A Review of

the

Radiological

Environmental Monitoring Data

at

U. S. Army

Jefferson Proving Ground

Madison, Indiana

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Introduction

The United States Army operates the Jefferson Proving Ground at Madison, Indiana. Acceptance testing of various depleted uranium containing ordnance items is performed under a license granted by the United States Nuclear Regulatory Commission. For the depleted uranium projectiles considered here, testing is limited to firing at soft targets only, which limits generation of aerosols. An extensive baseline survey was performed from November, 1983 to February, 1984, to characterize background isotopic uranium concentrations in various environmental media. Depleted uranium of anthropogenic origin began to be dispersed from the 500 Center firing position in March, 1984. As of May, 1988, approximately 50 metric tonnes of uranium had been introduced into the JPG environs, with about 4.5 tonnes having been recovered. About 30 days after testing began, the baseline study was essentially repeated. The routine Radiological Environmental Monitoring Program consists of twice a year collections of soil, sediments, surface water and groundwater. Vegetative undergrowth is regularly controlled through burning, at which time high volume particulate air samples are collected. Samples of deer tissue are regularly collected during hunting season. During the last four years two more firing positions have been added adjacent to 500 Center, positions "J" and "K". Several additional soil and a single additional water sampling location have been sampled to cover these new firing positions as well as to cover the impact area of "overs". This report is a review of data collected in

JPG's Radiological Environmental Monitoring Program through the Fall, 1987 samplings.

Air and Biota

Analyses of particulate air samples and deer samples have not detected any depleted uranium. A vast majority of results are less than detection limits. A statistical analysis of these data is therefore not warranted. There is no evidence that depleted uranium has impacted these two potentially important pathways to man. The remainder of this report will explore in detail the media for which voluminous data appear: soil, sediment, surface water and groundwater.

Frequency Distributions

Before lengthy statistical analyses are performed it is prudent to examine the statistical distribution of the data, because non-normal distributions commonly occur in environmental media which can have adverse impacts upon analysis. A plot of concentration versus frequency of occurrance reveals a distinctly bimodal distribution. A peak around 0.8 pCi/g is due primarily to soil samples, while a second peak at 0.1 to 0.2 pCi/g (or pCi/l) is caused by the other samples analyzed, sediment and water. Some of the cross-media comparisons to follow could thus be specious, since no obvious normalizing transformation could be found which would allow one to legitimately combine the data. Figures 1, 2 and 3 are probit plots of soil U-234, U-238 and U-235 respectively, in which concentration is plotted against cumulative frequency of occurrance as a percentage. A normally distributed population of data will plot out as a straight line, with no obvious breaks and little curvature. If a probit plot contains two or more distinctly different straight lines then the usual inference is that the data consist of two or more distinct statistically normal populations. A sigmoid, curve or other pattern different than a straight line indicates a non-normally distributed population. Oftentimes for large plots of environmental data of different media at different locations one will obtain combinations of different populations with different types of distributions. For example, one might obtain a plot showing three distinct populations, one normally distributed, one log-normally distributed, and one showing a negative binomial distribution. Environmental data containing large numbers of results near method detection limits will often show non-normality. In practice then, one is often confronted with data containing samples from different types of "real" statistical distributions to which has been added further deviation from normality as a result of analytical technique. For relatively simple cases, such as a single log-normally distributed population, one can perform a transformation on the data, in this case taking the logarithm of the concentration data, and then proceed with usual parametric statistical tests on the normally distributed log concentration data. Graphical analysis of both soil U-234 and U-238 reveals a distinctly two component curve. In both cases the inflection point is around 1 pCi/g. Soil uranium from the individual impact areas (6,8,10 and 12) and the impact area boundary locations (32/48,26/47,19/44 and 36/43) was tested for normality. Chi-squared significant deviations from normality ($p<0.01$) were discovered for U-238 at sites 6 and 12 and for U-234 at site 12. The two populations of data are undoubtedly natural and depleted uranium. This distinction will be confirmed in later considerations.

The U-235 distribution probit plotted in Figure 3 presents a problem. The same distinction between depleted and natural uranium could suffice to explain the plot, but analysis of baseline soil samples indicates that there may be an analytical problem. The ratios of U-235 to U-238 or U-234 do not reflect the fixed ratios characteristic of natural uranium. During the baseline period, all U-235 assays were very near method detection limits. "Tailing" into the U-235 region of the alpha spectrum may be the problem. Because of this, comparisons involving U-235 in soil will be treated lightly in this report, and not at all for media other than soil. Because of its importance to the overall program, soil uranium data will also be subjected to a number of nonparametric tests to assure that deviations from normality do not produce spurious results. In this report, unless explicitly stated, subsequent references to the isotopes of uranium will refer to U-234 and U-238.

Sediment uranium is plotted in figures 4 and 5. Both uranium isotopes appear to be normally distributed, with geometric means (50% intercept) at about 0.24 pCi/g. From the probit analysis alone one could conclude that depleted uranium is probably not present in sediments at JPG. Later analysis will substantiate this. One potential problem obvious from the probit plots is the detection limit problem, as the data distribution peaks very near method detection limits. As we shall later see, this does not appear to have caused any problem yet, but should be scrutinized for in the future. The highly normal data distribution for sediments should not cause any problem in later analyses. It would appear that sediment samples from both creeks at JPG are all members of a single statistical distribution, thus comparisons between creeks need not be limited.

Surface water U-234 is probit plotted in Figure 6 while surface water U-238 appears in Figure 7. Above about 0.05 pC/l, both isotopes appear to be approximately normally distributed. The lower concentration end of the distribution may be due to a second population having been sampled (depleted versus natural) or may be related to detection limits, which are generally about 0.03 pCi/l for water. Nevertheless, since most of the population is normally distributed and the aberration occurs so near the lower end, no untoward problems should be encountered using familiar parametric statistical tests unless a comparison uses mostly less than 0.05 pCi/l data.

Figures 8 and 9 display the groundwater U-234 and U-238. The U-234 shows a distinctly two component curve with a break at about 0.2 pCi/l. The U-238 data show a highly complicated pattern, with three or maybe four components. Figure 10 is the U-234 data plotted on log probability paper, which is the equivalent of plotting the logarithm of U-234 on linear probit paper. The log transform straightens out the curved low concentration data, but the entire distribution still shows at least two populations. The logarithmic probability plot of U-238 in groundwater in Figure 11 does not appear to have been aided by the transform. and is still composed of about 4 populations. Perhaps the simplest explanation for these somewhat aberrant statistical distributions is to conclude that the monitoring wells are simply sampling from two to four independent, different populations, although in this view it would also appear that U-238 and U-234 behave somewhat differently and don't display their close linkage as strongly as usual. Another possibility is that the wells are changing through time. Time constraints did not allow much time for the wells to "settle down" before baseline measurements. The different components could be a reflection of slight changes in the solubility of uranium in the vicinity of the monitoring wells. Another possible explanation for the discontinuous nature of the groundwater uranium concentrations is that the uranium is undergoing a change of valence and therefore solubility and soil exchange site changes. Unfortunately, the data become too sparse to break down into smaller subpopulations to get to the root of the problem. Groundwater is notorious for producing strange concentration and ratio data, so perhaps not too much should be made of these statistical distributions, although their effects on subsequent analyses should be kept in mind.

Initial Overview

In Table 1 are listed the results of various analyses of variance performed to detect "significant" factors at work at JPG. The last column lists the probability of such a relationship being due to chance, or a fortuitous selection of data which do not readily represent their underlying statistical distribution. This search for major trends illustrates the numerous factors potentially impacting the monitoring program at JPG and the possibility of factors interacting. In general, it would appear that time is the major influence on surface water uranium while location would appear to be most important for soils, sediments and groundwater. Some strong cross-media interactions also appear to be present at JPG. Subsequent analysis will show significant differences from these initial general trends.

Interactions

Before detailed analysis of data within a given medium was attempted, several combinations of media were examined for correlation in an attempt to elucidate the nature of some of the strong interactions indicated in the analysis of variance. Table 2 shows the correlation matrix for surface water and groundwater at JPG. For the correlation coefficients in the body of the table to show a significant correlation between two variables it must exceed the critical value shown at the bottom. As expected from the analysis of variance, surface water shows a strong positive correlation with time. As in all analyses in this study, time is considered as the number of months since firing of depleted uranium commenced at 500 Center, with baseline (when included) being assigned a value of -3. The notation "op" will refer to the operational phase of the DU Program at JPG, and will include all sampling periods except baseline. Within a given medium, strong positive correlations are also obtained for the two uranium isotopes, as expected. The lack of correlation between groundwater and site is somewhat misleading, as the correlation is really between the site number and uranium concentration. The heart of the matrix is the intersection of surface and groundwater, where only very weak insignificant negative correlations were found. The strong positive correlation between time and surface water uranium, if indicative of a causal relationship, must be kept in mind, since any other variable with a similar relationship might show a strong covariance with surface water and be mistaken for a causal factor. The conclusion to be drawn from Table 2 is that surface water and groundwater uranium do not appear to be linked at JPG.

Since groundwater and surface water did not appear to be linked, the correlation between surface water and sediment was next examined in Table 3. Like groundwater, sediment uranium also did not show a significant correlation with time, nor did it correlate well with surface water. The linkage between uranium isotopes appeared to be very strong for sediments, more so than for groundwater or surface water.

A four medium, two isotope correlation matrix (Table 4) was next prepared. For this particular combination of locations, only surface water showed a significant correlation with time. A strong negative correlation was found between site and soil uranium. Again, this is really a correlation between site number and uranium concentration and indicates that the lower numbered sites had the highest uranium concentrations. This in turn is simply a consequence of the numbering of locations as one moves down the 500 Center Line of Fire impact area (6,8,10,12). The only other significant correlation involving soil uranium, albeit an extremely strong one, was between the isotopes of uranium. Except for the isotopic correlations and the previously mentioned effects of time, no significant cross-media correlations were found.

Surface Water U-234 Correlations

In Table 5 is shown the correlation coefficients for the different combinations of surface water sampling sites for U-234. As might be expected for a medium that flows from one location to the next, most of the locations show strong positive correlations with each other. Within Middlefork Creek, the relations are all significantly positive. Probably the most noteworthy result is the lack of significant correlations between sites on Big Creek, specifically the Line of Fire and downstream locations 2 and 3. If these lacks of correlation are due to the presence of dissolved depleted uranium, then it also indicates that the influence is very limited spatially and do[illegible] not carry to the boundary. Leaving aside arguments of causation and consequence for the time being, it should be pointed out that surface water locations 2 and 3, Big Creek Line of Fire and immediately downstream, do not correlate with other surface water samples nor do they correlate with sediment uranium concentration.

Sediment U-234 Correlations

Sediment U-234 was next examined in Table 6. No combination of locations within a creek showed a significant correlation, but the Line of Fire locations neared significance when compared to their respective boundary sampling locations, with Big Creek being positive while Middlefork Creek was negative. The situation with sediment U-234 contrasts greatly with surface water dissolved U-234, where most sites except the Line of Fire showed strong positive correlations. To a certain extent, this conforms to common sense. Sediment does not move as fast as surface water, and significant sediment movement and concentration probably only occur during high run-off events. Conversely, highest dissolved uranium concentrations are likely to occur during periods of reduced flow. A different time scale is thus probably at work. The great differences between dissolved surface water U-234 and sediment U-234 would also tend to argue against one being the source term for the other. If either were a strong source for the other, then one might expect a strong correlation to exist. Besides not correlating with each other, the site to site correlations are also vastly different and tend to argue against a strong interaction.

Groundwater U-234 Correlations

Groundwater U-234 correlations were next examined in Table 7. A strong negative correlation was observed between monitoring wells numbers 1 and 6. Monitoring well number 6 has consistently shown relatively high uranium concentrations, even during the baseline study, while well number 1 has been one of the lower ones. Well number 6 is also the only well which does not penetrate all the way to bedrock. The original baseline study conclusion, that well number 6 samples a distinctly different source of water, is still believed to be correct. With this one exception, none of the monitoring wells correlates significantly with any of the others and, thus appear to be independent, or unlinked. This corroborates the conclusions arrived at in the earlier examination of frequency distributions.

Soil Uranium - 234

The correlation matrix for impact area soils versus neighboring non-impact area soils for U-234 appears in table 8. Sites 36/43 show a strong correlation with sites 26/47. This is of little consequence. Within the impact area, sites 6 and 12 show a very strong positive correlation. It is tempting to speculate that rounds which ricochet from area 6 tend to land in area 12. Whatever the reason, these sites are directly in the Line of Fire. Perhaps more surprising is the lack of significant correlation between the other impact area soils.

Sediment U-238 Correlations

Table 9 illustrates correlation coefficients for sediment U-238 concentrations. The situation is the same as U-234, with no real strong correlations. The closest to significance is a negative correlation between Middlefork Creek Line of Fire and the boundary location. The sediment sampling locations appear to be essentially unlinked, or independent of each other.

Surface Water U-238 Correlations

The correlation matrix for U-238 in surface water is in Table 10. Again the situation is like that of U-234, with most of the sampling locations showing significant, and in all cases positive, correlations. Again the weakest correlations appeared between locations 2 and 3 and between either of them and all others. The conclusion that surface water samples show strong linkage and interdependence for U-234 is also true for U-238.

Groundwater U-238 Correlations

Groundwater U-238 monitoring well correlations (Table 11) show the same bordering on significance negative correlation between wells 1 and 6; however, a significant negative correlation now also occurs between locations 2 and 7. As will later be seen, well 2 has shown an unusual steady decrease in concentration through time, probably the most inexplicable pattern among any of the monitoring wells. For each of the pairs of negative correlations, the well with the highest concentration of U-238 occurs on opposite sides of the impact area. No causative explanation is apparent to explain this behavior other than the previously viewed conjecture that the wells are sampling different sources which just happen to be moving in opposite directions.

Soil U-238 Correlations

The correlation matrix for U-238 in impact and non-impact areas appears as Table 12. The same significant correlations which appeared for U-234 also appear for U-238. Two pairs of locations show significant positive correlations: sites 6 and 12 in the impact area and sites 36/43 and 28/47 in the non-impact area. The impact area correlations for U-234 and U-238 both involve non-normally distributed variables, however. It is highly probable that the impact area correlations reflect causation, that being the impact of depleted uranium projectiles.

Regressions - U-238 in Sediments

Concentrations of U-238 in Big Creek sediments appear in Figure 12, while isotopic ratios for the same samples appear in Figure 13. Results of regressions involving these same locations appear in the top half of Table 13. A cursory examination of the concentration data might lead one to suspect the presence of depleted uranium during two periods. The Big Creek boundary sampling location showed slightly elevated concentrations first during months 1 and 9 after firing commenced and appears to be joined by downstream location 8 during a second peak during months 25 and 32. During the first peak the isotopic ratios at the boundary location appear to be perfectly natural, and thus show that at least the first peak is not depleted uranium. The second peak, during months 25 and 32, do show somewhat the depressed isotopic ratios characteristic of depleted uranium, however, the concentrations of U-238 at that time are still less than half of background soil for the area. Regressions of U-238 on U-234 for each Big Creek sampling location, and for all of them combined, all have slopes of approximately one, which is consistent with the isotopic ratio of one characteristic of natural uranium. Regressions of U-234 on time for the Line of Fire sampling location does show a significant effect, although it is negative and of extremely small magnitude. There is no unequivocal evidence for the presence of depleted uranium in Big Creek sediments. A majority of the evidence indicates only natural uranium is present. If there has been an impact, it was very slight and is declining with time.

Middlefork Creek U-238 in sediment concentrations appear in Figure 14, with isotopic ratios illustrated in Figure 15. The associated regressions appear in the lower half of Table 13. All the uranium appears to be natural, with the only significant trend being negative with respect to time for both isotopes at the Line of Fire sampling location. Since the trend is negative, the uranium is natural, and the concentrations higher than in Big Creek, the uranium movement observed is probably the result of erosion from the construction activities associated with building the observation post in the area. Since both creeks show a significant regression of uranium on time for only the Line of Fire locations, it implies causality. The most likely candidates for a cause are disturbance of substrate due to impact or disturbance from construction. Since both trends are negative and both involve natural uranium (isotopic ratios about 1), the initial construction in the areas followed by run-off is most likely the cause.

Regressions - Uranium in Surface Water

Uranium 238 concentrations in Big Creek appear in Figure 16. Figure 17 illustrates U-238 in Middlefork Creek, while figures 18, 19 and 20 show isotopic ratio for both creeks. Table 14 contains the results of regressions involving dissolved uranium in the creeks. With the exceptions of the more recent location NE and the upstream Middlefork Creek location SE, all regressions of U-238 and U-234 on time and on each other were significantly positive. This pattern is suggestive of a basin-wide natural effect, since the Big Creek upstream location is included. However, the ratio U-238/U-234 for Big Creek was 7.08 to 1, highly indicative of depleted uranium, while the same ratio for Middlefork Creek was 0.86 to 1, indicating natural uranium. It would thus appear that there is a natural pattern of increasing uranium concentration in water, perhaps weather related, upon which is superimposed in Big Creek a significant amount of depleted uranium. The isotopic ratio of 0.99 to 1 for the upstream Big Creek location NE reflects natural uranium while the Line of Fire location N shows a ratio of 8.2 to 1, clearly depleted uranium. Also with the exception of location N, all uranium concentrations are well less than 1 pCi/l. So although the Big Creek has clearly been impacted by test activities, the low concentrations do not indicate any substantial hazard exists. With respect to uranium, all water samples would meet existing or proposed Safe Drinking Water Act regulations. The apparently natural increase in uranium concentration tends to exaggerate this effect. This increasing trend will probably continue with the low precipitation, near drought conditions of 1987 and 1988, but will be well worth observing closely whenever high moisture conditions return to Jefferson Proving Ground.

Regressions - Groundwater Uranium

Figures 21 and 22 illustrate groundwater U-238 concentrations in wells to the East and West of the impact area, while isotopic ratios are shown in figures 23 and 24. Several difficult to explain patterns are evident from the regressions in Table 15. The wells along the East side show a significant decrease in U-234 concentration with time. U-238 shows no such pattern overall, but is clearly in a decline in monitoring well number 2. This decline is not present in West side wells, which are believed to be located down gradient from the East side wells and the impact area. In contrast, U-238 in West side wells shows a nearly significant, although slight, increase with time. There appears to be an excess of U-234 relative to U-238. Excess U-234 commonly occurs in groundwater. A U-238/U-234 ratio as low as 0.33 to 1 would not be unexpected. The biggest problem with the U-234 excess is that it may mask somewhat depleted uranium.

However, if the baseline and 1 month samples are excluded, the uranium concentrations and ratios appear to fluctuate randomly and do not indicate a significant trend. The changing concentrations of uranium with time may be related to construction, either of the wells themselves or other structures in the area. At any rate, the monitoring wells do not show the presence of depleted uranium.

Regressions - Uranium in Soil

Figures 25 through 33 show soil uranium and isotopic ratios for the three firing positions, both Line of Fire sites and impact area boundary sites. Depleted uranium in the impact areas appears to be distributed in a narrow band, with little lateral movement. The length of the band would appear to be at least 1200 meters long, the distance from location 6 to location 12. Special samples taken around location 6 indicates that most of the depleted uranium is on or near the surface. Some regressions, significant and otherwise, are shown in Table 18. Interestingly, none of the regressions of uranium on time during the operational phase show significance, although the lack of normality for some of the soil data may be influencing the regression analysis. The extreme values taken on by the isotopic ratios clearly indicates depleted uranium, as do concentration data relative to baseline. To get around the lack of normality problem, Mann-Whitney U tests were performed comparing each sampling period soil results against baseline and each other. Month 1 results do not differ significantly from baseline, but all subsequent months except month 32 are significantly different than baseline. A Kruskal-Wallis test, a sort of "nonparametric analysis of variance", was then run, which indicated that time was a significant factor in soil concentrations of both U-238 and U-234. Generally, Mann-Whitney U tests do not show significant differences between adjacent sampling periods from month 9 onwards, however the month 32 samples are different than the month 25 samples, and differ from month 37 at a lower confidence level ($p < 0.1$). Month 32 was an unusual sampling period, in that the highest uranium concentration yet found, about 200 pCi/g, was detected at location 6, but at the same time the "J" and "K" Lines of Fire showed no depleted uranium. Impact areas more typically show concentrations of U-238 from background to around 60 pCi/g and ratios U-238/U-234 of about 8 to 1. Although the Kruskal-Wallis test did identify time as a significant factor affecting soil uranium concentration, it does not appear that uranium concentrations are increasing with time. It appears to be more of a case of the uranium being either elevated or not. Once depleted uranium reaches an area it appears to be persistent but not dramatically changing. About the clearest effect of time involves location 12, which did not show depleted uranium until several hundreds of meters of trees were cleared by impacts.

Cross-media Regressions

Table 17 shows the results of regressing uranium concentrations across different media. The first two regressions, which were the only ones significant ($p < 0.05$), relate U-238 in monitoring wells with sediments or U-238 in monitoring wells with U-234 in sediments. Since both media had components which were decreasing with time, the relationship may be fortuitous, although as previously mentioned construction activity may have impacted both of them. The rest of the relations are insignificant. It is somewhat surprising that none of the media at JPG appear to be linked.

Summary of Major Trends

Several major trends are evident from the data produced in the Radiological Environmental Monitoring Program at Jefferson Proving Ground. First, soft target firing of DU rounds causes a fairly rapid build-up in soil along a narrow band over a kilometer long along the line of fire in the impact area. Concentrations in these areas do not appear to dramatically change with time, although due to the non-normal distribution "hot spots" will occasionally be sampled. Uranium concentration in sediment has shown a steady decrease in time. This decrease is natural uranium and probably was caused by the initial construction in the depleted uranium ranges. It thus appears that natural uranium in soil becomes leachable when it enters the creeks as sediment. This leaching could cause increased dissolved uranium in surface water, but the statistical relations one would expect if this were the case have yet to appear. Groundwater showed an initial decline, probably related to the construction of the wells themselves, with little change since but subject to much well to well variability. Probably the most troublesome trend is the steady increase in dissolved uranium in surface waters at JPG. This increase consists of both natural and depleted uranium, although the concentrations are at levels well below concern. The cause of this trend is unknown, but may be related to precipitation and run-off patterns, erosion and leaching of sediment, or both. Evaporation during low flow periods will naturally cause an increase in dissolved substances. This trend should be observed closely in the future, particularly after moisture levels and run-off return to more normal levels.

Recommendations

In general, the DU monitoring program at JPG appears to be doing what it is supposed to, that is monitoring the presence of depleted uranium in major environmental pathways and compartments. Because of the large inventory of unrecovered uranium and the heterogeneity of groundwater, the program could be improved by the installation of several additional monitoring wells in the immediate impact area. Several additional soil samples should also be collected further down range, as the projectiles appear to carry farther than originally anticipated. However, since the contaminated zone appears to be very narrow, there is no need to expand the sampling grid sideways. If resources become restrictive, consideration should be given to a tradeoff between soil sampling off the line of fire and more sampling down range. Particular care should be exercised in the future surface water collections to avoid any possible contamination of the samples. The increasing trend with time for surface water uranium could be the result of sample contamination. It is very important that this trend be closely watched, as surface water contamination will have an immediate impact off site if it continues. The advisability of cleaning up soil to 100 pCi/g is also questionable, as the impacted area is obviously much larger than the sample areas. As long as the sampling sites remain stationary, such cleanup could seriously bias the sampling program, with soil above 100 pCi/g occurring everywhere along the line of fire except the sampling locations. This source of bias should be removed, or a systematic sampling program devised which does not use fixed sampling sites. The cleanups should cover a larger area, or special high density sampling should be performed to verify that cleanup activities have not compromised the routine sampling program.

Table 1. Analyses of variance for Jefferson Proving Ground Radiological Monitoring Program media. S.W.=surface water; G.W.=groundwater; op=operational; sed=sediment; 1-W, 2-W, 3-W = one, two and three way ANOVA.

Location	Medium	Time	Type	Variable	Probability
Big Cr.	S.W.	op	1-W	U-238 by month	.0680
Big Cr.	S.W.	op	1-W	U-234 by month	5.9E-3
Big Cr.	S.W.	op	2-W	by isotope	.2917
				by month	.3141
				interaction	.4771
Middlefork Cr.	S.W.	op	2-W	by isotope	.8461
				by location	.7867
				interaction	.9107
Middlefork Cr.	S.W.	op	2-W	by isotope	.6748
				by month	4.9E-11
				interaction	.9984
Middlefork Cr.	S.W.	op	1-W	U-238 by location	.9404
Middlefork Cr.	S.W.	op	1-W	U-234 by location	.7789
Middlefork Cr.	S.W.	op	1-W	U-238 by month	8.2E-6
Middlefork Cr.	S.W.	op	1-W	U-234 by month	5.7E-5
All	S.W.	op	1-W	U-234 by location	.9633
All	S.W.	op	1-W	U-238 by location	.4339
All	S.W.	op	1-W	U-234 by month	1.29E-8
All	S.W.	op	1-W	U-238 by month	.0264
All	S.W.	op	2-W	by isotope	.2902
				by month	1.1E-3
				interaction	.4382

Table 1 continued.

Location	Medium	Time	Type	Variable	Probability
All	all	all	1-W	U-238 by month	8.7E-4
All	soil	all	1-W	U-238 by month	.0113
All	soil	all	1-W	U-234 by month	.0125
500C impact vs nonimpact	soil	op	1-W	U-238 by location	4.4E-7
500C impact vs nonimpact	soil	op	1-W	U-234 by location	2.7E-7
All	sed	op	2-W	U-238 by location	1.8E-6
				U-238 by month	.6905
All	sed	op	2-W	U-234 by location	2.5E-7
				U-234 by month	.8183
Wells 1-6	G.W.	op	2-W	U-234 by location	1.9E-4
				U-234 by month	.5939
All	G.W.	op - 25	2-W	U-234 by location	2.8E-4
				U-234 by month	.5268
Wells 1-6	G.W.	op	2-W	U-238 by location	1.9E-4
				U-238 by month	.0546
All	G.W.	op - 25	2-W	U-238 by location	1.1E-4
				U-238 by month	.0660
Sites 1-8	sed	op	3-W	U-238 by medium	2.9E-13
	S.W.			U-238 by month	.1729
	G.W.			U-238 by location	1.8E-7
				medium by month	7.0E-4
				medium by locat.	2.8E-28
				month by location	[illegible].2E-6
				medium by month by location	<.0001

Table 2. Correlation matrix, surface water (SW) and groundwater (GW) for uranium at Jefferson Proving Ground. Missing values deleted and duplicates averaged before analysis.

	Month	Site	SW-234	SW-238	GW-234	GW-238
Month	1					
Site	.00973	1				
SW-234	.60307	-.04579	1			
SW-238	.32714	-.14292	.62859	1		
GW-234	-.08966	.02309	-.13655	-.10656	1	
GW-238	.13642	.17984	-.05552	-.10863	.82351	1

Critical value (1-tail, .05) = + or - .20595

Critical value (2-tail, .05) = +/- .24395

Table 3. Correlation matrix, sediment (M) and surface water (SW), Jefferson Proving Ground. Missing values deleted and duplicates averaged before analysis.

	Month	Site	M-234	M-238	SW-234	SW-238
Month	1					
Site	.06435	1				
M-234	-.05654	-.12671	1			
M-238	-.03761	-.12804	.96672	1		
SW-234	.59721	-.00518	-.12476	-.05366	1	
SW-238	.32545	-.13659	-.11206	-.10521	.02601	1

Critical value (1-tail, .05) = + or - .20436

Critical value (2-tail, .05) = +/- .24208

Table 4. Correlation matrix, 500 Center impact area soils (S), Big Creek sediments (M) and surface water (SW), and East side groundwater (GW), Jefferson Proving Ground. Missing values deleted and duplicates averaged before analysis.

	Month	Site	S-234	S-238	M-234	M-238	SW-234	SW-238	GW-234	GW-238
Month	1									
Site	.0000	1								
S-234	.2170	-.4011	1							
S-238	.2139	-.3936	.9990	1						
M-234	-.0431	-.0964	.0400	.0523	1					
M-238	-.0419	-.1479	.0880	.1009	.9697	1				
SW-234	.5744	-.0126	.0450	.0490	-.1884	-.1468	1			
SW-238	.3458	-.0760	-.0520	-.0463	-.1566	-.1603	.8713	1		
GW-234	-.2440	-.1862	-.0390	-.0445	-.0634	-.0622	-.1370	-.1025	1	
GW-238	.0145	-.2351	-.0192	-.0254	.0717	.1119	-.0169	-.1102	.8033	1

Critical value (1-tail, .05) = + or - .2788

Critical value (2-tail, .05) = +/- .3286

Table 5. Correlation matrix for U-234 in surface water during operational phase of JPG Radiological Environmental Monitoring Program.

	Big Creek				Middlefork Creek			
	up	LOF	down	BN	up	LOF	down	BS
	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Loc 7	Loc 8
Loc 1	1							
Loc 2	.8468	1						
Loc 3	.7218	.7011	1					
Loc 4	.9183	.9212	.8569	1				
Loc 5	.8561	.8353	.4684	.7209	1			
Loc 6	.8570	.8926	.5603	.7770	.9383	1		
Loc 7	.9166	.7816	.7672	.8711	.8339	.8516	1	
Loc 8	.8573	.9359	.8594	.9462	.7956	.8660	.9055	1

Critical value (1-tail, .05) = + or - .7397

Critical value (2-tail, .05) = +/- .8116

Table 6. Correlation matrix for U-234 in sediments during operational phase of JPG Radiological Environmental Monitoring Program.

	Big Creek				Middlefork Creek			
	up	LOF	down	BS	up	LOF	down	BS
	Loc 4	Loc 5	Loc 8	Loc 2	Loc 3	Loc 6	Loc 7	Loc 1
Loc 4	1							
Loc 5	.4380	1						
Loc 8	.1583	.0923	1					
Loc 2	.3138	.5964	.0108	1				
Loc 3	-.6741	-.0594	-.0704	-.3369	1			
Loc 6	.2439	.3831	-.2090	.7592	.0102	1		
Loc 7	.0376	.0195	-.5076	-.0789	-.2429	-.3245	1	
Loc 1	.4148	.1929	.3009	-.2075	-.5340	-.6354	.5248	1

Critical value (1-tail, .05) = + or - .6266

Critical value (2-tail, .05) = +/- .7048

Table 7. Correlation matrix for U-234 in groundwater during operational phase of JPG Radiological Environmental Monitoring Program.

	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Loc 7	Loc 8
Loc 1	1							
Loc 2	-.4326	1						
Loc 3	.0619	-.5216	1					
Loc 4	-.2766	.2471	-.5768	1				
Loc 5	-.2196	-.2341	.5943	-.4168	1			
Loc 6	-.9453	.4226	-.1813	.2828	-.0490	1		
Loc 7	-.1850	-.6694	.1443	.2184	.3876	.1316	1	
Loc 8	-.6351	.3828	-.2823	-.0429	.3204	.6226	.2294	1

Critical value (1-tail, .05) = + or - .6765

Critical value (2-tail, .05) = +/- .7532

Table 8. Correlation matrix for U-234 in soils from impact areas (sites 6,8,10 and 12) and neighboring non-impact areas (sites 36/43,19/44,26/47 and 32/48).

	6	8	10	12	36	19	26	32
6	1							
8	.5016	1						
10	.1896	-.2070	1					
12	.9328	.4611	.2445	1				
36	-.3464	-.0804	-.7089	-.3858	1			
19	-.6826	-.3962	-.2877	-.7362	-.0578	1		
26	-.5325	-.1619	-.6198	-.7008	.8589	.2823	1	
32	-.2263	.3473	-.4046	-.4514	.5051	.0664	.7092	1

Critical value (1-tail, .05) = + or - .6765

Critical value (2-tail, .05) = +/- .7532

Table 9. Correlation matrix for U-238 in sediment during operational phase of JPG Radiological Environmental Monitoring Program.

	Big Creek				Middlefork Creek			
	up	LOF	down	BN	up	LOF	down	BS
	Loc 4	Loc 5	Loc 8	Loc 2	Loc 3	Loc 6	Loc 7	Loc 1
Loc 4	1							
Loc 5	.1900	1						
Loc 8	-.2483	-.2784	1					
Loc 2	.2928	.2472	.1928	1				
Loc 3	-.5685	-.0199	-.2262	-.2112	1			
Loc 6	.2154	.0937	-.4687	.6104	.0126	1		
Loc 7	-.1766	.3903	.0782	-.2704	-.2725	-.3497	1	
Loc 1	.1093	.4922	.5313	-.0487	-.3932	-.6109	.5809	1

Critical value (1-tail, .05) = + or - .6266

Critical value (2-tail, .05) = +/- .7048

Table 10. Correlation matrix for U-238 in surface water during operational phase of JPG Radiological Environmental Monitoring Program.

	Big Creek				Middlefork Creek			
	up	LOF	down	BN	up	LOF	down	BS
	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Loc 7	Loc 8
Loc 1	1							
Loc 2	.7982	1						
Loc 3	.7954	.7815	1					
Loc 4	.9124	.9534	.8260	1				
Loc 5	.9007	.8339	.5614	.8929	1			
Loc 6	.7990	.9308	.5850	.9344	.9359	1		
Loc 7	.8006	.7356	.5348	.8707	.8746	.8878	1	
Loc 8	.8517	.8987	.8573	.9682	.8046	.8680	.8710	1

Critical value (1-tail, .05) = + or - .7397

Critical value (2-tail, .05) = +/- .8116

Table 11. Correlaton matrix for U-238 in groundwater during operational phase of JPG Radiological Environmental Monitoring Program.

	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Loc 7	Loc 8
Loc 1	1							
Loc 2	-.6072	1						
Loc 3	.1607	-.4608	1					
Loc 4	.1208	-.0150	.2752	1				
Loc 5	.3715	-.1490	.4624	.7056	1			
Loc 6	-.7496	.1616	.3702	.1749	.1421	1		
Loc 7	.4626	-.7961	.3905	.5588	.5139	1		
Loc 8	-.1171	.1353	.2077	.5611	.6254	.4735	.3221	1

Critical value (1-tail, .05) = + or - .6765

Critical value (2-tail, .05) = +/- .7532

Table 12. Correlation matrix for U-238 in soils from impact areas (sites 6,8,10 and 12) and neighboring non-impact areas (sites 36/43,19/44,26,47 and 32/48).

	6	8	10	12	36	19	26	32
6	1							
8	.5610	1						
10	.1949	-.1773	1					
12	.9346	.5198	.2957	1				
36	-.2877	-.1203	-.5908	-.4069	1			
19	-.5709	-.0614	-.4192	-.6063	.0818	1		
26	-.3352	-.1866	-.5448	-.5732	.8346	.4206	1	
32	-.1833	.3149	-.4376	-.3934	.7079	.0475	.6615	1

Critical value (1-tail, .05) = + or - .6765

Critical value (2-tail, .05) = +/- .7532

Table 13. Results of regressions of uranium in sediments, JPG Radiological Environmental Monitoring Program.

Variables	Location	slope	intercept	r	r^2	prob.
U-238 x time	M-4	-2.5E-3	.24	-.48	.23	.1585
U-234 x time	M-4	-2.2E-3	.22	-.49	.24	.1520
U-238 x U-234	M-4	1.12	-.0168	.945	.892	.0004
U-238 x time	M-5	-1.7E-3	.22	-.33	.11	.3804
U-234 x time	M-5	-3.1E-3	.22	-.75	.56	.0208
U-238 x U-234	M-5	1.04	.022	.84	.71	.0042
U-238 x time	M-8	9.6E-4	.17	.10	.01	.8129
U-234 x time	M-8	-5.3E-4	.16	-.09	.01	.8326
U-238 x U-234	M-8	.9615	.0482	.61	.38	.1048
U-238 x time	M-2	-5.5E-3	.39	-.44	.20	.2302
U-234 x time	M-2	-6.4E-3	.38	-.51	.26	.1565
U-238 x U-234	M-2	.9369	.0406	.937	.877	.0002
U-238 x time	Big Creek	-2.5E-3	.26	-.28	.08	.1003
U-234 x time	Big Creek	-3.3E-3	.20	-.41	.17	.0133
U-238 x U-234	Big Creek	.959	.032	.87	.76	<.0001
U-238 x time	Mdlfk Cr.	1.4E-4	.55	.008	<.01	.9615
U-234 x time	Mdlfk Cr.	-7.1E-5	.56	-.004	<.01	.9812
U-238 x U-234	Mdlfk Cr.	.954	.023	.974	.948	<.0001
U-238 x time	M-3	-9.2E-4	.74	-.05	.00	.8886
U-234 x time	M-3	6.1E-4	.73	.03	.00	.9355
U-238 x U-234	M-3	.8466	.0944	.961	.923	<.0001
U-238 x time	M-6	-.01	.82	-.71	.50	.0334
U-234 x time	M-6	-.0099	.81	-.72	.52	.0295
U-238 x U-234	M-6	1.052	-.034	.991	.982	<.0001

Table 13 continued.

Variables	Location	slope	intercept	r	r^2	prob.
U-238 x time	M-7	7.5E-3	.23	.48	.23	.2312
U-234 x time	M-7	6.4E-3	.28	.40	.16	.2196
U-238 x U-234	M-7	.9827	-.0154	.989	.978	<.0001
U-238 x time	M-1	7.3E-3	.32	.53	.28	.1119
U-234 x time	M-1	5.7E-3	.32	.46	.21	.1796
U-238 x U-234	M-1	1.065	-1.5E-4	.967	.936	<.0001
U-238 x time	All	-9.4E-4	.40	-.05	.003	.6636
U-234 x time	All	-1.4E-3	.40	-.08	.006	.5177
U-238 x U-234	All	.94	.03	.973	.946	<.0001
U-234 x U-234	M-4 x M-2	.0708	.1435	.31	.10	.4490
U-238 x U-238	M-4 x M-3	-.0802	.2132	-.57	.32	.1414
U-238 x U-238	M-6 x M-8	-.794	.737	-.47	.22	.2414
U-238 x U-238	M-6 x M-1	-.676	.908	-.65	.42	.0830

Table 14. Results of regressions of uranium in surface water. JPG Radiological Environmental Monitoring Program.

Variables	Location	slope	intercept	r	r^2	prob.
U-238 x time	All	1.15E-2	-.044	.33	.11	.0022
U-234 x time	All	3.71E-3	.043	.58	.33	<.0001
U-238 x U-234	All	3.64	-.289	.69	.48	<.0001
U-238 x time	Big Cr.	1.71E-2	-.0525	.39	.15	.0083
U-234 x time	Big Cr.	3.39E-3	.061	.62	.38	<.0001
U-238 x U-234	Big Cr.	7.08	-.61	.91	.83	<.0001
U-238 x time	Mdlfrk Cr.	5.3E-3	.0044	.71	.50	<.0001
U-234 x time	Mdlfrk Cr.	5.4E-3	.0095	.68	.46	<.0010
U-238 x U-234	Mdlfrk Cr.	.87	.009	.98	.96	<.0010
U-238 x time	NE up	2.8E-3	.064	.67	.45	.0232
U-234 x time	NE up	2.1E-3	.064	.73	.54	.0103
U-238 x U-234	NE up	.99	.014	.70	.49	.0168
U-238 x time	N LOF	.053	-.320	.70	.49	.0117
U-234 x time	N LOF	6.7E-3	.041	.78	.60	.0033
U-238 x U-234	N LOF	8.2	-.68	.98	.96	<.0001
U-238 x time	NW down	3.8E-3	.061	.74	.55	.0094
U-234 x time	NW down	2.0E-3	.078	.65	.42	.0301
U-238 x U-234	NW down	1.07	.0060	.64	.41	.0326
U-238 x time	BN	2.7E-3	.066	.77	.59	.0096
U-234 x time	BN	2.0E-3	.071	.80	.64	.0118
U-238 x U-234	BN	1.33	-.030	.94	.88	<.0001
U-238 x time	SE up	1.6E-3	-.043	.69	.47	.0603
U-234 x time	SE up	8.8E-3	-.05	.69	.47	.0599

Table 14 continued.

Variables	Location	slope	intercept	r	r^2	prob.
U-238 x U-234	SE up	.86	-.0014	.997	.993	<.0001
U-238 x time	S LOF	5.1E-3	9.5E-4	.81	.65	.0087
U-234 x time	S LOF	4.5E-3	-4.0E-4	.79	.63	.0110
U-238 x U-234	S LOF	1.10	.0052	.983	.966	<.0001
U-238 x time	SW down	5.7E-3	-.022	.87	.75	.0025
U-234 x time	SW down	6.0E-3	-.018	.81	.67	.0071
U-238 x U-234	SW down	.86	3.4E-3	.975	.95	<.0001
U-238 x time	BS	3.0E-3	.070	.76	.57	.0294
U-234 x time	BS	3.8E-3	.066	.83	.70	.0135
U-238 x U-234	BS	.80	.017	.978	.957	<.0001
U-238 x time	ME	1.1E-3	.020	.24	.06	.6390
U-234 x time	ME	7.1E-4	.032	.17	.03	.7487
U-238 x U-234	ME	1.0	-.0027	.967	.935	.0016

Table 15. Results of regressions of uranium in groundwater, JPG Radiological Environmental Monitoring Program.

Variables	location	slope	intercept	r	r^2	prob.
U-234 x time	All	-.0081	1.132	-.11	.01	.2768
U-238 x time	All	.0048	.708	.11	.01	.2843
U-238 x U-234	All	.4956	.3028	.82	.68	<.0001
U-234 x time	East side	-.0259	1.423	-.30	.09	.0339
U-238 x time	East side	-1.26E-3	.714	-.03	<.01	.8354
U-238 x U-234	East side	.3814	.3320	.79	.62	<.0001
U-238 x time	West side	.0117	.6981	.26	.07	.0722
U-234 x time	West side	.0106	.8605	.18	.03	.2014
U-238 x U-234	West side	.7501	.1166	.944	.891	<.0001
U-234	MW-6 x MW-1	-3.91	3.07	-.945	.894	<.0001
U-234	MW-7 x MW-2	-.2494	1.35	-.67	.45	.1000
U-238	MW-6 x MW-1	-1.916	2.152	-.75	.56	.0524
U-238	MW-7 x MW-2	-.5037	1.0724	-.80	.63	.0322
U-238	MW-8 x MW-3	.3569	.3393	.82	.68	.0222

Table 16. Results of regressions of uranium in soil, JPG Radiological Environmental Monitoring Program.

Variables	Location	slope	intercept	r	r^2	prob.
U-234 x time	All w/base	.0258	.982	.17	.03	.0224
U-238 x time	All w/base	.217	2.62	.17	.03	.0231
U-235 x time	All w/base	.006	.065	.17	.03	.0166
U-238 x U-234	All w/base	8.41	-5.64	.994	.988	<.0001
U-235 x U-234	All w/base	.218	-.143	.984	.968	<.0001
U-235 x U-238	All w/base	.0258	.0031	.988	.975	<.0001
U-238 x U-234	Baseline	.9653	.0737	.934	.873	<.0001
U-235 x U-234	Baseline	.0171	.0154	.21	.04	.1915
U-235 x U-238	Baseline	.0140	.0170	.18	.03	.2684
U-234 x time	Operational	.0214	1.12	.11	.01	.1704
U-238 x time	Operational	.1859	3.60	.12	.01	.1596
U-238 x U-234	Operational	8.41	-5.71	.994	.988	<.0001
U-235 x time	Operational	.0055	.0808	.13	.02	.1125
U-235 x U-234	Operational	.2182	-.1467	.984	.968	<.0001
U-235 x U-238	Operational	.0259	.0017	.987	.975	<.0001
U-234 x U-238	500C LOF	.1177	.7323	.999	.998	<.0001
U-234 x time	500C LOF	.0448	2.06	.14	.02	.4330
U-238 x time	500C LOF	.3880	11.13	.15	.02	.4238
U-234 x U-238	Non-impact	.8406	.0838	.922	.851	<.0001
U-234 x U-238	45,46,52	.1402	.6720	.999	.998	<.0001

Table 17. Cross media regressions, JPG Radiological Environmental Monitoring Program.

Variables	Location	slope	intercept	r	r^2	prob.
U-238	MW x sediments	.6744	.4412	.28	.08	.0207
U-238 x U-234						
	MW x sediments	.5820	.4823	.25	.06	.0388
U-234	MW x sediments	.574	.657	.16	.025	.1960
U-234 x U-238						
	MW x sediments	.60	.64	.16	.025	.1960
U-234	SW x MW	-.0134	.1337	-.14	.02	.2781
U-238	MW x SW	-.155	.7275	-.11	.01	.3890
U-234	SW x sediments	-.0438	.1407	-.12	.02	.3182
U-238	SW x sediments	-.1691	.2406	-.10	.01	.4005

Figure 1 Soil U-234

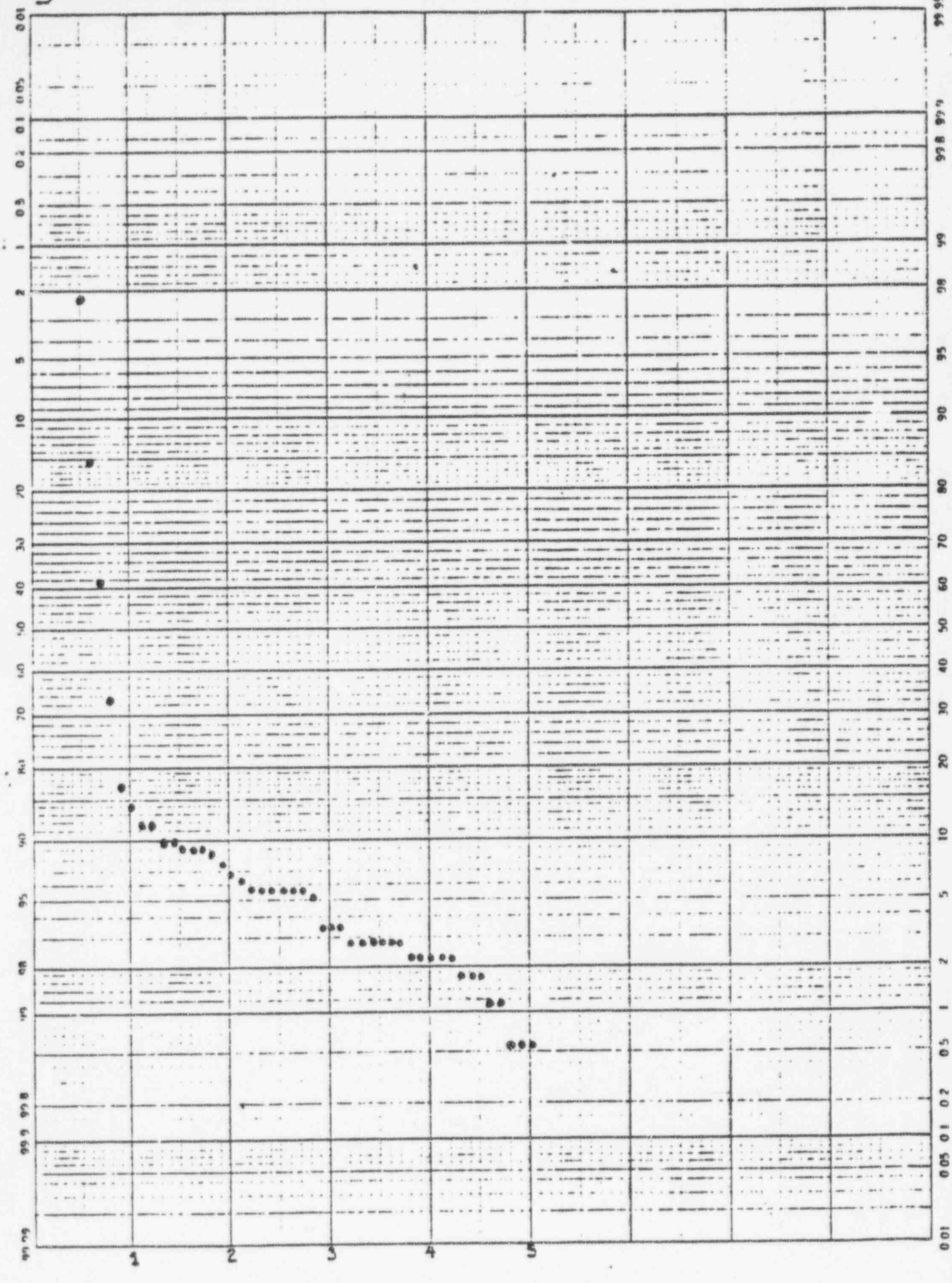


Figure 2 Soil U-238

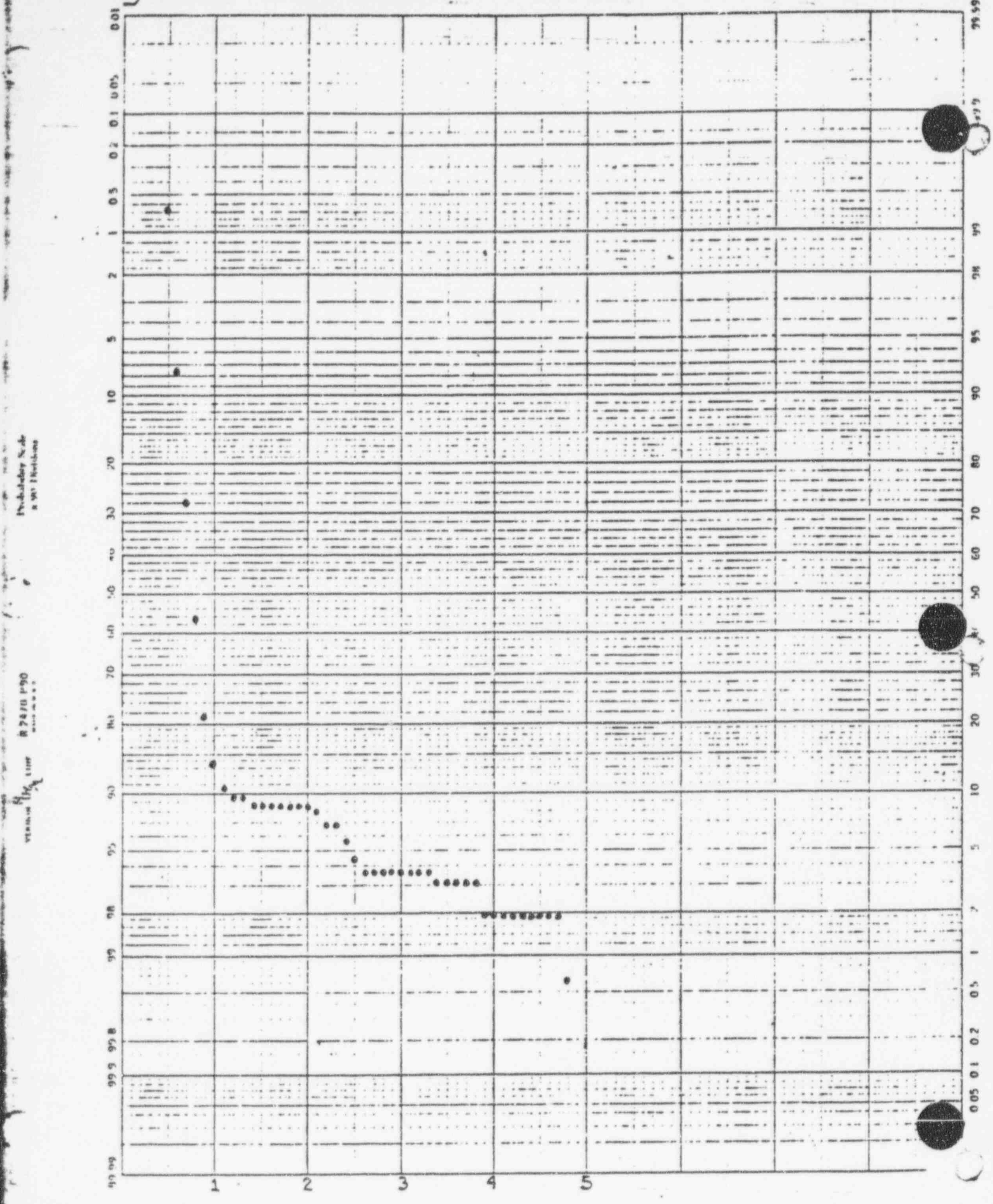


Figure 3 Soil U-235

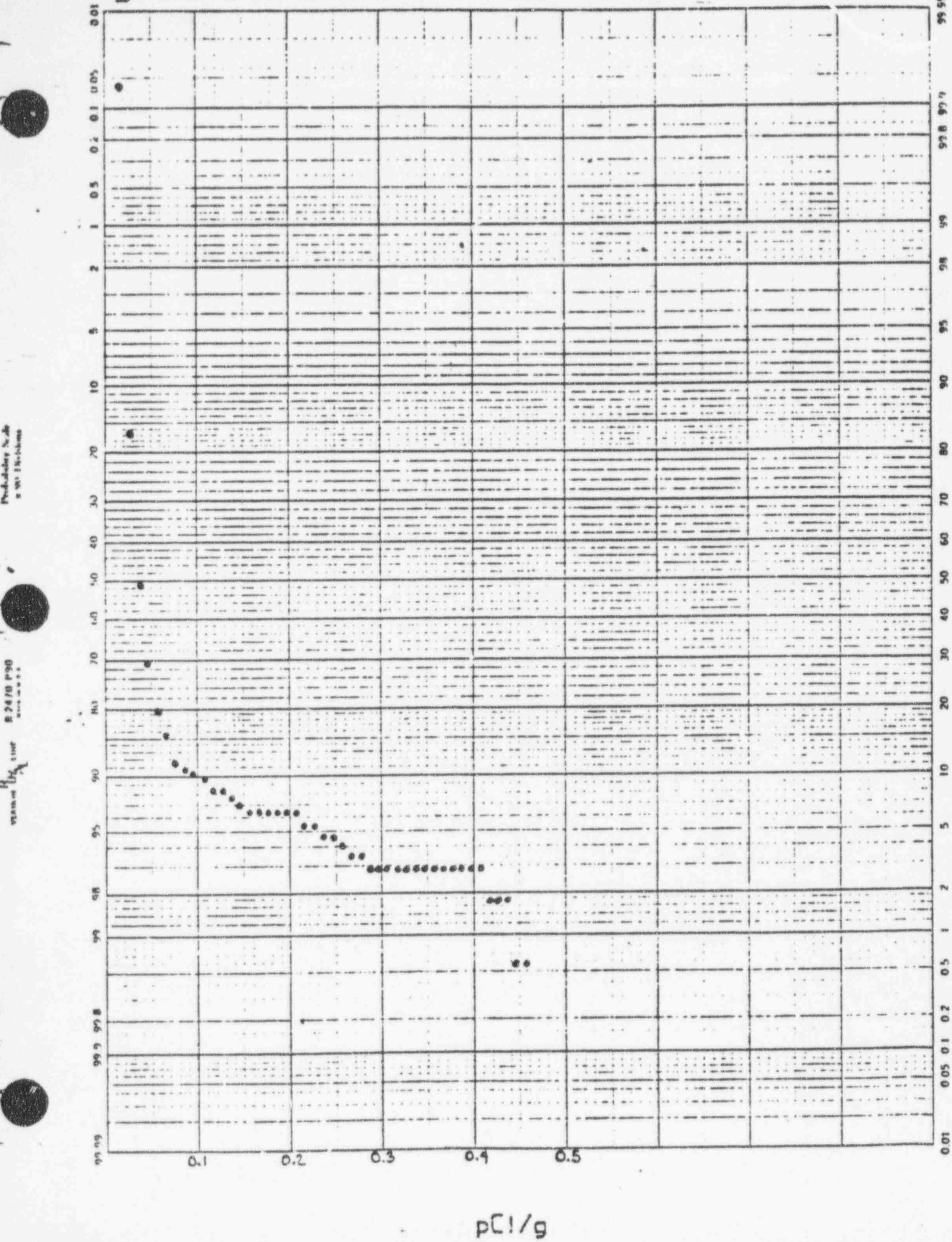


Figure 4 Sediment U-234

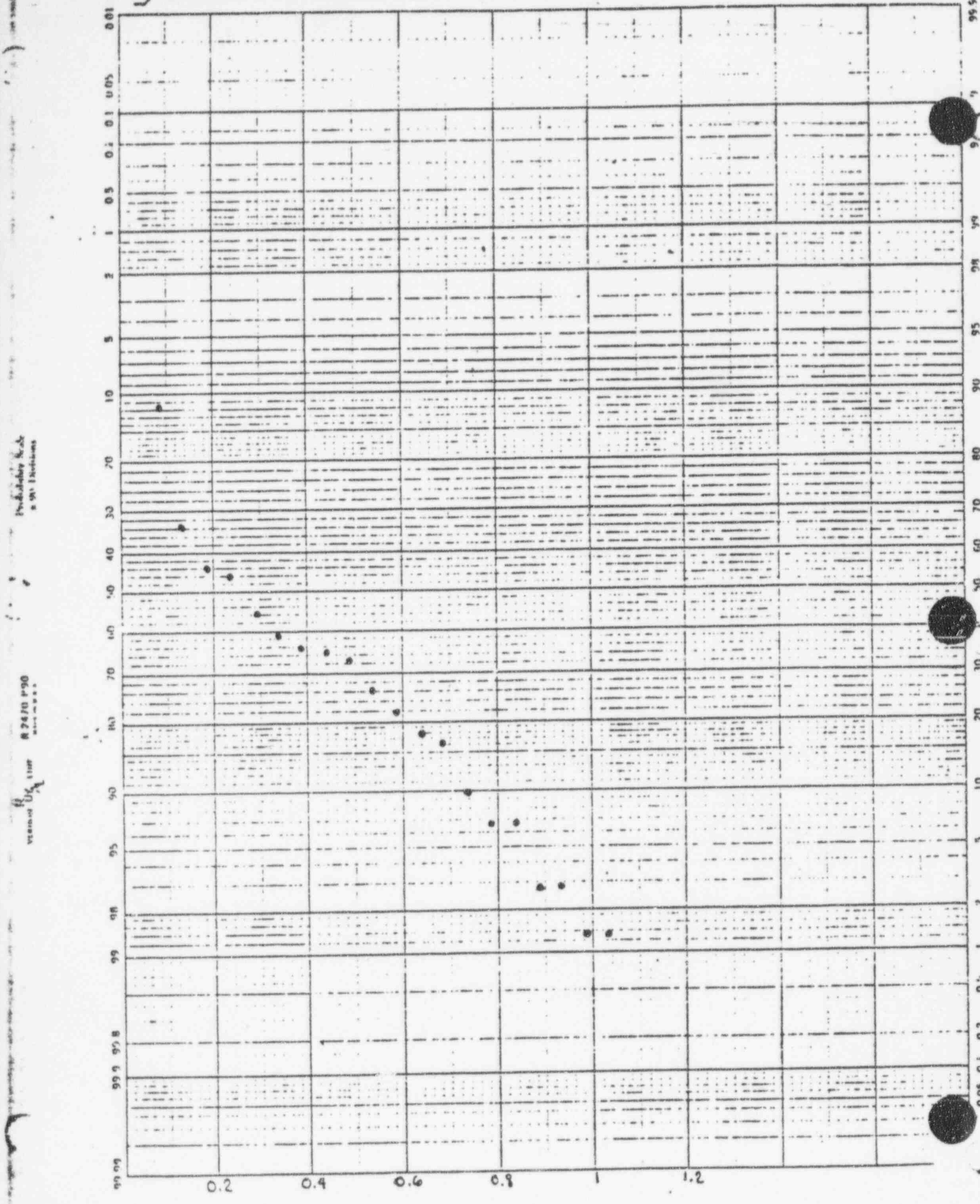


Figure 5 Sediment U-238

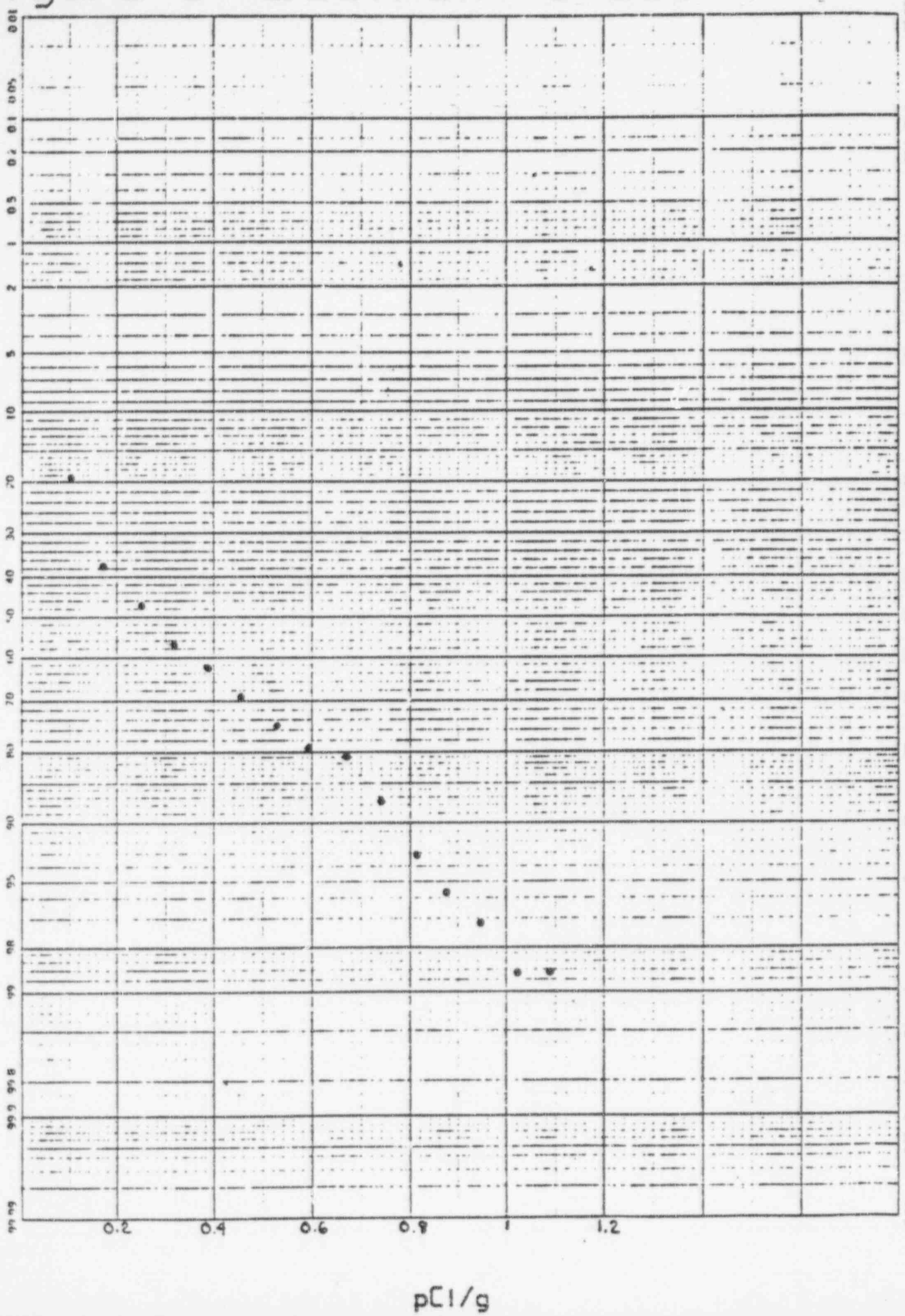


Figure 6 Surface Water U-234

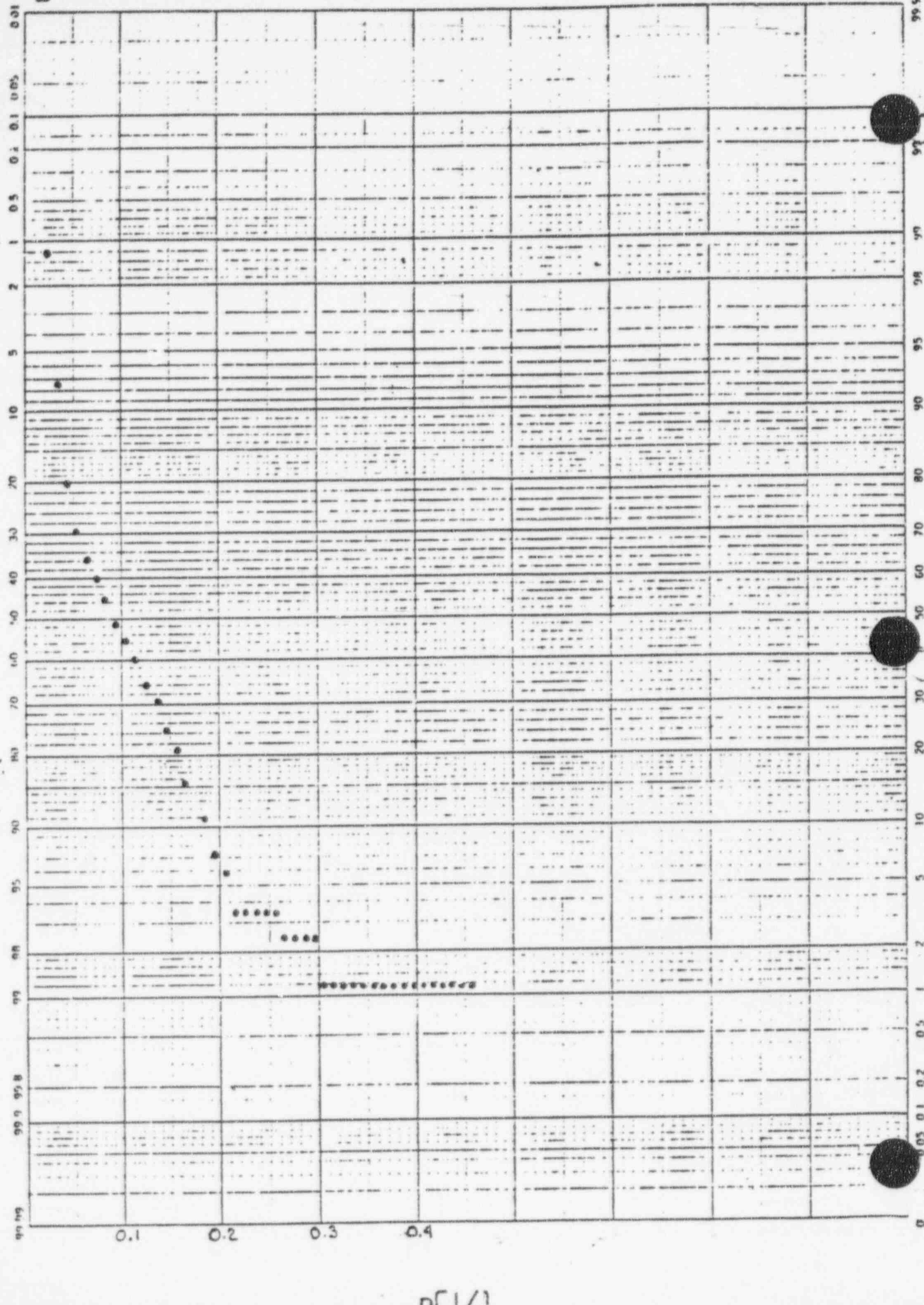


Figure 7 Surface Water U-238

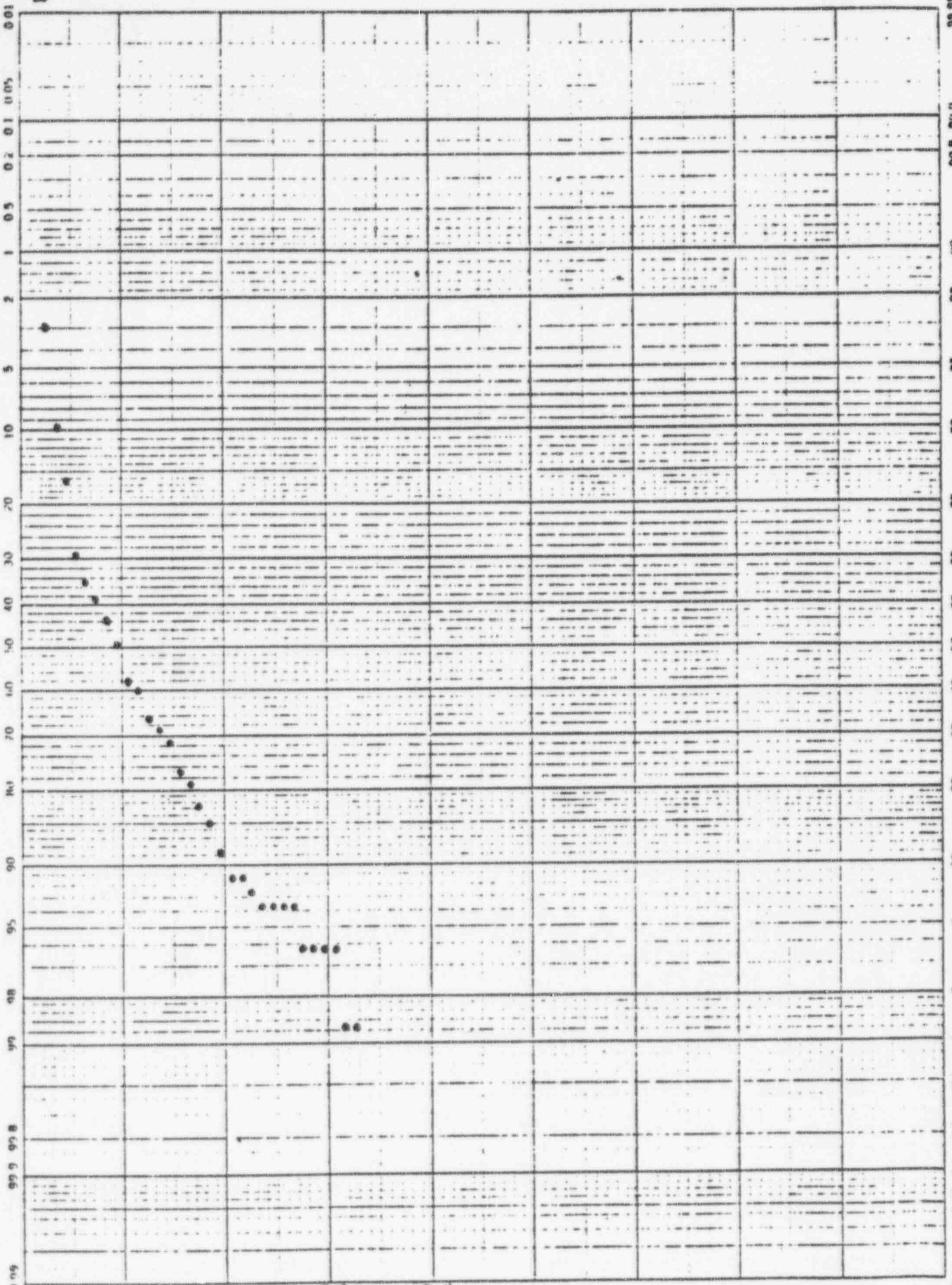


Figure 8 Groundwater U-234

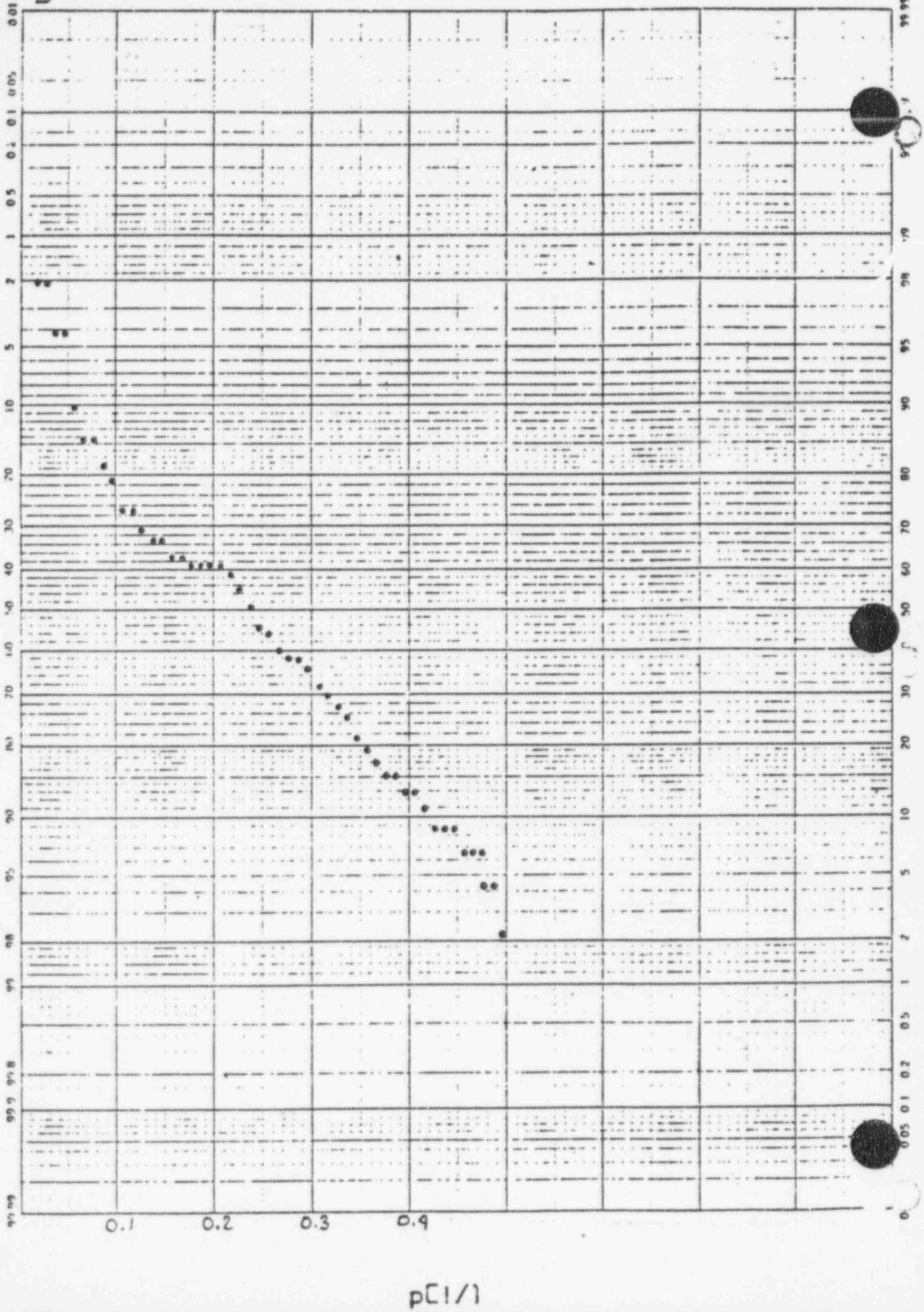


Figure 9 Groundwater U-238

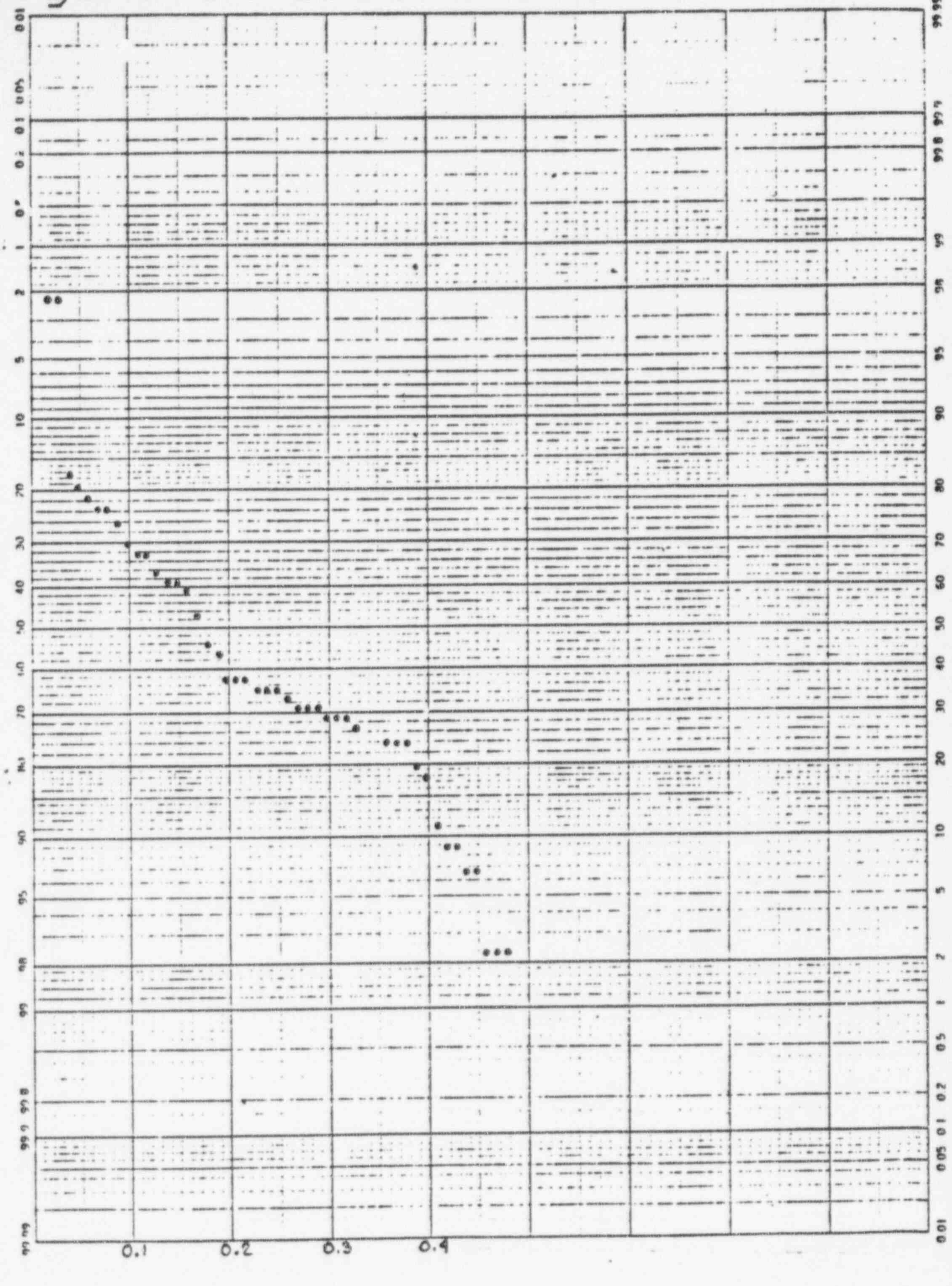


Figure 10 Groundwater U-234

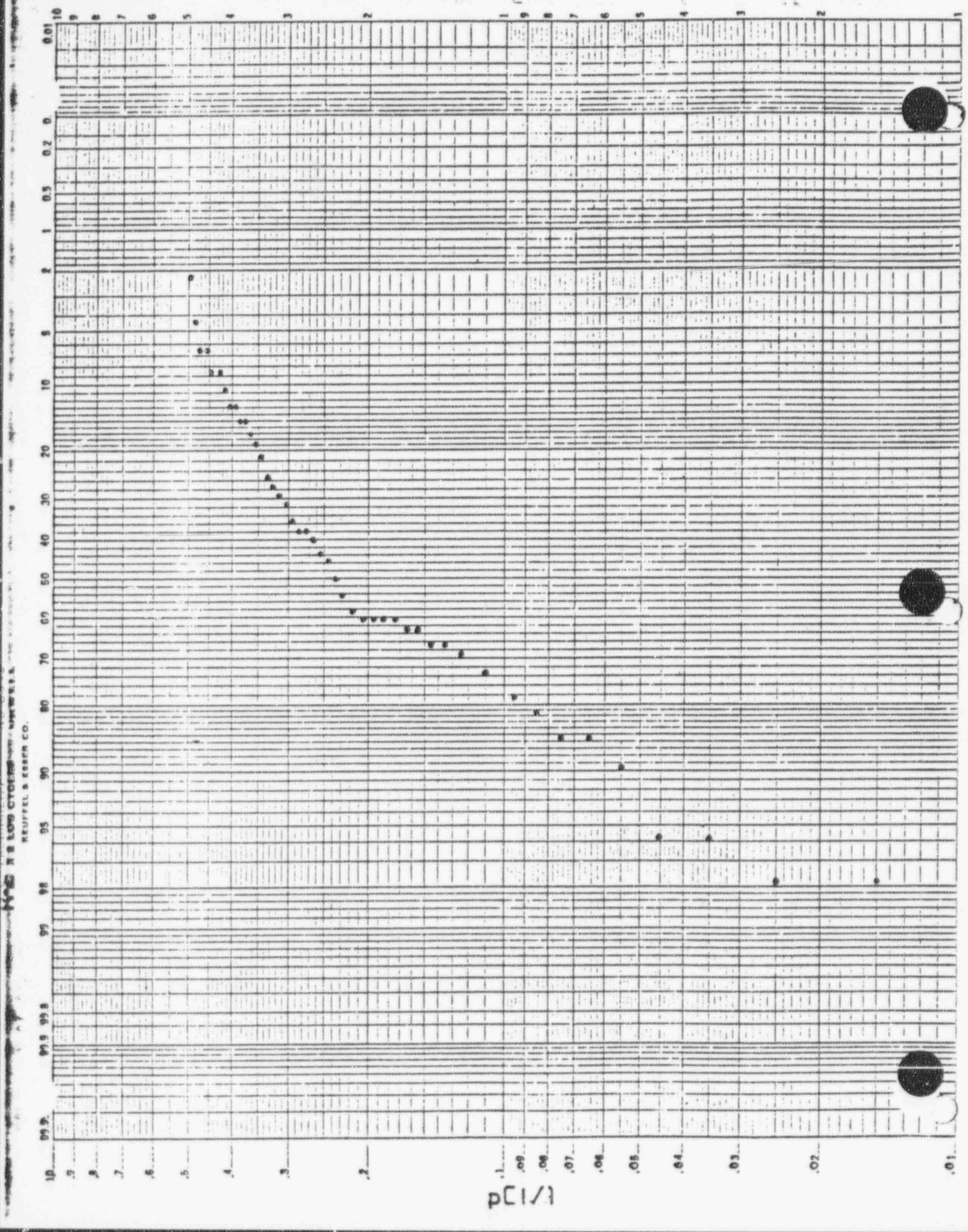


Figure 11 Groundwater U-238

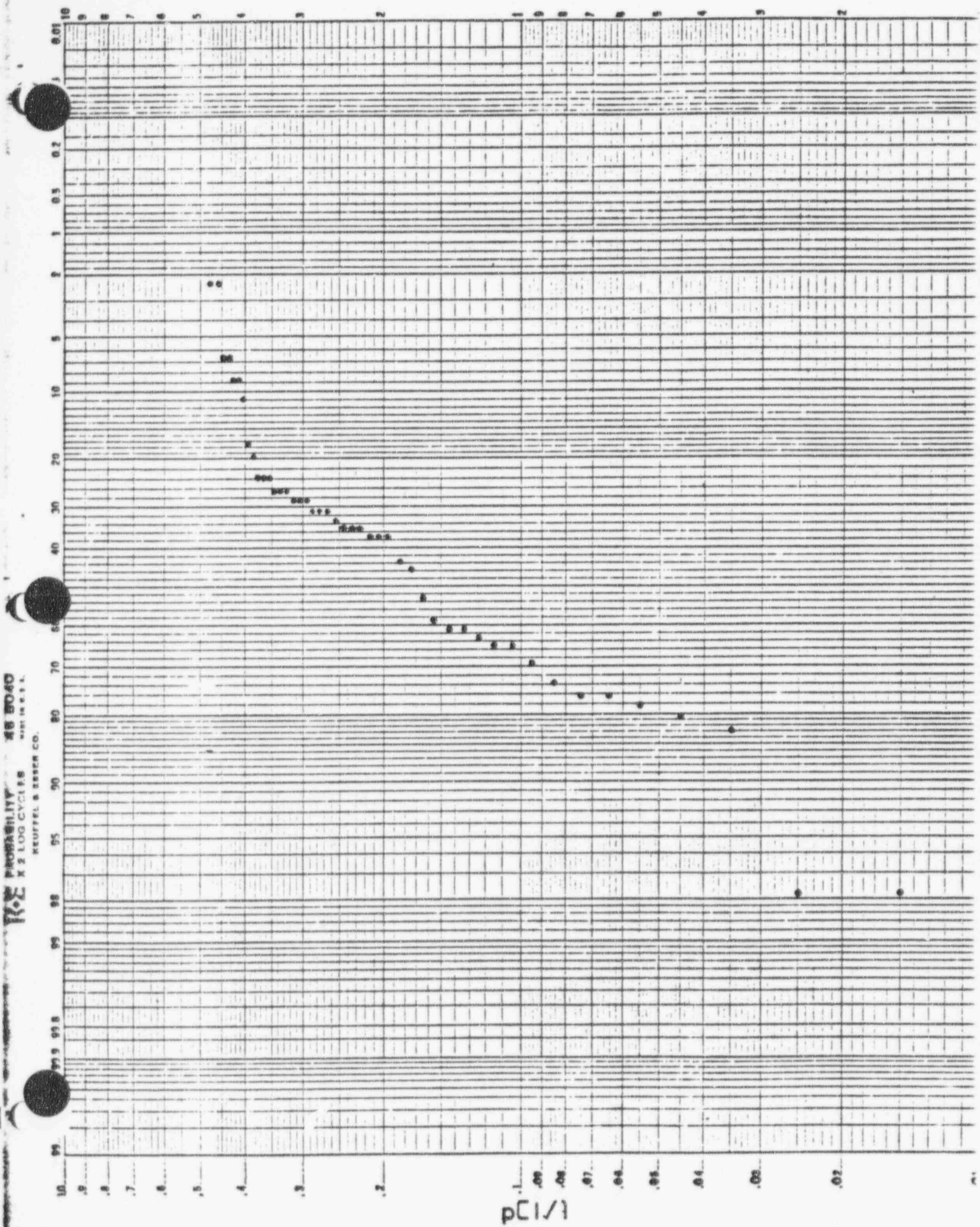


Figure 12
Big Creek Sediment U-238

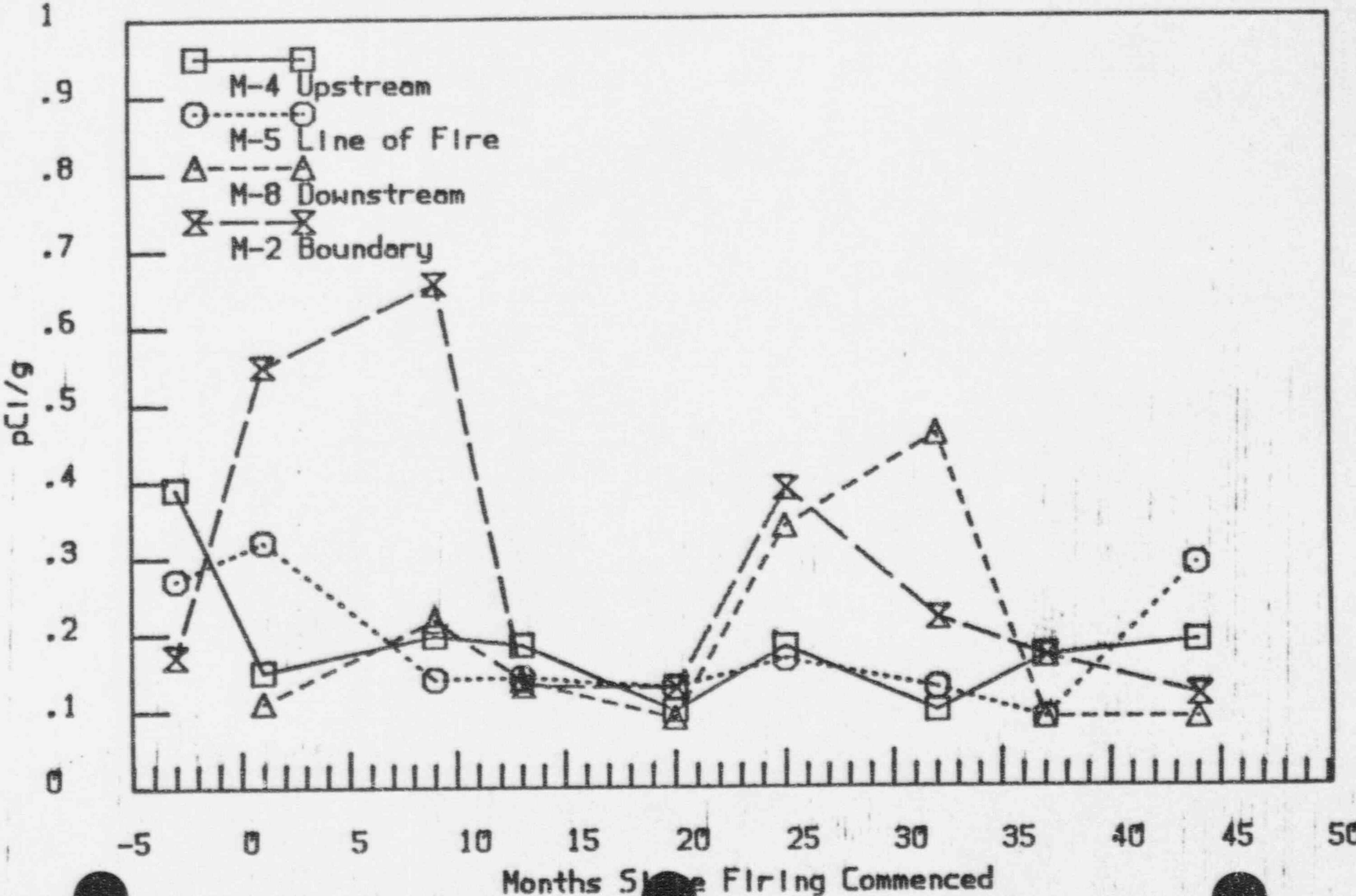


Figure 13

Big Creek Sediment Ratios JPG

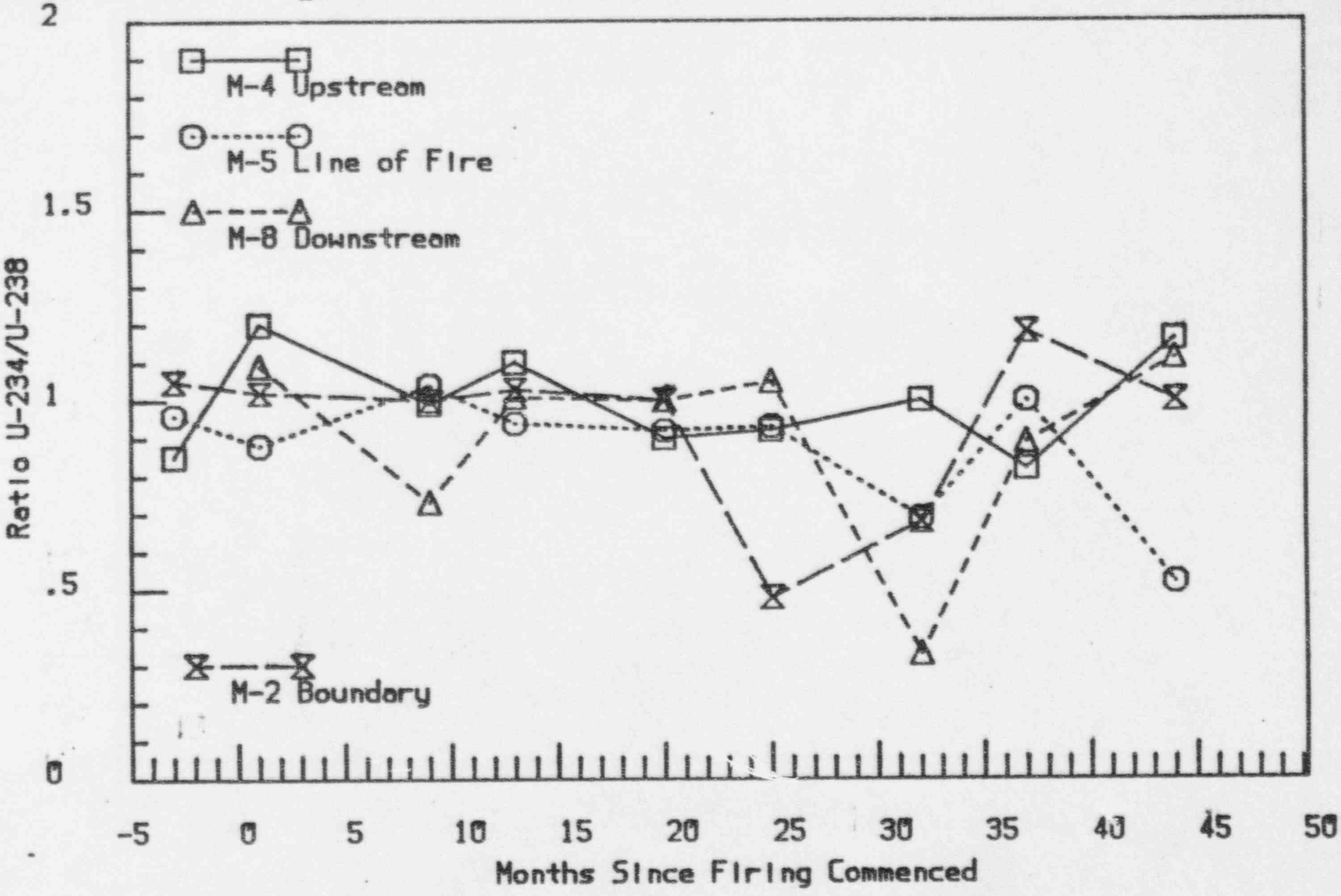


Figure 14
Middlefork Creek Sediment U-238

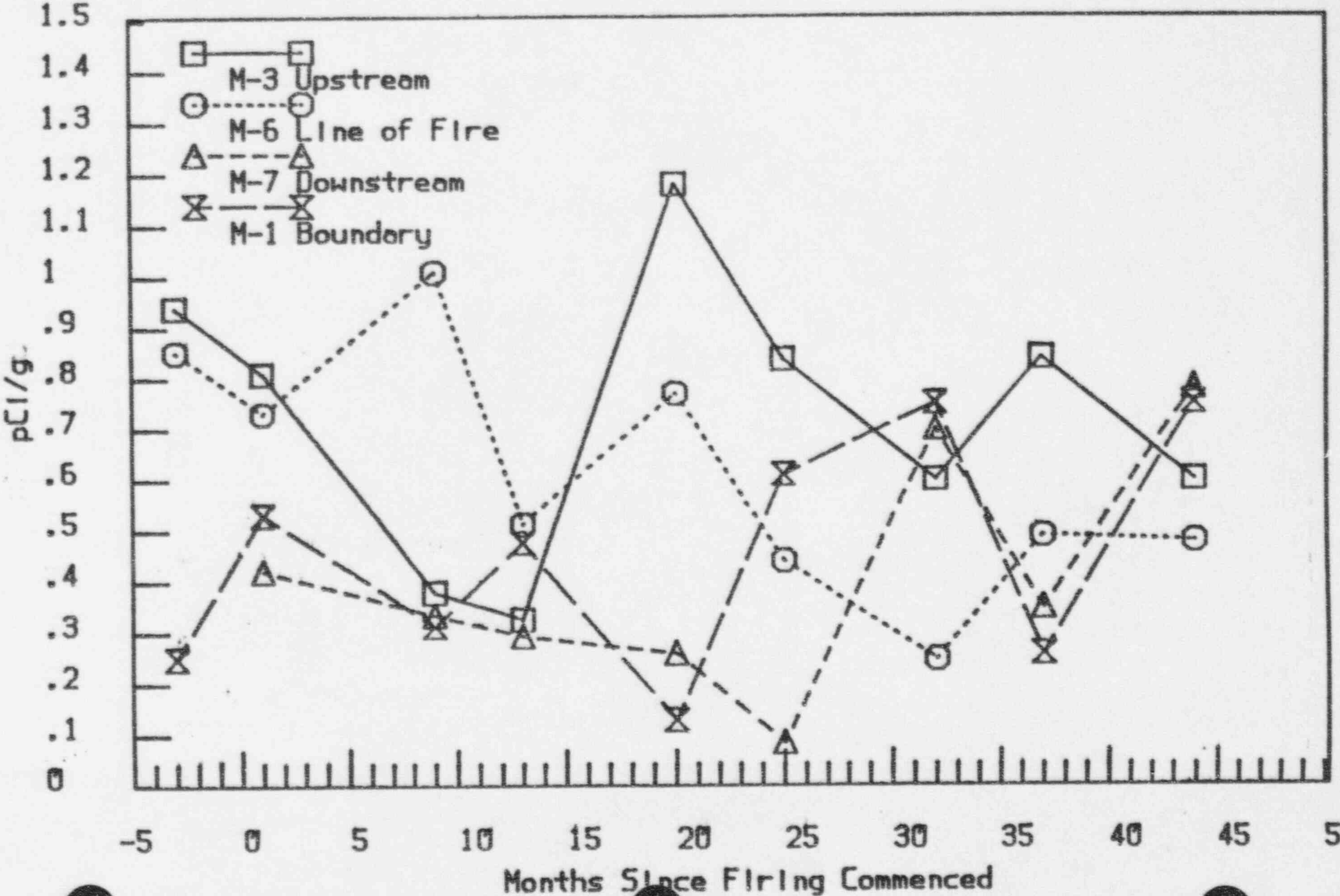


Figure 15
Middlefork Creek Sediment JPG

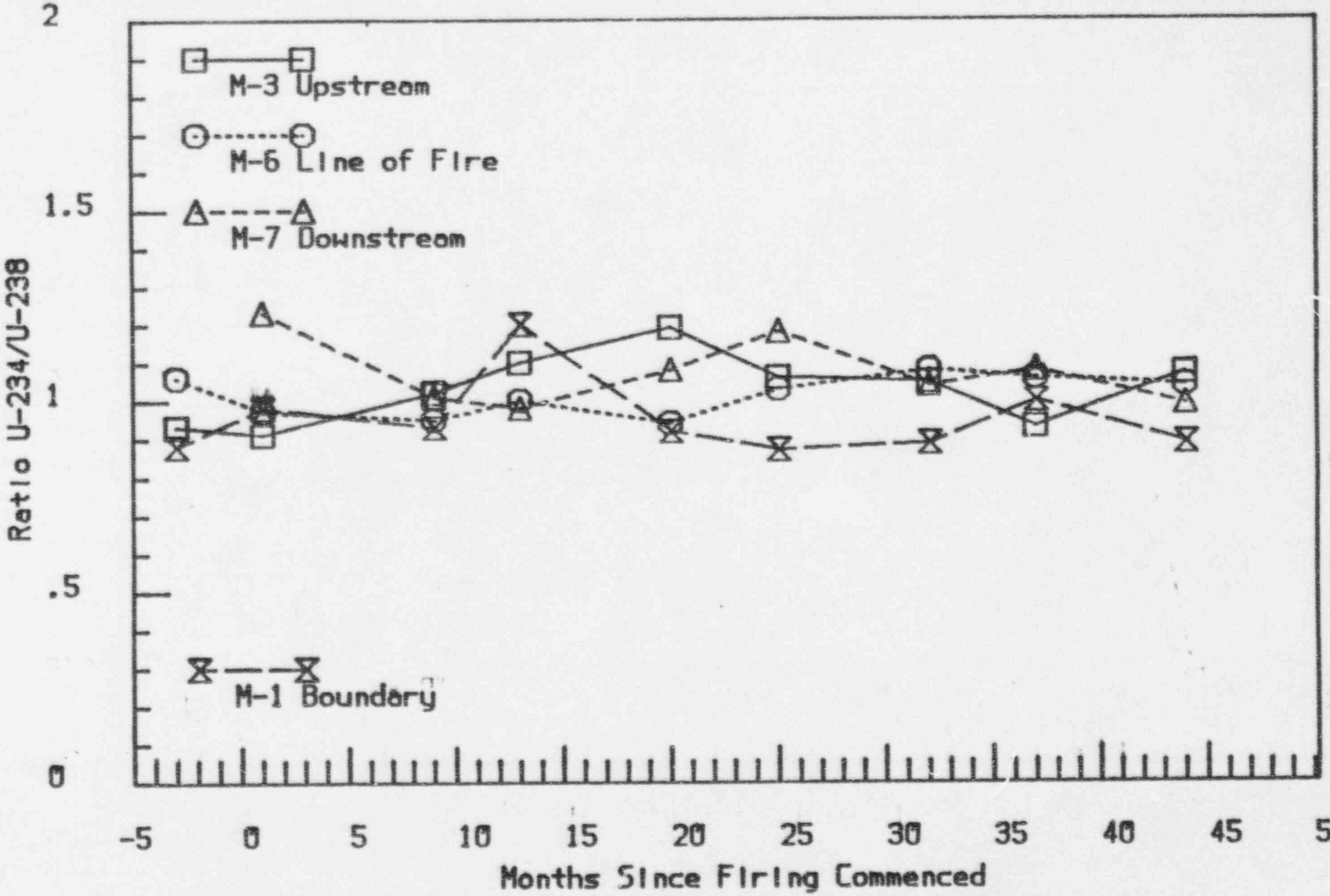


Figure 16
Big Creek Uranium - 238

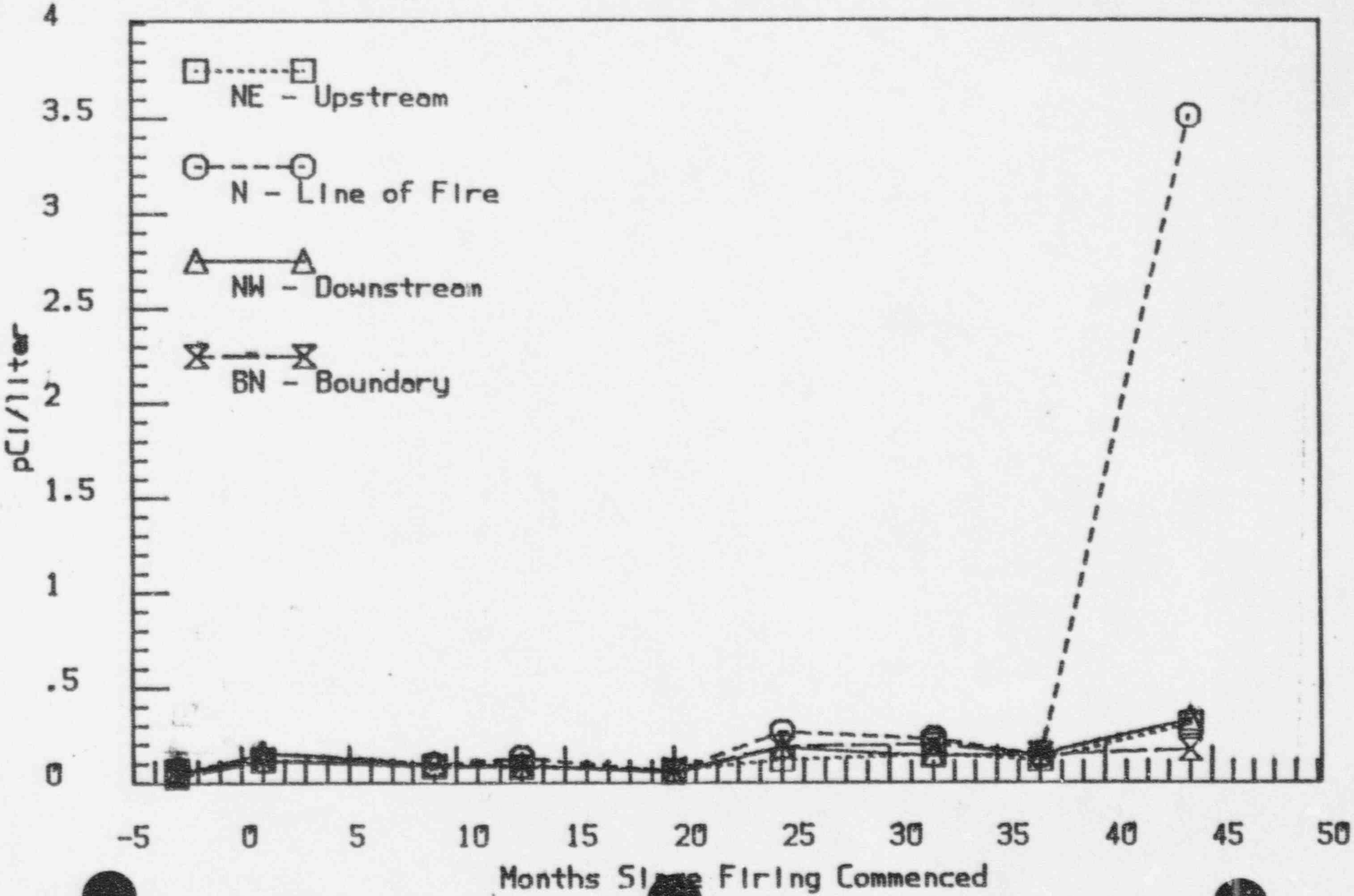


Figure 17
Middlefork Creek U-238

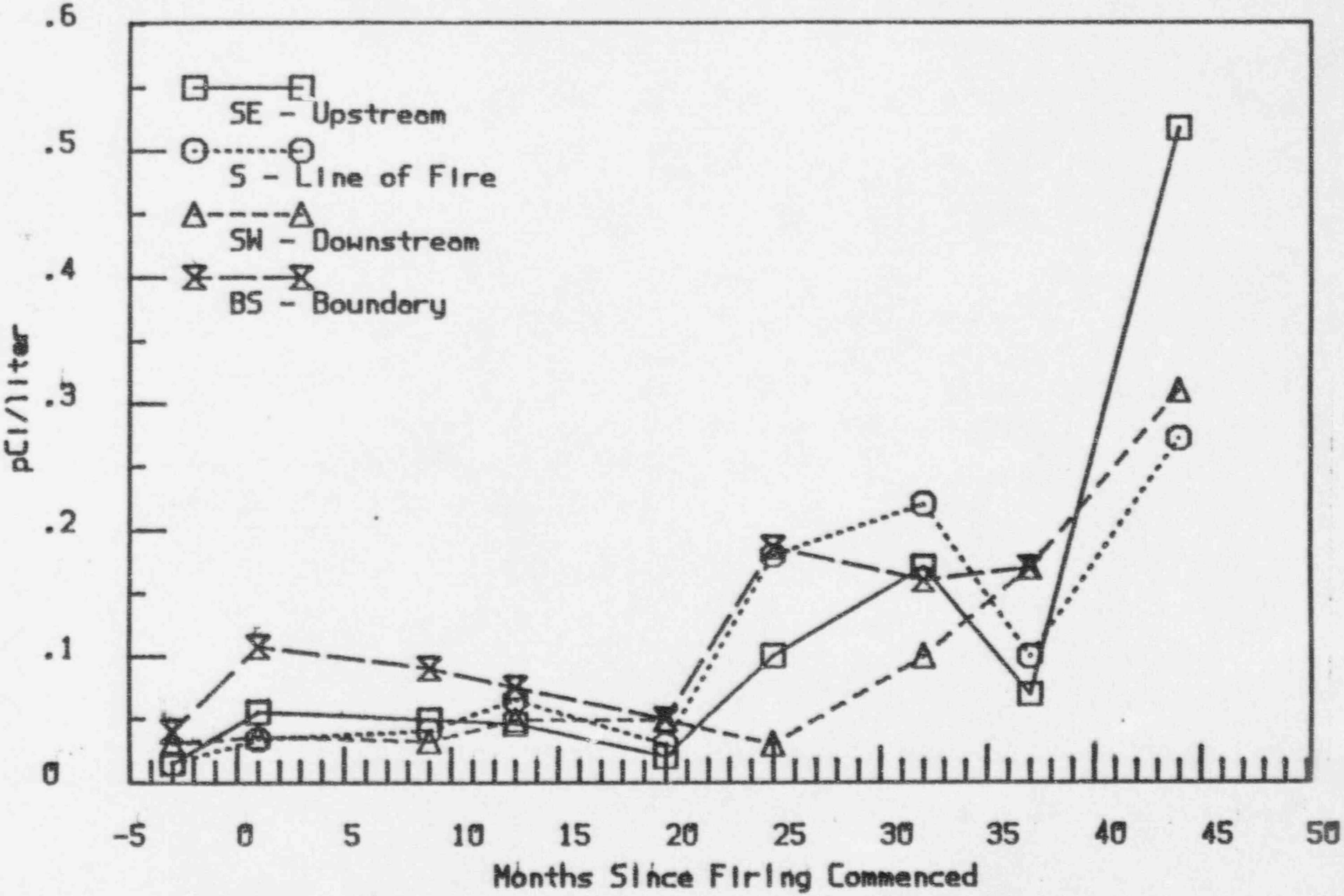


Figure 18

Surface Water Ratio U-234/U-238 JPG

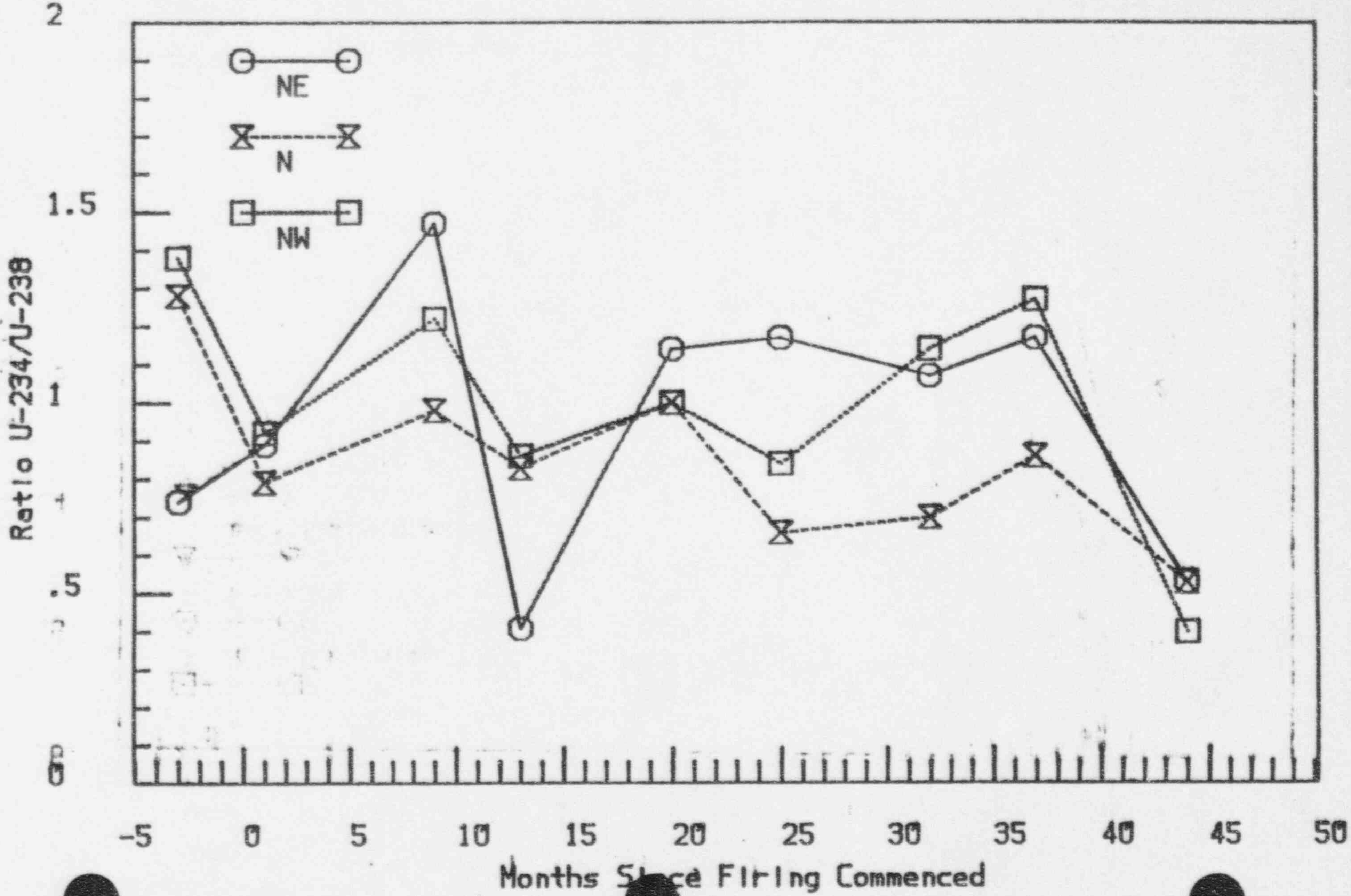


Figure 19
Surface Water Ratio U-234/U-238 JPG

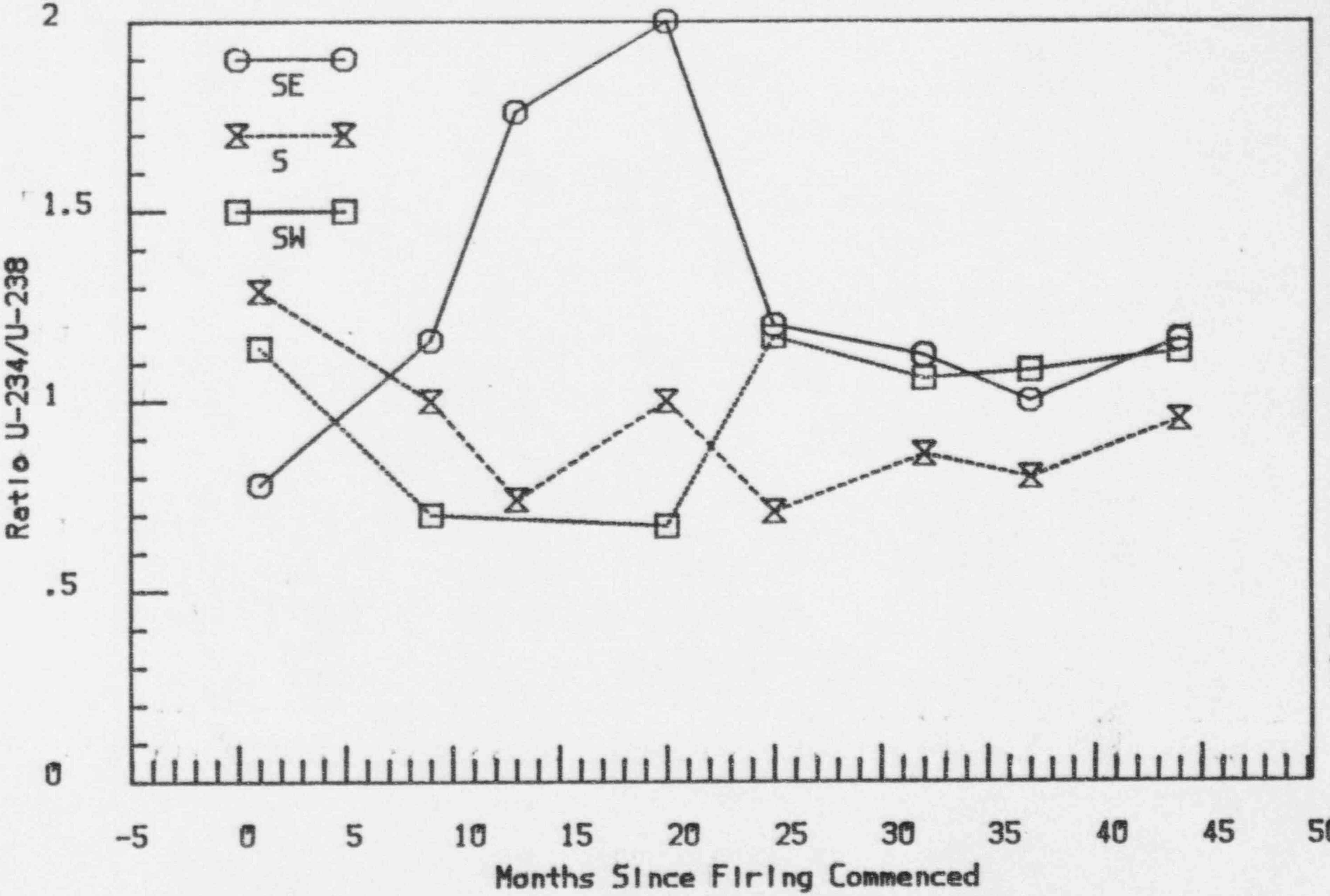


Figure 20

Surface Water Ratio U-234/U-238 JPG

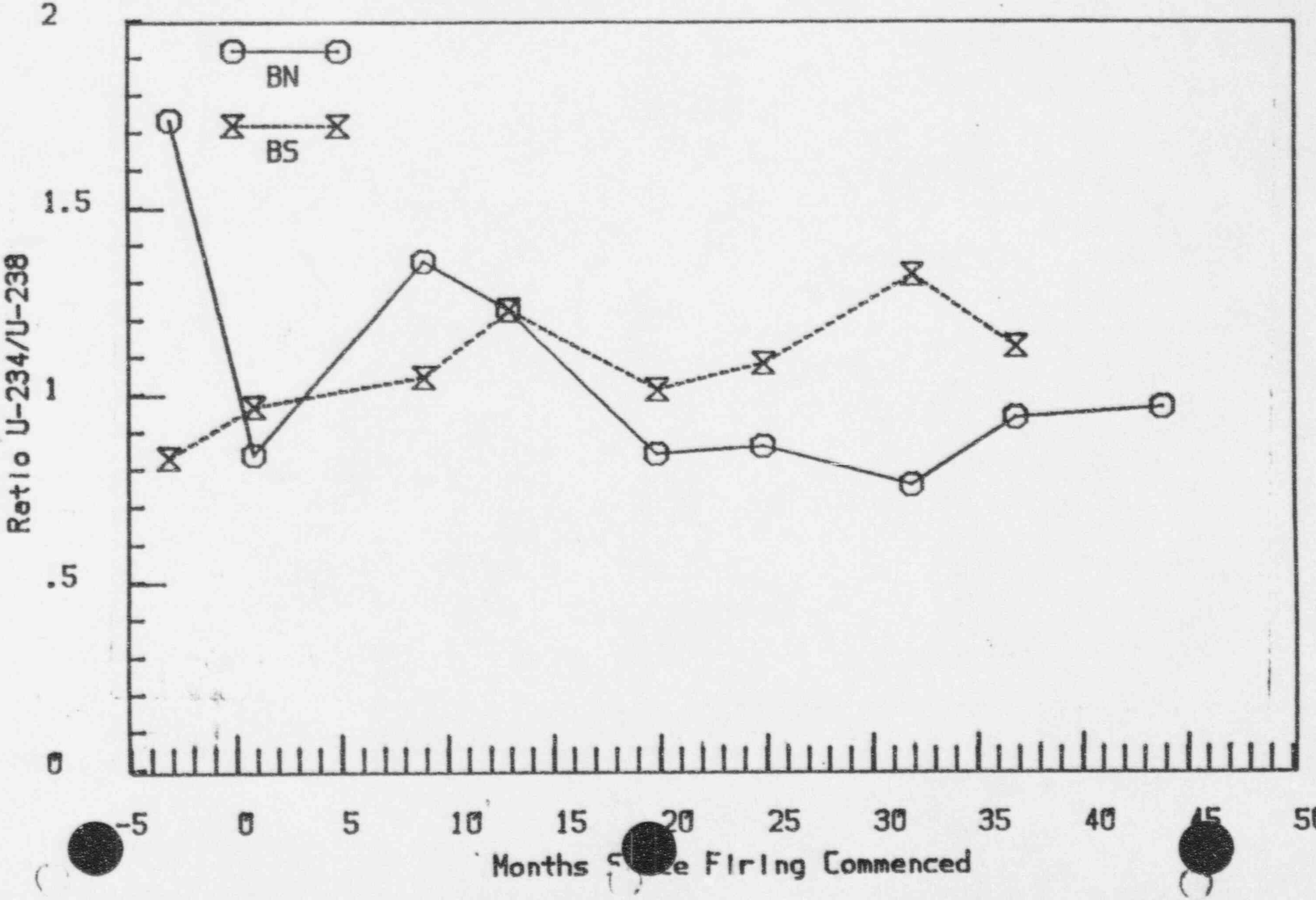


Figure 21
Groundwater U-238 East Side

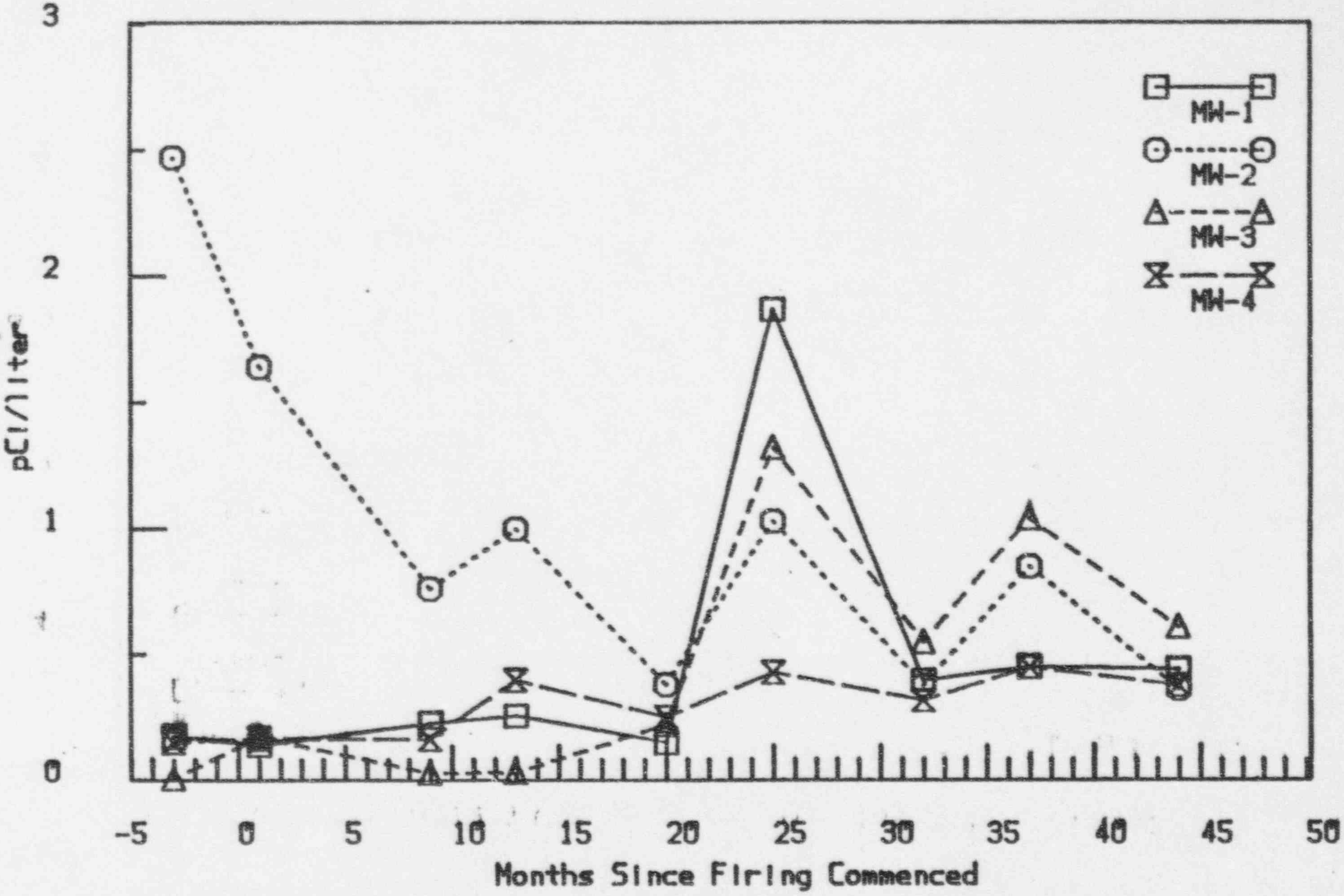


Figure 22
Groundwater U-238 West Side

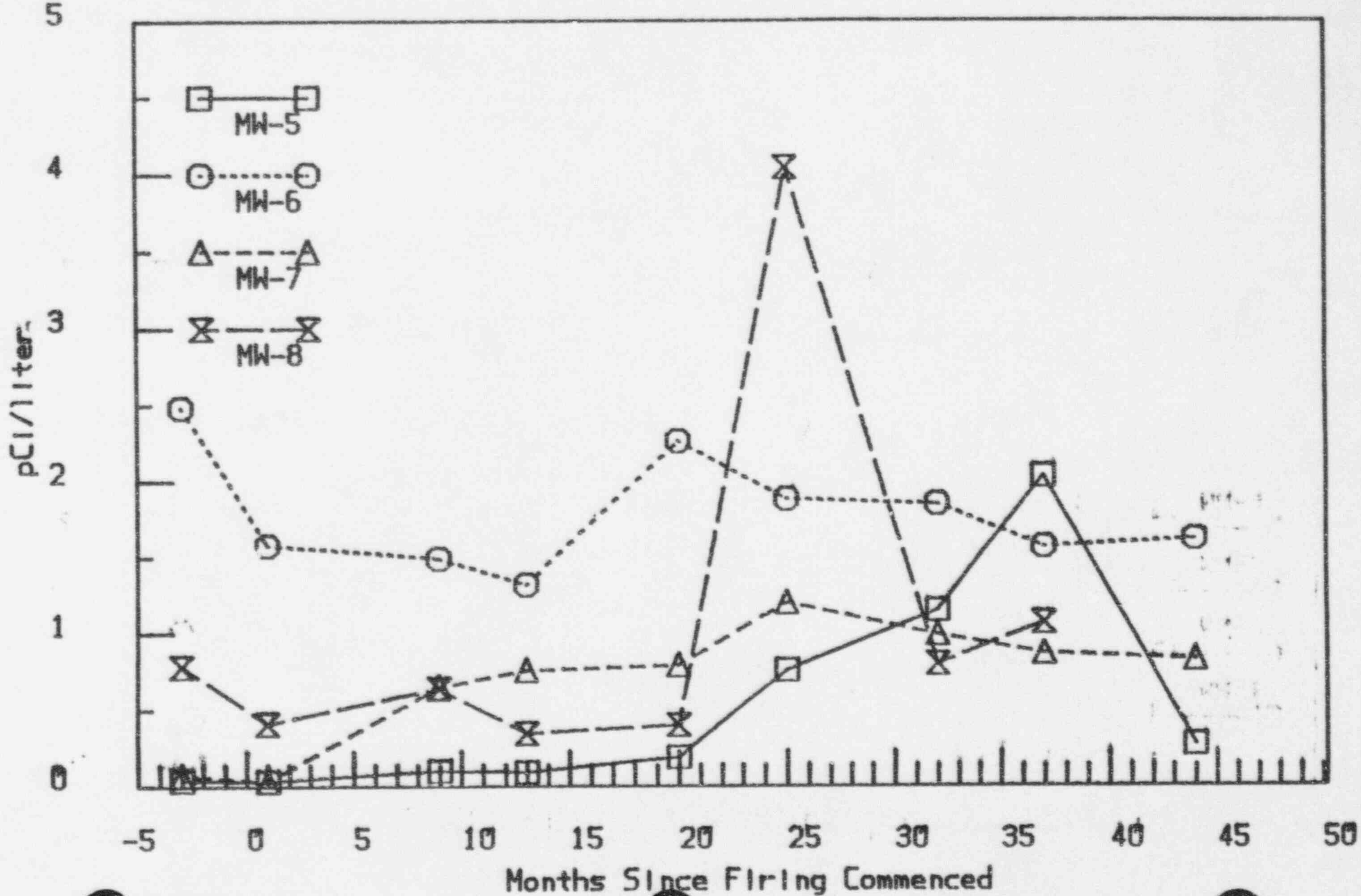


Figure 23
Ground Water Ratio U-234/U-238 JPG

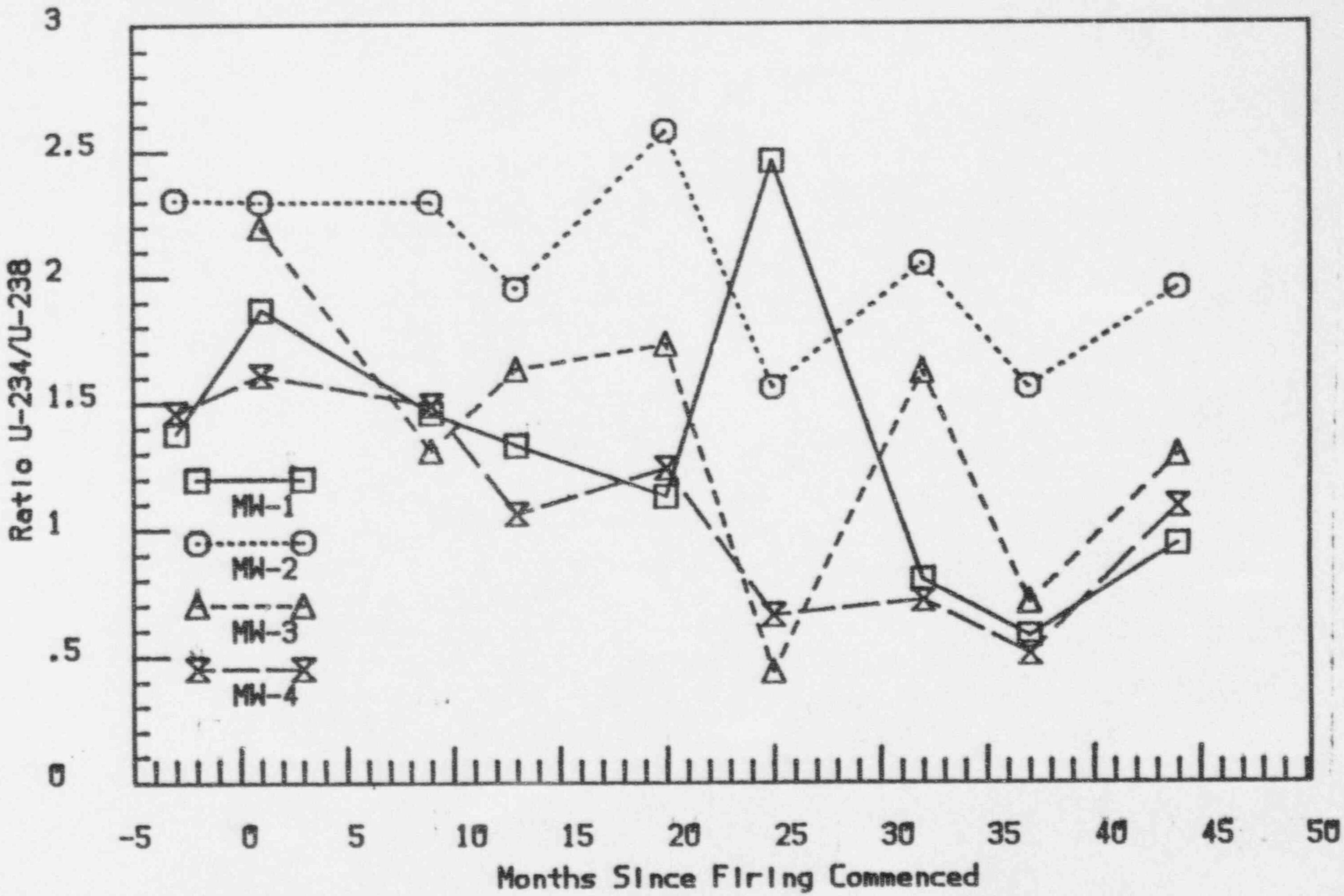


Figure 24
Ground Water Ratio U-234/U-238 JPG

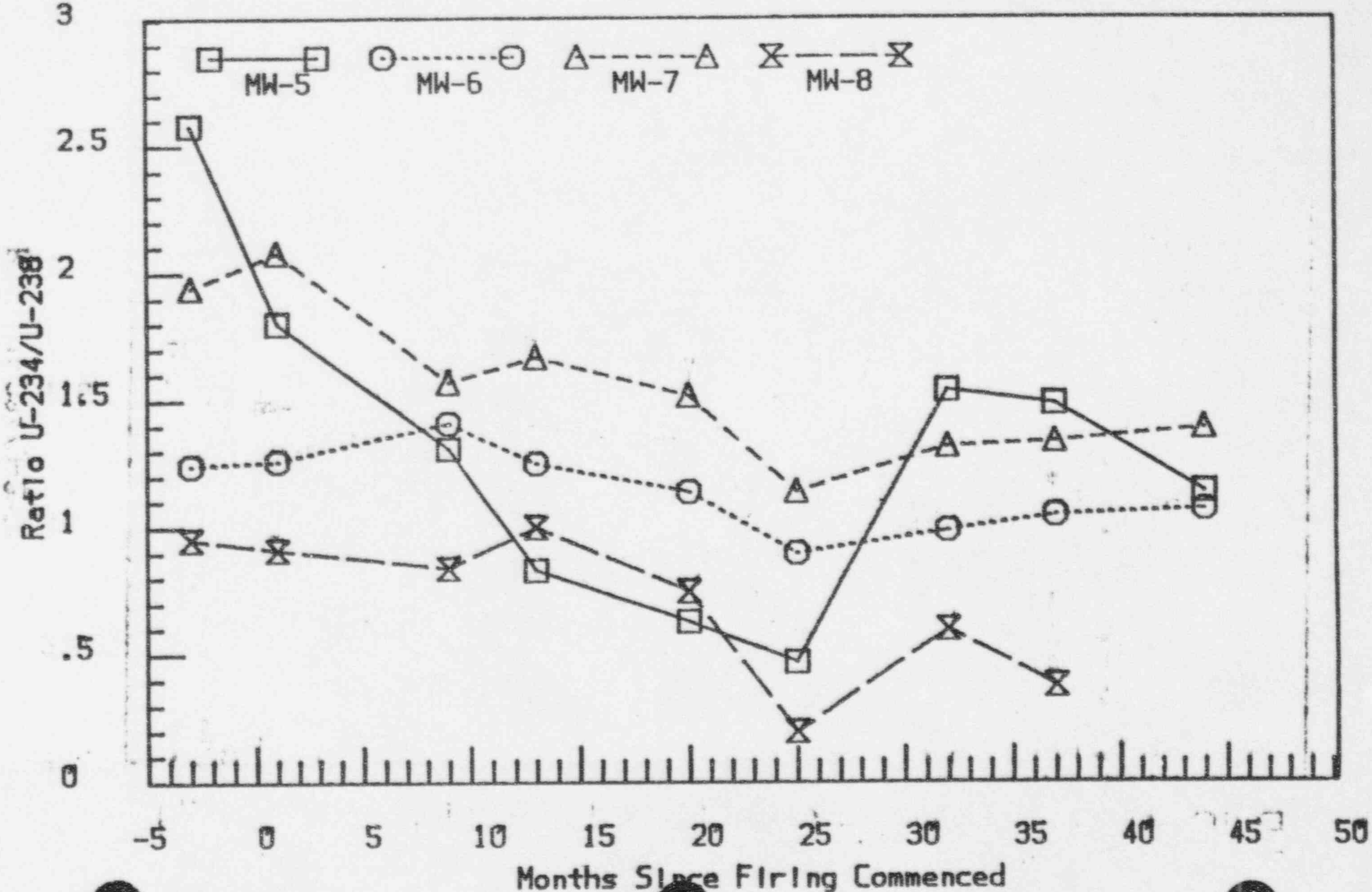


Figure 25

500 Center Line of Fire Soil U-238

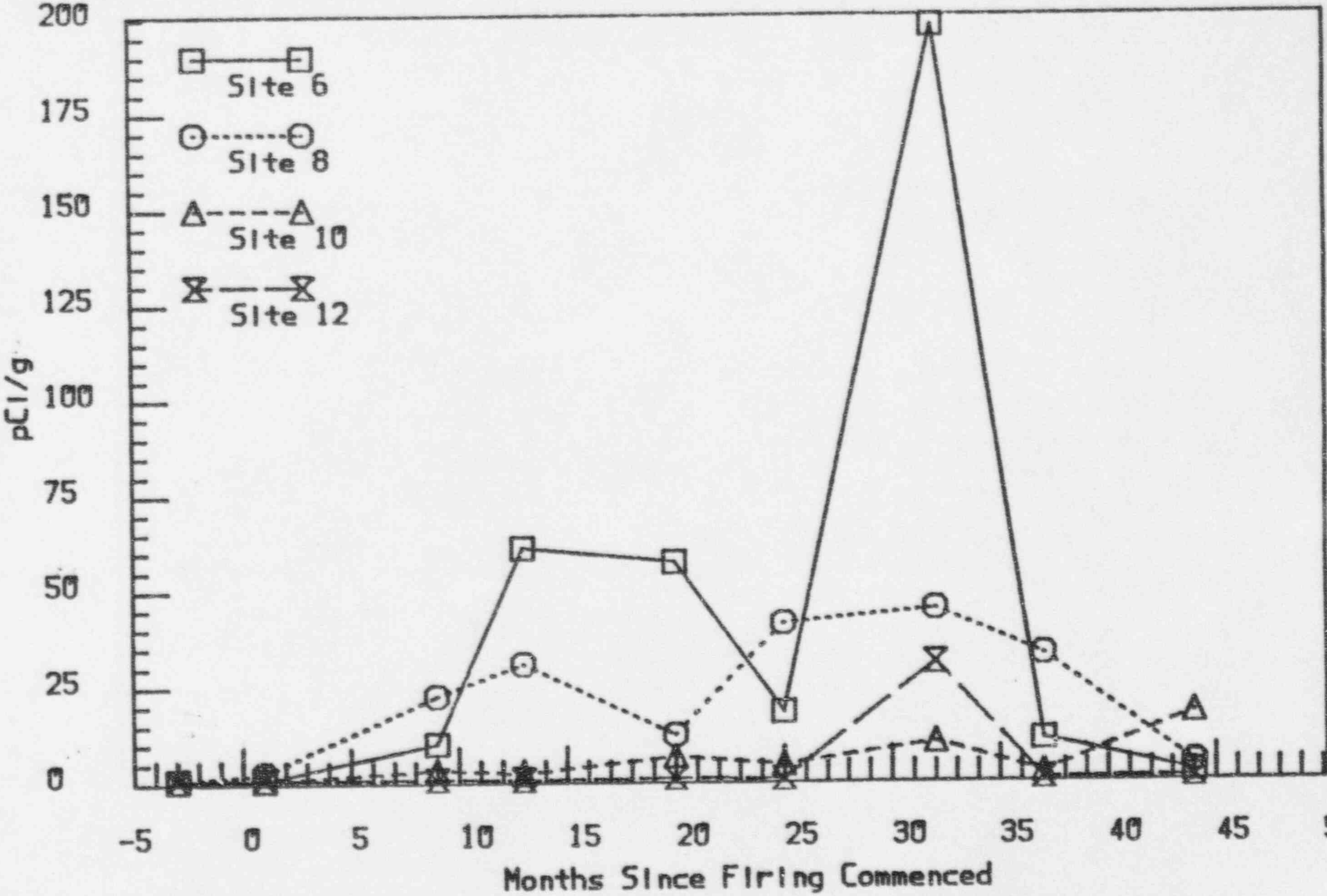


Figure 26

Soil Ratio U-234/U-238 JPG

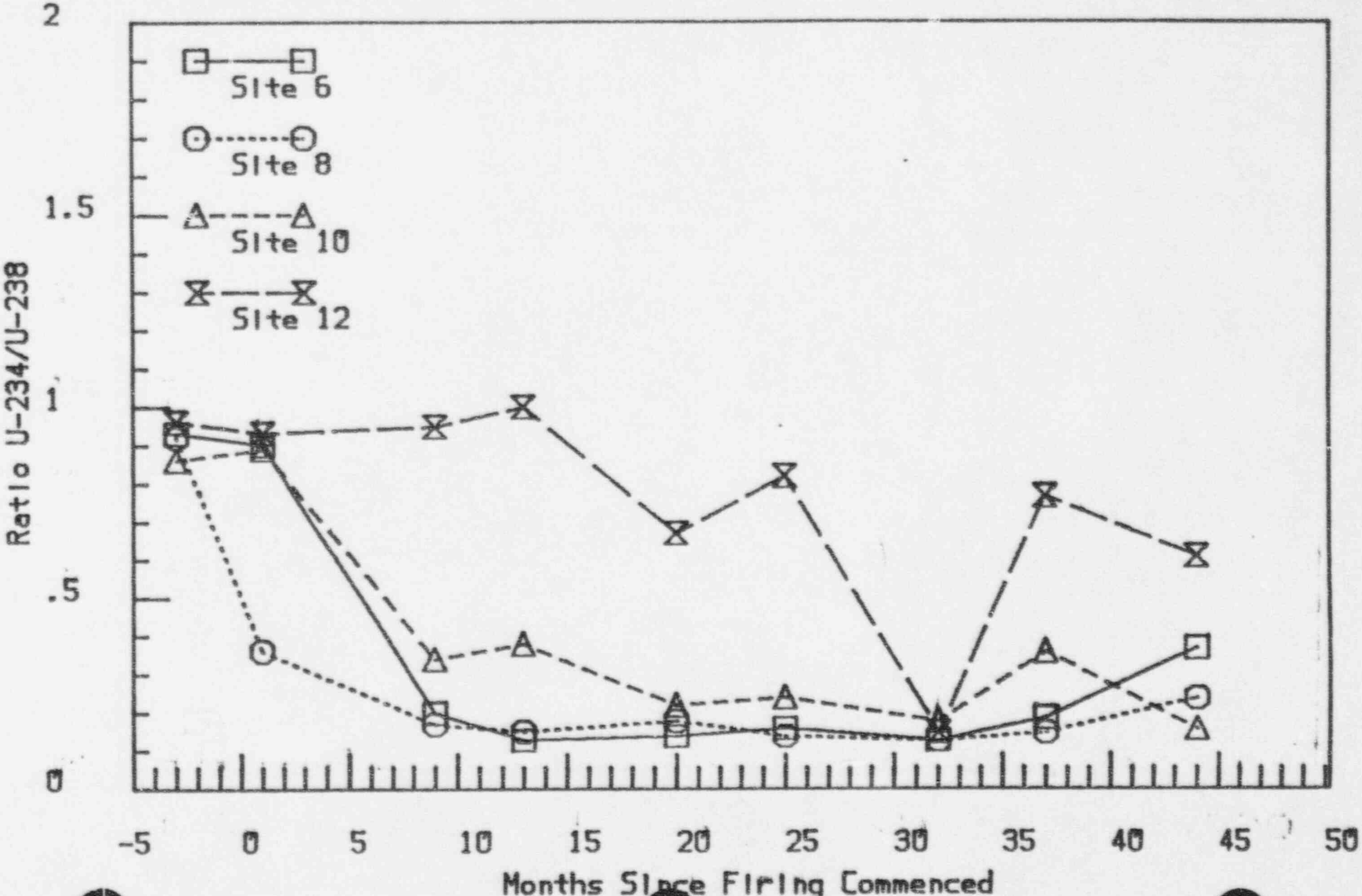


Figure 27

Position K Line of Fire Soil U-238

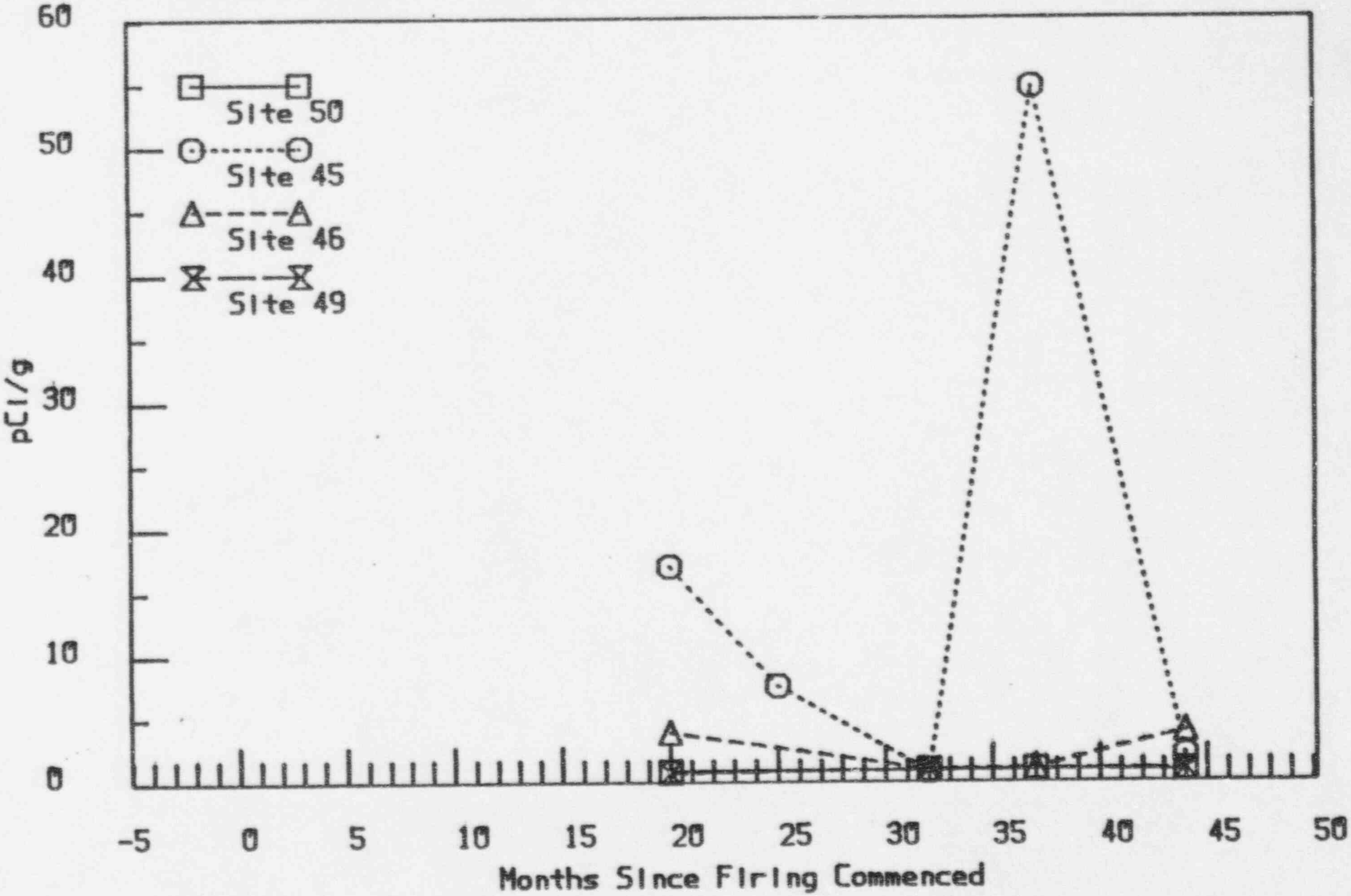


Figure 28
Soil Ratio U-234/U-238 JPG

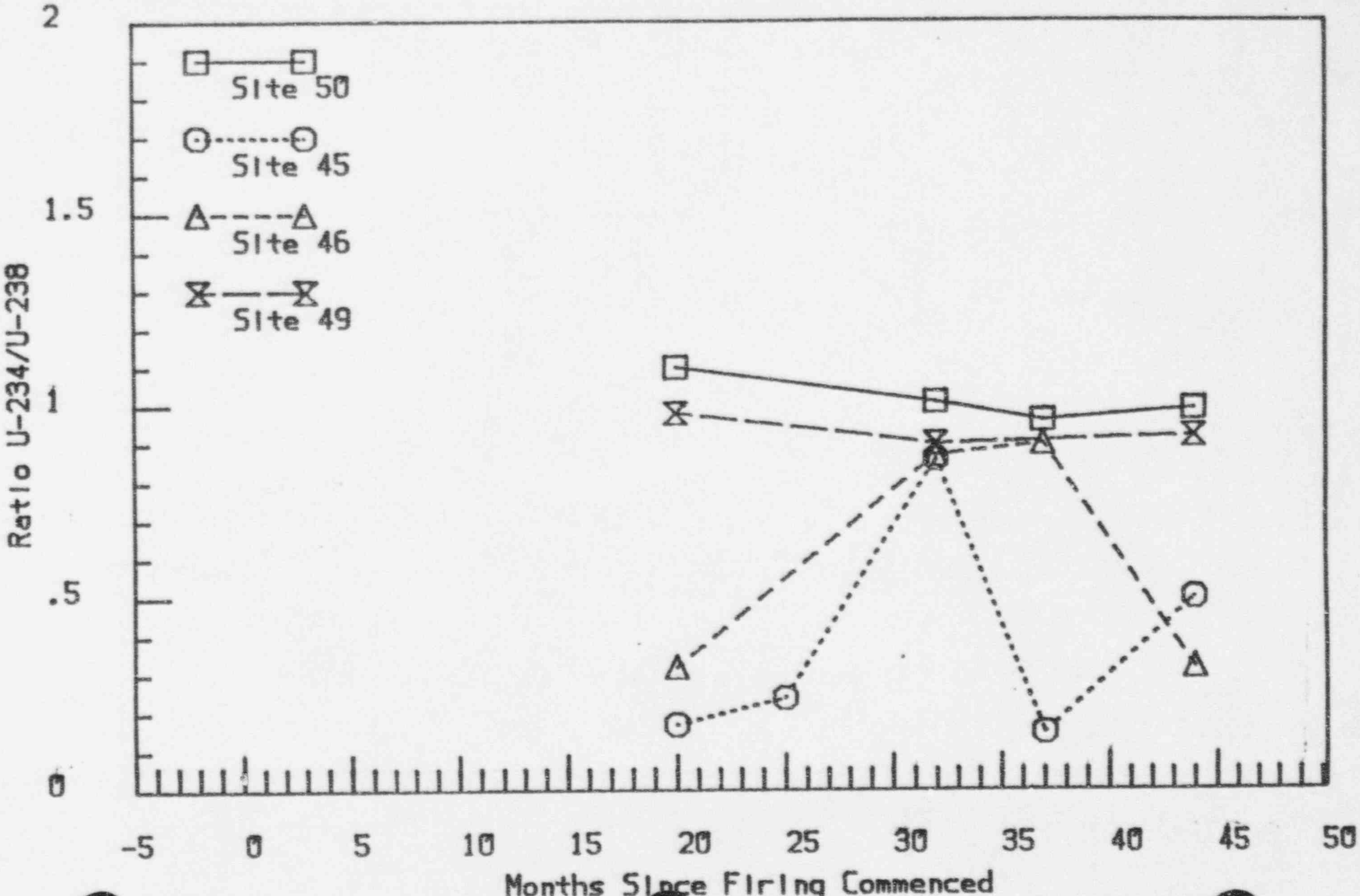


Figure 29
Position J Line of Fire Soil U-238

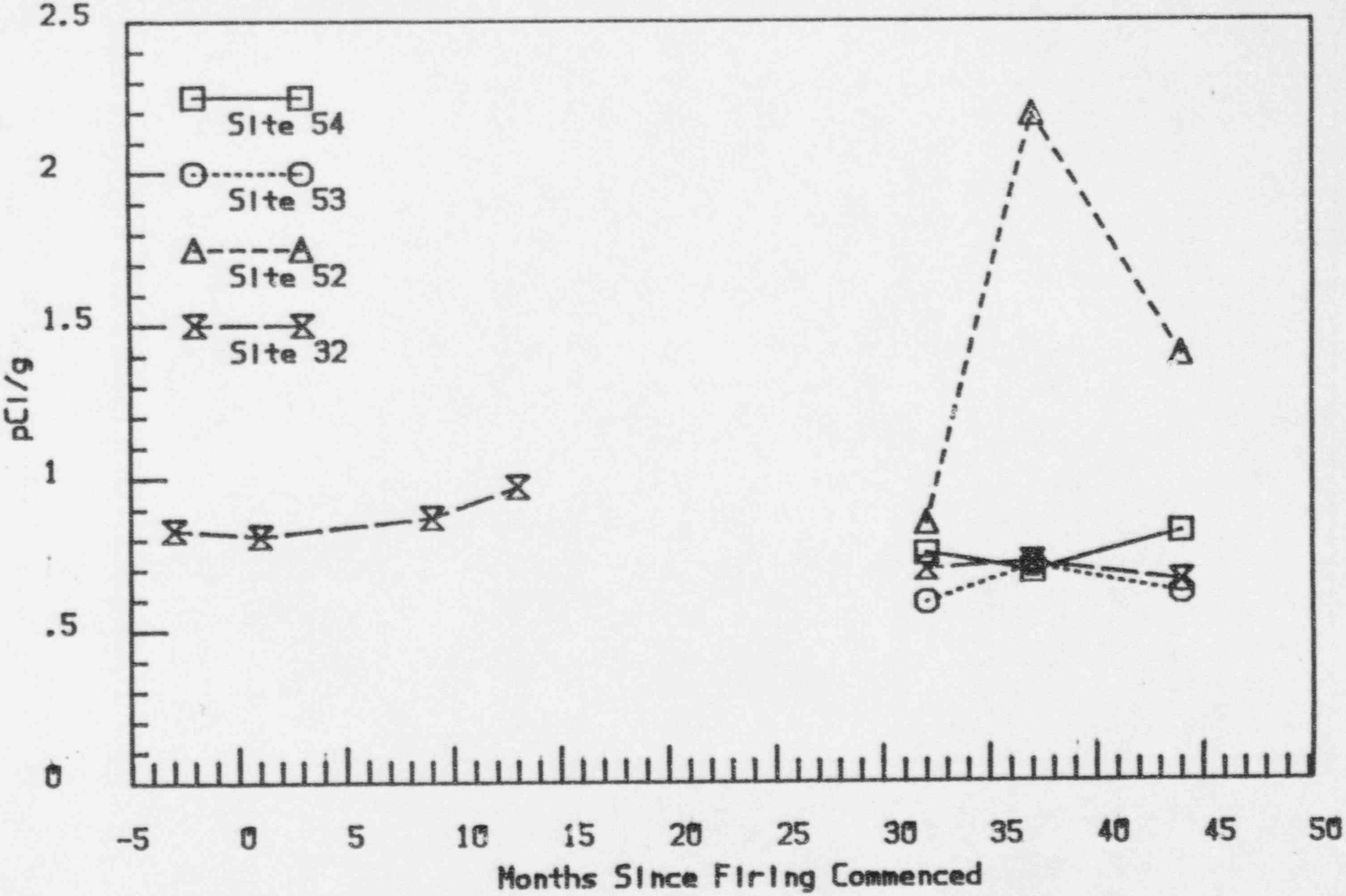


Figure 30
Soil Ratio U-234/U-238 JPG

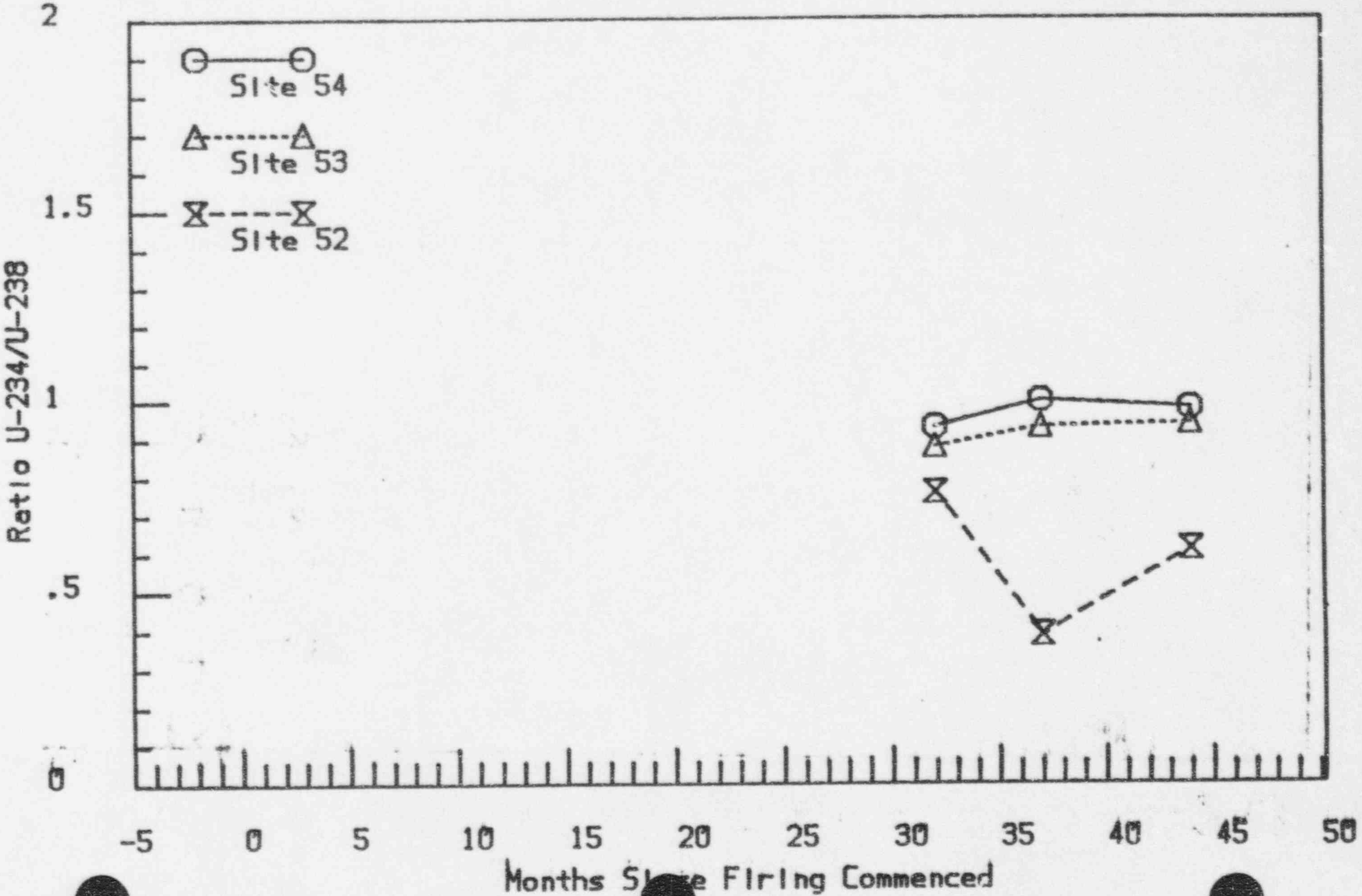


Figure 31

Impact Boundary Soil U-238

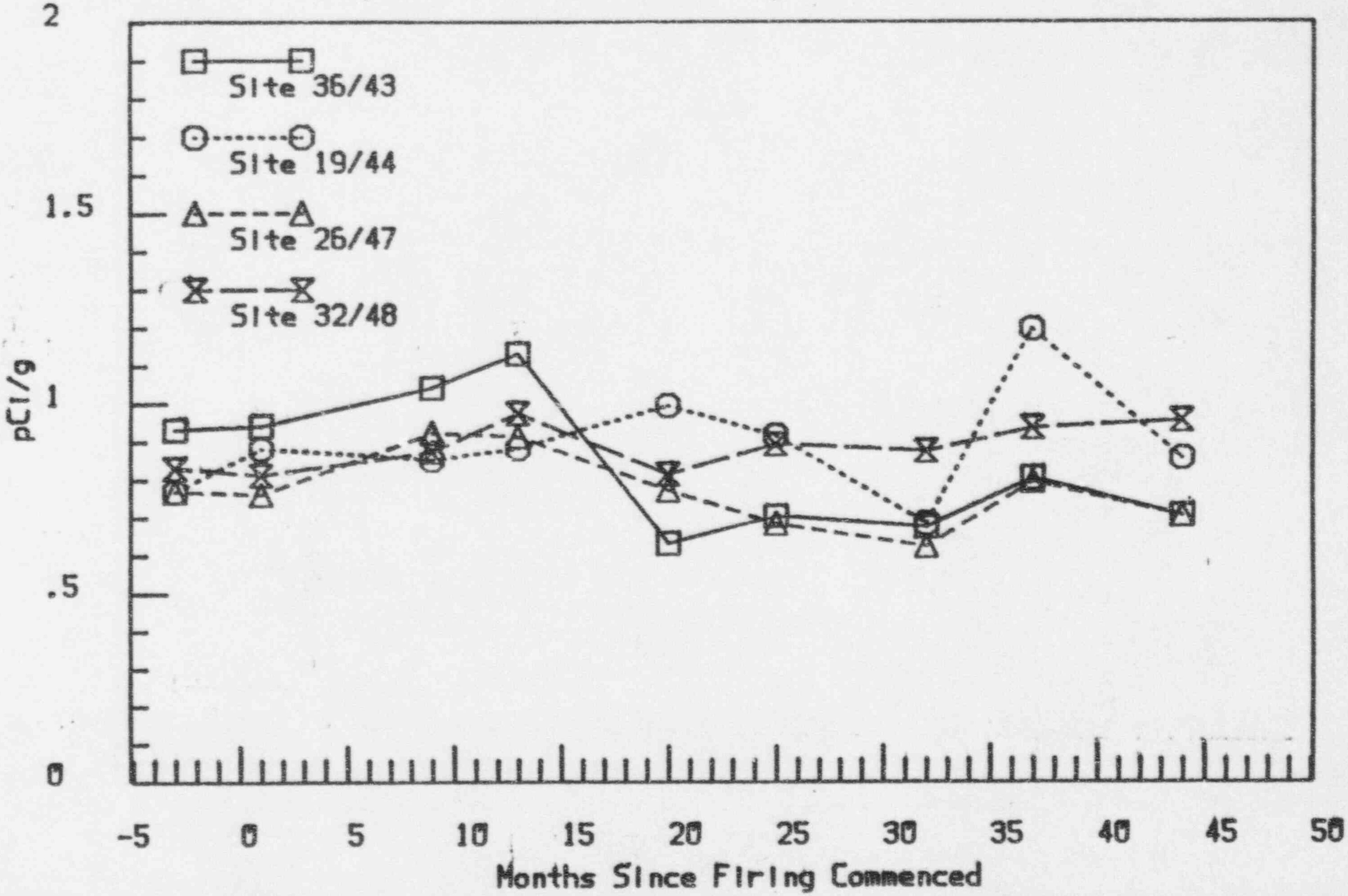


Figure 32

Soil Ratio U-234/U-238 JPG

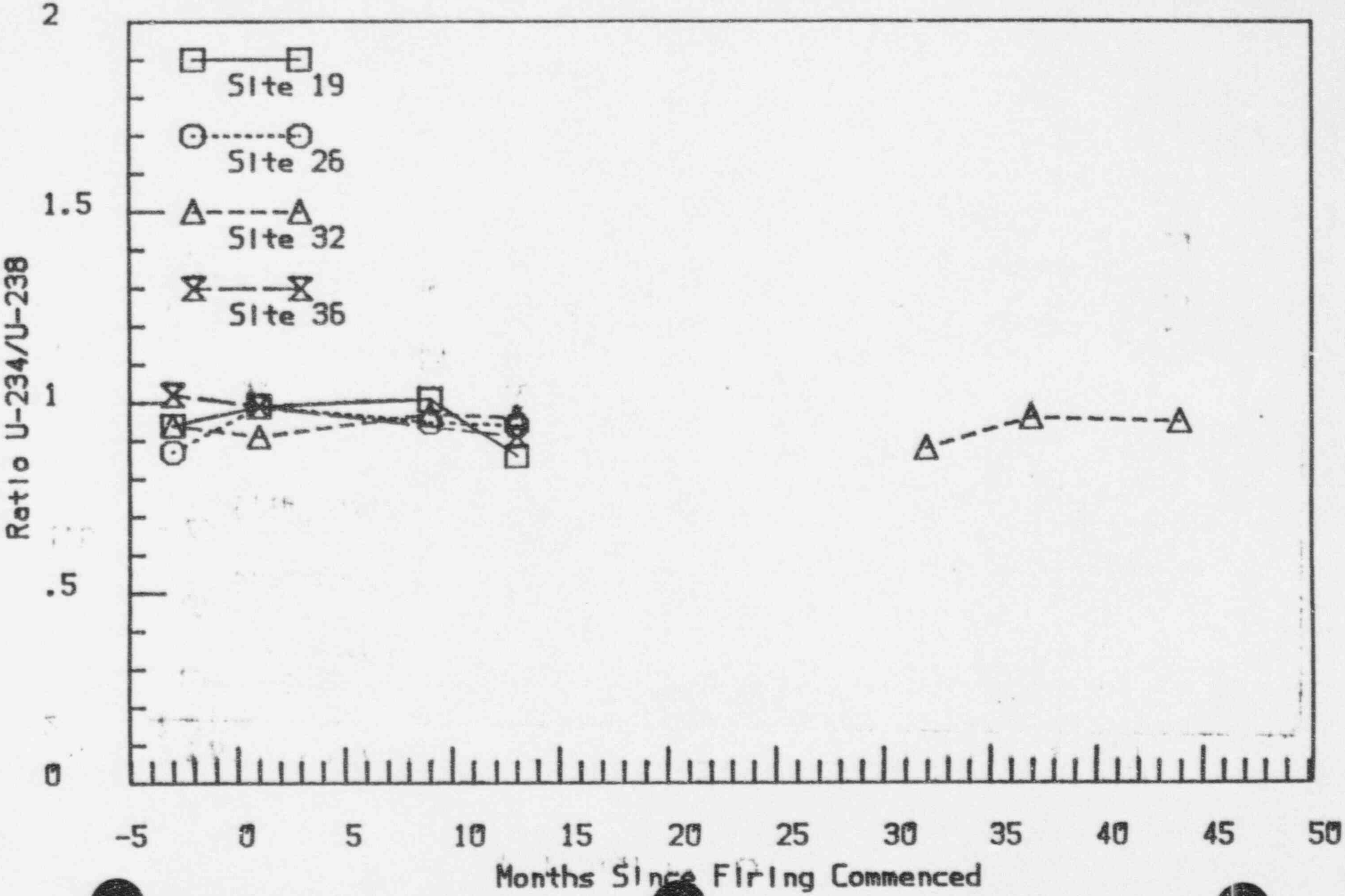
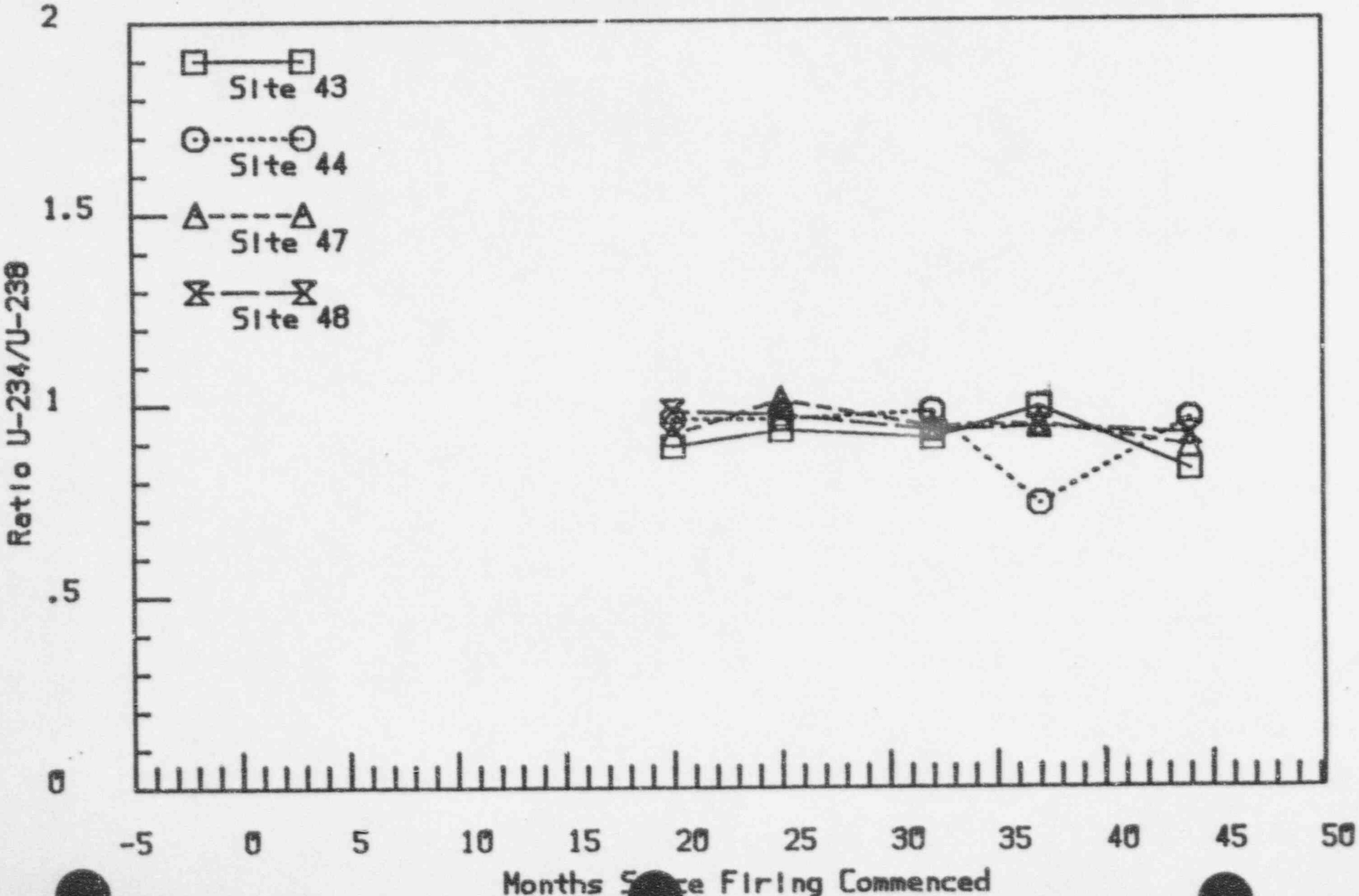


Figure 33
Soil Ratio U-234/U-238 JPG



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