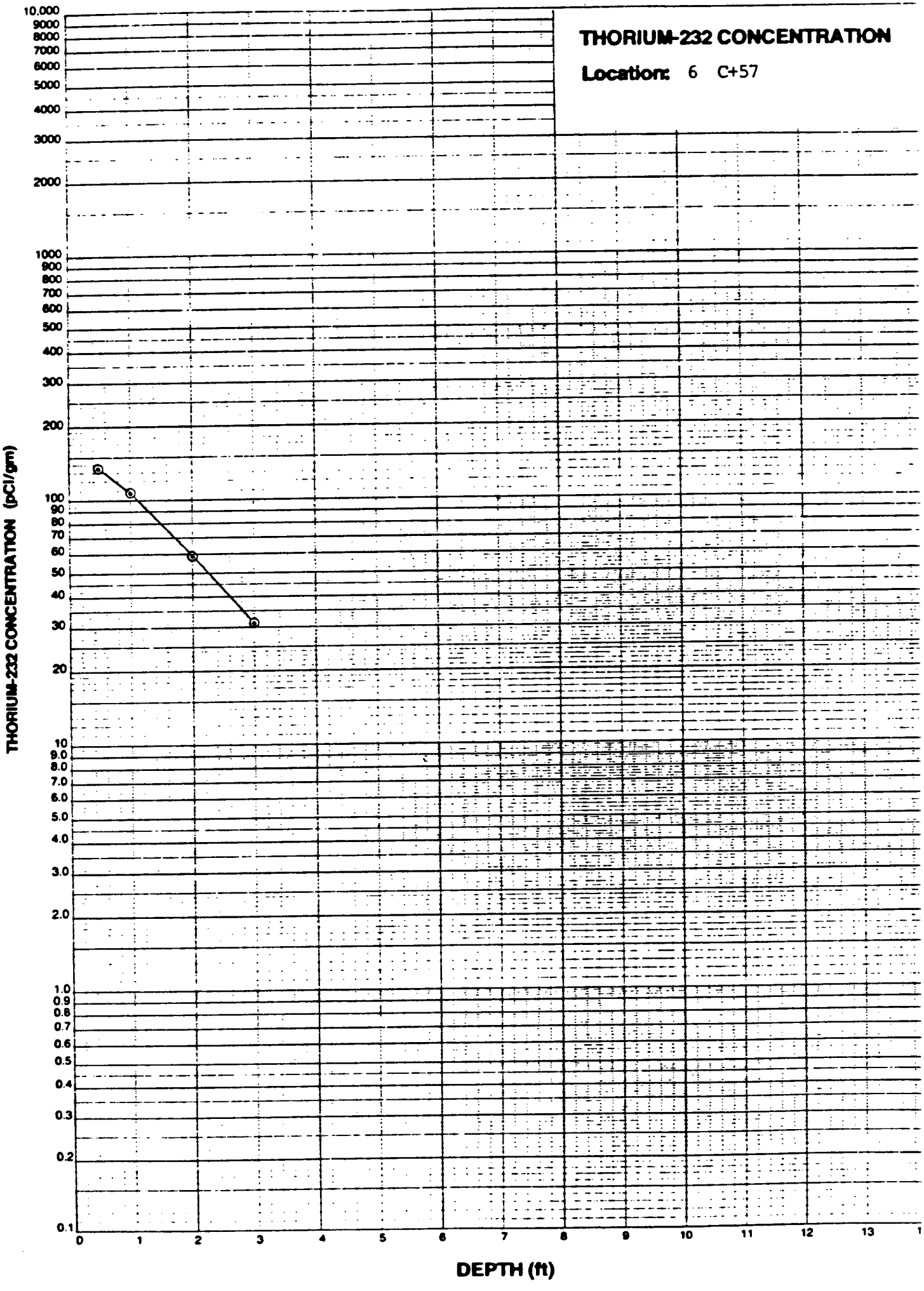
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 6 C+57
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
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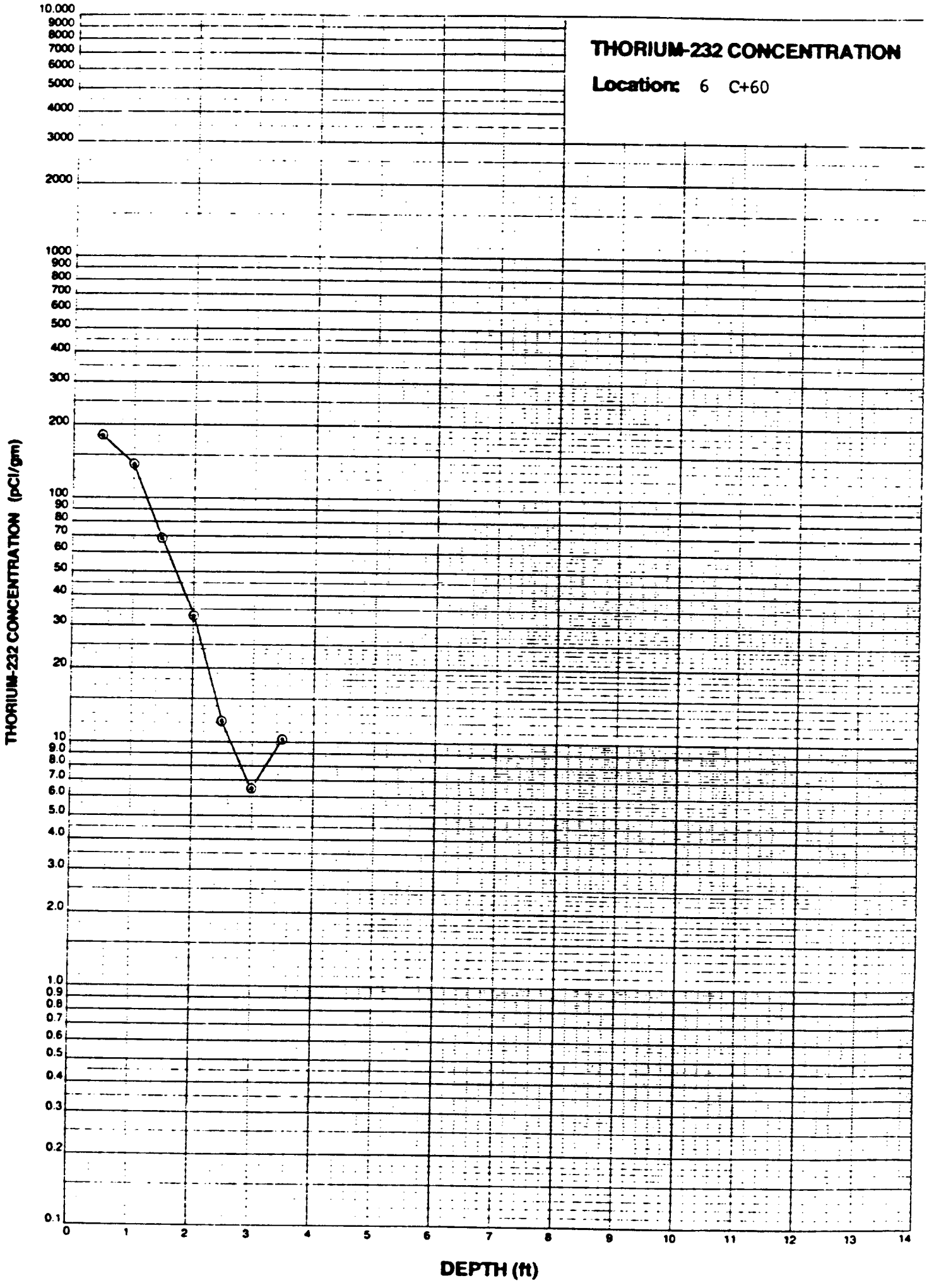
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 6 C+60
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
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700
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9.0
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4.0
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
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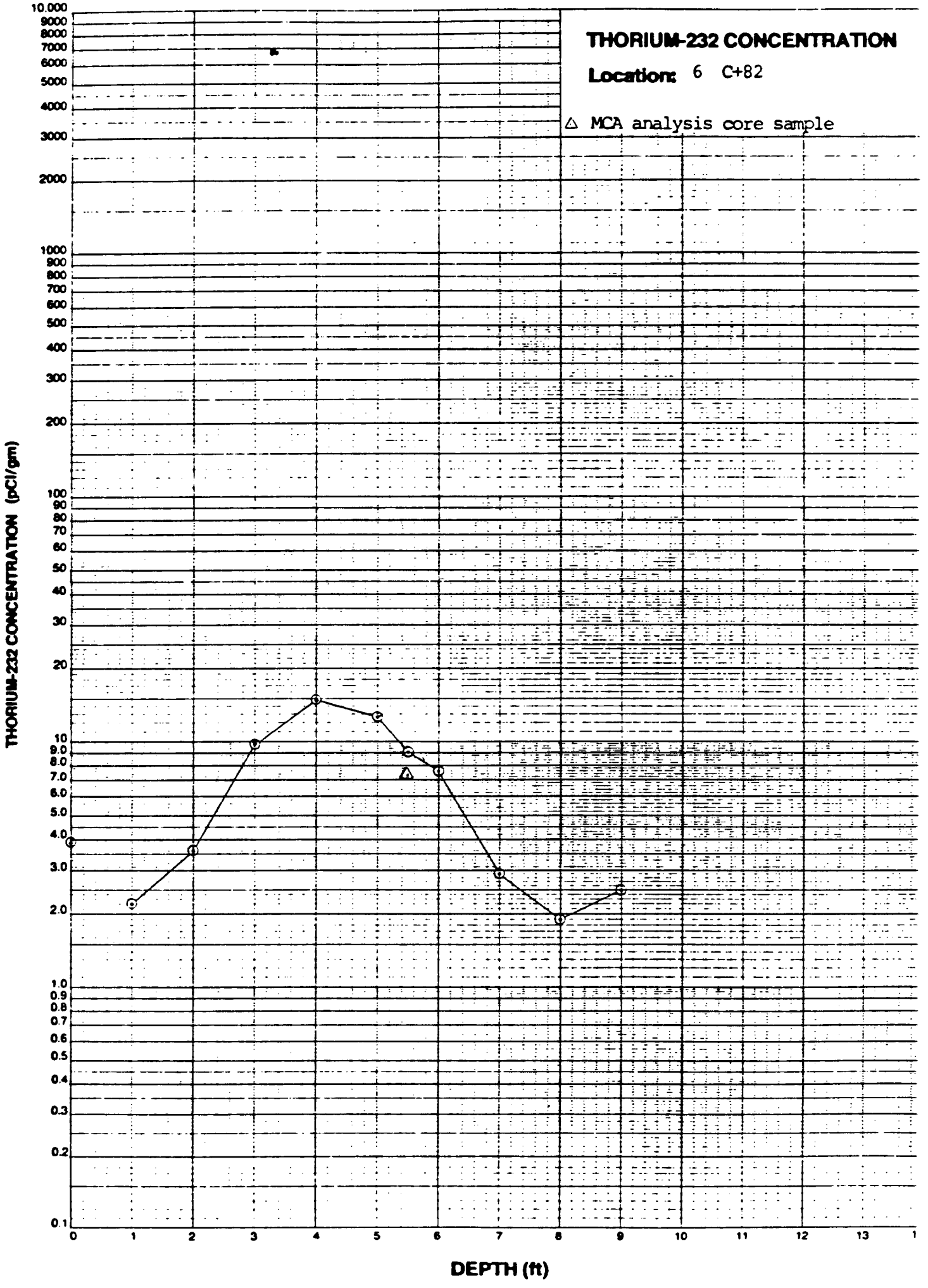
2
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 6 C+82
△ MCA analysis core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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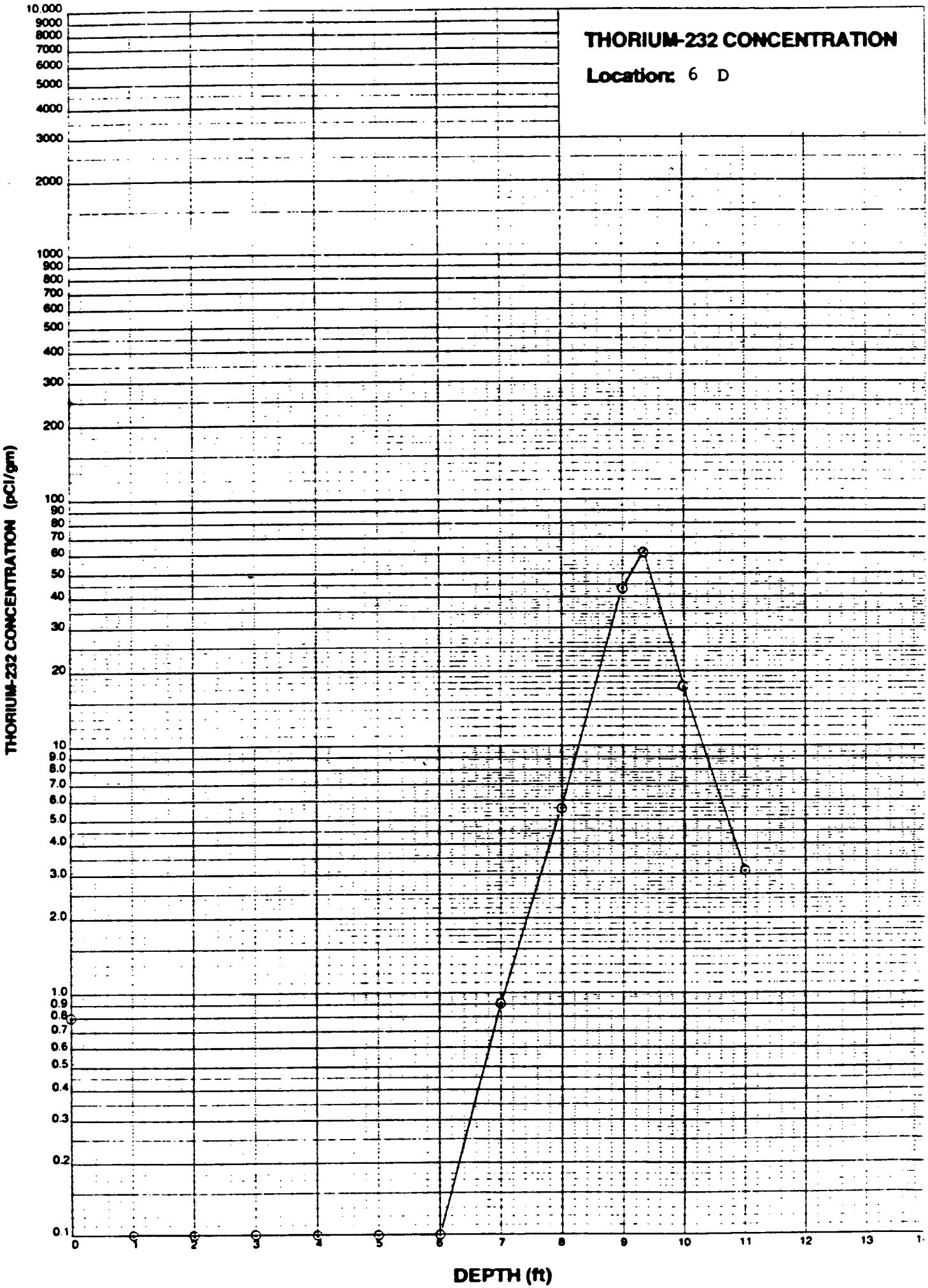
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 6 D
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
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20
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9.0
8.0
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6.0
5.0
4.0
3.0
2.0
1.0
0.9
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0.6
0.5
0.4
0.3
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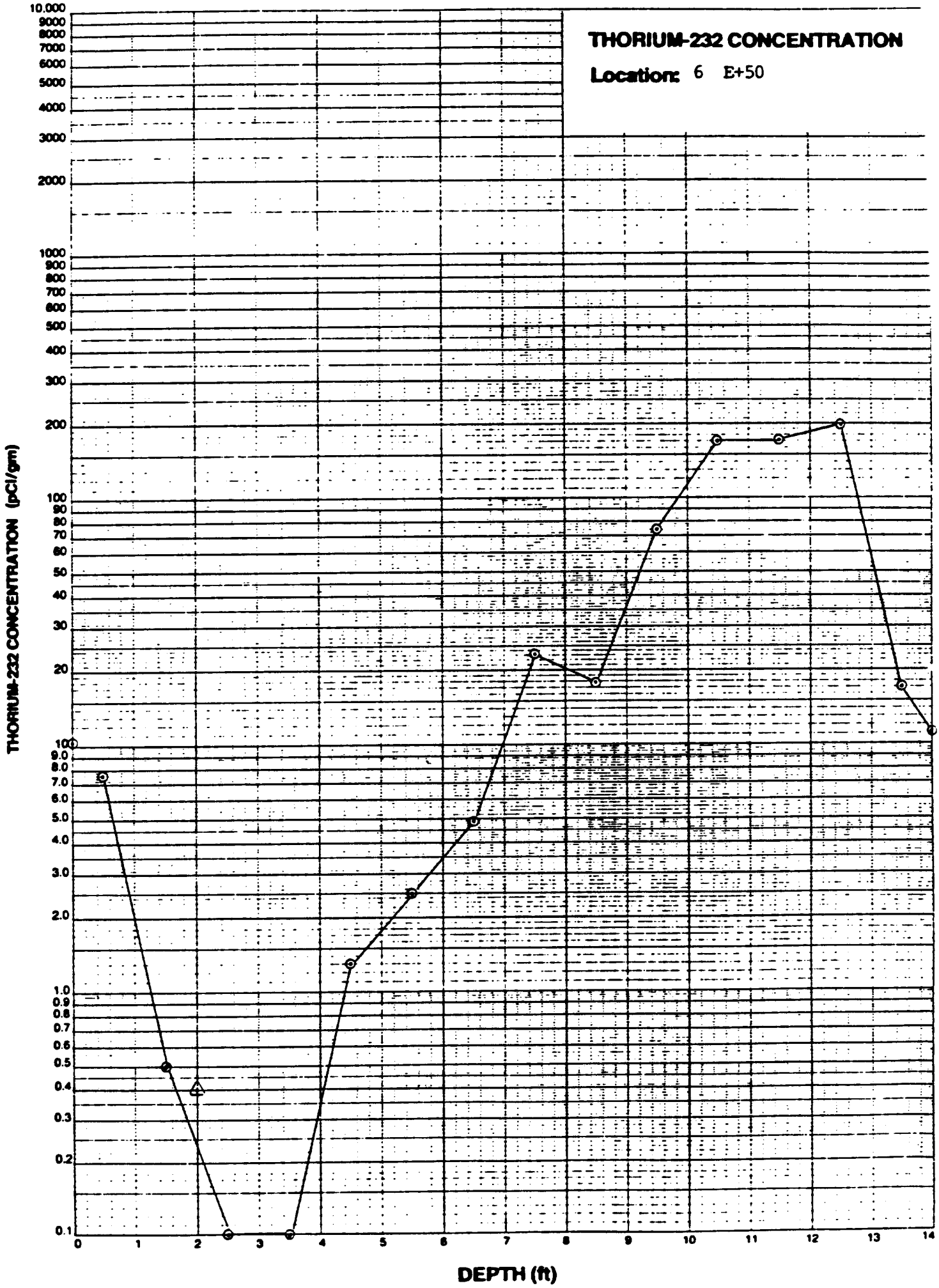
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 6 E+50
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
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9.0
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7.0
6.0
5.0
4.0
3.0
2.0
1.0
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0.7
0.6
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0.4
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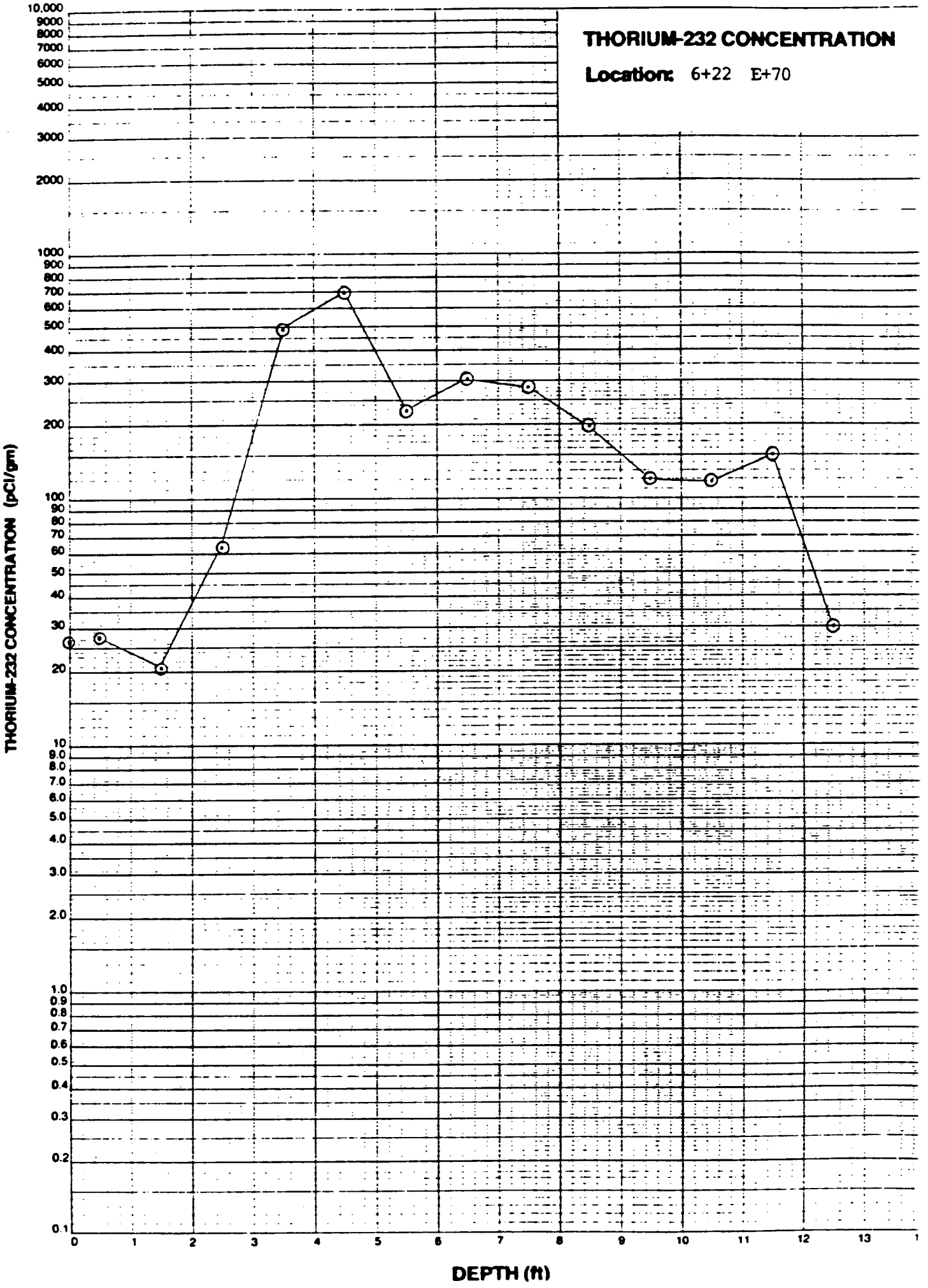
THORIUM-232 CONCENTRATION
Location: 6+22 E+70
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
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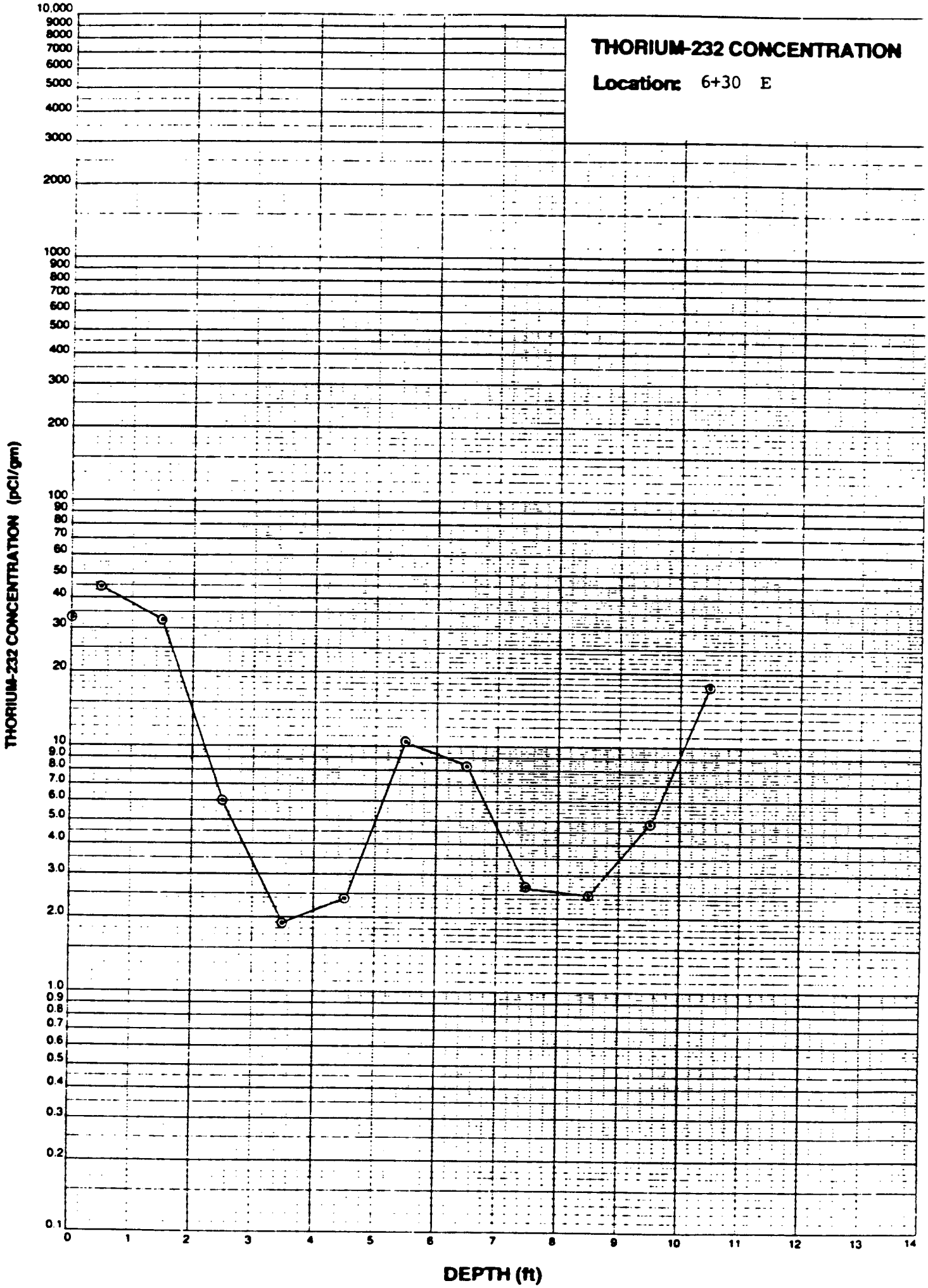
THORIUM-232 CONCENTRATION
Location: 6+30 E
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
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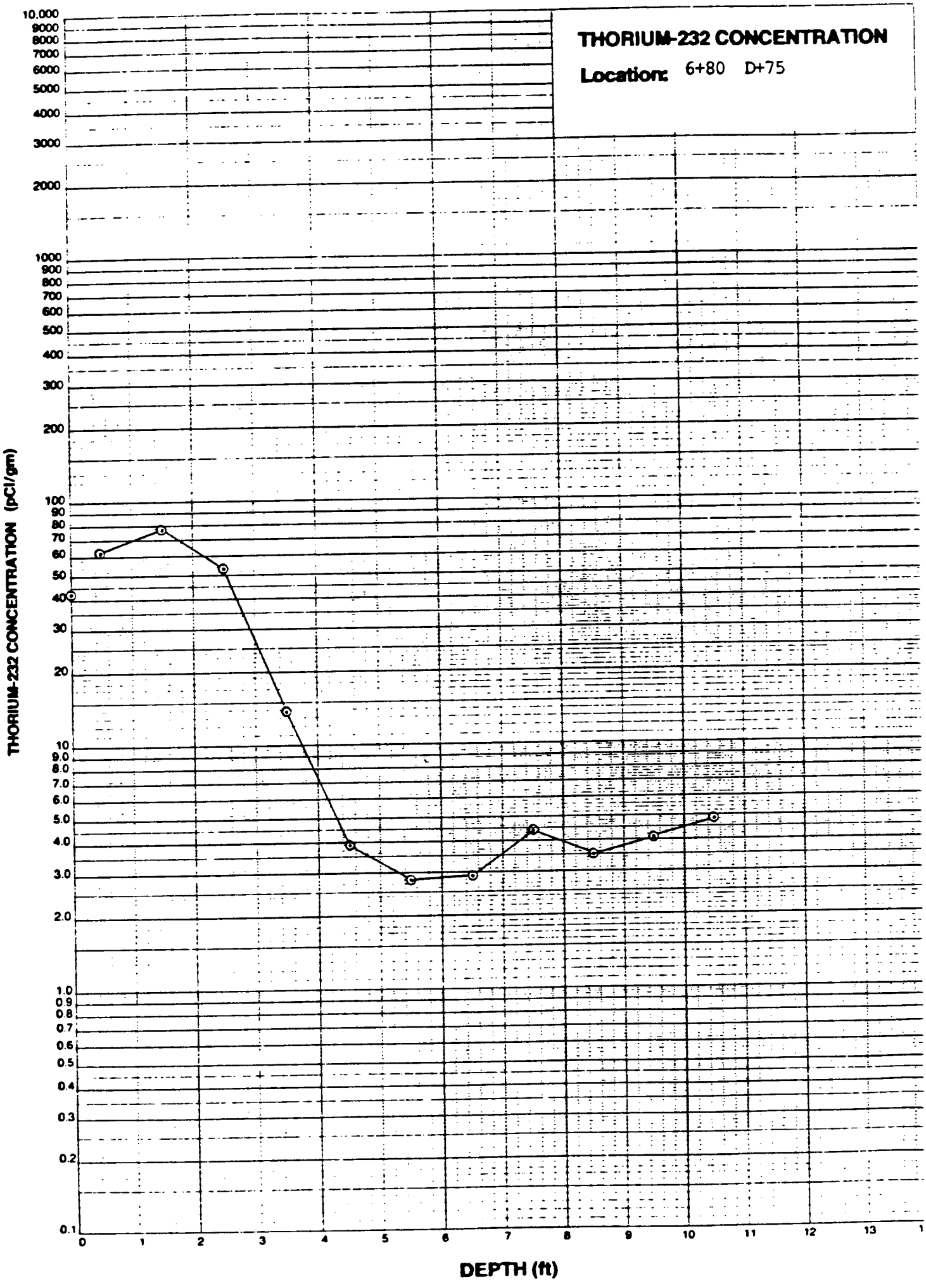
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 6+80 D+75
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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1
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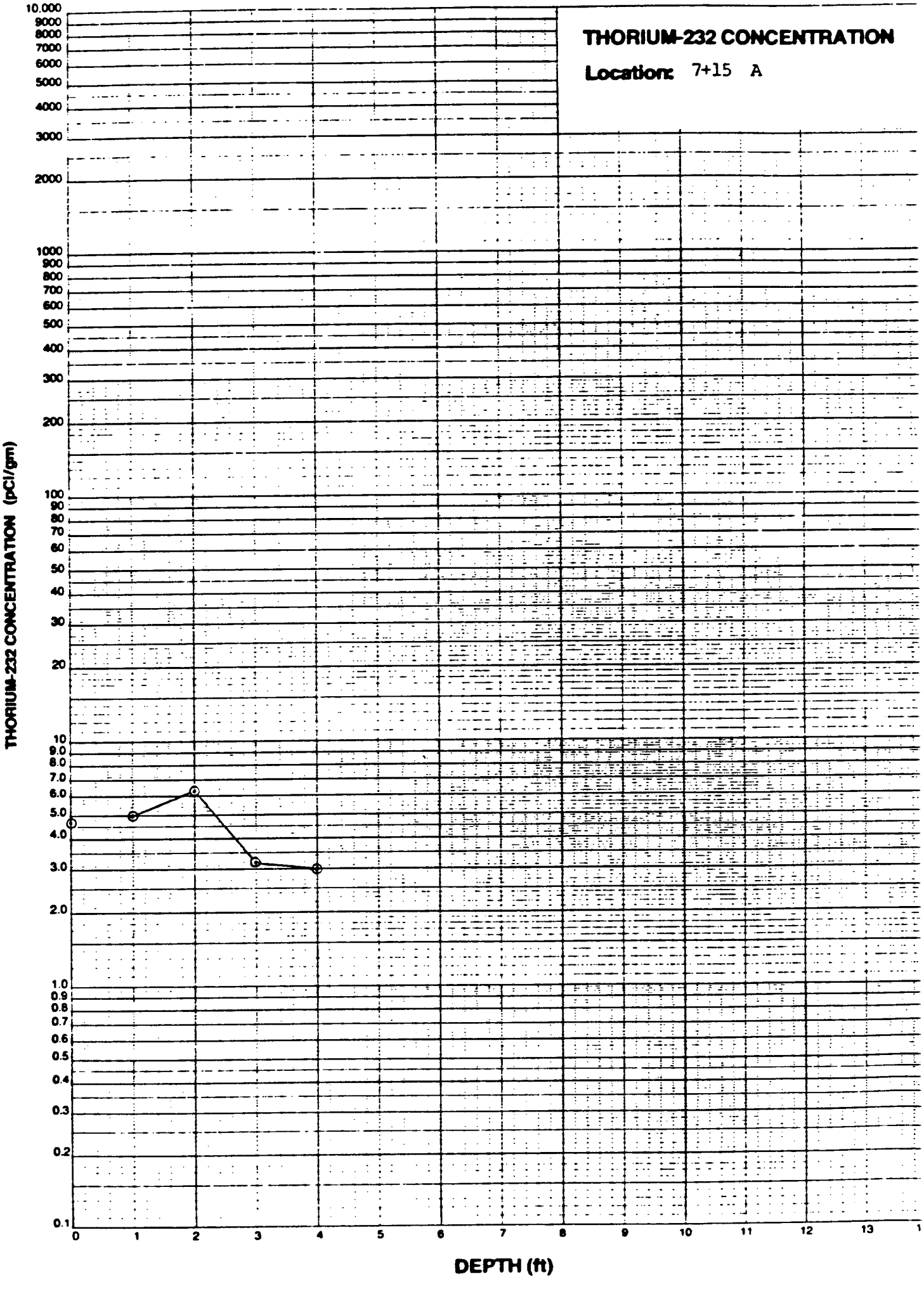
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 7+15 A
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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0.1
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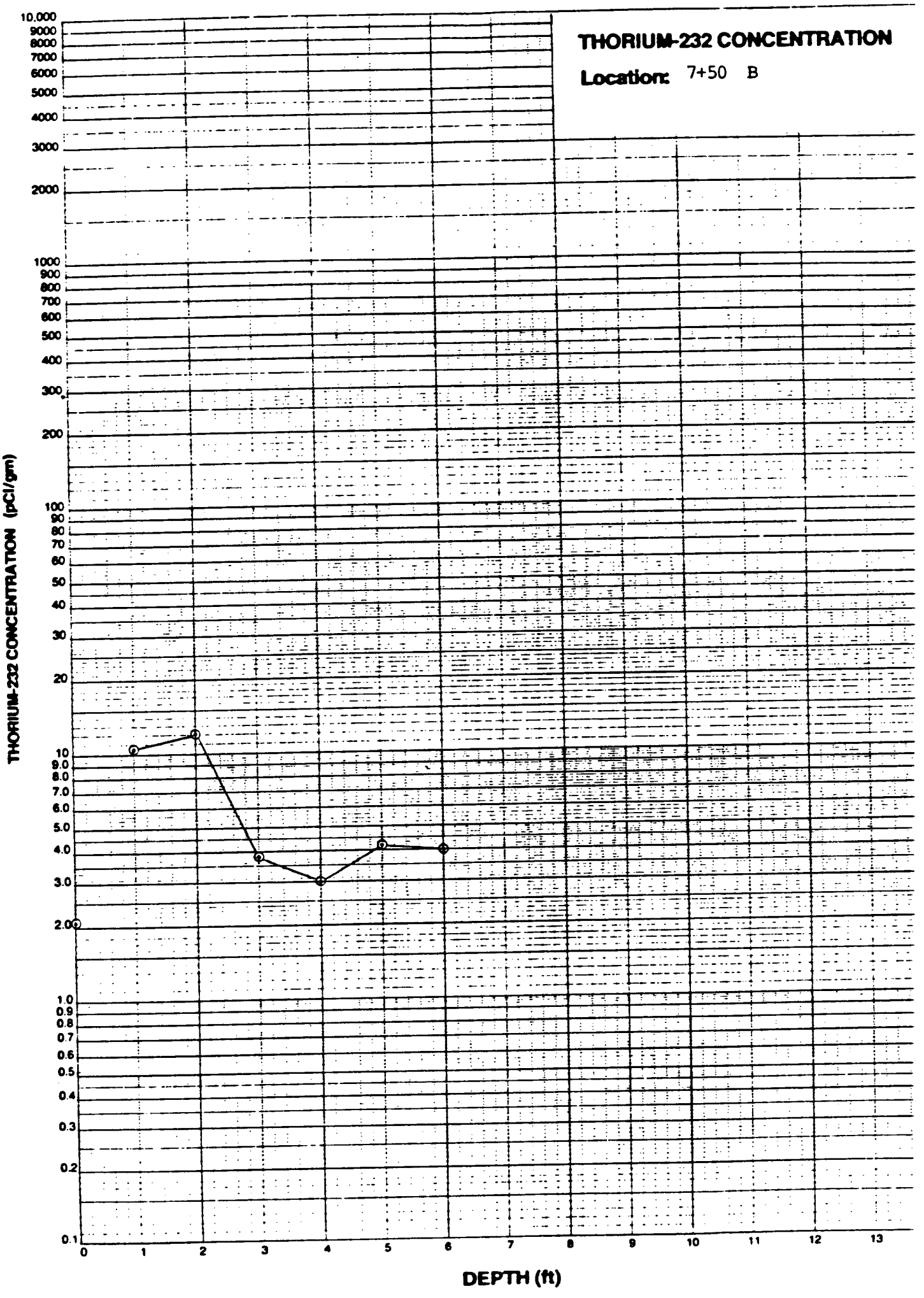
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 7+50 B
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
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12
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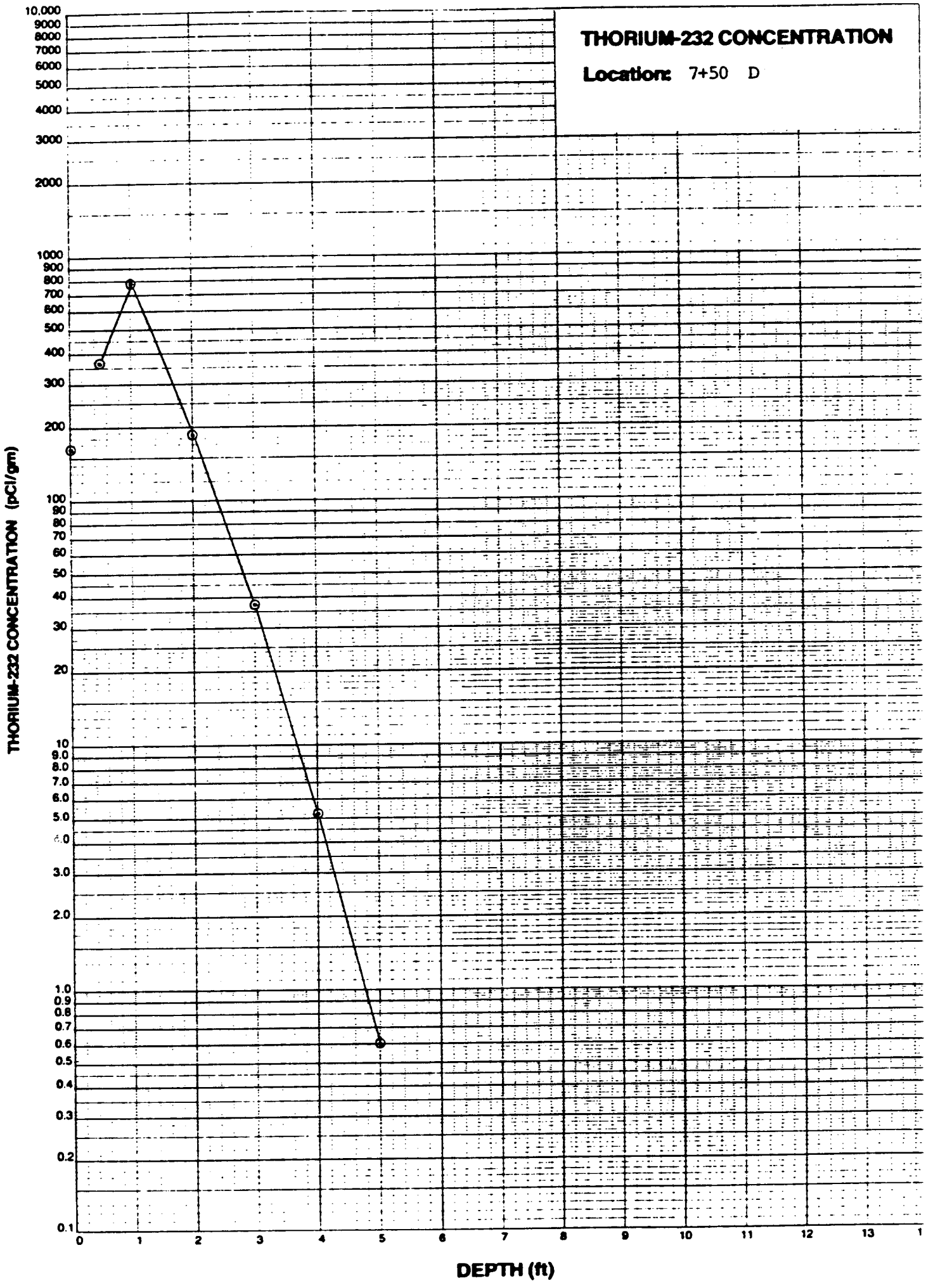
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 7+50 D
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
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500
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300
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100
90
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5.0
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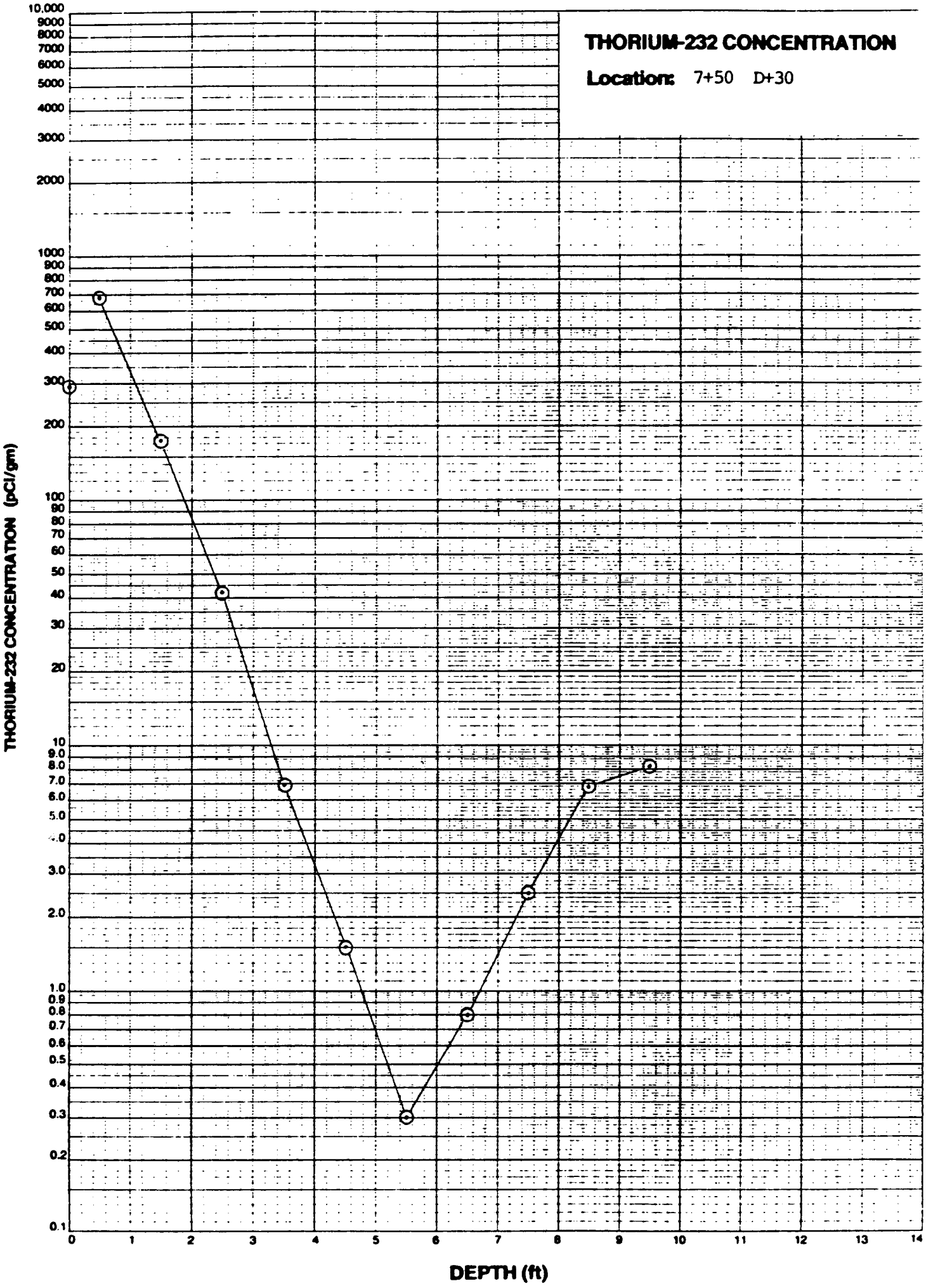
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 7+50 D+30
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
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500
400
300
200
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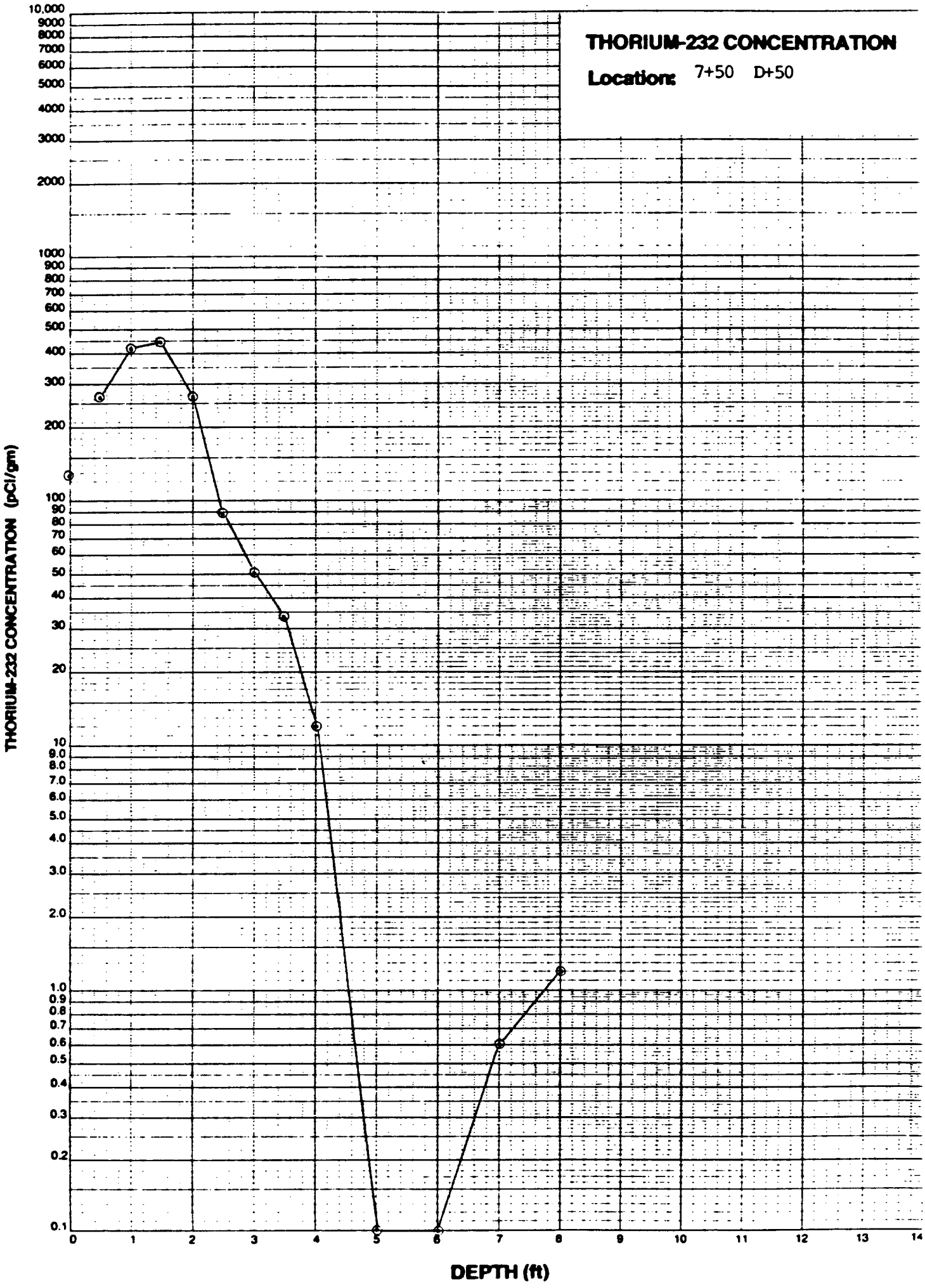
THORIUM-232 CONCENTRATION
Location: 7+50 D+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
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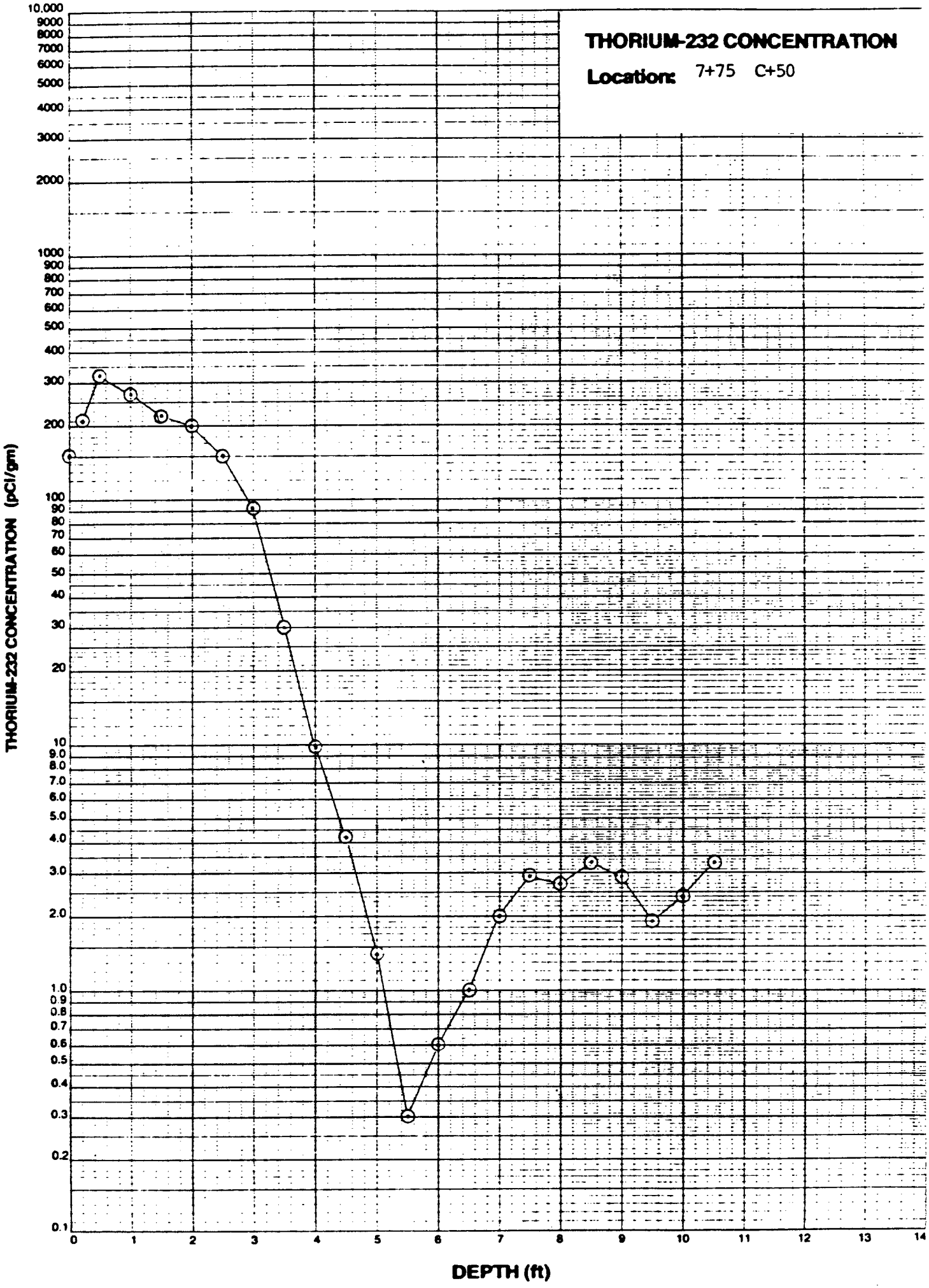
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 7+75 C+50
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
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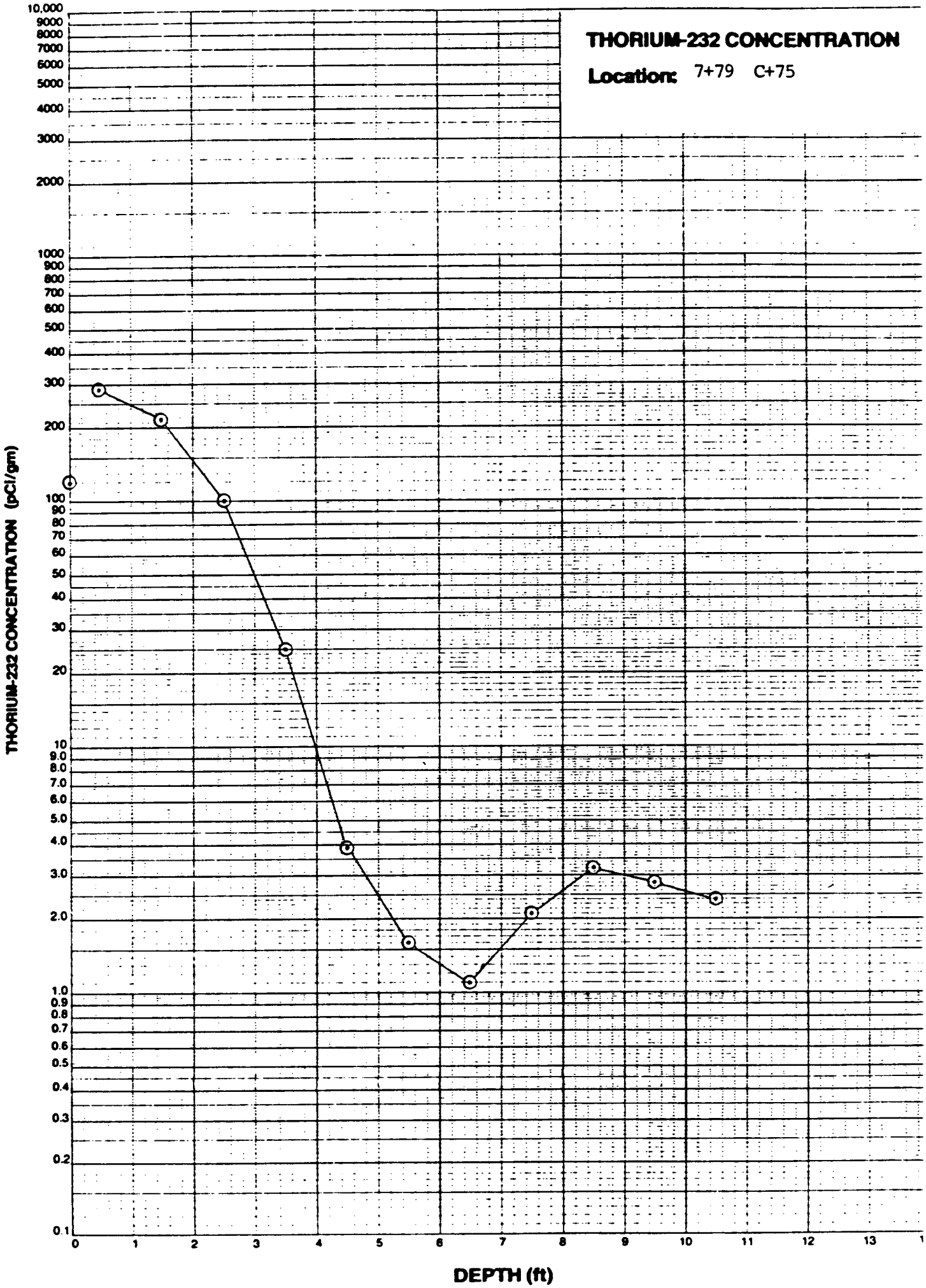
THORIUM-232 CONCENTRATION
Location: 7+79 C+75
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
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7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
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90
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9.0
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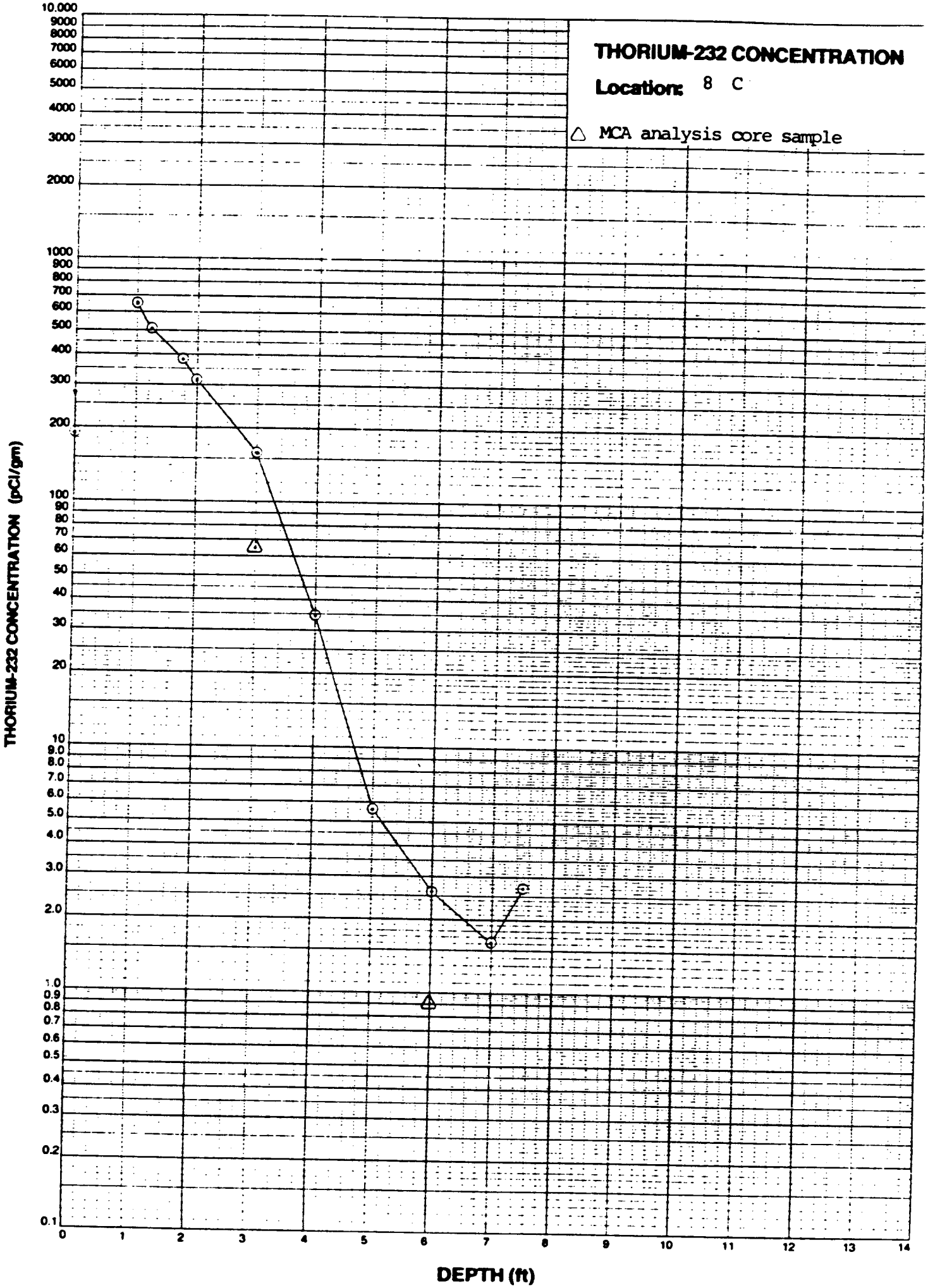
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8 C
△ MCA analysis core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
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4.0
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1.0
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0.6
0.5
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0.3
0.2
0.1
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1
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7
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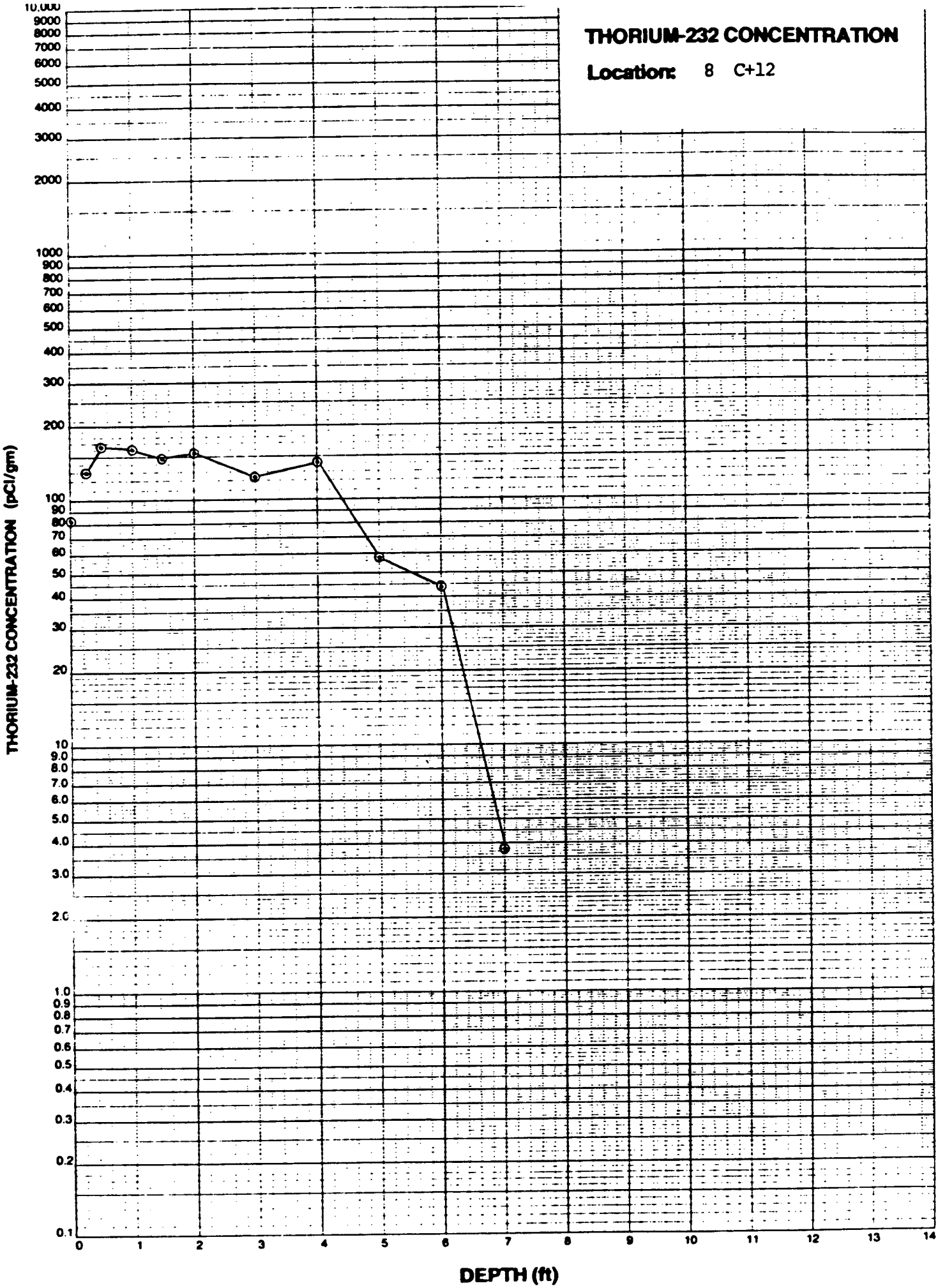
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8 C+12
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
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9.0
8.0
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1.0
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0.8
0.7
0.6
0.5
0.4
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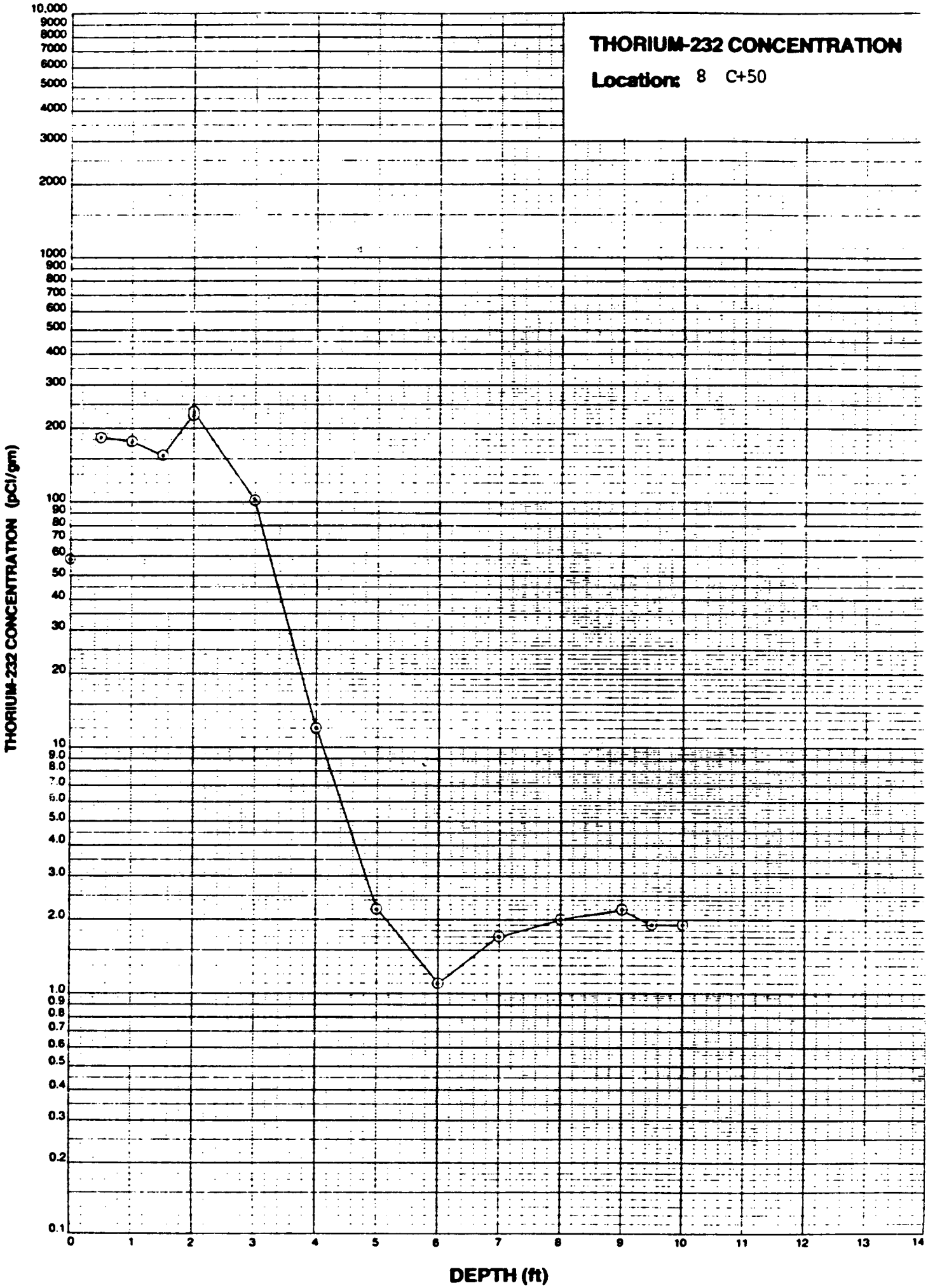
THORIUM-232 CONCENTRATION
Location: 8 C+50
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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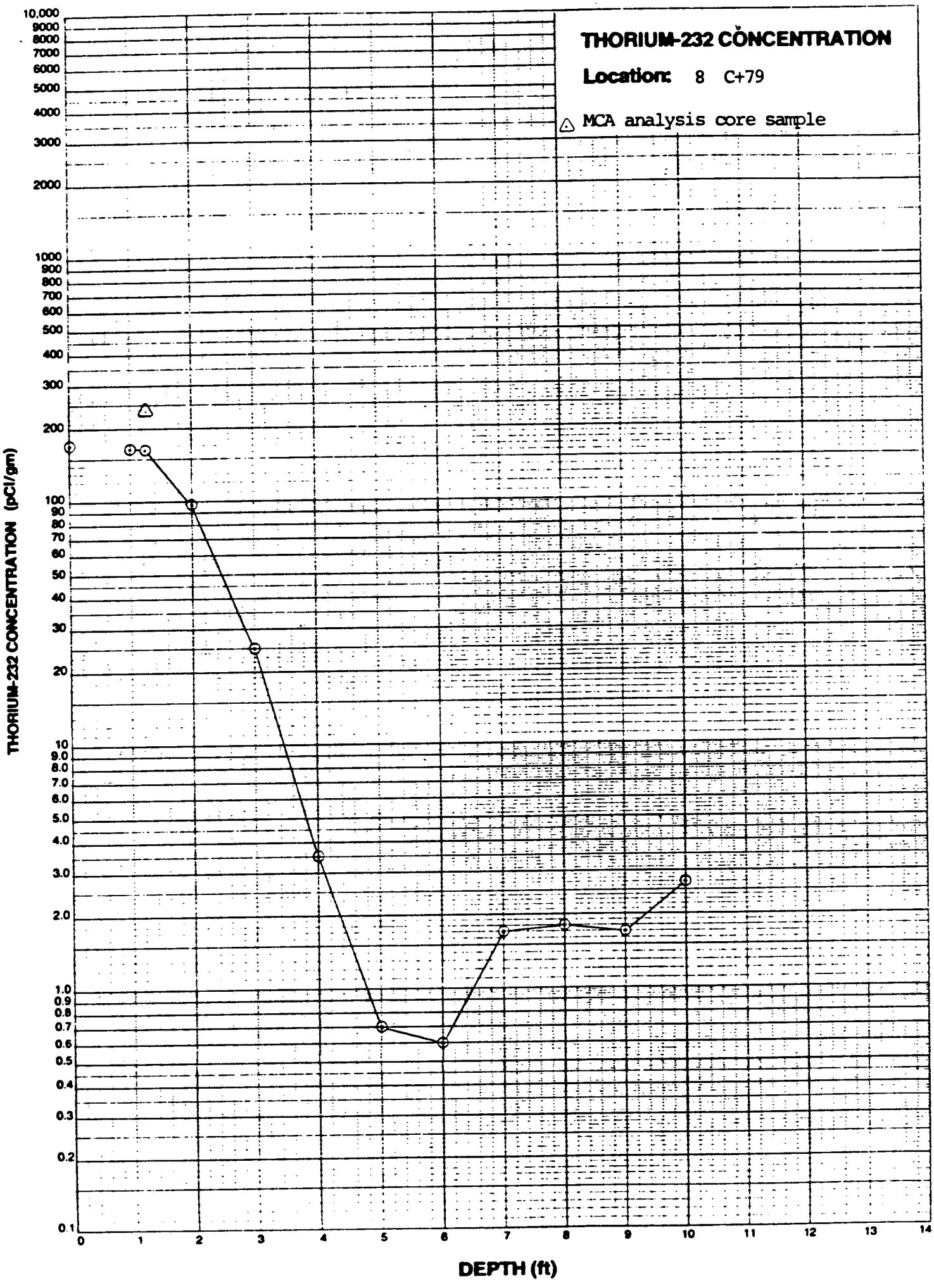
14


THORIUM-232 CONCENTRATION
Location: 8 C+79
MCA analysis core sample
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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1
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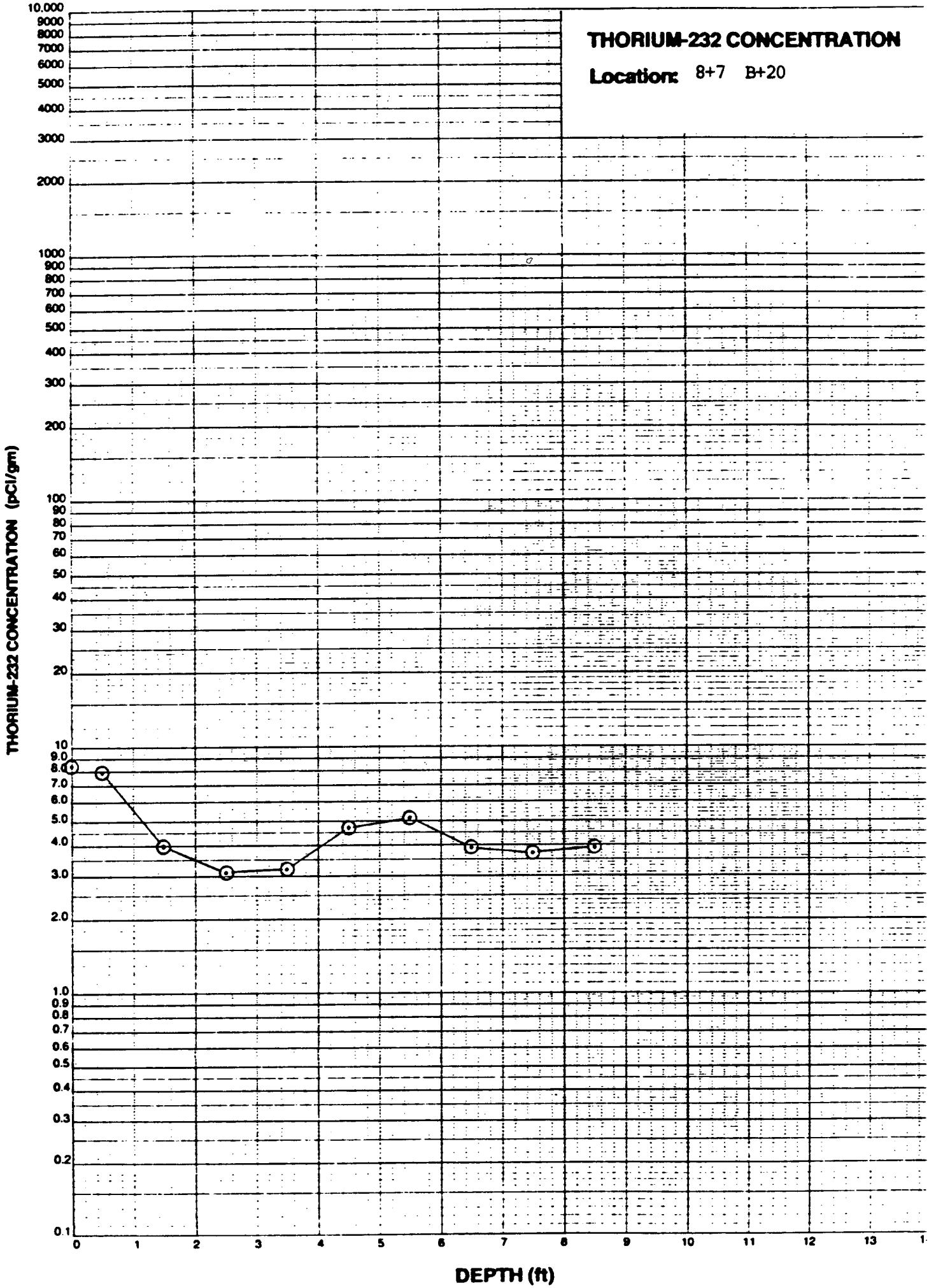
3
4
5
6
7
8
9
10
11
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+7 B+20
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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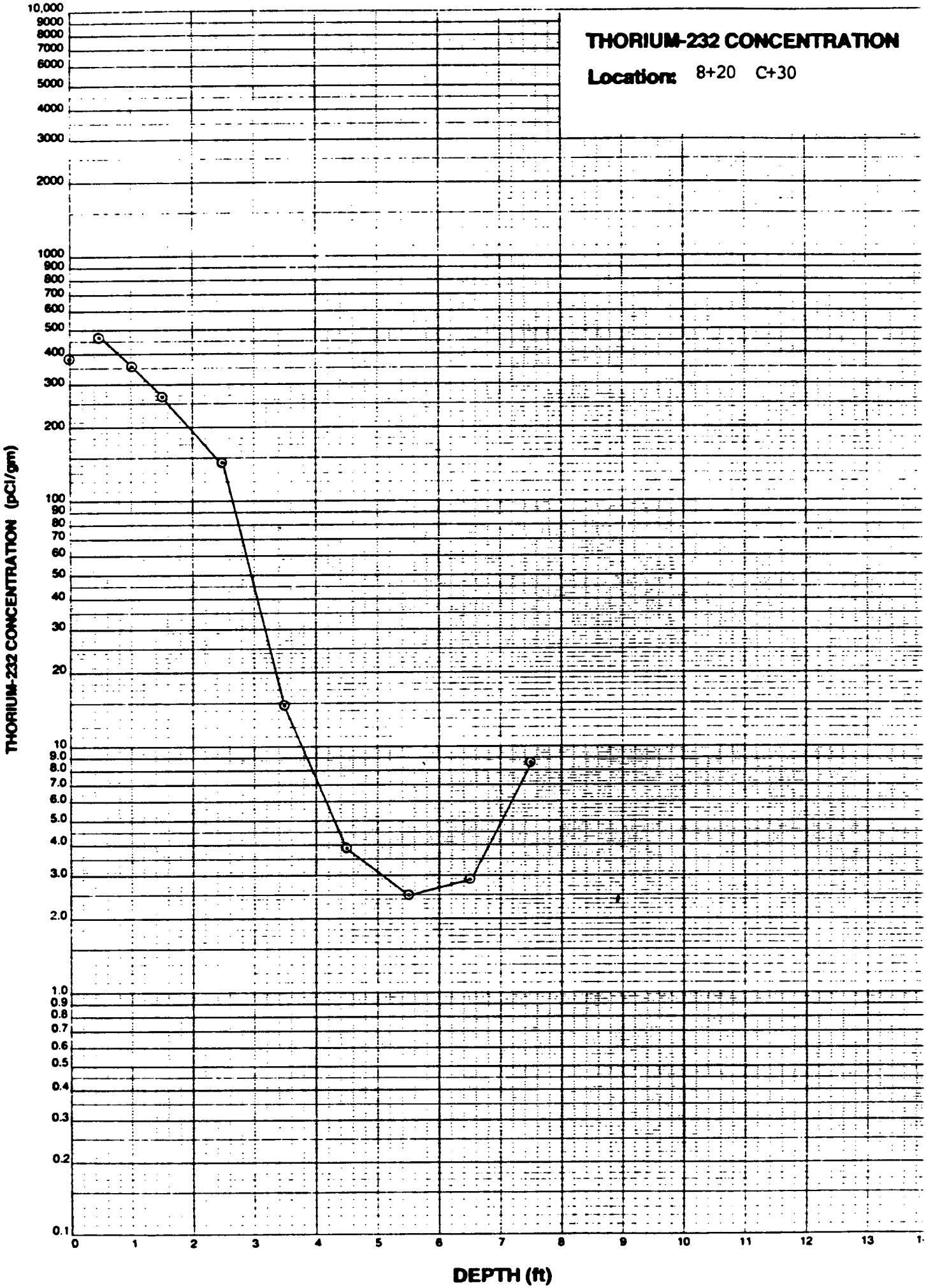
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+20 C+30
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
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0.7
0.6
0.5
0.4
0.3
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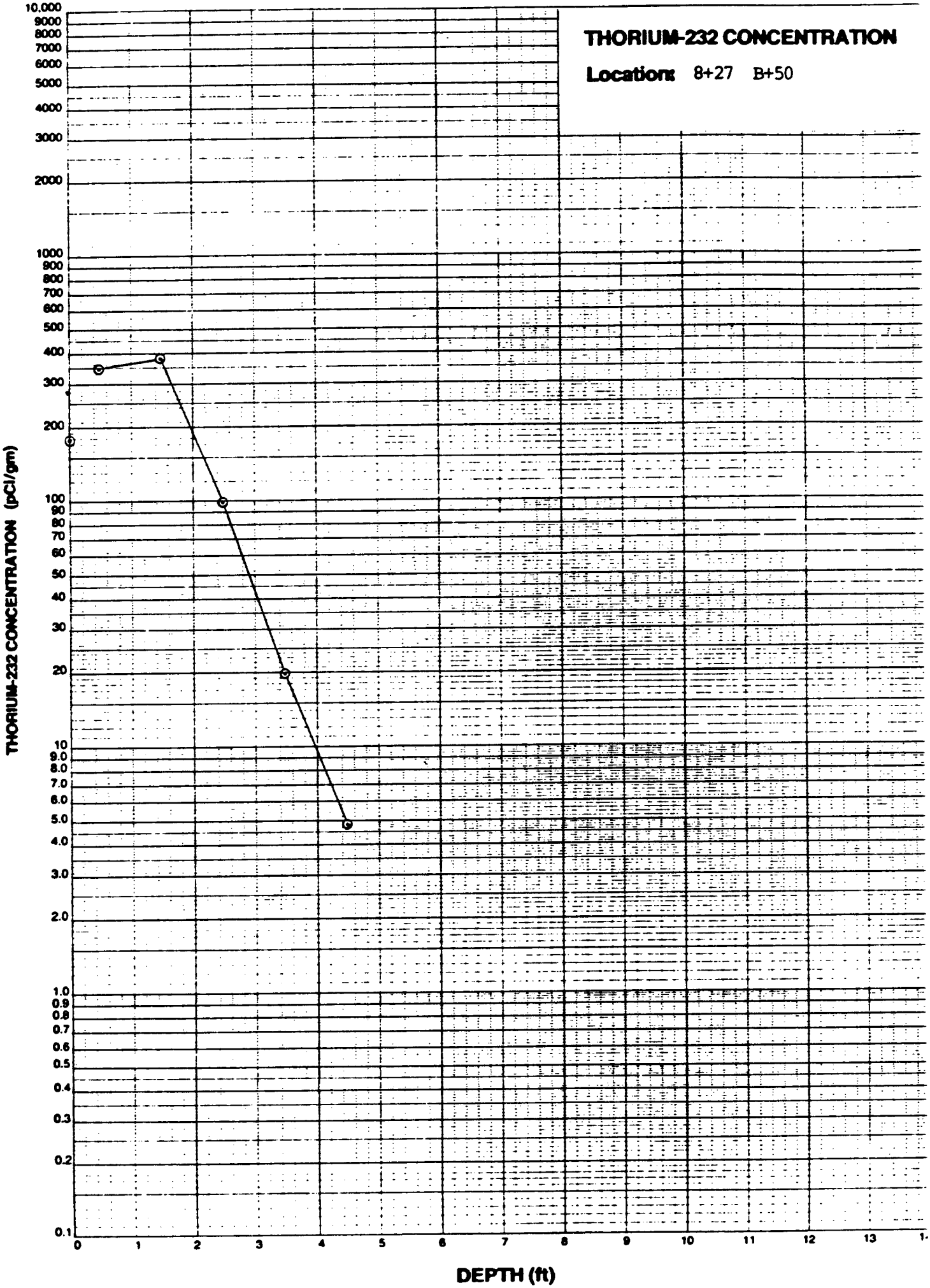
0
1
2
3
4
5
6
7
8
9
10
11
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+27 B+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
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40
30
20
10
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
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0.7
0.6
0.5
0.4
0.3
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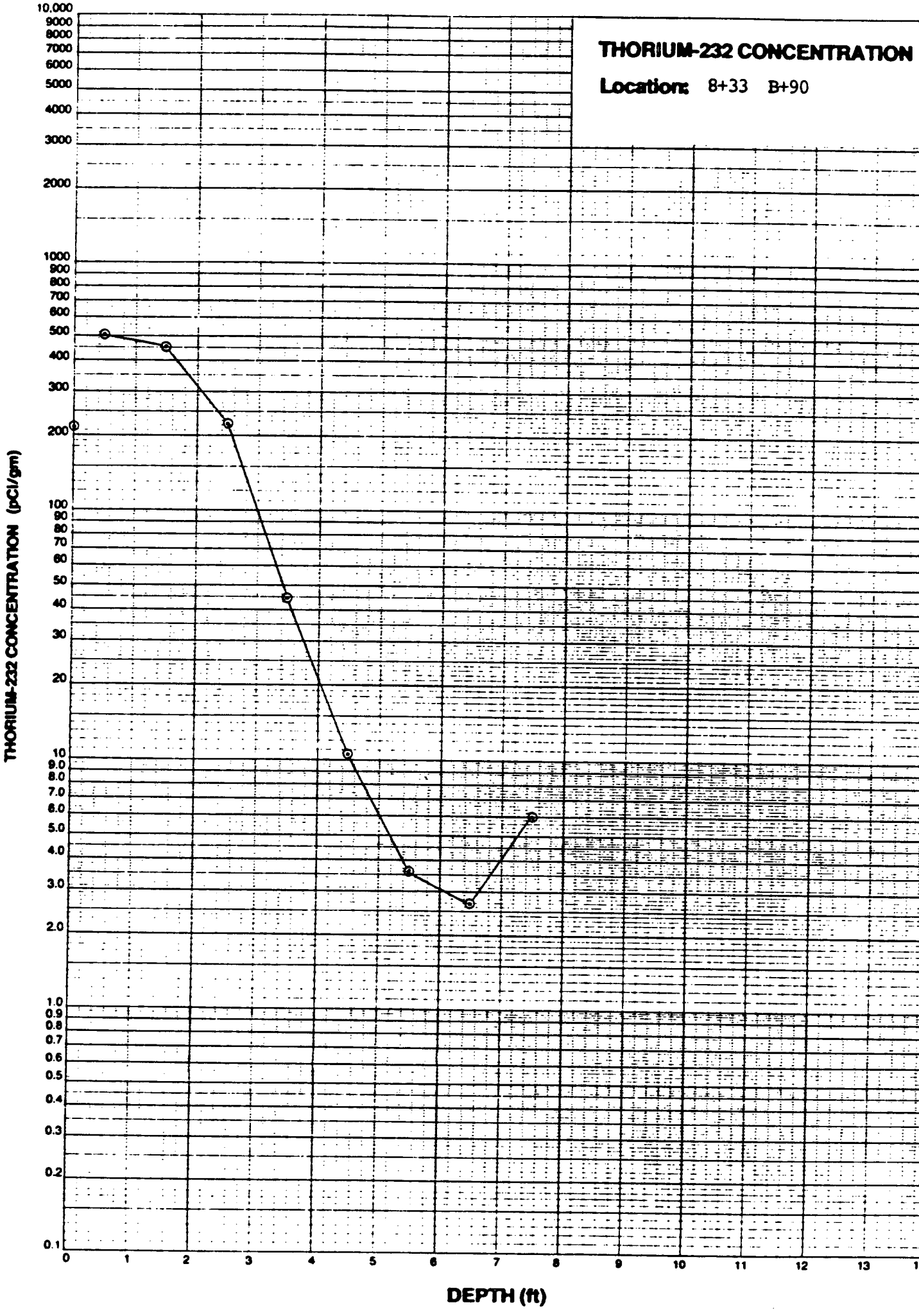
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+33 B+90
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
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0.3
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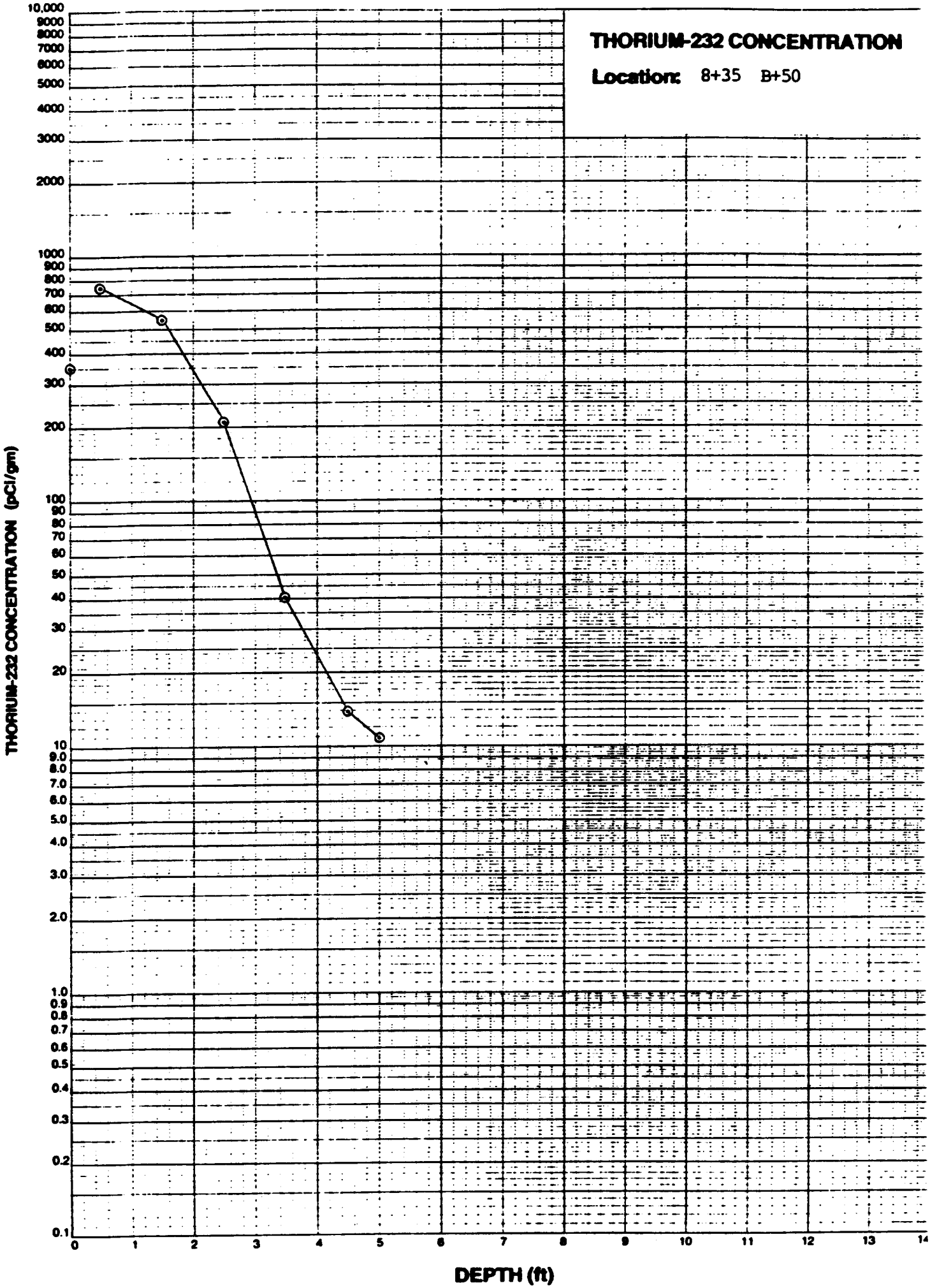
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+35 B+50
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
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6.0
5.0
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1.0
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0.7
0.6
0.5
0.4
0.3
0.2
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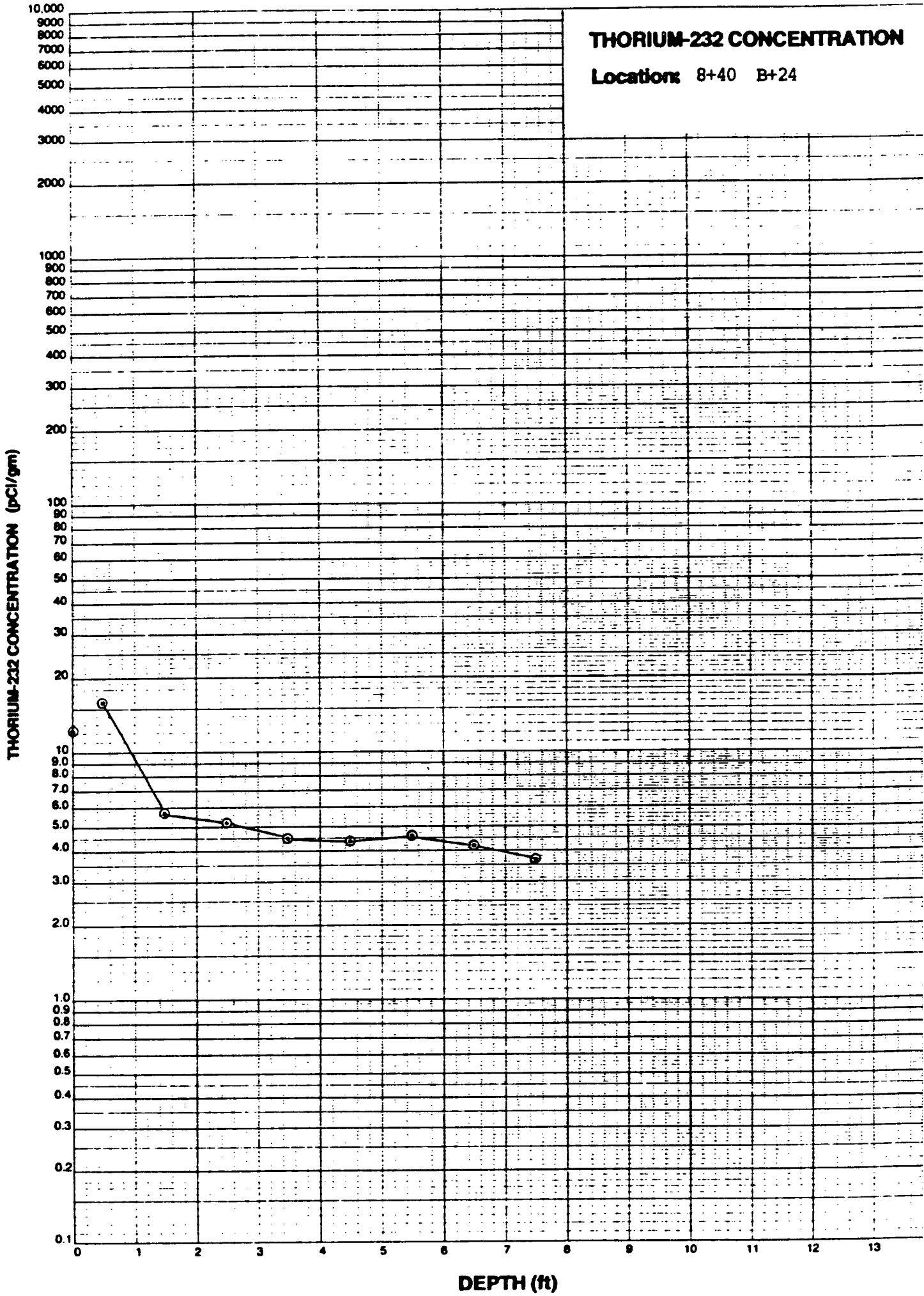
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+40 B+24
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
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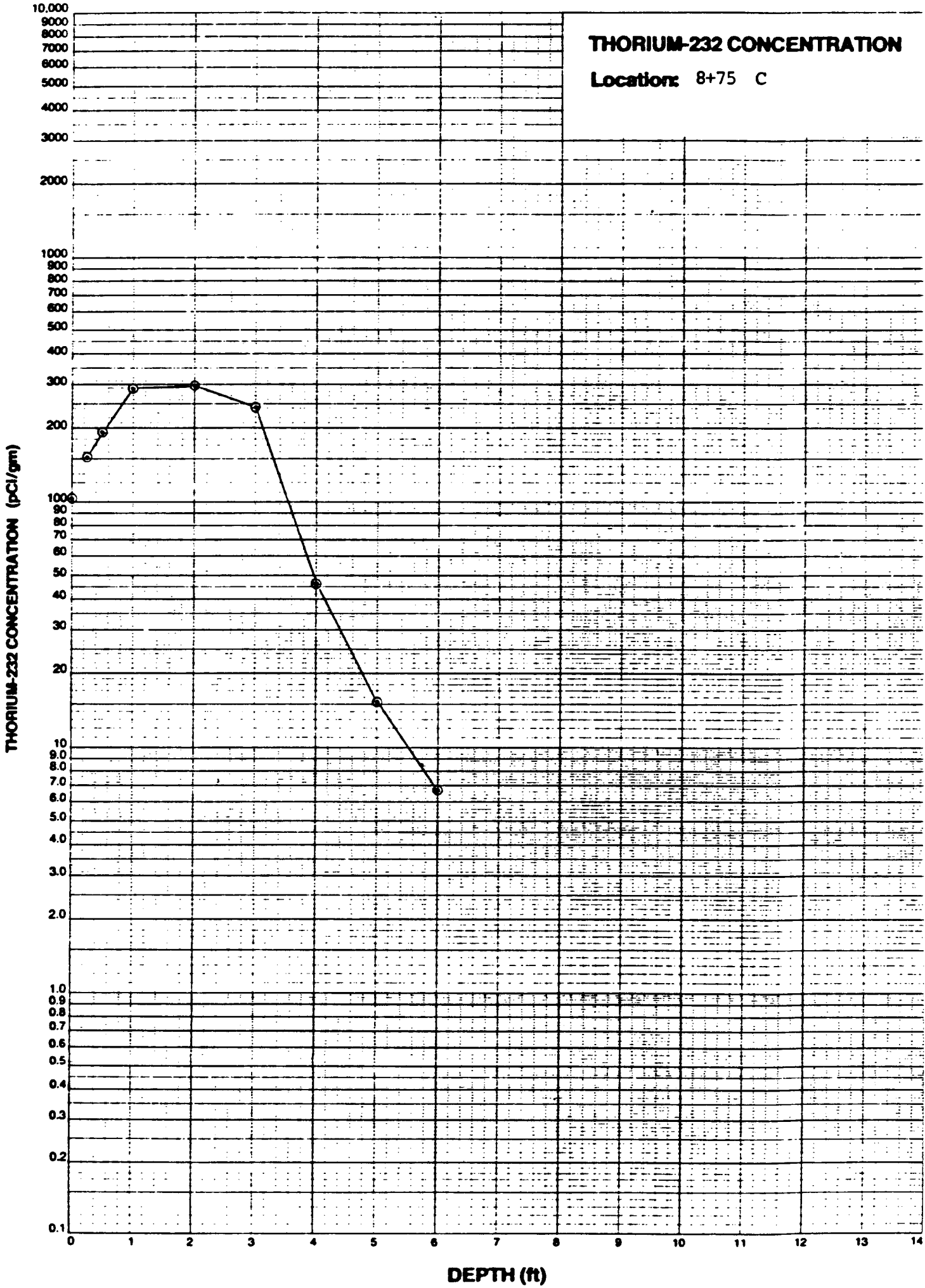
12
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+75 C
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
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400
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200
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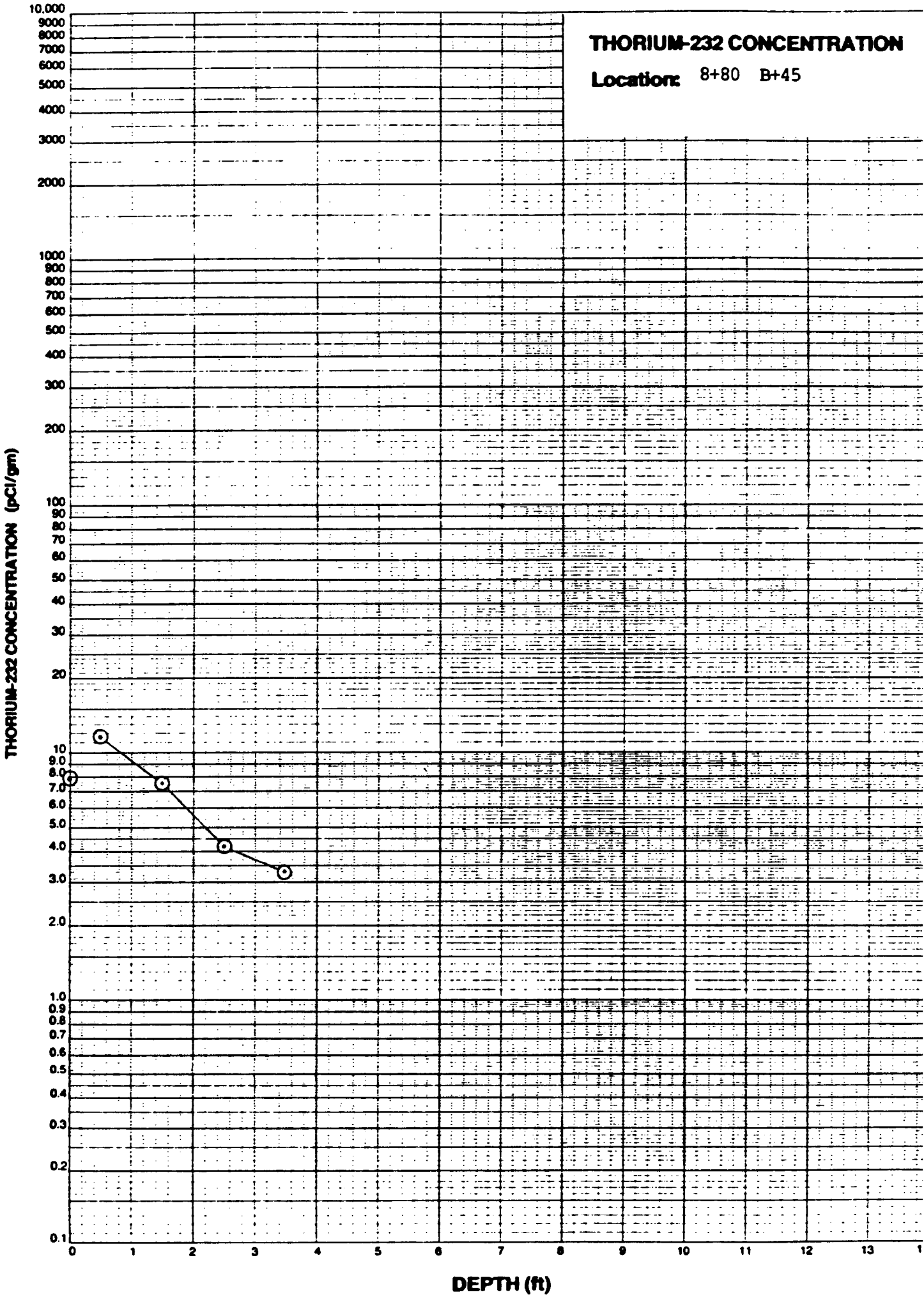
12
13
14
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+80 B+45
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9000
8000
7000
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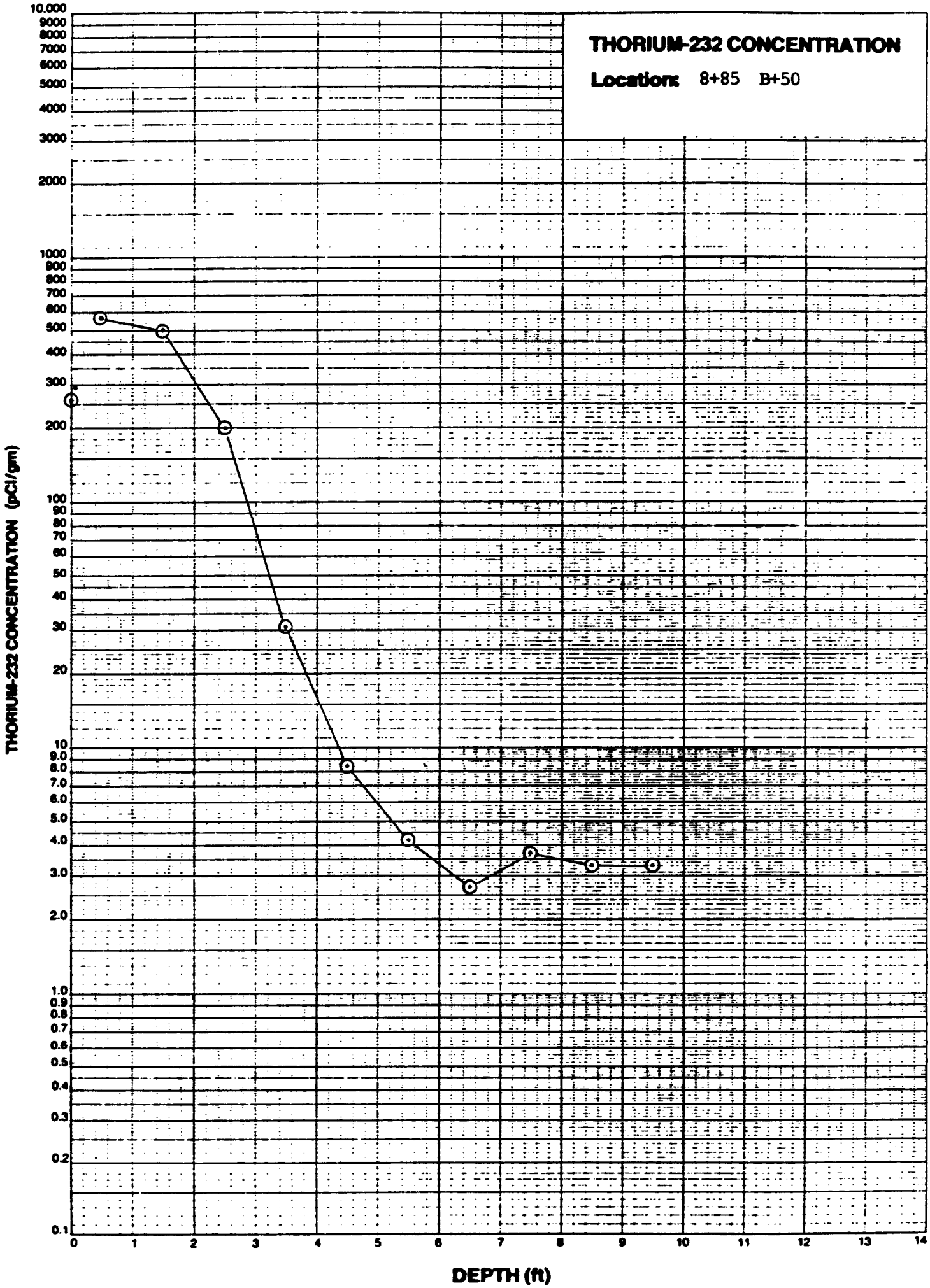
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: 8+85 B+50
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
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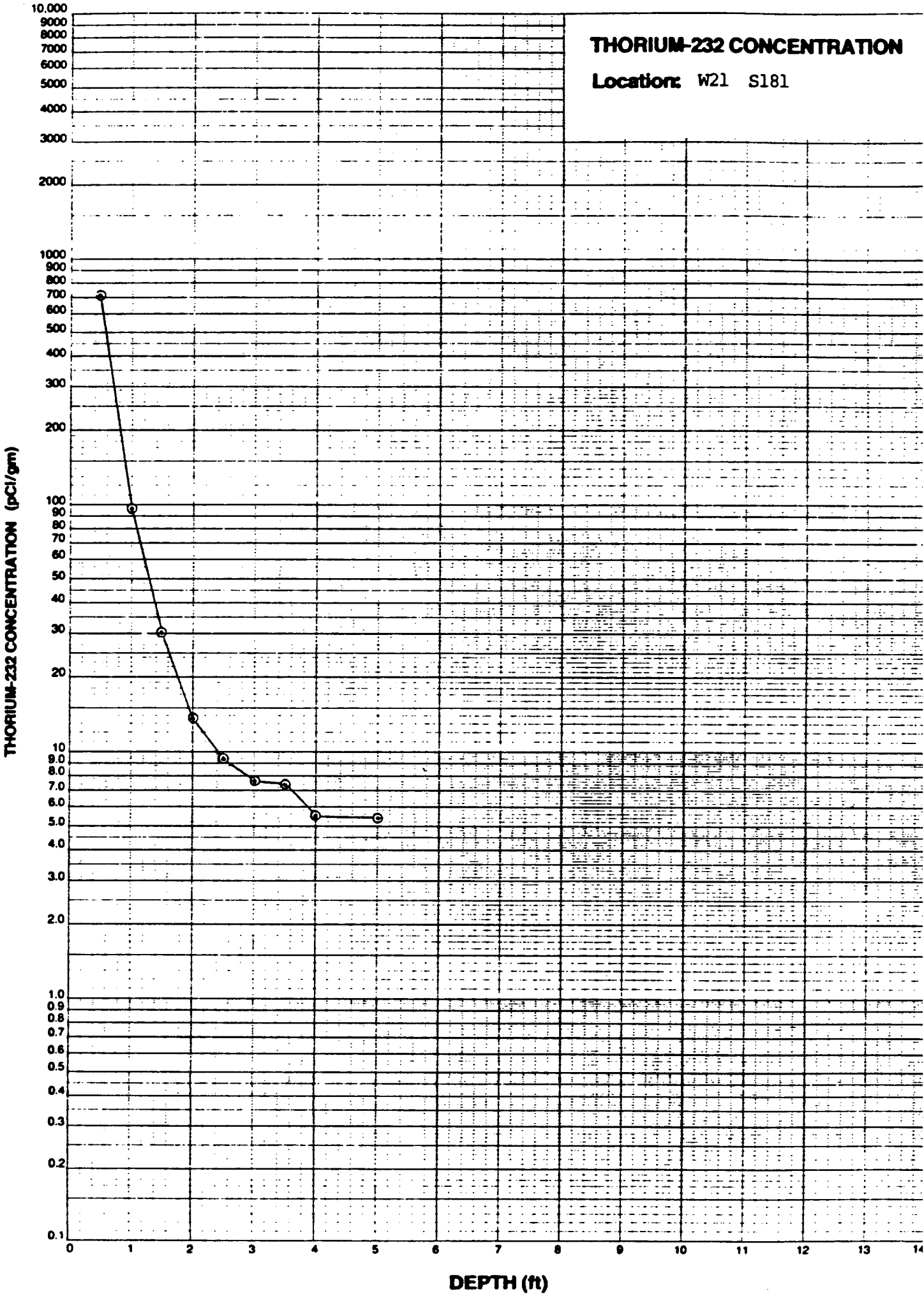
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Location: W21 S181
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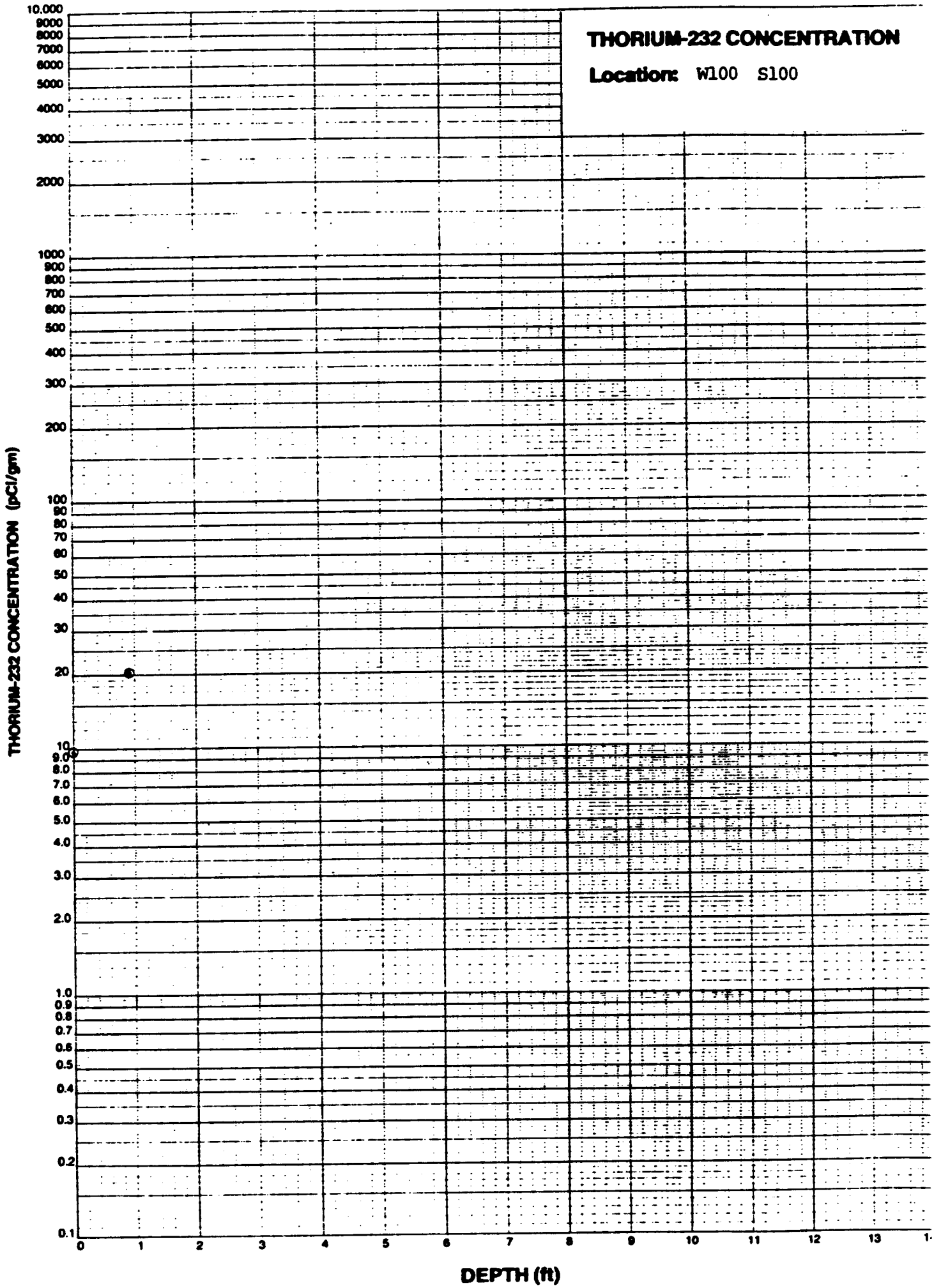
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W100 S100
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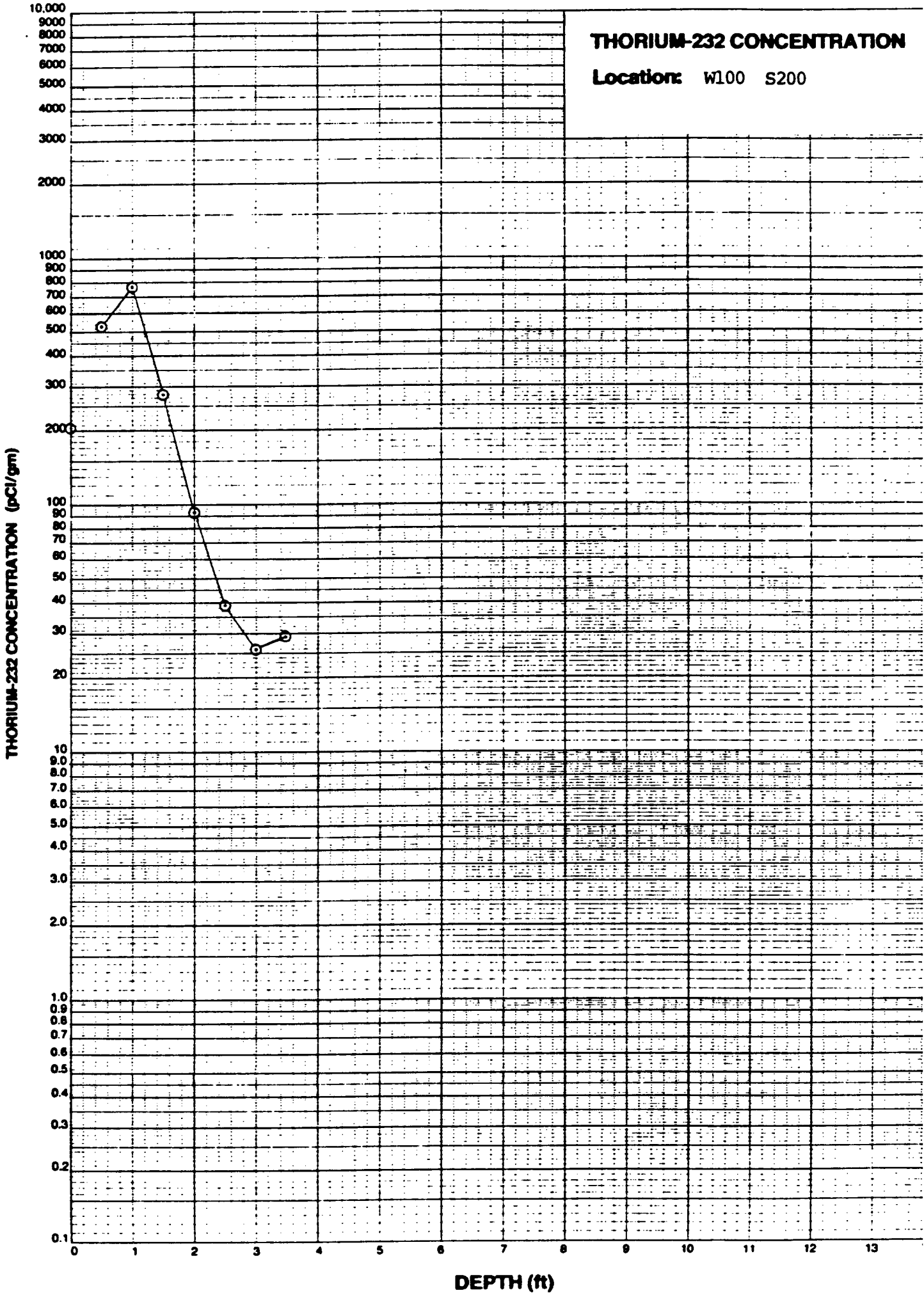
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W100 S200
THORIUM-232 CONCENTRATION (pCi/gm)
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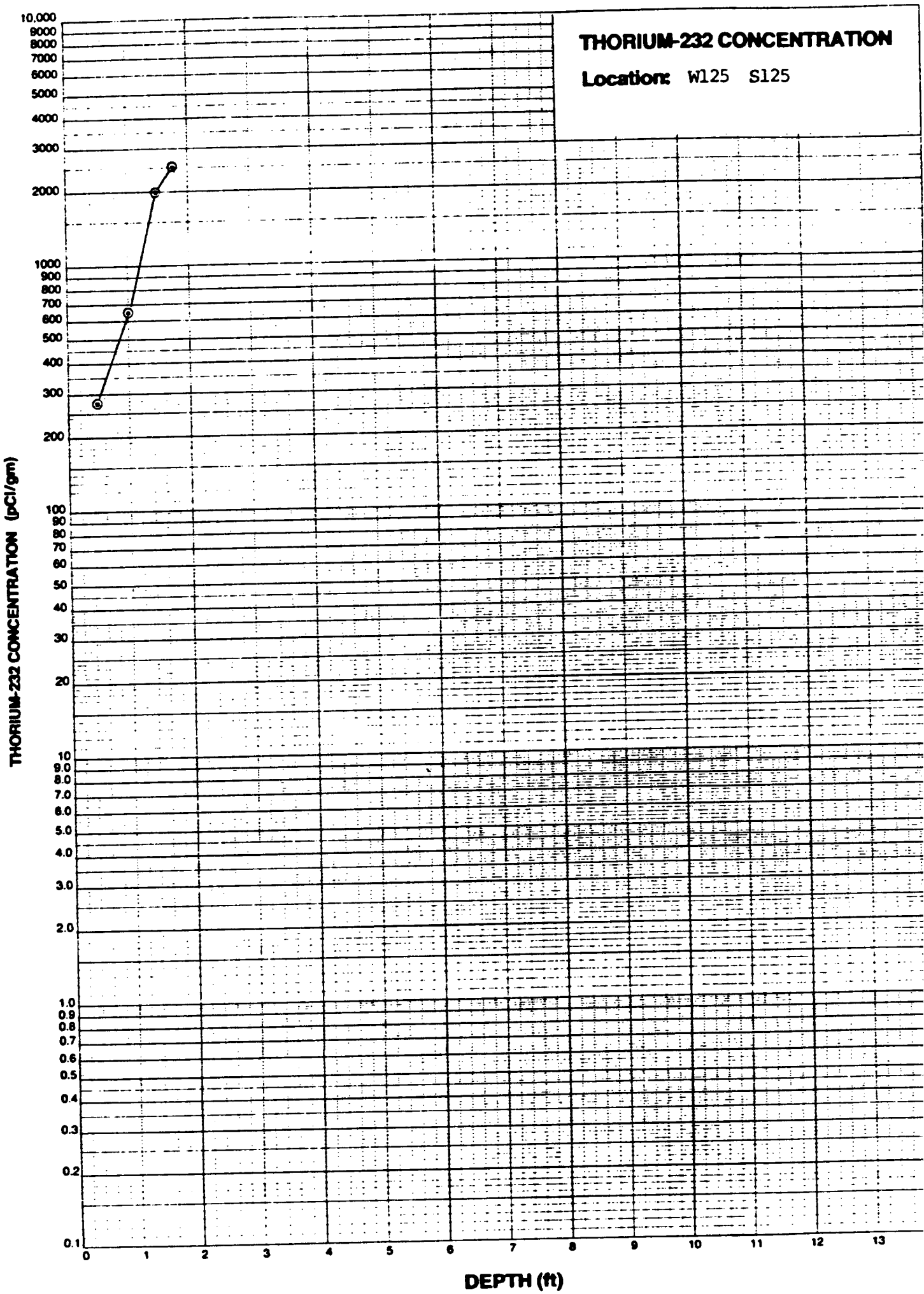
DEPTH (ft)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THORIUM-232 CONCENTRATION (pCi/gm)
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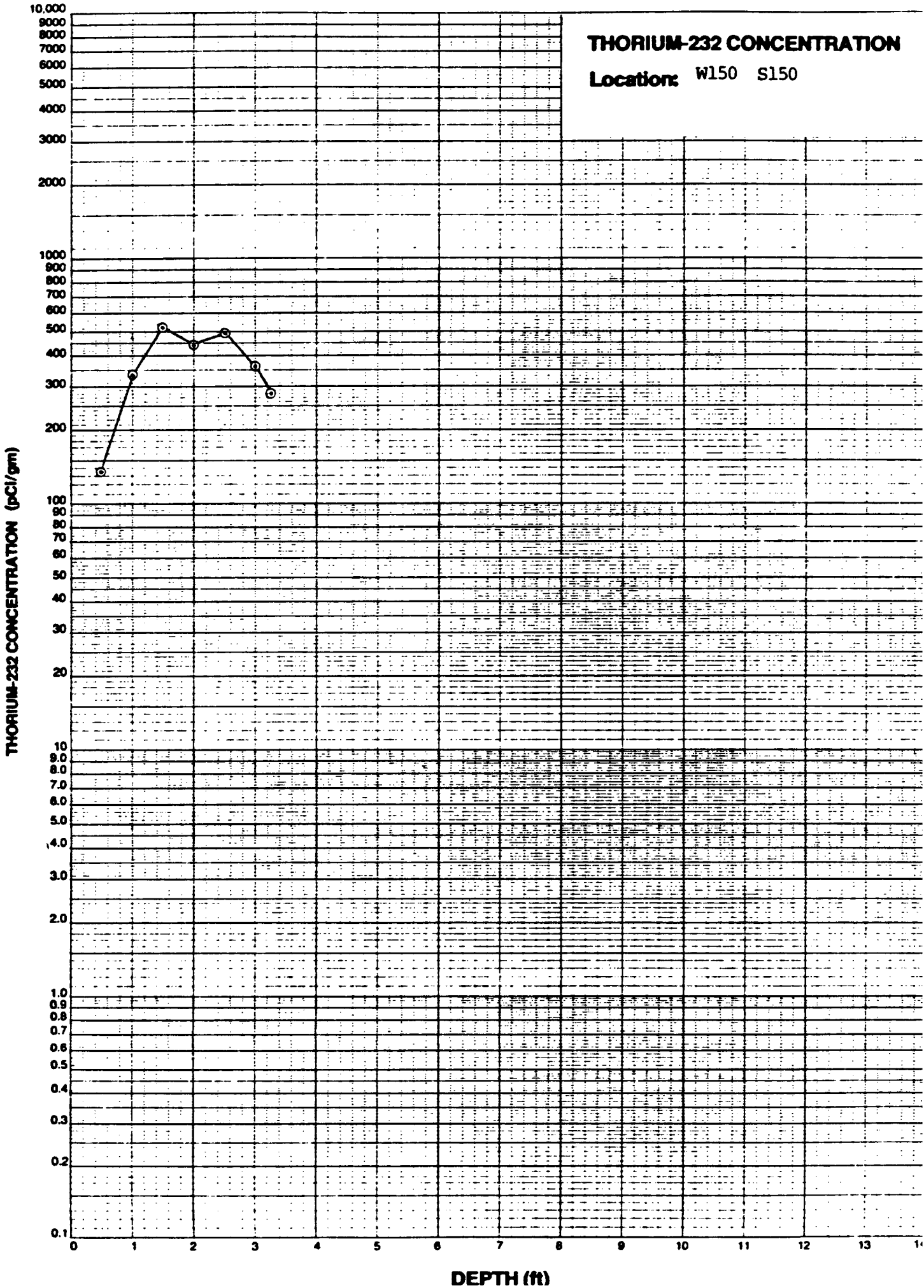
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W150 S150
THORIUM-232 CONCENTRATION (pCi/gm)
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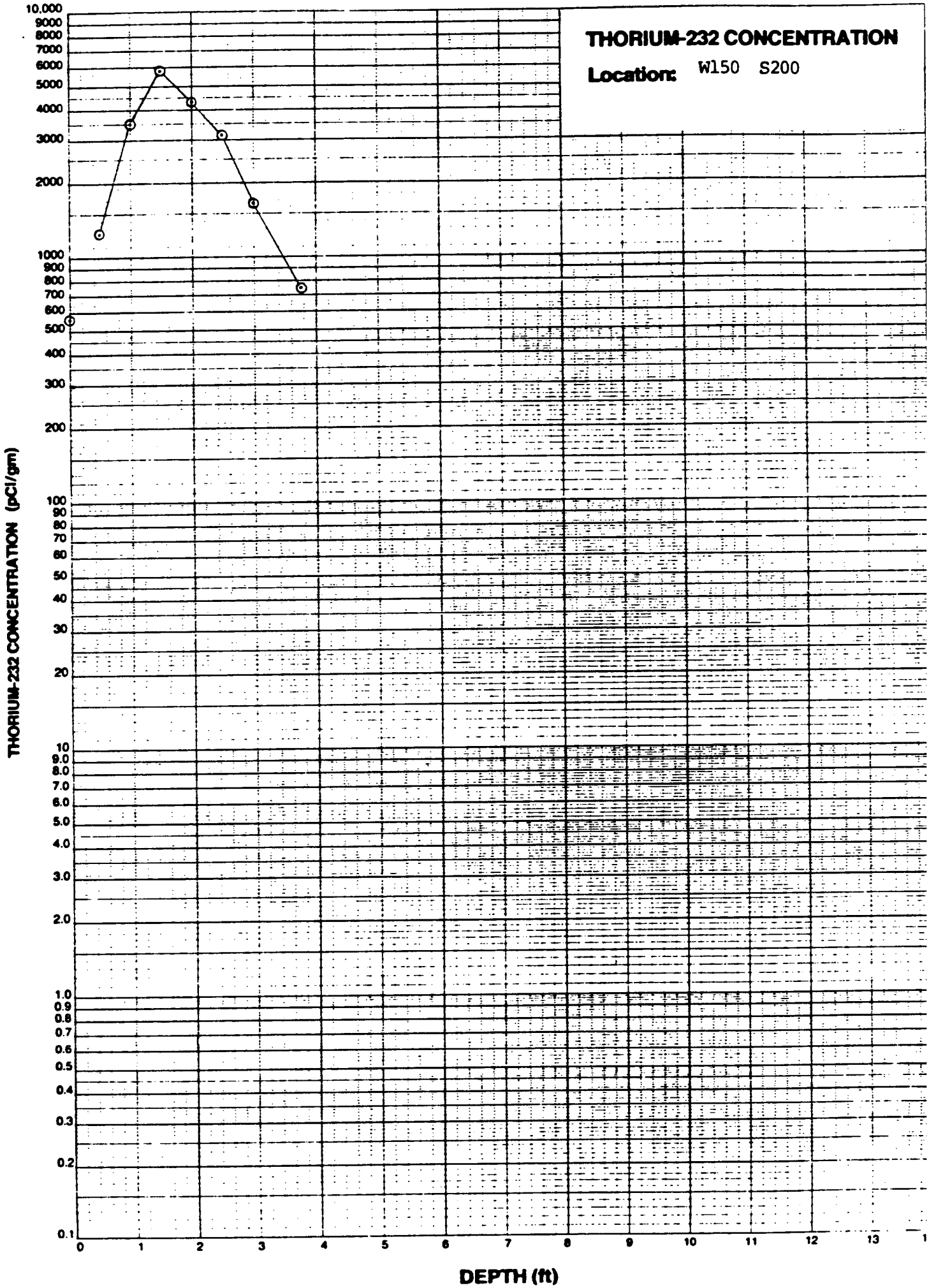
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W150 S200
THORIUM-232 CONCENTRATION (pCi/gm)
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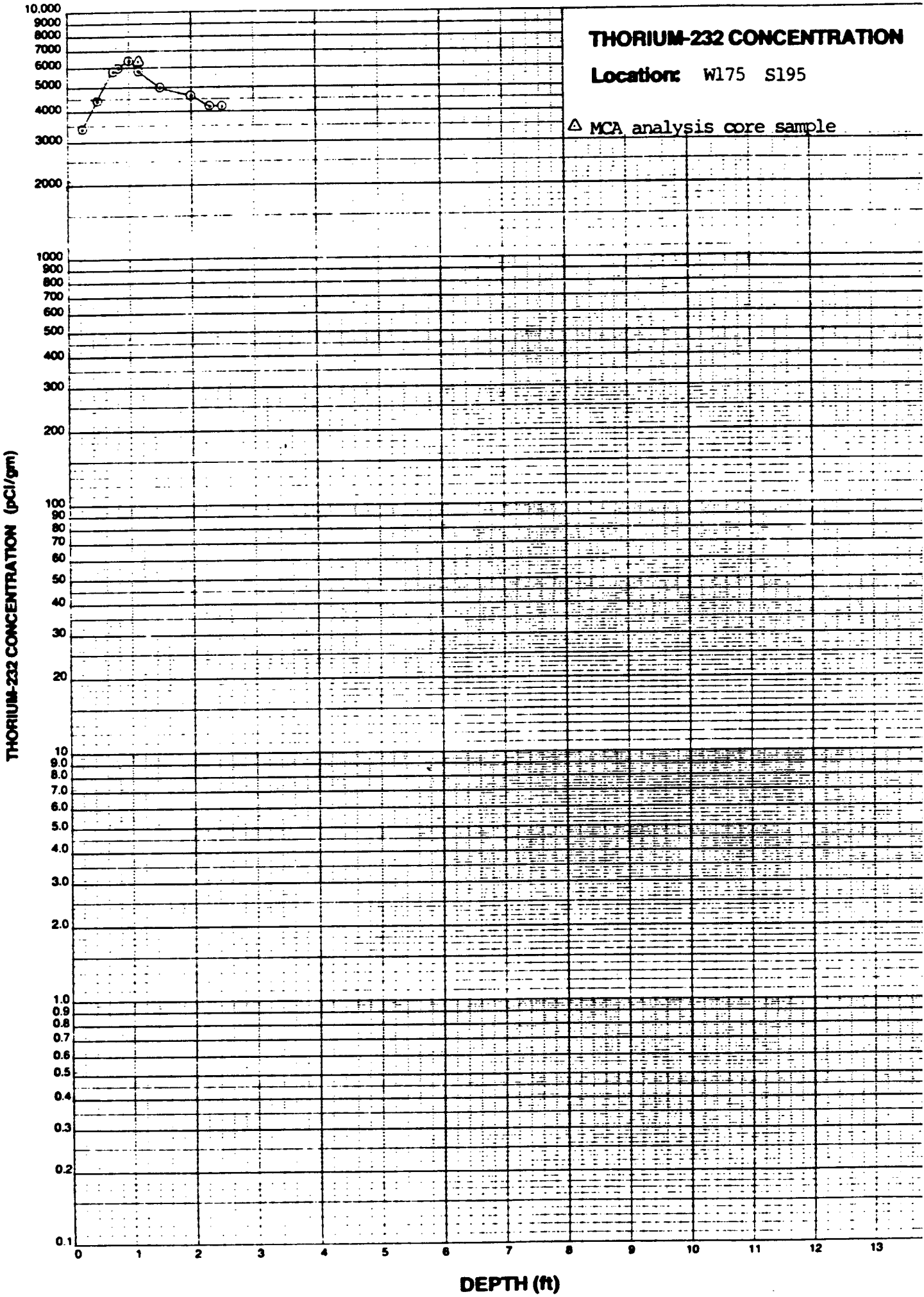
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W175 S195
△ MCA analysis core sample
THORIUM-232 CONCENTRATION (pCi/gm)
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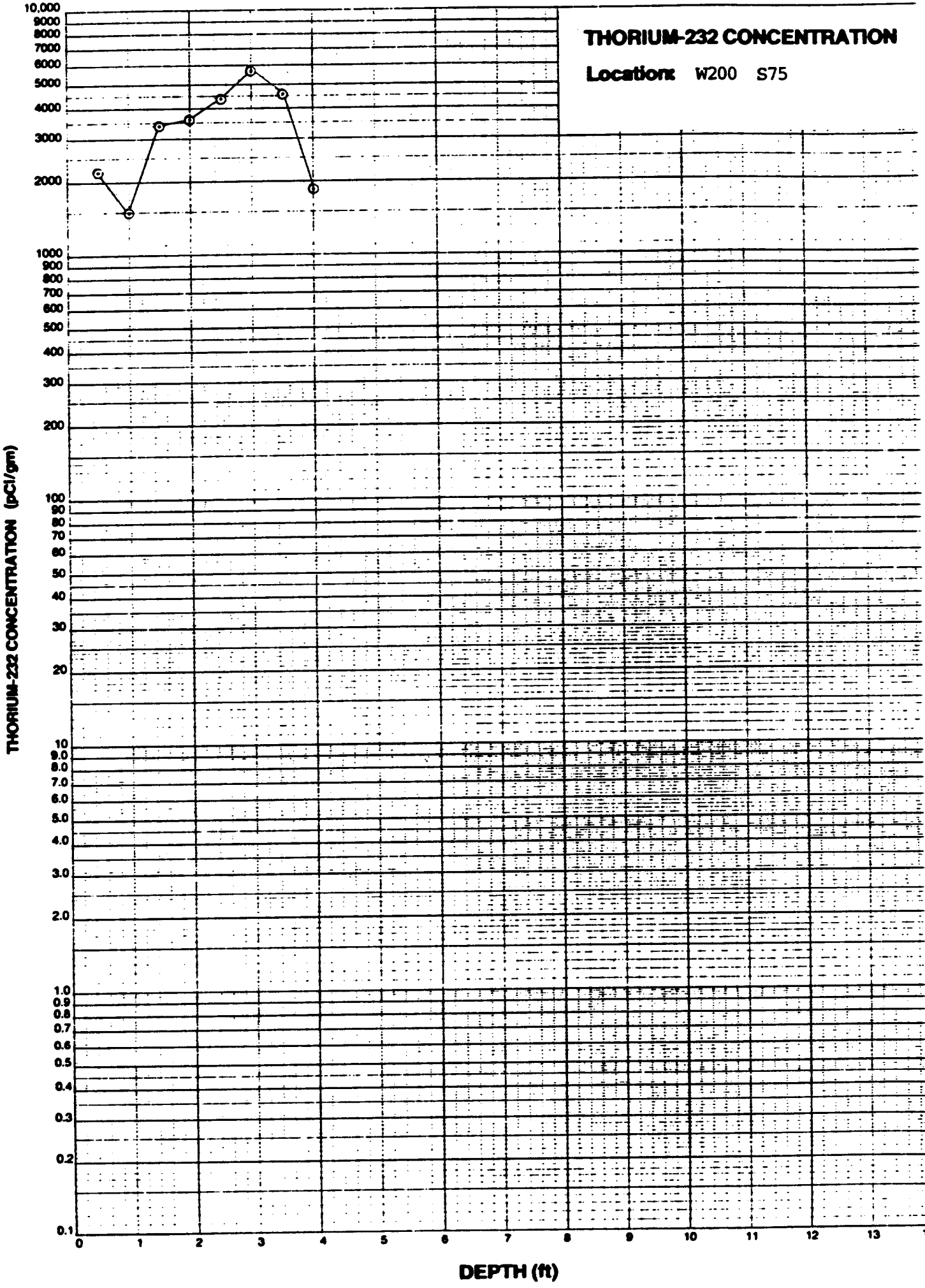
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W200 S75
THORIUM-232 CONCENTRATION (pCi/gm)
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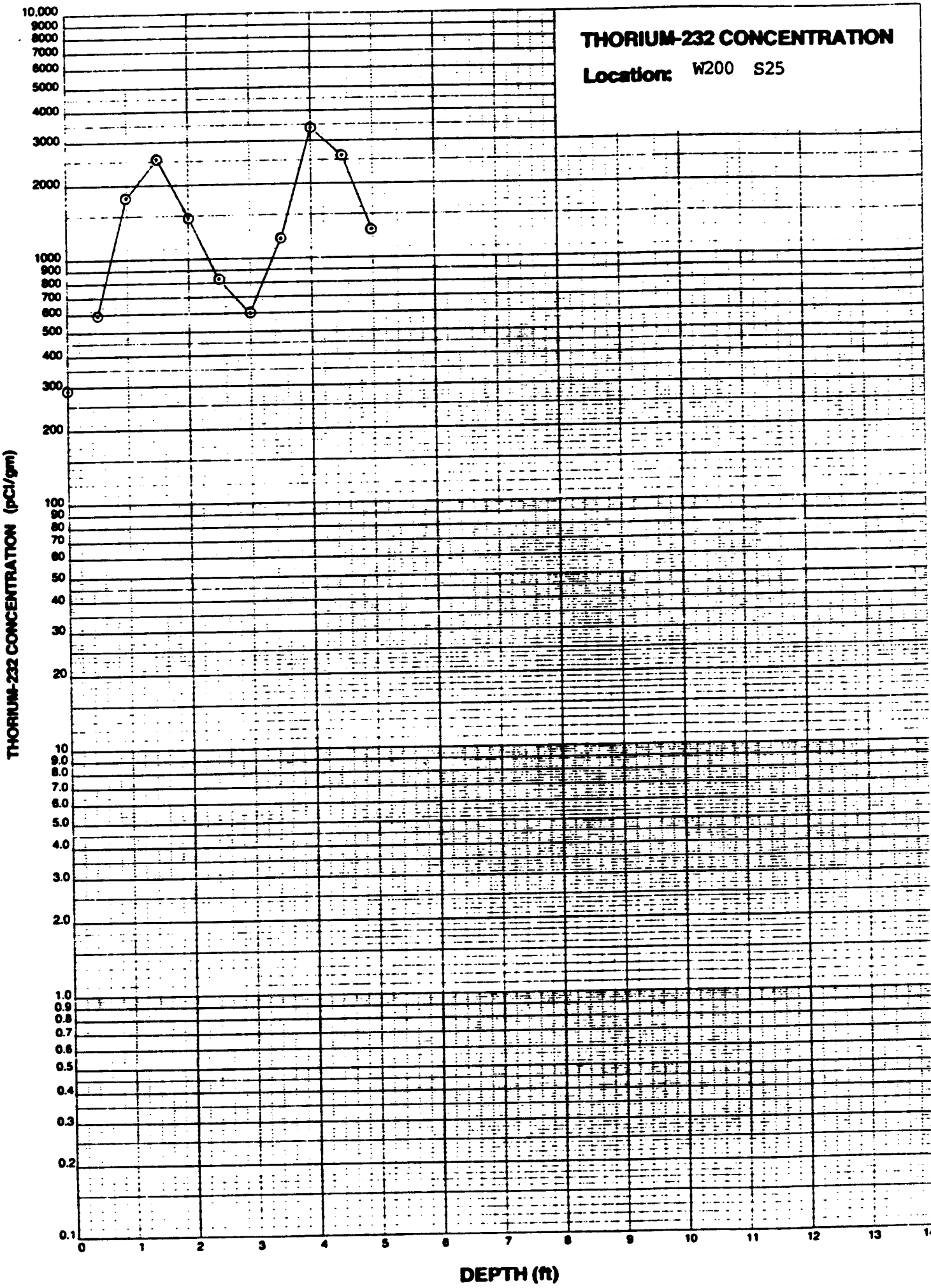
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W200 S25
THORIUM-232 CONCENTRATION (pCi/gm)
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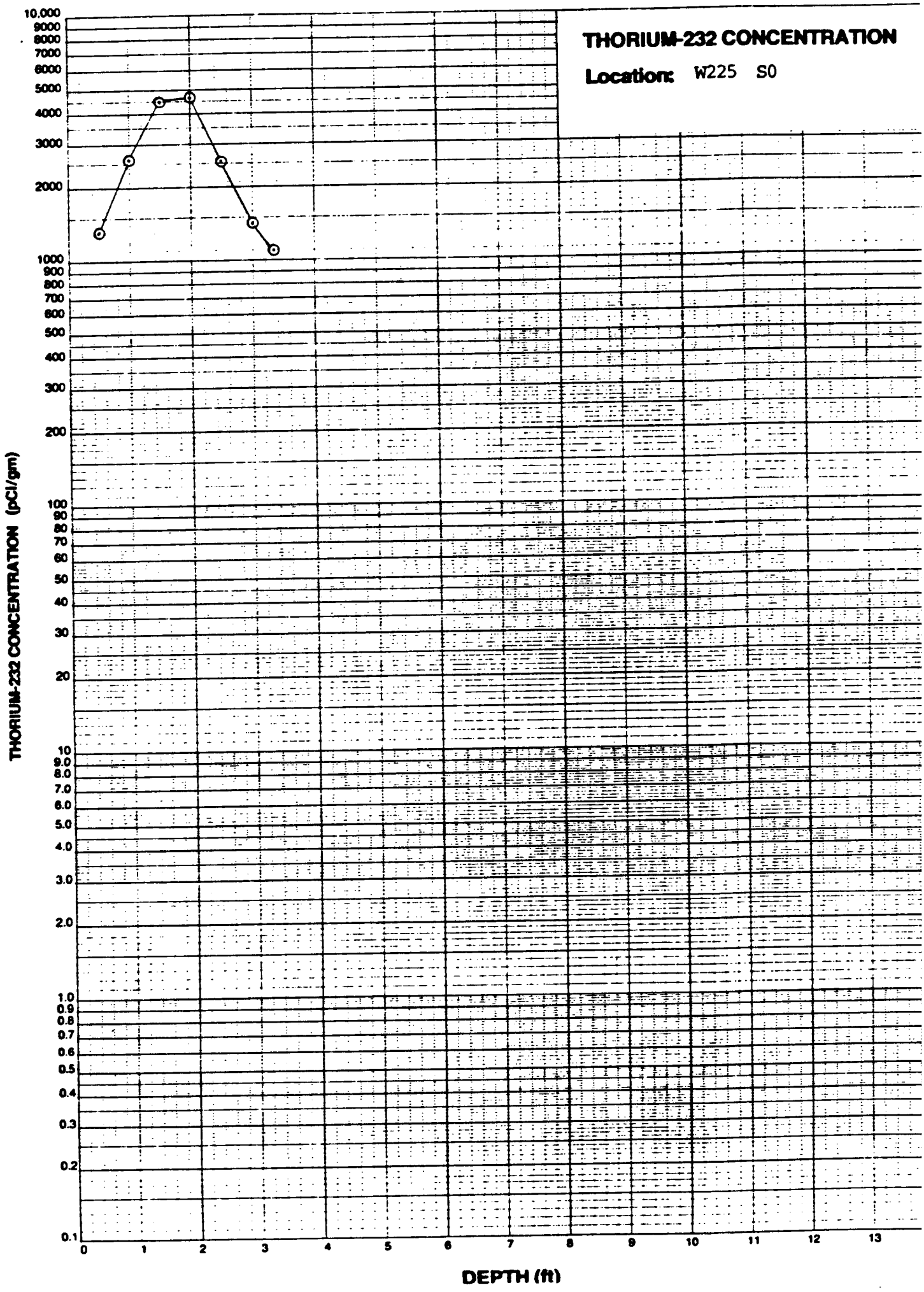
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W225 S0
THORIUM-232 CONCENTRATION (pCi/gm)
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9000
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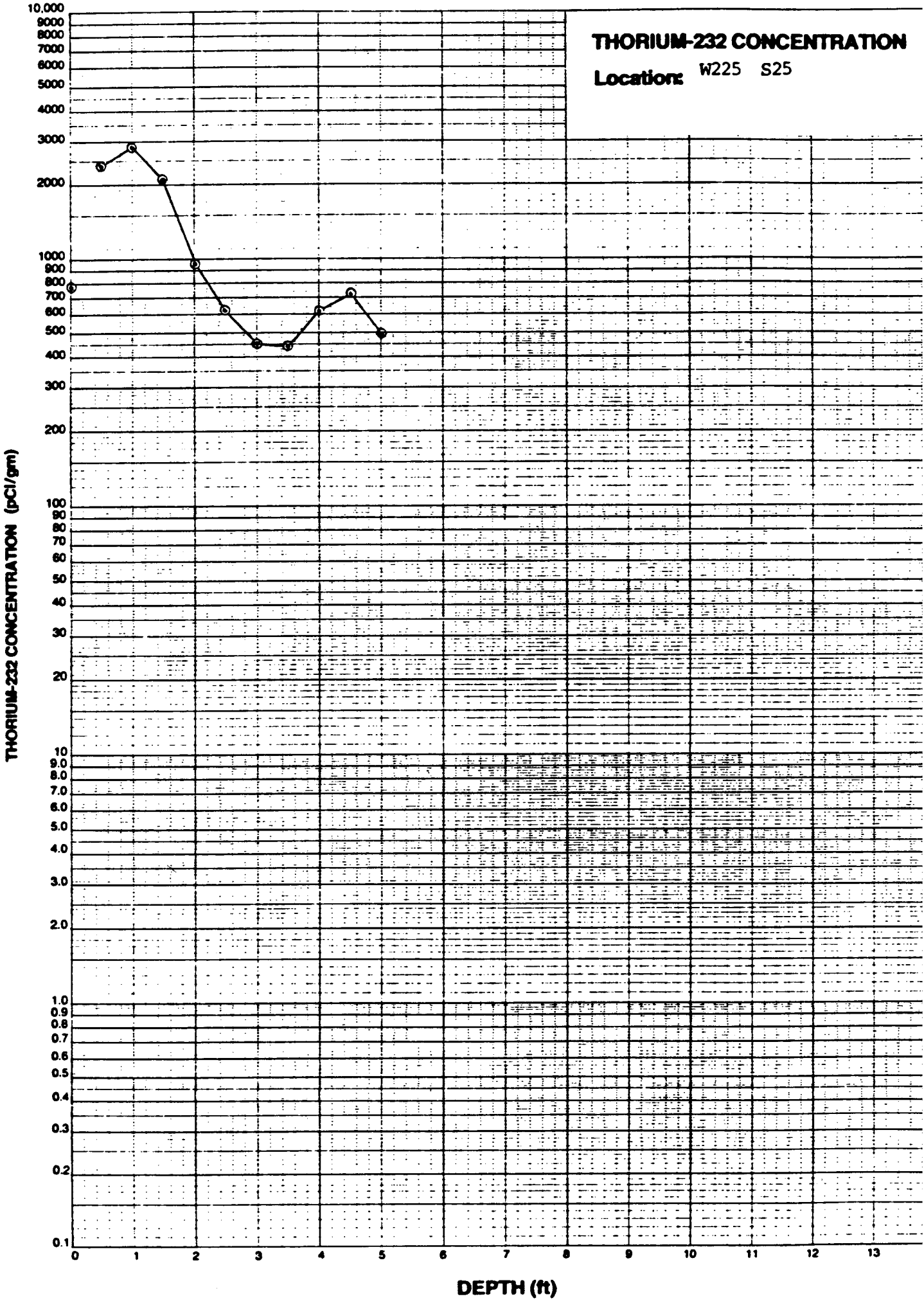
13
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W225 S25
THORIUM-232 CONCENTRATION (pCi/gm)
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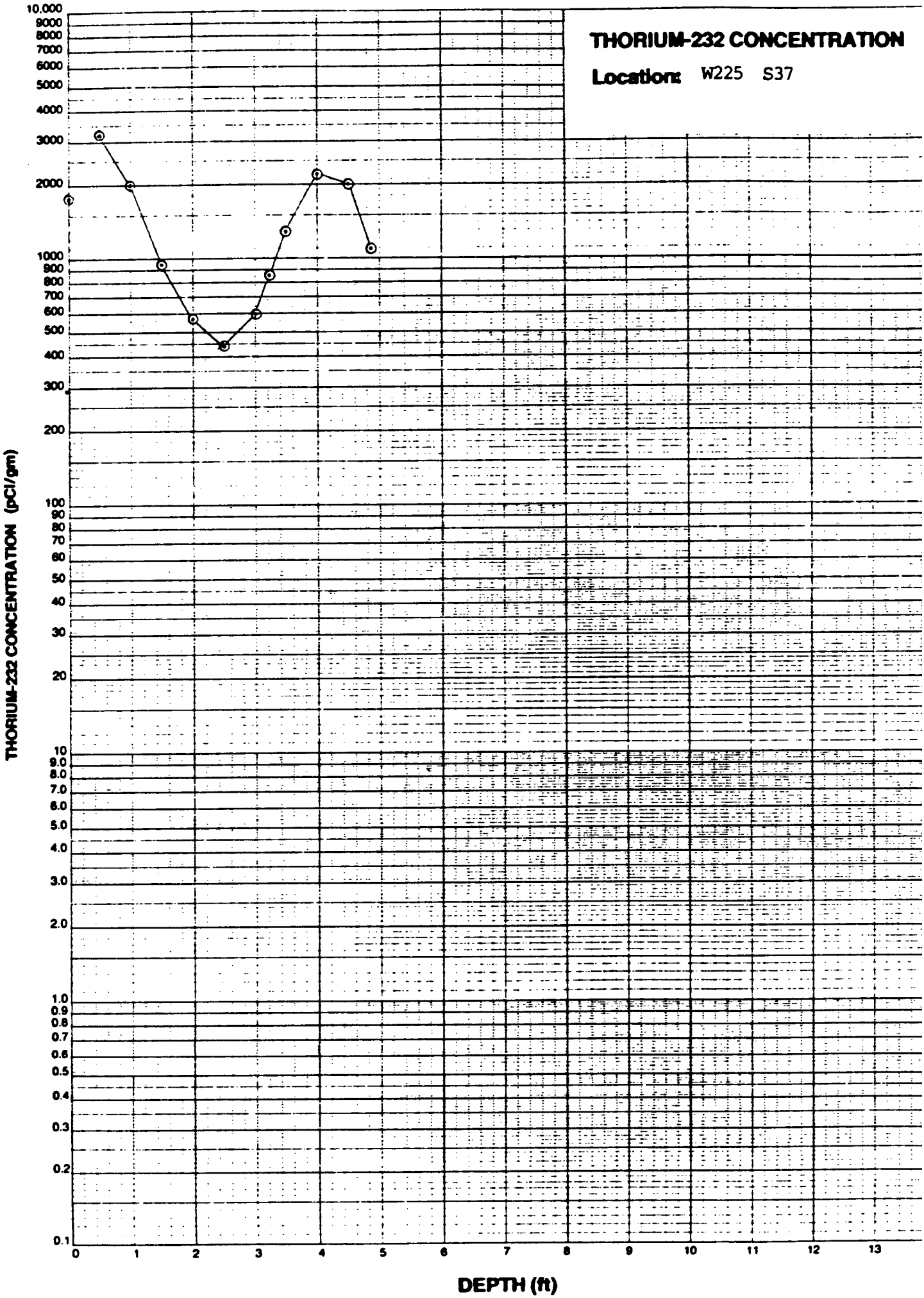
DEPTH (ft)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Location: W225 S37
THORIUM-232 CONCENTRATION (pCi/gm)
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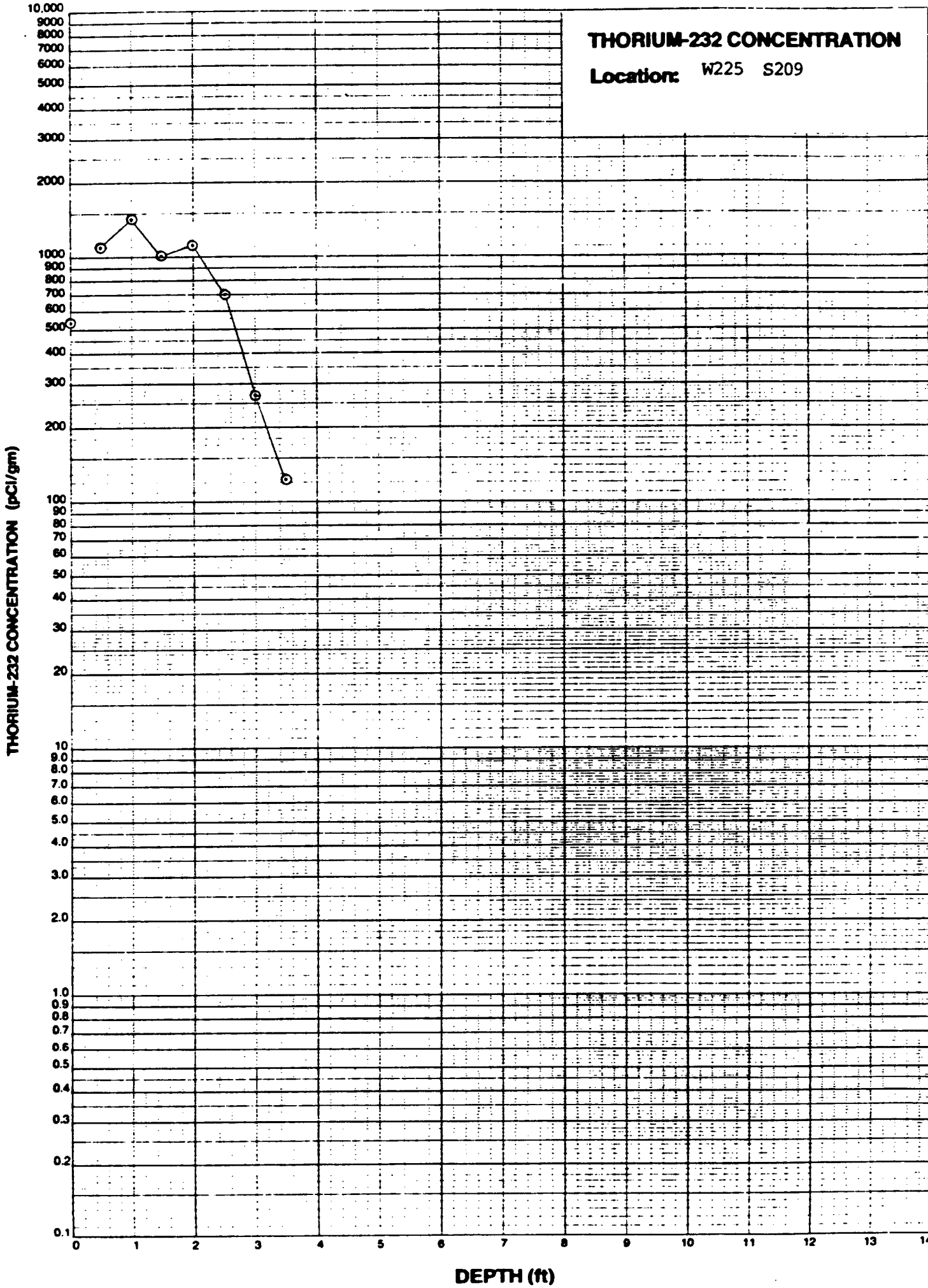
DEPTH (ft)


THORIUM-232 CONCENTRATION
Location: W225 S209
THORIUM-232 CONCENTRATION (pCi/gm)
DEPTH (ft)
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9000
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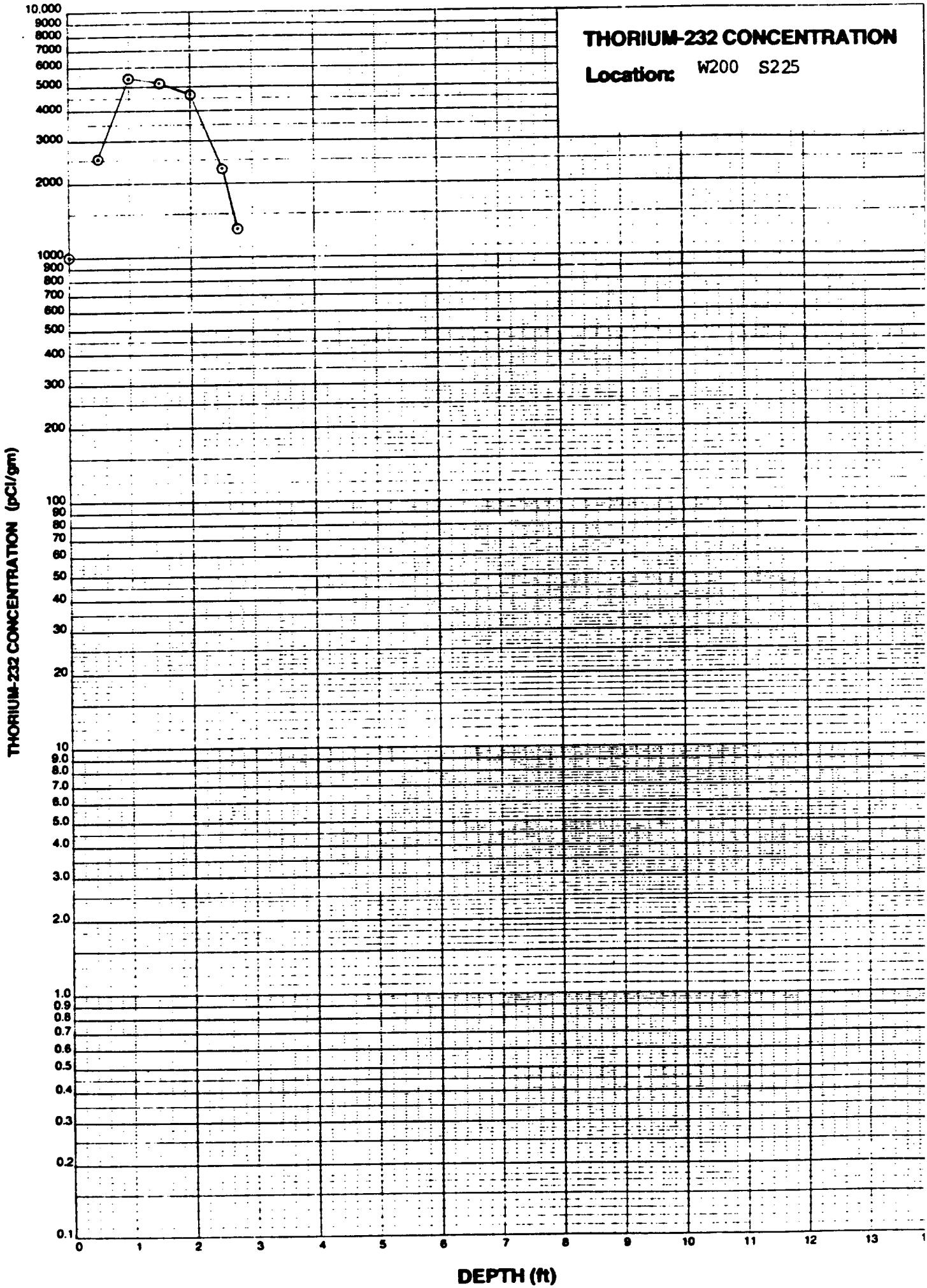
THORIUM-232 CONCENTRATION
Location: W200 S225
THORIUM-232 CONCENTRATION (pCi/gm)
10,000
9000
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DEPTH (ft)

Regional Geology

The proposed burial site is centrally located within the Piedmont Plateau of north central New Jersey. The geology of the Piedmont Plateau in this area of New Jersey is characterized by thick sedimentary rocks deposited during the Late Triassic Epoch and concorcurrently intruded by a brabase sill, dikes, and covered by several flows of basalt. Collectively, this group of sedimentary and associated igneous rocks of Triassic Age are known as the Newark Group. They outcrop in a band 16 to 30 miles wide trending northeast-southwest from the Delaware River to the Hudson River. The Newark Group is thought to consist of some 15,000 to 20,000 feet of non-marine shales, mudstone, sandstone, and conglomerates which unconformally overlie rocks of Paleozoic and Precambrian age.

The rocks of the Newark group which directly underlie and form the bedrock throughout this area of New Jersey are the Brunswick Formation, the Watchung Basalt, and the Palisades diabase. The Brunswick Formation forms the bedrock for the majority of the area and consists of thin-bedded shales, mudstones, and sandstones which range in color from redish-brown to gray. The Brunswick Formation exhibits a regional strike N 50° E with dips of 9° to 13° NW and has a thickness of 6,000 to 8,000 feet. The Watchung Basalt consists of three extensive basaltic lava sheets that are intercalated with the sedimentary rocks of the Brunswick Formation. Due to their greater resistance to erosion than that of the sedimentary rocks of the Brunswick Formation, they form prominent ridges running northeast-southwest through the area. Two of these ridges are known as the first and second Watchung Mountains and are located some 5 to 7 miles, respectively, to the west of the burial site. Similiarly, the Palisades diabase is a sill intruded between sedimentary deposits of the Brunswick and older formations of the Newark group. The Palisades diabase is located approximately 6 miles to the southeast of the proposed burial site and forms the ridge known as the Palisades of the Hudson.

Bedrock in the area is overlain by unconsolidated sand, gravel, silt, and clay deposited largely during the last glaciation of the Pleistocene Epoch. These deposits can be broadly subdivided into till and stratifred drift. Till, an unsorted mixture of sand, gravel, silt, and clay deposited directly by the glacier, can be found in many locations throughout the area. Similarly, layers of stratified drift, material transported and deposited by water in flood, plains , deltas, or lakes as it flowed away from the glacier during and after the retreat of the ice, can be found in many locations throughout the area. Stratified drift found in the area consists of sand, gravel, silt and clay and is poorly to well sorted. The depth of the glacial deposits are variable and are generally thickest in present day valleys while they are absent on hill crests. The actual thickness of the glacial deposits is controlled largely by the underlying bedrock topography. Before the last glaciation, rivers in the area cut several deep valleys into the Brunswick formation which were then filled and buried by glacial material. These buried valleys form the thickest deposits of glacial material. The most stricking of these valleys roughly underlies the Hackensack river basin in the area now known as the Hackensack Meadowlands. Drift deposits are known to exceed 165 feet in selected locations of the area, while deposits of stratified drift as much as 300 feet are know to exist as well.

In addition to the glacial deposits, more recently deposited alluvial materials are found in the area. These deposits are relatively thin and are located primarily along present river and estuary boundaries.

Regional Hydrology

The area of interest lies within two drainage basins, those of the Hackensack and Passaic Rivers. The Hackensack River basin contains 116 square miles of drainage area, of which about one-half lies within New Jersey. After draining highland areas of New Jersey

and New York, the river flows through Hackensack meadows and into Newark Bay. The Hackensack Meadows in an area 10 miles long and as much as four miles wide is only a few inches above high tide. The Hackensack River becomes tidally influenced in the meadows. The western boundary of the Hackensack River Basin is located along a crest of northward-trending ridges which lie approximately one mile east of the Stepan Chemical Plant. From these ridges surface water drains into the Saddle River which is a tributary of the larger Passaic River. The Passaic River and its tributaries drain a large area exterding from the highland areas of New Jersey to the lowland areas adjacent Newark Bay. The river flows into Newark Bay just north of the city of New York approximately 1 mile from the mouth of the Hackensack River.

The boundaries of groundwater basins of the area correspond closely with those of the surface drainage basins. In the lowland areas of the Piedmont, ground water gradients are low and follow closely the contours of the land surface. Although groundwater is present in both bedrock aquifers and the more superficial unconsolidated deposits, aquifers in the Brunswick Formation and generally considered more productive and provide the majority of groundwater utilized in the area. Due to the inherently low porosity of the consolidated materials of the Brunswick Formation, groundwater occurs primarily in a network of interconnected openings formed along joints, fractures, and solution channels. Intervening, unfractured rock has negligible capacity to store and transmit water, and at depth existing fractures tend to be non-extent or greatly reduced, lowering greatly the potential for locating a producing zone greater than 400 feet in depth. In addition, different layers in the Brunswick formation possess differing amounts of fractures, resulting in a system of alternating tabular aquifers and aquacludes only several tens of feet thick but extending along the strike of the formation and dipping to the northwest. Water-bearing fractures in each aquifer are reportedly more or less continuous, but hydraulic connection between aquifer through intervening aquicludes is poor. Fractures are oriented largely along the strike, resulting in a highly anisotropic

permeability which greatly facilitates groundwater flow parallel to the direction of the strike. Both high yielding industrial and municipal wells with yields of as much as 500 gallon per minute and smaller domestic wells with more moderate yields have been developed in the Brunswick Formation in this area of New Jersey. More productive wells are generally 300 feet deep or more and screened over numerous aquifers. Water quality is generally good, but elevated hardness which requires treatment is not uncommon, particularly from deep wells. Wells have also been developed in the nearby basaltic formations, but their yields are low and generally suitable only for domestic purposes.

Some groundwater is available from the unconsolidated, glacial deposits which cover the area. Small quantities of water are stored in the glacial till which can be found in many areas of this region of New Jersey. However, the till characteristically has low permeability because of its poorly sorted nature. In contrast, stratified drift common to the area frequently contains lenses of well sorted sands or gravels which have high permeabilities and can yield useable quantities of water to wells. Wells screened in these deposits are commonly low yielding, domestic wells; but in thicker deposits of stratified drift, higher yielding industrial and public supply wells have been developed.

Due to the discontinuous nature of most of the aquifers in the area, there appears to be no well developed, regional, groundwater flow system except for the flow through the glacial deposits which underlie many of the rivers in the area. Ground-water gradients follow the slope of land surface and the water table is generally close to surface of the ground (10-15 feet), particularly the low lying areas. Recharge occurs mostly from local precipitation (47 inches per year) or from infiltration through local streambeds. However, confined or semi-confined groundwater conditions are common, particularly in stratified glacial materials confined by overlying, less permeable silts or clays and in downgradient portions at the porous beds of the Brunswick Formation which are intercalated with other less porous beds. These confined conditions are rechanged locally and do not generally represent significant regional flow patterns except at great depth.

Site Geology and Hydrology

The plant site is located within the drainage basin of the Saddle River, approximately 1/2 mile east of the Saddle River and one mile east of the drainage divide of the Hackensack River Basin. Local, surface drainage is into a small drainage brook which crosses the Stepan property. The brook has been encased in a concrete pipe and covered with 2 to 5 feet of fill material in the Stepan property.

Local geology follows closely the pattern presented for regional geology. Bedrock in the area is comprised of consolidated deposits of the Brunswick Formation, mostly of mudstone and siltstone. Borings made at the plant site indicate that bedrock lies close to the surface, with between 3 to 15 feet of weathered bedrock and unconsolidated deposits overlying the bedrock. A weathered zone between 2 and 8 feet commonly overlies hard bedrock. Unconsolidated material overlying the bedrock is comprised largely of stratified drift which exhibits considerable variability both areally and with depth. In addition, borings indicate that considerable amounts of fill material have been placed on this site during its many years of industrial use.

The watertable is located relatively close to the surface, particularly in the low lying areas on the site in the immediate vicinity of the culverted brook. Borings have indicated in these areas that during December 1981 the water table generally lies wthin 7 to 10 feet of the surface. The watertable is readily observable in the more porous unconsolidated materials present on the site, while in areas in which the consolidated materials of the Brunswick Formation lie close to the surface no watertable is observable. Based on local topography, the groundwater gradient in the area is low. Flow is to the southeast towards the Saddle River where superficial groundwater flow is likely discharged.

Description of Burial Site 3

Burial site 3 is located in the southern corner of Stepan's property. It includes five burial trenches arranged as shown in Figure 1. The dimensions of the trenches and the volume of thorium bearing residues buried therein are given in Figure 1 and in Table 1.

Table 1

Trench Identity	Nominal Dimensions of Trench (ft)	Volume of Waste Buried (cu yd)
3-1	90 x 90 x 12	3000
3-2	150 x 24.5 x 15	2000
3-3	139 x 25.5 x 15	1520
3-4	96 x 27 x 15	1250
3-5	117 x 24 x 10	830
	total	8600 cu yds

How does he justify

The trenches in burial site 3 were excavated 10 to 15 feet deep from grade, to the depth of a shale and rock base. In the vicinity of the Maywood Plant, solid rock occurs at a depth about equal to the depth of the burial trenches. The excavated burial sites at the Maywood Plant were observed to be free of ground water.

The residues buried in site 3 contain about 0.25% thorium in the form of thorium hydroxide or thorium phosphate. On that basis, burial site 3 is estimated to contain 36000 pounds of thorium. The corresponding activity concentration of throium-232 is calculated to be 270 pCi/g. Thorium progeny are assumed to be present in radioactive equilibrium with the thorium.

The waste in each trench was covered with two feet of earth. Later, a nine inch thick reinforced concrete slab floor was poured atop the burial site and Building 3 was erected thereon. Ground within the fenced area around Building 3 is paved with macadam. The concrete slab is a permanent cover and both the slab and the macadam pavement prevent inleakage of rain water.

The potential for radionuclide movement away from the burial site is minimized by several attributes of the site.

1. The excavated burial sites were observed to be free of ground water.
2. The thorium compounds buried, thorium hydroxide and thorium phosphate, are insoluble in water.
3. Sites 1 and 2 were covered with at least three feet of soil.
4. Site 1 is paved with macadam.
5. Site 3 is covered with a building having a 9 inch thick concrete slab floor and surrounded by macadam pavement.
6. There has been no noticeable settling of any of the burial sites.

In view of these favorable burial site characteristics and the fact that Stepan is presently evaluating radioactive materials and their disposal on the property, additional monitoring of the burial sites is not proposed at this time.

Figure 2-39

Alternative 4A: Schedule and Manpower Requirements

Radiological Survey of Building 3

Building 3, a warehouse, and the grounds near it were recently surveyed to assess whether employees working there or material stored therein were exposed or affected by natural thorium residues buried under the building. The survey was performed by Nuclear Safety Associates during November 1980 and June and July 1981.

The survey indicates that radiation levels in and around Building 3 are not elevated significantly and are comparable to naturally occurring levels. The presence of thorium containing residues beneath Building 3 has not resulted in any detectable radioactive contamination of the building or the material stored therein.

Survey Description

Six types of radiological measurements were made in Building 3:

1. Gamma radiation
2. Alpha radiation on surfaces
3. Alpha radiation removable from surfaces (smearable)
4. Alpha activity in floor sweeping ash
5. Airborne particulate
6. Airborne radon and thoron

Gamma radiation levels were also measured above the ground around Building 3.

Survey Results

Figure 3 is a histogram of 103 gamma radiation exposure rates measured on the floor in Building 3. Most of the readings in the building are in the range of naturally occurring background radiation in the Maywood, New Jersey area. Eight readings on the order of 11 or 12 μR/hr observed in one small area may indicate detectable, although not significantly elevated levels.

One-minute alpha radiation readings were taken at 33 places on the floor in all four quadrants of the building. No detectable alpha activity was found. Numerous readings were also taken on walls of the building and on the stored material. Again no activity was detected. Some of the stored material was found on the floor, retrieved, and checked for alpha activity. None was found. The contents of the vacuum cleaner used for cleaning the floors of the building were also checked. Again no alpha activity was found. These results clearly indicate there is no detectable alpha radiation emitting material inside the building.

A few checks were made on the macadam surrounding the building, but no alpha activity was detected.

Nineteen smear samples, each covering about 900 cm^2 area, were taken in Building 3 to check for removable alpha activity on surfaces. All of the samples were below 0.365 dpm, or 0.04 dpm/100 cm^2, the detection limit for 50 minute counts on a Beckman Wide Beta 2 alpha proportional counter.

An airborne particulate sample from filtering 1200 cubic feet of air in quadrant A of Building 3 was counted for gross alpha activity. After short-lived radon progeny decay, the total alpha activity on the filter was less than 0.66 pCi, equivalent to 0.04 dpm/m^3 air.

Measurements were made on an ash sample prepared from the contents of the building vacuum cleaner bag. This sample was also below the 50-minute limit of detection of 10.8 pCi/gram of ash. The sample contained 0.2 gram thus the total count was less than 2 pCi equivalent to 4.4 dpm. It is not known how much area was cleaned equivalent to this ash sample but clearly this reading also indicated the lack of any radioactive contamination within the building.

On June 29, 1981 after the building had been closed for two days or longer, air in Building 3 was surveyed for short-lived radon and thoron progeny. Three separate procedures were used. Radon progeny concentrations in each of the four quadrants of the building, determined using Rolle's single gross alpha count method, are tabulated below.

Location Sampled	Radon Progeny Concentration (Working Level)
A 4	0.0054
B, 12	0.0079
C_2 3	0.0051
D_2 12	0.011

A time interval optimized, modified Tsivoglou procedure, a three count method, was used to measure radon progeny concentrations quadrants C and D. The results were:

Location Sampled	Radon Progeny Concentration (Working Level)
C_2 3	0.0042
D_2 12	0.011
D_2 12	0.0088

A measurement made in quadrant D, location D_2 12 using a procedure based on the Kusnetz method to differentiate between radon and thoron progeny gave:

Radon plus thoron progeny	0.0083 WL
Thoron progeny	0.0024 WL

That thoron progeny concentration measured in Building 3 was only a fraction of the radon progeny concentration agrees with the usual observation in nature. Overall, radon progeny concentrations measured in Building 3 were low and in the same range as reported measurements[1] in ten houses within about 35 miles of Maywood, New Jersey.

Figure 4 displays the results of the gamma radiation survey on the ground around Building 3 in the natural products area. Individual readings taken three feet above ground, are recorded on the figure at about the location corresponding to where they were measured. Figure 5 is a histogram of the gamma exposure rate measurements presented in Figure 4.

Inspection of Figures 4 and 5 indicates that the three maximum values may be elevated with respect to naturally occurring levels. The three measurements were made in a small, localized spot near the east end of the area which is well away from the buildings and is normally unoccupied. Otherwise, the distribution of radiation exposure rates around natural products buildings compares favorably with the aerial measurements by EG&G. In an area including the natural products area, EG&G reported the exposure rate at 3 feet above ground to be in the range 7.5 to 11 μR/hr. EG&G also reported that the naturally occurring radiation exposure rate in the Maywood area is generally in the range of 6 to 7.5 μR/hr.[2] The average gamma exposure rate measured by NSA around Building 3 and the natural products area, 7.8 μR/hr, compares favorably with the natural background exposure rate in the Maywood area reported by EG&G.

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[1] A C George and A J Breslin, The Distribution of Ambient Radon and Radon Daughters in Residential Buildings in the New York-New Jersey Area, symp. Nat. Rad. Envir. III, April 23-28, 1978.

[2] EG&G, An Aerial Radiologic Survey of the Stepan Chemical Company and Surrounding Area, NRC-8109, April 1981.

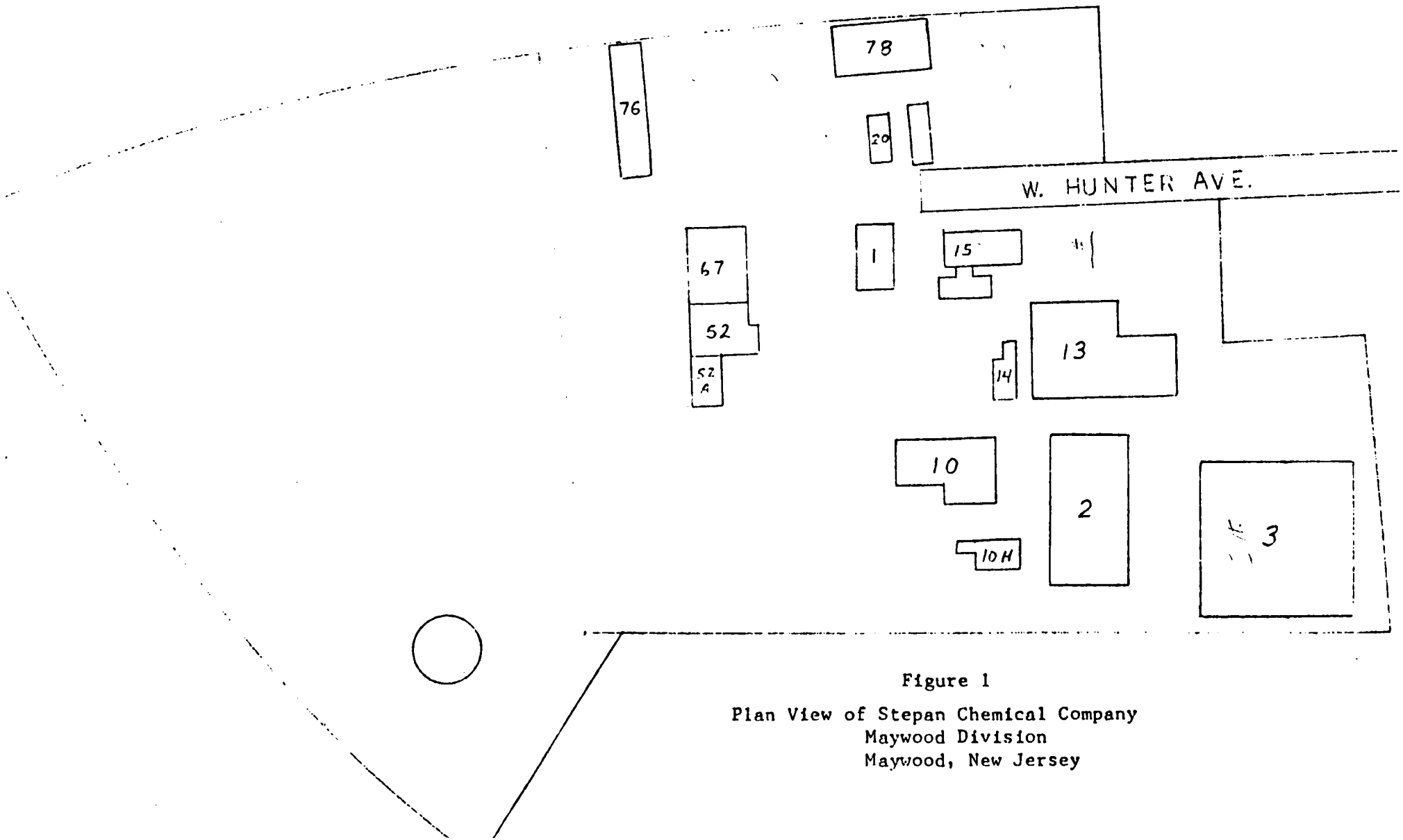

Figure 1

Plan View of Stepan Chemical Company
Maywood Division
Maywood, New Jersey

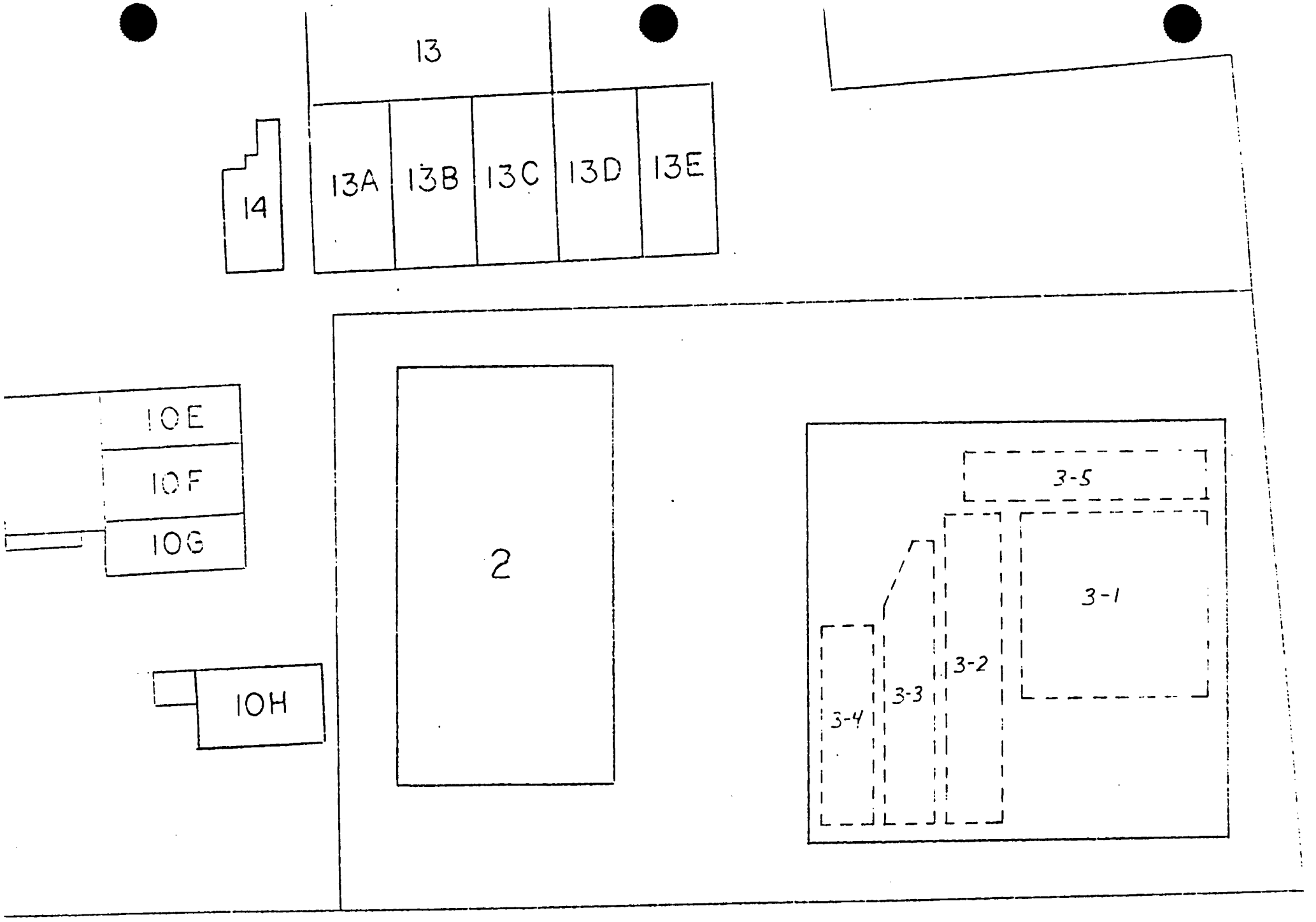

Figure 2 Plan View of Burial Site 3

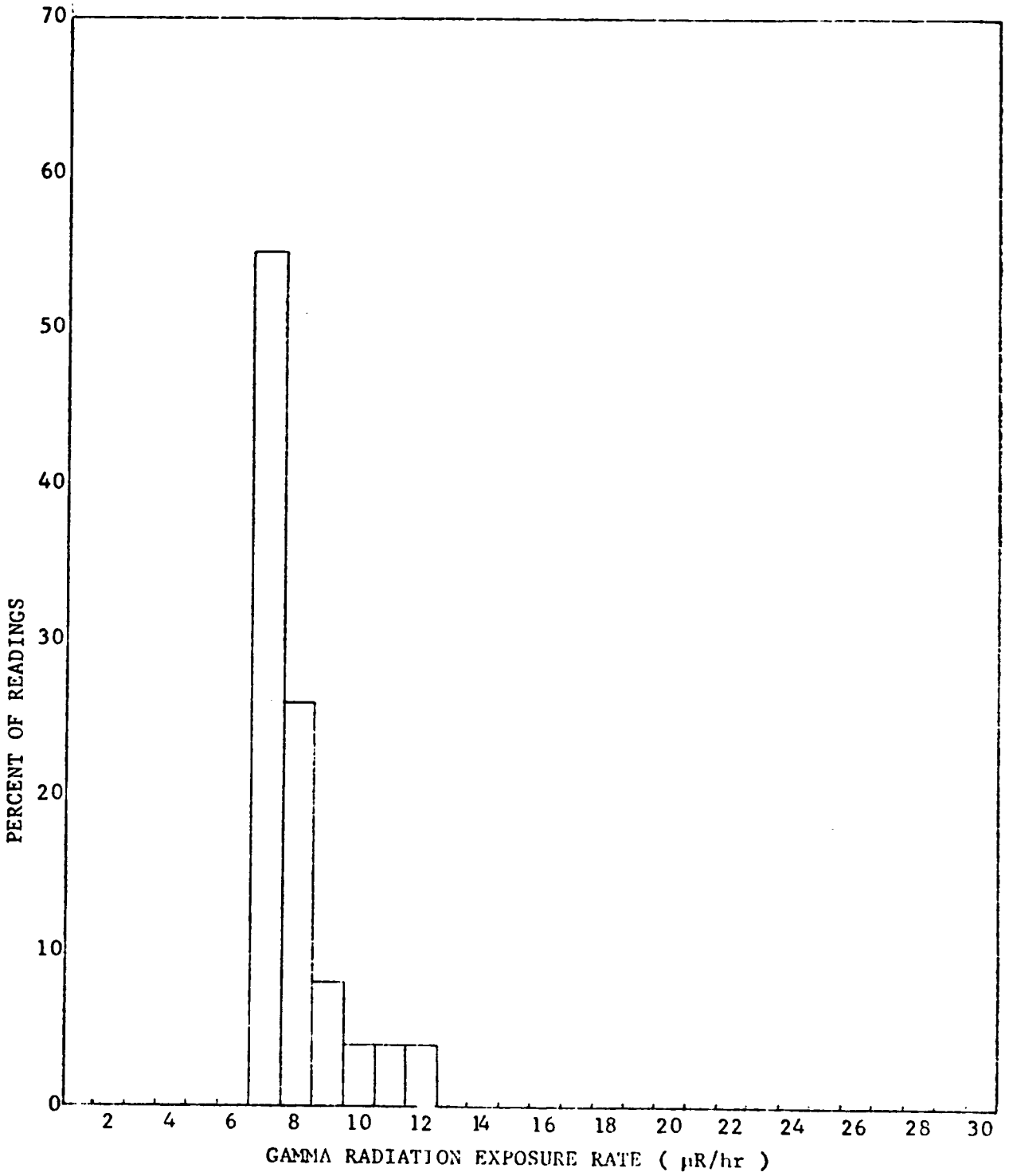

Figure 3 Histogram of Gamma Radiation Survey in Building 3

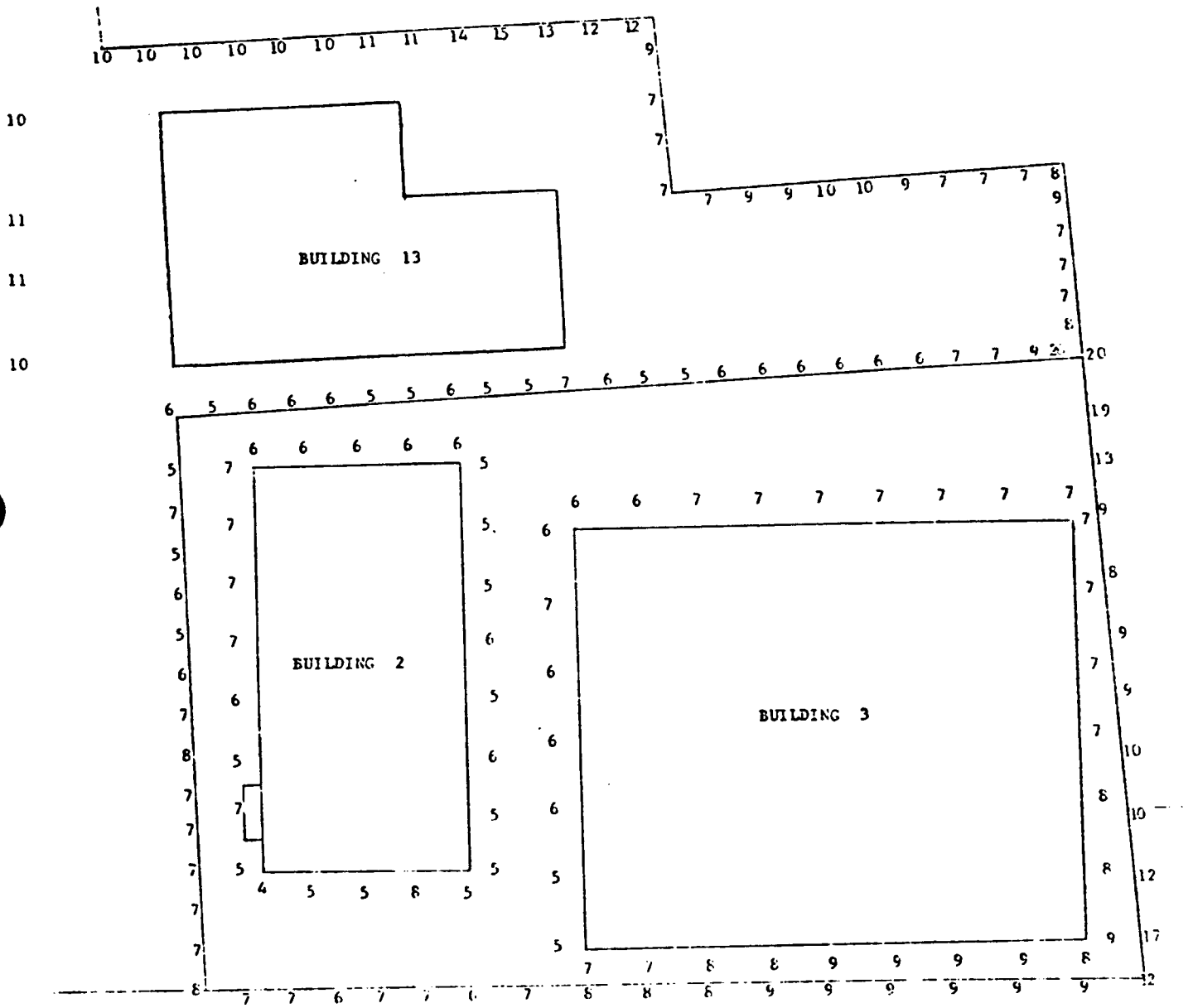

Figure 4 Gamma Radiation Exposure Rates in the Natural Products Area

(Exposure rate units are microroentgens per hour.)

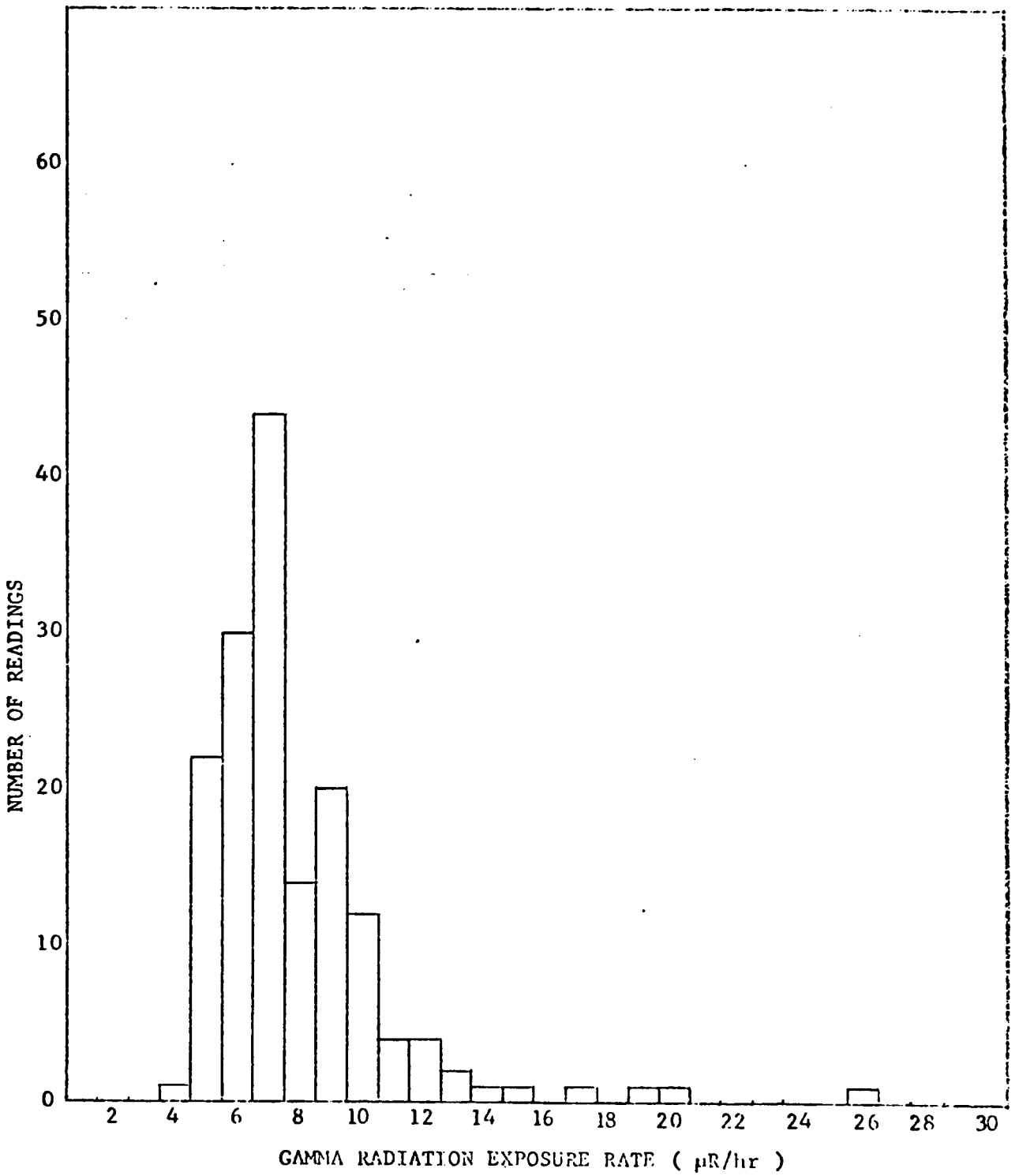

Figure 5 Histogram of Gamma Radiation Survey of of Ground in the Natural Products Area