

**Final
Application for
Alternate Concentration Limits
For
Gas Hills, Wyoming**

**Volume II
Appendices**

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Appendix A

Ambient Groundwater Quality Characterization

Umetco Gas Hills Site

Fremont and Natrona Counties, Wyoming

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Acronyms and Abbreviations

<u>Acronym</u>	<u>Definition</u>
ACL	Alternate Concentration Limits
AGTI	Above-Grade Tailings Impoundment
AML	Abandoned Mine Lands (State of Wyoming program)
As	Arsenic
Be	Beryllium
Cl	Chloride
IQR	Interquartile range (= difference between lower and upper quartile values)
K-S	Kolmogorov-Smirnov (test for normal distribution)
mg/l	milligrams per liter
n or N	number of samples or data points
Ni	Nickel
NRC	U. S. Nuclear Regulatory Commission
Pb-210	Lead-210
pCi/l	picocuries per liter
PRI	Power Resources Inc.
Ra-226	Radium-226
Ra-228	Radium-228
Ra-226+228	Radium-226 + Radium-228
s.d.	standard deviation
Se	Selenium
SWFR	Southwestern Flow Regime, historically referred to as Upper Wind River aquifer
TDS	Total Dissolved Solids
Th-230	Thorium-230
TU	tritium unit
UL	upper confidence or tolerance limit (all derived herein are nonparametric ULs)
UL _{0.95} (x _{0.95})	95% upper confidence limit on 95 th quantile
Umetco	Umetco Minerals Corporation
U-nat	Natural Uranium
WFR	Western Flow Regime, historically referred to as Lower Wind River aquifer

1.0 INTRODUCTION

This characterization of ambient groundwater conditions was prepared in support of the Alternate Concentration Limits (ACL) application developed for the Umetco Minerals Corporation (Umetco) Gas Hills site. The representative background levels derived for groundwater constituents are based on the historical and hydrogeological information presented in Sections 1 and 2 of the ACL application. Additionally, unlike previous assessments of groundwater quality at the site, this evaluation accounts for the highly heterogeneous geochemical environment that characterizes the Gas Hills region.

1.1 Background

Previous determinations of ambient groundwater quality for the site were based on short-term monitoring of two wells (LA2 and MW2) approximately 10 years ago. Groundwater protection standards, specified in Condition 35 of the Gas Hills License SUA-648, were developed based on these results. These standards are not representative of current ambient groundwater conditions, however, because the underlying data reflect a narrow range of geochemical conditions and a limited geographic area and monitoring time frame.

According to the NRC (1993), ambient groundwater quality is defined as follows:

“...the chemical quality of water that would be expected at a site if contamination had not occurred from the uranium milling operation. Ambient contamination from uranium ore bodies, mining operations, or other human activities are considered as part of the background water quality.”

Consistent with this definition, this evaluation of ambient conditions characterizes the distributions of constituents in groundwater that would exist at the site if milling activities had not occurred. Therefore, in addition to using groundwater data from background wells exhibiting no apparent impacts (e.g., due to human activities), data from wells installed in surrounding reclaimed mined areas or in uranium ore bodies were also used. This approach was taken to ensure that the background levels derived herein adequately reflect the impacts of former adjacent mining operations, as well as the presence of extensive ore bodies to the south of the site.

1.2 Scope of the Evaluation

This evaluation of background groundwater quality focuses on the following fourteen constituents: radium-226 (Ra-226), radium-228 (Ra-228), radium-226+228 (Ra-226+228), natural uranium (U-nat), thorium-230 (Th-230), lead-210 (Pb-210), gross alpha, arsenic, beryllium, nickel, selenium, chloride, sulfate, and total dissolved solids (TDS).

Background values were previously established for nine of these parameters—Ra-226+228, U-nat, Th-230, Pb-210, gross alpha, arsenic, beryllium, nickel, and selenium—as reflected in the groundwater protection standards specified in Condition 35 (B) of the Gas Hills License SUA-648, Amendment 43. Chloride, sulfate, and TDS are addressed herein because these constituents

require semiannual analysis in accordance with Condition 35 (A) of the license and are also useful indicators of groundwater quality trends.

Consistent with the hydrological evaluation presented in Appendix C of the ACL application, ambient groundwater quality is characterized for two separate flow regimes. The Southwestern Flow Regime includes groundwater above the mudstone unit in the area of the A-9 Repository. The Western Flow Regime includes groundwater beneath the mudstone unit in the vicinity of the above-grade tailings impoundment (AGTI).

1.3 Organization and Contents

Following this introduction, Section 2 identifies the background wells selected for both flow regimes and documents the rationales supporting their selection. Section 3 describes the technical approach used in the background characterization, including the data management and exploratory analysis procedures used in the initial stages of the evaluation, as well as the statistical approaches used to derive the background values. As a preface to the presentation of results—i.e., the final derivation of background values—Section 4 presents pertinent information related to the background evaluation. Section 5 presents the background levels of constituents derived for the Southwestern and Western Flow Regimes. References are provided in Section 6.

In accordance with the NRC standard format and content guide for ACL applications (NRC 1996), Sections 1 and 2 of the ACL provide supporting information related to the background evaluation, including a description of mill-related constituents, information on site hydrogeology (e.g., flow directions and rates), and a detailed description of the local, naturally-occurring sources of ambient groundwater contamination. Attachment A-1 of this appendix provides additional information related to the selection (and/or exclusion) of background wells from the background database. The groundwater analytical data used in the background evaluation are provided in Attachment A-2.

To facilitate review, the bulk of the information in this appendix is provided in the tables and figures, which detail the assumptions, methods, and results used to characterize background groundwater quality. The text is generally limited to a discussion of key assumptions and salient findings.

2.0 SELECTION OF BACKGROUND WELL LOCATIONS

This section identifies the background wells selected for the Gas Hills site. Section 2.1 describes the criteria used in their selection. Sections 2.2 and 2.3 identify the wells used to characterize ambient groundwater conditions for the Southwestern and Western Flow Regimes, respectively.

2.1 Criteria for Background Well Selection

Given the NRC's definition of background groundwater quality described in the previous section—i.e., "*the chemical quality of water that would be expected at a site if contamination had not occurred from the uranium milling operation*"—the primary criterion for selection of background wells was location outside the influence of potential mill-related impacts. Therefore, the wells selected to characterize background groundwater quality at the Gas Hills site met one of the following criteria:

- 1) hydrologically upgradient of the mill facilities,
- 2) hydrologically crossgradient from the A-9 Repository, or
- 3) distant downgradient of the above-grade tailings impoundment (AGTI).

The background wells selected for the Southwestern Flow Regime met one of the first two criteria listed above (see Table A.1). For the Western Flow Regime, however, downgradient wells initially selected were screened further to ensure that the well was located at a sufficient distance downgradient from the AGTI, outside the influence of mill-related contaminant sources. The latter was achieved by making conservative estimations of groundwater velocity and travel times (based on the information discussed in Appendix C of the ACL) and by evaluating the corresponding analytical results to verify the lack of milling-related impacts. Where available, results of previous tritium analyses were also evaluated, as discussed briefly below.

Age Dating of Groundwater Using Tritium

In 1997, tritium analyses were performed for a subset of Gas Hills site monitoring wells. Tritium is a naturally-occurring radioactive isotope of hydrogen that is formed from interactions of cosmic rays with gas in the atmosphere and that has a half life of 12.3 years (Eisenbud and Gesell 1997). Beginning around 1952, large quantities of man-made tritium entered the atmosphere as a result of atmospheric testing of thermonuclear bombs (Freeze and Cherry 1979). Prior to the atmospheric testing, the ambient tritium content of precipitation is estimated to have been approximately 5–20 tritium units (TU). Therefore, groundwater that has been isolated from the atmosphere since the early 1950s is expected to have a tritium concentration of less than 5 TU (Fetter 1994). Consequently, wells with low tritium concentrations have water quality pre-dating mining and milling activities at the site, and therefore qualify as suitable background wells.

The following table documents the results of the 1997 groundwater tritium analyses, including Western Flow Regime background wells MW28, MW30, and MW77, and additional wells potentially exhibiting mining and/or mill-related impacts.

Results of Tritium Analyses in Selected Gas Hills Site Monitoring Wells

Location	Tritium Concentration (TU)	Error (TU)
<i>Southwestern Flow Regime Wells</i>		
EPW1	11.3	0.4
EPW2	48.0	1.6
HW2	35.5	1.2
MW10	31.4	1.0
<i>Western Flow Regime Wells</i>		
MW28	-0.06	0.09
MW30	0.62	0.09
MW76*	9.9	0.3
MW77	0.06	0.09
	0.01	0.09

*Well MW76 is located within or downgradient of a known mined/mineralized area (the Rim Pit). Groundwater was encountered in this Pit, and thus exposed to the atmosphere.

As indicated above, tritium results for Western Flow Regime wells MW28, MW30, and MW77 are less than 2 TU. These results are indicative of groundwater that has been isolated from the atmosphere since before mining and milling began at the site. Tritium results for the remaining wells reflect more recent recharge and therefore may indicate potential mining and/or milling related impacts.

2.2 Background Wells Identified for the Southwestern Flow Regime

Table A.1 lists the background wells selected for the Southwestern Flow Regime and documents the rationales supporting their selection. Corresponding well locations are shown in Figures A.1 and A.2. Figure A.1 shows both Umetco and Power Resources Inc. (PRI) monitoring wells and demonstrates the extensiveness of the PRI mining area relative to the Gas Hills site. Figure A.2 is a subset of Figure A.1, showing only Umetco wells and the nearest PRI (Mine Unit 5) background wells.

Using the selection criteria described in Section 2.1, thirty-six (36) wells were selected as background wells for the Southwestern Flow Regime. Wells LA1, LA2, LA3, LA5, LA6, LA7, LA8, and PW7 are located upgradient of the A-9 repository. Twenty-eight (28) PRI mine unit wells were also selected, including GW11, Veca 1, and Veca 3A. These PRI wells are located crossgradient from the Gas Hills site, outside the influence of milling-related activities. They were included in the background data set to account for the background groundwater quality associated with ore bodies and PRI's ongoing mining activities. The rationales for excluding selected candidate wells from the background evaluation for the Southwestern Flow Regime are documented in Attachment A-1, Table A-1.1.

2.3 Background Wells Identified for the Western Flow Regime

Table A.2 lists the background wells selected for the Western Flow Regime and documents the rationales supporting their selection. Corresponding well locations are shown in Figure A.2.

Eleven (11) wells were identified as being representative of background groundwater quality for the Western Flow Regime: A8, Adobe 4, DOMW1, MW27, MW28, MW30, MW76, MW77, and Rim Wells 1, 2 and 3. Background wells located upgradient or crossgradient from the AGTI include MW27, DOMW1, A8, and MW30 (Figure A.2). Downgradient background wells include (in order of increasing distance from the site): MW28, MW77, MW76, Rim Wells 1, 2, & 3, and Adobe 4. Attachment A-1, Table A-1.2 documents the rationales for excluding selected candidate wells from the Western Flow Regime background database. Wells MW28 and MW77 were included as background wells based on results of tritium analyses: -0.06 TU and 0.01-0.06 TU, respectively. As discussed in the conclusion to Section 2.1, these results are indicative of pre-milling (and pre-mining) groundwater conditions. Based on the tritium analyses, combined with the corresponding analytical results indicating no mill-related impacts, MW28 and MW77 were selected as background wells for the Western Flow Regime.

Conservative analyses of groundwater velocity and travel times indicate that downgradient wells MW 76, Rim 1, Rim 2, and Rim 3 are located a sufficient distance downgradient from the site, outside areas exhibiting mill-related impacts. MW76 and the Rim wells are located within a mineralized area, southwest of the Rim Pit. The extent of this mineralization is visible from some distance, even from the County Road. Data from these wells are important in that they characterize the ambient groundwater quality associated with naturally-occurring mineralization.

3.0 TECHNICAL APPROACH

This section describes the technical approach used in the background groundwater quality evaluation. Section 3.1 describes the data management and exploratory analysis procedures used in the initial stages of the background evaluation. Section 3.2 documents the general statistical methodologies used to determine background values. Analytical data are provided in Attachment A-2.

3.1 Data Management

Identification of the Final Background Data Set

For the background wells identified in Tables A.1 and A.2, initially, all available data were reviewed. This was done to assess temporal trends and to ensure that the candidate background wells exhibited generally stable groundwater chemistry trends. However, for wells with recent data available, data from the last five years (1996-2000) were used.

The initial goal of this background evaluation was to define a data set that was temporally consistent, and therefore consistent in the number of data points as well—i.e., to have data for *all* background wells for each monitoring effort, allowing several "snapshots" of background groundwater chemistry over time. This was not possible due to differences in dates of construction for individual wells, as well as differences in monitoring frequency and duration (a function of well ownership and/or the well type).

Treatment of PRI Groundwater Data

As indicated in Table A.1, 28 PRI mine unit wells were included in the background database. Some wells have only one data point, and several wells are colocated (see Figure A.1). To account for the colocated wells, all non-radium results for colocated wells were averaged for each monitoring period. This approach was taken so as to not unduly weight the background database, and to facilitate review of the graphical plots presented in this report. The reason that Ra-226 results were not treated similarly is due to the great variability in radium concentrations exhibited within even the colocated well clusters.

Treatment of Non-Detects

For this evaluation, non-detects within the background data were replaced with the detection limit values. As demonstrated in the following section, beryllium was not detected in Southwestern Flow Regime background samples, and beryllium and selenium exhibit very low frequencies of detection in Western Flow Regime background samples.

3.2 Exploratory Analysis and Identification of Outliers

The first step in the data analysis was to plot the well-specific background concentrations for each parameter and visually examine the results. The latter was achieved using box plots and distribution (quantile-quantile) plots as demonstrated in the example provided in Figure A.3. As reflected in the accompanying tables and figures, this process facilitated the selection of representative background concentrations.

Box plots were used to identify possible outliers in the background data set. Hunt, et al. (1987, in Gilbert 1987), defines an outlier as “an observation that does not conform to the pattern established by other observations in the data set.” As shown in Figure A.3, outliers are defined as values greater than the upper quartile (75th percentile) plus 1.5 times the interquartile range (IQR), where the IQR is equal to the difference between the upper quartile and lower quartile (25th percentile) values. Extreme outliers are defined as values greater than the upper quartile plus 3 times the IQR. In this evaluation, extreme outliers were generally excluded from the background data set. Exceptions to this approach occurred when an extreme outlier reflected a small variance, low constituent concentrations, or if exclusion of the outlier had a negligible impact on the overall data set. Outliers excluded from the data set are identified in the figures and in Attachment A-2, Tables A-2.1 through A-2.4.

3.3 Characterization of Data Distributions

Many statistical tests (e.g., t tests) and estimators (e.g., the mean, standard deviation, and confidence limits about the mean) assume a normal distribution. Given this common normality assumption, an evaluation of whether variables approximated a normal distribution was undertaken for all parameters. This was achieved by examining descriptive statistics (e.g., skewness and kurtosis), statistical graphics (e.g., probability plots and frequency histograms), and results of statistical tests (e.g., Shapiro Wilk's test and Lillifors test) to identify departures from normality that would not support use of a parametric test or estimator. For most constituents (in both flow regimes) a normal distribution could not be assumed, as the associated null hypothesis was rejected for the aforementioned tests (see Tables A.3 through A.7).

3.4 General Methods Used to Determine Background Groundwater Concentrations

As indicated above, the data are not normally distributed for most parameters in both flow regimes. Consequently, use of a parametric confidence interval or estimator would not be valid. Similarly, very few of the parameters fit a lognormal distribution, so transformations of the data sets were not meaningful. Therefore, in accordance with EPA guidance for assessment of groundwater monitoring data (EPA 1992), non-parametric estimators were used for most analytes. In general, the 95 percent confidence limit about the 0.95 quantile, or $UL_{0.95}(x_{0.95})$, was used unless examination of spatial and/or temporal trends suggested that use of an alternative estimator would be more representative (see following section).

Based on Gilbert (1987), the equation used to derive a one-sided $100(1-\alpha)\%$ upper confidence limit about the p th quantile is as follows:

$$u = p(n + 1) + Z_{1-\alpha} [np(1 - p)]^{1/2}$$

where:

u = sample number corresponding to the $100(1-\alpha)\%$ confidence limit of the p th quantile

p = the quantile

n = number of samples

$Z_{1-\alpha}$ = standard normal variable

α = probability of occurrence outside the quantile

A one-sided test was used in this evaluation, representing a conservative approach. For all parameters addressed in this evaluation, $UL_{0.95}$ about the 99th quantile, or $UL_{0.95}(x_{0.99})$, was equal to the maximum value.

The general rule was to use the 95 percent confidence limit about the 0.95 quantile as the basis for the background groundwater concentrations. However, as discussed in the following section and in Table A.5 (Southwestern Flow Regime) and Table A.8 (Western Flow Regime), alternative estimators were used if examination of spatial and/or temporal trends suggested that use of an $UL_{0.95}(x_{0.95})$ did not yield a sufficiently conservative value.

4.0 PERTINENT INFORMATION RELATED TO THE BACKGROUND GROUNDWATER EVALUATION

Although several guidance documents address the assessment of background conditions (e.g., EPA 1992, NRC 1995, and NRC 1997), there is no single, well-established method for defining background groundwater quality or, more importantly, for assessing the natural variability inherent in the geochemical conditions at Gas Hills. This finding is particularly true for data that are not normally distributed—a characteristic exhibited for most of the parameters evaluated herein. Additionally, a concept implicit in much of the guidance related to background determinations is that wide variability in a background data set is not acceptable. This assumption holds for those sites characterized by a homogenous physical, geological, and radiological environment, but not for the Gas Hills region, which is highly heterogeneous. This heterogeneity is attributable to the presence of naturally-occurring radioactive materials, as well as the well-documented disturbance of adjacent areas by mining activities and subsequent reclamation efforts. Temporal considerations and the non-static nature of the medium further complicate the characterization of background groundwater quality.

Acknowledging the factors discussed above, the groundwater background concentrations proposed herein are not intended to represent estimates of central tendency. Rather, to the extent possible, they were derived to account for the variability inherent in background conditions. The goal of this evaluation is to derive a single estimator for highly diverse non-normal and (for many parameters) non-lognormal data sets. Given this objective, and the constraints imposed by the variability of the underlying data, several caveats are warranted. These caveats are identified as follows:

- 1) In undertaking this evaluation, the initial intent was to adopt a consistent technical approach—for example, to use a single statistical estimator as the basis for the background levels derived for all parameters (see item 4 below). However, this approach was not possible, due to either temporal inconsistencies in the data or characteristics of a distribution which warranted special consideration and/or treatment. Although the available statistical guidance was generally adhered to, ultimately professional judgement was used to determine the proposed background levels. This judgement was facilitated by visual examination of the plotted data. For example, for Ra-226 in Southwestern Flow Regime background wells, the slope of the plotted data changes abruptly, warranting use of a more conservative estimator than that used for the remaining parameters (see Table A.5 and Figures A.4 and A.5).
- 2) As indicated in Tables A.1 and A.2, the background data set is extensive. This is particularly true for the Southwestern Flow Regime, which includes data from 28 PRI wells. Although inclusion of the PRI well data complicated the background analysis, failure to do so would have been inappropriate, especially if cumulative impacts are considered in future site decommissioning evaluations.

It is important to reiterate that the purpose of this evaluation is to account for the spatial variability that characterizes background groundwater quality in the Gas Hills region and to ensure that the background values derived adequately reflect the totality of the background environment, including the presence of ore bodies south of the site.

- 3) The heterogeneity inherent in the background groundwater environment could not be addressed by defining subpopulations. For example, for Ra-226 in Southwestern Flow Regime background wells, partitioning of the PRI data into ore zone vs. non- ore zone categories was not meaningful given the wide variation exhibited within the ore zone data subset. Similarly, categorizing wells according to their location relative to mineralized zones did not prove useful given the variability exhibited within even localized mineralized areas.
- 4) As discussed in the previous section, for most parameters in both flow regimes, the data are not normally distributed. Similarly, very few of the parameters fit a lognormal distribution, so transformations of the data sets were not meaningful. Therefore, non-parametric estimators were used for most analytes. In general, the 95 percent confidence limit about the 0.95 quantile, or $UL_{0.95}(x_{0.95})$, was used unless examination of spatial and/or temporal trends suggested that use of an alternative estimator would be more representative (see items 1, 5, and 6).
- 5) Due to differences in monitoring frequency for individual wells (a function of well ownership and type), there is little temporal consistency in the data set. For example, for the Western Flow Regime, Rim well data are available only prior to 1994, whereas MW76 (located in the same westernmost vicinity) has been sampled more recently. In cases like this, the more recent measurements are given greater weight than those that are dated. This reasoning formed the basis for selection of the 90th percentile as the TDS background value for the Western Flow Regime (vs. the higher $UL_{0.95}(x_{0.95})$, discussed in Table A.8). However, although the Rim well data are admittedly dated, they do serve to corroborate more recent measurements from MW76.
- 6) For some parameters, the difference between results from a single well and those for the remaining background wells is marked. In these cases—i.e., when there was only a single driving well (e.g., nickel in Southwestern Flow Regime well LA8)—background estimates were derived for two scenarios: (1) background with the driving well data included, and (2) background excluding the elevated results from the single driving well. However, in selecting a final background value, the lower estimate was chosen.

The approach described above is very conservative, given that the excluded results still represent valid background data points. Additionally, the assumption that there is only a single driving background well may be spurious. The background characterization or "snapshot" presented in this evaluation reflects the available data. Obviously, there are many background areas in the Gas Hills site region that have not been sampled. Therefore, trends apparently exhibited in only a single well (e.g., uranium in LA8) may also be exhibited in areas that have not been characterized.

5.0 CHARACTERIZATION OF BACKGROUND GROUNDWATER QUALITY

This tables and figures accompanying this section present the results of the background characterization. These exhibits characterize the parameter-specific data and document the basis for the background values chosen for both flow regimes.

5.1 Southwestern Flow Regime

Tables A.3 and A.4 present summary statistics for radionuclide and non-radionuclide constituents, respectively. Table A.5 presents the background values chosen for the Southwestern Flow Regime and documents the supporting rationales. Figures A.4 through A.16 plot the well-specific distributions for each parameter evaluated and identify the factors accounting for the corresponding background value.

5.2 Western Flow Regime

Tables A.6 and A.7 present summary statistics for radionuclide and non-radionuclide constituents, respectively. Table A.8 presents the background values chosen for the Western Flow Regime and documents the supporting rationales. Figures A.17 through A.23 plot the well-specific distributions for each parameter evaluated and identify supporting data and information.

5.3 Summary and Conclusions

Table A.9 summarizes the background groundwater concentrations derived for both flow regimes. These background values are considered conservatively representative, especially given the treatment applied to some parameters exhibiting wide variation in the inter-well results.

As discussed previously, the Gas Hills site is situated in a heterogeneously mineralized area which has been significantly impacted by open pit uranium mining, mine reclamation, and impacted to a lesser extent by uranium processing. Therefore, any determination of background groundwater quality must take into account the presence of elevated constituents upgradient and crossgradient of the site resulting from mining and reclamation activities. These factors have been accounted for conservatively herein.

6.0 REFERENCES

- Eisenbud, M. and T. Gesell. 1997. *Environmental Radioactivity From Natural, Industrial, and Military Sources*, Fourth Edition, Academic Press, San Diego, California, 1997.
- Fetter, C. 1994. *Applied Hydrogeology*, Third Addition, Macmillan Publishing Company, Inc., New York, New York, 1994.
- Freeze, R.A. and Cherry, J.A. 1979. *Groundwater*. Prentice Hall, Inc. Englewood Cliffs, N.J. 604 pp.
- Gilbert, R. 1987. *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, New York, 1987.
- Hunt *et al.* 1981. *U. S. Environmental Protection Agency Intra-Agency Task Force Report on Air Quality Indicators*, EPA-450/4-81-015, Environmental Protection Agency, National Technical Information Services, Springfield, Virginia. 1981.
- Umetco Minerals Corporation. 1997. *Background Land Conditions at the Gas Hills Uranium Project*, Volume I, Revision 1, June 30, 1997.
- Umetco Minerals Corporation. 2000. *Final Background Characterization Report, Revision 1*, September 2000, (Soils Background Characterization).
- Power Resources Inc. (PRI). 1998. *Gas Hills Project, Application for WDEQ Permit to Mine, Volume 3 of 4, Appendix D6 – Hydrology, Addendum D6-7, Ground Water Quality Data*, December 1996 (Revised, February 1998).
- U. S. Environmental Protection Agency (EPA). 1992. *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance, Office of Solid Waste, Permits and State Programs Division*, U. S. Environmental Protection Agency, Washington, D.C., July 1992.
- U. S. Nuclear Regulatory Commission (NRC). 1993. *Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites under Title I of the Uranium Mill Tailings Radiation Control Act*, Revision 1, Office of Nuclear Material Safety and Safeguards, Division of Low-Level Waste Management and Decommissioning, June 1993.
- U. S. Nuclear Regulatory Commission (NRC). 1996. *Staff Technical Position, Alternate Concentration Limits for Title II Uranium Mills*, U. S. Nuclear Regulatory Commission, Washington, D.C., January 1996.

U. S. Nuclear Regulatory Commission (NRC). 1997. *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, NUREG-1575, multi-agency consensus document developed collaboratively with the U. S. Environmental Protection Agency (EPA 402-R-97-018), U. S Department of Energy (DOE), and the U. S. Department of Defense, December 1997.

Appendix A

Tables

Table A.1. Background Wells Selected for the Southwestern Flow Regime Gas Hills, Wyoming

Monitoring Well ¹	Description	Available Data	Data Used ²
LA1	LA1 is located east of the site, outside of and upgradient of the disturbed areas. It was selected as a background well based on its upgradient location and the historical lack of impacts from any milling-related contamination.	September 1989 through June 1998; only 2 measurements prior to 1996 (n=7)	Excluded 1989 and 1993 data, used 1996-1998 results only (n=5)
LA2	Upgradient well LA2 is the designated background well according to the site license.	September 1989 through February 2000 (n=35)	Excluded 1989 through 1995 data, used 1996-2000 results only (n=16)
LA3	LA3 was completed in backfilled spoils associated with the A-8 Pit, upgradient from the site.	September 1989 through June 1998; measurements were sporadic prior to 1996 (n=11)	Excluded 1989 through 1993 data, used 1996-1998 results only (n=7)
LA5	LA5, located east (upgradient) of the site, was installed to characterize groundwater quality downgradient from the A-8 Reclamation Project.	September 1989 through March 2000; measurements were sporadic prior to 1996 (n=11)	Excluded 1989 through 1993 data, used 1996-2000 results only (n=7)
LA6	LA6, another upgradient well, was installed to characterize groundwater quality downgradient from the Tee and B2/B3 reclamation projects.	September 1989 through June 1998; measurements were sporadic prior to 1996 (n=11)	Excluded 1989 through 1993 data, used 1996-1998 results only (n=7)
LA7	Upgradient well; see description provided for well LA 1 (above).	September 1989 through June 1998; only 2 measurements prior to 1996 (n=8)	Excluded 1989 and 1993 data, used only 1996-1998 results (n=6)

n = number of measurements or data points

¹ Monitoring well locations are shown in Figures A.1 and A.2. Upgradient well LA 4 and crossgradient well Veca 2 were initially considered for inclusion in the Southwestern Flow Regime background database, but were ultimately excluded due to either suspect well construction and/or spurious analytical results. For example, LA 4's well casing was previously damaged, which resulted in debris falling into the casing and the screened portion of the well. The construction of Veca 2 is also questionable, data are limited, and results of the last monitoring (Sept-96) are clearly outliers. The rationales for excluding these and other wells from the Southwestern Flow Regime background evaluation are documented in Attachment A-1, Table A-1.1.

² Initially, all available data were reviewed to assess temporal trends and to ensure that the candidate background wells exhibited generally stable groundwater chemistry trends. However, for wells with more recent data available, only data from the last four years (1996-early 2000) were used in the background database. In selecting the data to use in the background database, the initial goal was to define a data set that was temporally consistent, and therefore also consistent in the number of data points per well. [Ideally, one would have data for *all* background wells for each monitoring effort, allowing several "snapshots" of background groundwater chemistry over time.] This was not possible due to differences in dates of construction for individual wells, as well as differences in monitoring frequency and duration (a function of well ownership and/or the well type).

Table A.1. Background Wells Selected for the Southwestern Flow Regime Gas Hills, Wyoming

Monitoring Well ¹	Description	Available Data	Data Used ²
LA8	LA8 was constructed in the backfill (spoils) portion of the reclaimed A-8 Pit in December 1993, approximately 400 feet southeast of well LA 5. Of the LA series wells, LA 8 generally exhibits the highest levels of constituents, in particular, uranium. These findings are attributable to the geochemical conditions in the backfill spoils.	January 1994 through March 2000 (n=9)	Eliminated 1994 datum, limited analysis to post-1995 measurements (n=8)
PW7	PW7 is located upgradient (east) of the site, and downgradient from the A-8 pit.	November 1990 through February 2000 (n=29)	Excluded 1990 through 1995 records, used 1996-2000 data only (n=14)
PRI Wells ^{3,4}			
GW11	GW11 is located southeast (up- to crossgradient) of the site, well outside the influence of milling-related contaminant sources.	PRI results for the period 1996-1997 (n=5).	No data excluded (n=5)
PRI Mine Unit 5 Wells	GW10A (n=1) PIXMO97-1 (n=1) PIXMP97-1* (n=1) ⁴ PIXMU97-1* (n=1) (colocate ID = PIXMx97-1*) Veca 1, n=5 Veca 3A, n=5	PRI results for the period 1996-1997 (n=14). Shaded wells are colocated (see Figure A.1); corresponding results were averaged for all non-radium parameters as discussed in Note 4 (below).	No data excluded. <u>All Data</u> Ore Zone: n=2 Remaining: n=12 <u>Colocates Averaged</u> Ore Zone: n=1 Remaining: n=12

³ The Power Resources Inc. (PRI) wells are located south of the Gas Hills site, within the area of uranium ore bodies. These wells are located crossgradient from the site, well outside the influence of milling related activities. PRI wells completed within the ore zone are denoted with an asterisk—e.g., PIXMP97-1*. For the data analyses and associated graphics, the PRI mine units are listed according to increasing distance from the Gas Hills site, thus Mine Unit 5, Mine Unit 4, Mine Unit 2, Mine Unit 1, and Mine Unit 3 (see Figure A.1).

⁴ A large number of PRI mine unit wells (n=28) were included in the background database. Some wells have only one data point, and several wells are colocated (see Figure A.1). To account for the colocated wells, all non-radium results for colocated wells were averaged for each monitoring period. This approach was taken so as to not weight the background database, and to facilitate review of the graphical plots presented in this report. The colocated wells are highlighted (shaded) above, and assigned a corresponding colocated well ID, as reflected in the parameter-specific box plots shown in Figures A.5 through A.16. The reason that radium (Ra-226) results were not treated similarly is due to the great variability in radium concentrations exhibited within even the colocated well clusters.

PRI Data Source: PRI 1998, *Gas Hills Project, Application for WDEQ Permit to Mine*, Volume 3 of 4, Appendix D6 – Hydrology, Addendum D6-7, *Ground Water Quality Data*. Detailed PRI analytical results are provided in Attachment A-2, Tables A-2.2 and A-2.3 of this report.

Table A.1. Background Wells Selected for the Southwestern Flow Regime Gas Hills, Wyoming

Monitoring Well ¹	Description	Available Data	Data Used ²
PRI Mine Unit 4 Wells	<p>BUMP97-1* (n=1)</p> <p>BUMU97-1* (n=1)</p> <p>(colocate ID = BUMx97-1*)</p> <p>GW5A (n=5)</p> <p>GW9 (n=6)</p> <p>WSL96M-1 (n=6)</p> <p>(colocate ID = GW9, WSL)</p> <p>WSL96MP-1* (n=6)</p>	<p>PRI results for the period 1996-1997 (n=25). The shaded well pairs are colocated (see Figure A.1). Associated results were averaged for all parameters except radium as described in Note 4.</p>	<p>No data excluded.</p> <p><u>All Data</u></p> <p>Ore Zone: n=8</p> <p>Remaining: n=17</p> <p><u>Colocates Averaged</u></p> <p>Ore Zone: n=7</p> <p>Remaining: n=11</p>
PRI Mine Unit 2 Wells	<p>BS96M-1 (n=6)</p> <p>BSMP-1* (n=6)</p> <p>BSMP-2* (n=6)</p> <p>BSMP-3* (n=6)</p> <p>BSPW-1* (n=6)</p> <p>(colocate ID = BS-ore)</p>	<p>PRI results for the period 1996-1997 (n=30). The four shaded wells are colocated; see Figure A.1 and Note 4.</p>	<p>No data excluded.</p> <p><u>All Data</u></p> <p>Ore Zone: n=24</p> <p>Remaining: n=6</p> <p><u>Colocates Averaged</u></p> <p>Ore Zone: n=6</p> <p>Remaining: n=6</p>
PRI Mine Unit 1 Wells	<p>MU96M-2 (n=3)</p> <p>MUMP97-1* (n=1)</p> <p>MP-1* (n=4)</p> <p>P-1* (n=4)</p> <p>(colocate ID = MP-1, P-1*)</p>	<p>PRI results for the period 1996-1997 (n=12). Shaded wells are colocated; see Figure A.1 and Note 4.</p> <p>Note: No data were reported for Mine Unit 1 well MU96M-1 in PRI's Addendum D.6-7 data tables (PRI 1998).</p>	<p>No data excluded.</p> <p><u>All Data</u></p> <p>Ore Zone: n=9</p> <p>Remaining: n=3</p> <p><u>Colocates Averaged</u></p> <p>Ore Zone: n=5</p> <p>Remaining: n=3</p>
PRI Mine Unit 3 Wells	<p>PC (n=2)</p> <p>PCHMP97-1* (n=1)</p> <p>PEACHM-1 (n=5)</p> <p>PEACHM-2 (n=4)</p> <p>PEACHMP-1* (n=4)</p> <p>PEACHMP-2 (n=5)</p>	<p>PRI results for the period 1996-1997 (n=21). Although wells PEACHMP-1* and PEACHMP-2 are colocated, results were not averaged because they were completed in different ore zones.</p>	<p>No data excluded</p> <p>Ore Zone: n=5</p> <p>Remaining: n=16</p>

Table A.2. Background Wells Selected for the Western Flow Regime Gas Hills, Wyoming

Monitoring Well ¹	Description	Available Data	Data Used ²
A8*	A8 is located east of the A9 repository (Figure A.2). Like Southwestern Flow Regime background well LA 8, A8 was completed in the spoils. It was selected based on its up- to crossgradient location.	21-Sep-89 02-Jul-96 08-Jul-96 19-Sep-96 08-Sep-97 14-Oct-98 (n=6)	Excluded 1989 datum, used remaining (1996-1998 results) (n=5)
Adobe 4	Adobe 4 is located north of the Rim wells, outside the influence of milling-related contaminant sources (Figure A.2).	June 1987 through November 1993 (n=15)	Excluded 1987-1989 data, used 1990-1993 data only (n=11)
Domestic Well (DOMW1)	DOMW1, located approximately 1,000 feet southeast of the AGTI, was selected based on its upgradient to crossgradient location.	June 1987 through November 1996 (n=23)	Excluded 1987-1993 data, used 1994-1996 data only (n=10)
MW27	MW27, located approximately 500 feet east of the northeastern edge of the AGTI, was selected as a background well based on its upgradient location.	March 1988 through January 2000 (n=38)	Excluded 1988-1995 data, used 1996-2000 data only (n=14)
MW28	MW 28 is located 2,100 feet downgradient of the AGTI, and results of tritium analyses (-0.06 TU) indicate that this well has not been influenced by milling activities (see Section 2.1). Corresponding monitoring results corroborate the latter assumption, as demonstrated in Figures A.17 through A.23.	June 1988 through January 2000 (n=36 records)	Excluded 1988-1995 data, used 1996-2000 data only (n=14)

*Denotes wells located within or downgradient of known mined/mineralized zones.

n = number of measurements or data points

¹ Corresponding monitoring well locations are shown in Figure A.2. MW2, the current background well according to the Gas Hills license, was not included in the Western Flow Regime background data set because it was considered to be potentially within the flow path of mill-related groundwater impacts (see Figure A.2). The rationales for excluding this and other wells from the Western Flow Regime background evaluation are documented in Attachment A-1, Table A-1.2.

² Initially, all available data were reviewed to assess temporal trends and to ensure that the candidate background wells exhibited generally stable groundwater chemistry trends. However, for wells with more recent data available, only data from the last four years (1996-early 2000) were used in the background database. For the Western Flow Regime, Rim well data are available only prior to 1994, whereas MW76 (located in the same westernmost vicinity) has been sampled more recently. As discussed in Section 4 and demonstrated in Section 5, this factor sometimes influenced the selection of statistical estimators. Refer to Table A.1, note 2 for a discussion of temporal consistency in the data set.

Table A.2. Background Wells Selected for the Western Flow Regime Gas Hills, Wyoming

Monitoring Well ¹	Description	Available Data	Data Used ²
MW30	MW30 was selected based on its crossgradient location and the results of tritium analyses (0.62 TU) indicating the lack of mill-related impacts.	September 1986 through January 2000 (n=44)	Excluded 1986-1995 data, used 1996-2000 data only (n=15)
MW76*	MW 76 is located 7,716 ft downgradient from the AGTI within a highly mineralized area, southwest of the Rim Pit. Conservative analyses of groundwater velocity and travel times indicate that MW 76 is located a sufficient distance downgradient from the site, outside the influence of mill-related contamination.	June 1997 through January 2000 (n=9)	Used all available data (n=9)
MW77	MW 77 is located approximately 4,000 feet downgradient from the AGTI, west of MW 28 (see Figure A.2). Like MW 28, MW 77 was selected as a background well based on low tritium content (0.01 to 0.06 TU), indicating lack of milling-related impacts (see MW 28 description above).	March 1997 through January 2000 (n=11)	Used all available data (n=11)
<i>Rim Wells</i>	The Rim wells were selected as background wells based on their far downgradient location and to substantiate (from a historical perspective) the more recent results obtained for MW 76 (see description above).	<u>Rim 1</u>	For all Rim wells, used 1990-1993 data only (i.e., the last 4 years of sampling data)
Rim 1*		June 1987 through November 1993 (n=13)	
Rim 2		<u>Rim 2</u>	Rim 1, Rim 2: n=10
Rim 3*		June 1987 through November 1993 (n=13)	Rim 3: n=11
		<u>Rim 3</u>	
		June 1987 through November 1993 (n=14)	

Table A.3. Summary Statistics for Southwestern Flow Regime Background Well Data: Radionuclide Parameters, Gas Hills, Wyoming

Summary Statistic ^{1,2}	Radium-226 (pCi/l)	Radium-228 (pCi/l)	Uranium (mg/l)	Thorium-230 (pCi/l)	Lead-210 (pCi/l)	Gross Alpha (pCi/l)
initial N	177	63	147	63	63	63
no. of outliers excluded	4	1	0	2	1	1
valid N	173	62	147	61	62	62
average, all data	150	6.5	0.34	0.38	0.92	451
average, excluding LA8	--	--	0.13	0.04	--	244
standard deviation, all data	360	2.5	0.93	1.42	0.86	660
std. dev., excluding LA8	--	--	0.22	0.28	--	274
<u>Ordinal Statistics</u>						
<i>(for all data unless otherwise noted)</i>						
minimum	0.6	1.1	0.0003	-0.93	-0.80	8.6
50th percentile (median)	15	6.5	0.042	0.05	0.80	110
90th percentile	525	9.7	0.7	0.8	1.9	1,300
95th percentile	1,100	10	2.0	1.8	2.3	2,190
maximum, all data	2,059	11	5.9	8.2	3.5	2,670
maximum, excluding LA8	--	--	1.2	0.8	--	906
<u>95% UL on nth quantile</u>						
90th quantile	1,005	10.7	1.30	5.6	3.0	2,210
95th quantile	1,327	11	4.4	8.2	3.5	2,670
95th quantile, excluding LA8	--	--	0.81	0.80	--	870
<u>Normality Test Results</u>						
K-S d statistic	0.39	0.08	0.36	0.35	0.10	0.27
K-S result	p<.01	p>0.20 (n.s.)	p<.01	p<.01	p>0.20 (n.s.)	p<.01
Lilliefors	p<.01	p>0.20 (n.s.)	p<.01	p<.01	p<.10	p<.01
Shapiro-Wilk W statistic	0.470	0.959	0.40	0.43	0.96	0.714
Shapiro-Wilk result	p<0.001	p<0.15 (n.s.)	p<0.001	p<0.0001	p<0.095	p<0.0001
Reject hypothesis of normal distribution?	Yes	No	Yes	Yes	No	Yes

Bolded and highlighted values correspond to the background value chosen for that parameter; see Table A.5 for supporting rationales.

¹ Of the parameters addressed in this table, PRI well samples were analyzed only for Ra-226 and uranium; consequently, the background sample Ns differ above. Additionally, as discussed in Table A.1, results for colocated PRI wells were averaged for uranium, but not for Ra-226 (thus the difference between Ra-226 and U-nat sample N). This averaging of colocated results was not done for Ra-226 due to the great variability exhibited within the colocated well clusters.

² As demonstrated in Figures A.9 through A.12, the highest levels of U-nat, Th-230, and gross alpha were detected in samples from LA8. Although LA8 is a valid background well, the difference between the levels of these parameters in LA8 vs. those measured in the other background wells is notable enough to warrant further evaluation (i.e., making a distinction between LA8 results and the remaining data). Therefore, some of the summary statistics listed above were recalculated to examine the impact of excluding LA8 from the global background.

Definitions

K-S	Kolmogorov-Smirnov
N	number of samples or data points
n.s.	not significant
p	probability
UL	Non-parametric upper confidence limit for quantiles, where $UL_{0.95}(x_{0.90})$ is the upper 95% confidence limit about the 90th quantile--
	For all parameters, $UL_{0.95}(x_{0.90})$ is equal to the maximum value; this is also true for $UL_{0.95}(x_{0.95})$ when $n < 100$.
--	not applicable and/or not calculated

Table A.4. Summary Statistics for Southwestern Flow Regime Background Well Data: Non-Radionuclide Parameters, Gas Hills, Wyoming

Summary Statistic ^{1,2}	Arsenic (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Selenium (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	TDS (mg/l)
valid N	147	63	147	147	146	147	147
no. of detects	107	0	48	25	146	147	147
frequency of detection	73%	0%	33%	17%	--	--	--
average	0.078	--	0.051	0.005	21.1	665.1	1,210
standard deviation	0.226	--	0.044	0.014	27.3	386.2	606
average excluding LA8	--	--	0.042	--	--	--	--
std. dev. excluding LA8	--	--	0.015	--	--	--	--
<u>Ordinal Statistics</u>							
minimum	0.001	--	0.01	0.001	1.0	60.6	360
50th percentile (median)	0.006	--	0.05	0.002	12.2	685	1,260
90th percentile	0.076	--	0.05	0.005	57.6	1100	1,857
95th percentile	0.81	--	0.08	0.025	97.0	1500	2,660
maximum, all data	1.26	--	0.28	0.097	138	1675	2,900
maximum exc. driving well	0.08	--	0.08	--	--	--	--
<u>95% UL on nth quantile</u>							
90th quantile (p=.9)	0.56	--	0.07	0.02	98.6	1,484	2,660
95th quantile (p=.95)	0.95	--	0.25	0.08	118	1,600	2,759
95th quantile, exc. LA8	--	--	0.06	--	--	--	--
<u>Normality Test Results</u>							
K-S d statistic	0.4631	--	0.4236	0.4172	0.3212	0.0941	0.1118
K-S result	p < .01	--	p < .01	p < .01	p < .01	p < .15	p < .10
Lilliefors	p < .01	--	p < .01	p < .01	p < .01	p < .01	p < .01
Shapiro-Wilk W statistic	0.3826	--	0.5012	0.3220	0.5992	0.9270	0.8927
Shapiro-Wilk result	p < 0.001	--	p < 0.001	p < 0.001	p < 0.001	p < 0.0001	p < 0.0001
Reject hypothesis of normal distribution?	Yes	--	Yes	Yes	Yes	Not based on K-S	Not based on K-S

Bolded and highlighted values correspond to the background value chosen for that parameter.

¹ PRI well samples were not analyzed for beryllium; this factor accounts for the difference in sample Ns listed above. As discussed in Table A.1 and Section 3.1, results for colocated PRI wells were averaged for all parameters except radium. Figures A.13 through A.16 plot the corresponding analytical results.

² For nickel, the difference between results from LA8, the single (driving) well, and those for the remaining background wells is marked (see discussion in Note 2 of the preceding table). In this case, the nickel background estimate was derived for two scenarios: 1) background with the driving well data included, and 2) background excluding the elevated results from LA8. As indicated above and in Table A.5, the lower estimate was conservatively chosen to represent the final nickel background value.

Definitions

K-S	Kolmogorov-Smirnov
N	number of samples or data points
n.s.	not significant
p	probability
std. dev.	standard deviation
UL	Non-parametric upper confidence limit for quantiles, where $UL_{0.95}(x_{0.95})$ is the upper 95% confidence limit about the 90th quantile--
	For all parameters, $UL_{0.95}(x_{0.95})$ is equal to the maximum value; this is also true for $UL_{0.95}(x_{0.95})$ when $n < 100$.
--	not applicable and/or not calculated

Table A.5. Groundwater Background Levels Derived for the Southwestern Flow Regime Gas Hills, Wyoming

Parameter	Background Value	Statistical Basis ¹	Driving Well(s) ²	Comment
Radionuclide Parameters				
Radium-226	150 pCi/l	Average value of Ra-226 distribution, including both AML and PRI well data also = $UL_{0.95}(x_{0.95})$ of distribution excluding driving PRI ore zone wells	PRI wells and Umetco wells LA5 and LA6 (see Figures A.4 and A.5)	A more conservative estimator was chosen for Ra-226 (vs. other parameters) given the highly skewed nature of the background data distribution. The 150 pCi/l value also corresponds to the point after which the slope of the plotted data changes markedly.
Radium-228	10 pCi/l	95 th percentile	LA2 (see Figures A.7 and A.8)	Ra-228 was analyzed for only 36% of the background samples and exhibited no strong correlation when compared with Ra-226 (see Figure A.8); this value is conservative in that it doesn't reflect the higher Ra-226 levels detected in PRI wells.
Radium ²²⁶⁺²²⁸	160 pCi/l	Sum of values listed above for Ra-226 and Ra-228	--	Summation of individual Ra-226 and Ra-228 background values is conservative given the factors discussed above
Uranium	0.81 mg/l	$UL_{.95}$ on 95 th quantile, excluding LA8 including LA8, $UL_{0.95}(x_{0.95}) = 4.4$ mg/l	LA6, PW7, and LA8 (Figure A.9)	The 0.81 mg/l value is conservative, given that LA8 results are valid and represent background conditions. See Note 2 and Table A.3 re: the treatment of LA8 results in deriving U-nat background.

-- Not Applicable

n number of samples or data points

SWFR Southwestern Flow Regime

$UL_{0.95}(x_{0.95})$ non-parametric 95% upper confidence limit ($UL_{0.95}$) about the 95th quantile ($x_{0.95}$) of the distribution

¹ Refer to Sections 3.3 and 4.0 for a more detailed discussion regarding the statistical basis for each background value. This basis sometimes differed between parameters because of the underlying distribution and/or other factors such as temporal considerations.

² The term "driving" refers to the well(s) exhibiting the highest levels of a parameter, and thereby having the greatest influence on the background value selected. For the Southwestern Flow Regime, the highest levels of uranium, Th-230, gross alpha, and nickel were detected in LA8. However, because LA8 results for these parameters tended to vary widely, these data were given less weight than those from other wells exhibiting more consistent trends (e.g., LA6). This conservative approach is apparent in Figures A.9, A.10, and A.12 and is discussed in greater detail in Table A.3 and Section 4. This has no bearing on the validity of LA8's selection as a background well, however. In fact, LA8 is probably most representative of impacts resulting from mine reclamation.

Table A.5. Groundwater Background Levels Derived for the Southwestern Flow Regime Gas Hills, Wyoming

Parameter	Background Value	Statistical Basis ¹	Driving Well(s) ²	Comment
Thorium-230	0.8 pCi/l	UL _{0.95} (x _{0.95}) excluding LA8 including LA8, UL _{0.95} (x _{0.95}) = 8.2 pCi/l (= max.)	LA6, PW7, and LA8	See comment above for U-nat (re: LA8 variability), Table A.3, and Figure A.10.
Lead-210	3.0 pCi/l	= UL _{0.95} (x _{0.90})	LA8, PW7, LA5	See data plots shown in Figure A.11.
Gross Alpha	870 pCi/l	UL _{0.95} (x _{0.95}) excluding LA8 This estimator is fairly consistent with the values listed above for the specific alpha emitters—i.e., summation of the Ra-226, Th-230, and U-nat background values yields 709 pCi/l.	LA6, PW7, and LA8 (Figure A.12)	See comment for uranium above and Note 2. Essentially, this background value is irrelevant because the gross alpha (screening tool) analysis is rendered moot by the standard analytical suite—i.e., the specific alpha emitters are already addressed, in particular radium. Additionally, gross alpha results are typically associated with a high degree of error, in particular for wells with high TDS concentrations.
Regulated Non-Radionuclide Parameters				
Arsenic	0.95 mg/l	UL _{0.95} (x _{0.95})	PW7 (Figure A.13)	Although PW7 is the single well driving the SWFR arsenic background value (see Figure A.13), no special consideration was taken (e.g., as applied to selected LA8 results above). The rationale supporting this approach is that PW7 is also the sole well driving the arsenic source concentration used in the SWFR groundwater model (see Appendix B).
Beryllium	--	--	--	Be was not detected in any (0/63) background samples
Nickel	0.06 mg/l	UL _{0.95} (x _{0.95}) excluding LA8 UL _{0.95} (x _{0.95}) inc. LA8 = 0.25 mg/l	LA8 (Figure A.14)	See comments above re: analytical treatment of LA8 results, as well as Table A.4, Note 2.
Selenium	0.02 mg/l	UL ₉₅ on 90 th quantile note that majority (83%) of results are < 0.001 mg/l	Veca 1, GW11 (Figure A.14)	A more conservative estimator was chosen—i.e., UL _{0.95} (x _{0.90}) vs. UL _{0.95} (x _{0.95})—to account for selenium's low (17%) detection frequency in background samples.

Table A.5. Groundwater Background Levels Derived for the Southwestern Flow Regime Gas Hills, Wyoming

Parameter	Background Value	Statistical Basis ¹	Driving Well(s) ²	Comment
Other Parameters				
Chloride	118 mg/l	UL ₉₅ on 95 th quantile	GW-11, Veca 1, and Veca 3A (Figure A.15)	Chloride levels are highest in GW11, Veca 1, and Veca 3A, located south of the Gas Hills site, outside the influence of any mill-related impacts.
Sulfate	1,600 mg/l	UL ₉₅ on 95 th percentile	Veca 1, LA8, LA6, Veca 3A (Figure A.16)	Like radium and TDS, sulfate levels vary widely in background wells (i.e., there is no distinct driving well as observed for other parameters). The 1,600 mg/l background value corresponds to historical Veca 1 measurements.
TDS	2,760 mg/l	UL ₉₅ on 95 th quantile	LA8, Veca 1, Veca 3A (Figure A.16)	As expected, TDS distributions are similar to those exhibited for sulfate (see comments above).

Table A.6. Summary Statistics for Western Flow Regime Background Well Data: Radionuclide Parameters, Gas Hills, Wyoming

Summary Statistic	Radium-226 (pCi/l)	Radium-228 (pCi/l)	Radium ²²⁶⁺²²⁸ (pCi/l)	Uranium (mg/l)	Thorium-230 (pCi/l)	Lead-210 (pCi/l)	Gross Alpha (pCi/l)
initial N	119	74	74	119	74	74	77
no. of outliers excluded	0	0	0	1	2	0	0
valid N	119	74	74	118	72	74	77
average	14.6	4.7	20.7	0.038	-0.10	1.7	67.5
standard deviation	13.1	2.7	16.1	0.061	0.46	1.4	82
<u>Ordinal Statistics</u>							
minimum	0.2	0.4	0.7	0.0009	-2.90	-2.8	1.0
50th percentile (median)	9.2	4.0	14.4	0.010	0.00	1.4	30
90th percentile	35	9.8	47.0	0.07	0.1	3.8	209
95th percentile	42	11	53	0.23	0.2	4.1	255
maximum	72	12	79	0.26	0.5	6.1	380
<u>95% UL on nth quantile</u>							
90th quantile	40.8	11	54.0	0.23	0.2	4.20	276
95th quantile	54.2	12	79.3	0.25	0.50	6.1	380
<u>Normality Test Results</u>							
K-S d statistic	0.179	0.149	0.231	0.271	0.375	0.127	0.243
K-S result	p<.01	p<.10	p<.01	p<.01	p<.01	p<.20	p<.01
Lilliefors	p<.01	p<.01	p<.01	p<.01	p<.01	p<.01	p<.01
Shapiro-Wilk W statistic	0.853	0.882	0.832	0.603	0.463	0.959	0.714
Shapiro-Wilk result	p<0.0001	p<0.0001	p<0.0001	p<0.001	p<0.0001	p<0.052	p<0.0001
Reject hypothesis of normal distribution?	Yes	Not based on K-S	Yes	Yes	Yes	No	Yes

Bolded and highlighted values correspond to the background value chosen for that parameter; see Table A.8 for supporting rationales.

Regarding Th-230, 35 of the initial 74 data points are negative values, and 18 are zero values.

Definitions

K-S	Kolmogorov-Smirnov
N	number of samples or data points
n.s.	not significant
p	probability
UL	Non-parametric upper confidence limit for quantiles, where $UL_{0.95}(x_{0.95})$ is the upper 95% confidence limit about the 90th quantile-- For all parameters, $UL_{0.95}(x_{0.95})$ is equal to the maximum value; this is also true for $UL_{0.95}(x_{0.95})$ when $n < 100$
--	not applicable and/or not calculated

Table A.7. Summary Statistics for Western Flow Regime Background Well Data: Non-Radionuclide Parameters, Gas Hills, Wyoming

Summary Statistic	Arsenic (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Selenium (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	TDS (mg/l)
initial N	119	83	119	118	119	119	119
number of outliers removed	0	0	0	0	3	2	0
valid N	119	83	119	118	116	117	119
no. of detects	101	6 (all = 0.01)	80	1 (all = 0.01)	116	117	119
frequency of detection	85%	7.2%	67%	0.85%	--	--	--
average	0.025	0.01	0.22	--	5.7	675	1,131
standard deviation	0.031	--	0.50	--	2.1	563	817
<u>Ordinal Statistics</u>							
minimum	0.001	0.01	0.01	0.01	1.0	125	366
50th percentile (median)	0.009	--	0.05	--	5.6	442	780
90th percentile	0.078	--	0.26	--	8.0	1,795	2,710
95th percentile	0.092	--	1.84	--	9.9	1,870	2,981
maximum	0.17	0.01	2.22	0.01	14.0	1,920	3,097
<u>95% UL on nth quantile</u>							
90th quantile	0.09	--	1.8	--	9.7	1,866	2,972
95th quantile	0.10	--	2.1	--	13.0	1,902	3,046
<u>Normality Test Results</u>							
K-S d statistic	0.3293	--	0.3747	--	0.1324	0.2290	0.2517
K-S result	p < .01	--	p < .01	--	p < .01	p < .01	p < .01
Lilliefors	p < .01	--	p < .01	--	p < .01	p < .01	p < .01
Shapiro-Wilk W statistic	0.73732	--	0.43063	--	0.92479	0.76338	0.74407
Shapiro-Wilk result	p < 0.001	--	p < 0.001	--	p < 0.0001	p < 0.0001	p < 0.0001
Reject hypothesis of normal distribution?	Yes	--	Yes	--	Yes	Yes	Yes

Bolded and highlighted values correspond to the background value chosen for that parameter; see Table A.8 for rationales.

Definitions

K-S	Kolmogorov-Smirnov
N	number of samples or data points
n.s.	not significant
p	probability
UL	Non-parametric upper confidence limit for quantiles, where $UL_{0.95}(x_{0.95})$ is the upper 95% confidence limit about the 90th quantile-- For all parameters, $UL_{0.95}(x_{0.95})$ is equal to the maximum value; this is also true for $UL_{0.95}(x_{0.95})$ when $n < 100$.
--	not applicable and/or not calculated

Table A.8 Groundwater Background Levels Derived for the Western Flow Regime Gas Hills, Wyoming

Parameter	Background Value	Statistical Basis	Driving Well(s) ¹	Comment
Radionuclide Parameters				
Radium-226	42 pCi/l	95 th percentile (this value also corresponds closely to the MW76 non-outlier maximum Ra-226 value, 42.8 pCi/l)	A8, MW76, and Rim3 (Figure A.17)	MW76 exhibits the most consistent trend in radium levels and also provides a current "snapshot" of background conditions (vs. Rim 3 and A8); see Note 1 below. The 95 th percentile was chosen vs. $UL_{0.95}(x_{0.95})$ because, when applied to all radium parameters, it yields a $Ra^{226+228}$ value that is consistent with those derived individually for Ra-226 and Ra-228 (see Table A.6).
Radium-228	11 pCi/l	95 th percentile	MW76	see comment above, Table A.6, and Figure A.18
Radium ²²⁶⁺²²⁸	53 pCi/l	95 th percentile	MW76	see above comment
Uranium	0.25 mg/l	$UL_{0.95}$ on 95 th quantile	MW76 (Figure A.19)	0.25 mg/l reflects current conditions in MW76, which exhibits a consistent U-nat trend.
Thorium-230	0.5 pCi/l	$UL_{0.95}(x_{0.95})$ = non-outlier maximum	-- (Figure A.19)	Thorium is consistently low in all WFR background wells.
Lead-210	4.2 pCi/l	$UL_{0.95}$ on 90 th quantile	MW30, MW76 (Figure A.20)	Pb-210 exhibits no apparent trend in WFR background wells. $UL_{0.95}(x_{0.90})$ was chosen because $UL_{0.95}(x_{0.95})$ is equal to the maximum, an historic (7/8/96) A8 measurement.
Gross Alpha	276 pCi/l	$UL_{0.95}$ on 90 th quantile	MW76 (Figure A.20)	$UL_{0.95}(x_{0.90})$ was chosen because it is more representative of current conditions in MW76, the driving well.

-- Not Applicable

WFR Western Flow Regime

$UL_{0.95}(x_{0.95})$ non-parametric 95% upper confidence limit ($UL_{0.95}$) about the 95th quantile ($x_{0.95}$) of the distribution

¹ The term "driving" refers to the well(s) exhibiting the highest levels of a parameter, and thereby having the greatest influence on the background value selected. As indicated above, MW76 is the driving well for most parameters. A8 and Rim wells showed similar values, but A8 tends to be highly variable and Rim data require a caveat given the limited and earlier time frame considered.

Table A.8 Groundwater Background Levels Derived for the Western Flow Regime Gas Hills, Wyoming

Parameter	Background Value	Statistical Basis	Driving Well(s) ¹	Comment
Regulated Non-Radionuclide Parameters				
Arsenic	0.1 mg/l	UL _{0.95} on 95 th quantile	MW76, Rim1, and Adobe 4	0.1 mg/l corresponds to non-outlier maximums for MW76 and Rim 1 (see Fig. A.21)
Beryllium	--	= 0.01 mg/l, equal to all Be detections	-- (detections in MW77 only)	Be was detected in only 6/83 samples (7.2% frequency) at levels equal to the detection limit, 0.01 mg/l
Nickel	2.1 mg/l	UL _{0.95} on 95 th quantile	MW76 (Figure A.21)	See data plot shown on Figure A.21.
Selenium	-- (99% are nondetects)	single detect = 0.01 mg/l	--	Se detected in only 1/118 samples (<1% frequency)
Other Parameters				
Chloride	13 mg/l	UL _{0.95} on 95 th quantile	A8 (A8 impact is minor, however, as all chloride levels in WFR background wells are generally low; see Fig. A.22)	Chloride (Cl) exhibits no apparent trend in WFR background wells. The 13 mg/l background value should be evaluated considering historical Cl levels in Iron and Cole 80 springs. For example, Cl in Iron Spring ranged from 16 mg/l to 29 mg/l during the last 3 years of monitoring (see Figure A.22 inset).
Sulfate	1,900 mg/l (1,902 mg/l shown to 2 significant figures)	UL _{0.95} on 95 th quantile	MW76, Rim3 (Figure A.23)	1,900 mg/l reflects current conditions in MW76, which exhibits a consistent trend for most parameters.
TDS	2,710 mg/l	90 th percentile	Rim 3, MW76 (Figure A.23)	The 90 th percentile was used, vs. UL _{0.95} (x _{0.95}), because this estimator is most representative of current background conditions in MW76. TDS levels in Rim 3 were higher (ranging to 3,046 mg/l), but these data received less weight because Rim 3 was last sampled in Nov-93.

**Table A.9. Summary of Background Values Selected for Southwestern and Western Flow Regimes
Gas Hills, Wyoming**

Parameter	<u>Southwestern Flow Regime</u>			<u>Western Flow Regime</u>		
	Background	Basis	Range	Background	Basis	Range
Radionuclide Parameters						
Radium-226 (pCi/l)	150	average [also = $UL_{0.95}(x_{0.95})$ excluding driving ore zone wells]	0.6 - 2,059	42	95th percentile	0.2 - 72
Radium-228 (pCi/l)	10	95th percentile	1.1 - 11.0	11	95th percentile	0.4 - 12
Radium ²²⁶⁺²²⁸ (pCi/l)	160	sum of above		53	95th percentile, as well as sum of above	0.7 - 79
Uranium (mg/l)	0.81	$UL_{0.95}(x_{0.95})$ exc. LA8	0.0003 - 5.9	0.25	$UL_{0.95}(x_{0.95})$	0.0009 - 0.26
Thorium-230 (pCi/l)	0.8	$UL_{0.95}(x_{0.95})$ exc. LA8	-0.93 - 8.2	0.5	$UL_{0.95}(x_{0.95})$	-2.9 - 0.5
Lead-210 (pCi/l)	3.0	$UL_{0.95}(x_{0.90})$	-0.80 - 3.5	4.2	$UL_{0.95}(x_{0.90})$	-2.8 - 6.1
Gross Alpha (pCi/l)	870	$UL_{0.95}(x_{0.95})$ exc. LA8	8.6 - 2,670	276	$UL_{0.95}(x_{0.90})$	1.0 - 380
Regulated Non-Radionuclides						
Arsenic (mg/l)	0.95	$UL_{0.95}(x_{0.95})$	0.001 - 1.26	0.10	$UL_{0.95}(x_{0.95})$	0.001 - 0.17
Beryllium (mg/l)	--	(not detected)	--	0.01	value equal to all detections	0.01 - 0.01
Nickel (mg/l)	0.06	$UL_{0.95}(x_{0.95})$ exc. LA8	0.01 - 0.28	2.1	$UL_{0.95}(x_{0.95})$	0.01 - 2.22
Selenium (mg/l)	0.02	$UL_{0.95}(x_{0.90})$	0.001 - 0.097	--	(detection frequency is < 1%)	0.01 - 0.01
Other Parameters						
Chloride (mg/l)	118	$UL_{0.95}(x_{0.95})$	1.0 - 138	13	$UL_{0.95}(x_{0.95})$	1.0 - 14.0
Sulfate (mg/l)	1,600	$UL_{0.95}(x_{0.95})$	60.6 - 1675	1,900	$UL_{0.95}(x_{0.95})$	125 - 1,920
TDS (mg/l)	2,760	$UL_{0.95}(x_{0.95})$	360 - 2,900	2,710	90th percentile	366 - 3,097

-- Not applicable (e.g., in cases of low or zero detection frequencies)

UL Non-parametric upper confidence limit for quantiles, where $UL_{0.95}(x_{0.95})$ is the upper 95% confidence limit about the 95th quantile

See Tables A.5 and A.8 and Sections 3 and 4 for a discussion of the basis for the background values proposed above.

Appendix A

Attachment A-1

Table A-1.1. Rationale for Exclusion of Candidate Wells from the Southwestern Flow Regime Background Evaluation, Gas Hills, Wyoming

Monitoring Well	Description	Rationale for Exclusion as Background Well ¹
LA4	Like the other LA series wells shown on Figures A.1 and A.2, LA4 is located east of the site, upgradient of the disturbed areas.	Upgradient well LA 4 was initially considered for inclusion in the Southwestern Flow Regime background database, but was ultimately excluded due to suspect well construction. Its well casing was previously damaged, which resulted in debris falling into the casing and the screened portion of the well. Water quality data are therefore limited for this well.
MW75	MW 75 is located east and hydraulically upgradient of the site.	Data are available for only two monitoring periods in 1997, precluding meaningful analysis.
Veca 2	Crossgradient well located in the same vicinity as background wells Veca 1 and Veca 3A, beyond the ore body of PRI mine unit No. 5 (see Figures A. 1 and A.2).	Veca 2 was initially considered for inclusion in the Southwestern Flow Regime background database, but was ultimately excluded due to spurious analytical results. Like well LA4 (described above), Veca 2's well construction is also questionable and data are available for only three monitoring periods. Additionally, results of the last (Sept-96) period are apparent outliers, as evidenced by the following historical Ra-226 results: 5/18/89 – 46 pCi/l 6/26/89 – 22 pCi/l 9/20/96 – 198 pCi/l

Note:

¹As discussed in Section 2.1 of the text, the primary criterion for selection of background wells was location outside the influence of potential mill-related impacts. Therefore, the wells selected to characterize background groundwater quality for the Southwestern Flow Regime at the Gas Hills site met one of the following criteria:

- 1) hydrologically upgradient of the mill facilities,
- 2) hydrologically crossgradient from the A-9 Repository, or
- 3) distant downgradient of the above-grade tailings impoundment (AGTI).

The Southwestern Flow Regime wells listed above met the initial background selection criteria, but further evaluation suggested that inclusion within the background database might not be valid. Rationales for exclusion from the background data base are documented above. Wells that did not meet the three criteria listed above include all wells located within the site boundary and those wells located immediately downgradient (within the flow path) of mill-related contaminant sources (see Figures A.1 and A.2).

Table A-1.2. Rationale for Exclusion of Candidate Wells from the Western Flow Regime Background Evaluation, Gas Hills, Wyoming

Monitoring Well	Description	Rationale for Exclusion as Background Well ¹
MW2	MW2, located west of the above-grade tailings impoundment, is the current background well for the Western Flow Regime (Lower Wind River aquifer) according to the Gas Hills license.	Despite its designation as a background well, MW 2 was not included in the Western Flow Regime background data set because it was considered to be potentially within the flow path of mill-related groundwater impacts (see Figure A.2).
MW19	MW 19 is located northeast (upgradient) of the above-grade tailings impoundment (Figure A.2).	Although technically upgradient from the site, MW 19 was not selected as a background well because data from earlier monitoring periods indicated potential influence from the site. Although recent data generally exhibit stable groundwater chemistry trends, MW 19 was conservatively excluded from the Western Flow Regime background data set.
MW20	MW 20 is located directly adjacent to (east and upgradient from) the above-grade tailings impoundment, in the vicinity of former sumps and seeps (Figure A.2).	Although technically upgradient from the site, MW 20 was not selected as a background well given historical detections of elevated concentrations of milling-related constituents. These findings may be attributable to seepage from the above grade impoundment.
DW4	DW 4 is located south of the A-9 repository, in an area where the Western Flow Regime is confined.	Although apparently well outside the influence of Western Flow Regime, DW 4 was excluded as a background well because previous extraction of water resulted in increases in chloride concentrations, indicating the potential presence of mill-related constituents.

Note:

¹As discussed in Section 2.1 of the text, the primary criterion for selection of background wells was location outside the influence of potential mill-related impacts. Therefore, the wells selected to characterize background groundwater quality for the Western Flow Regime at the Gas Hills site met one of the following criteria:

- 1) hydrologically upgradient of the mill facilities,
- 2) hydrologically crossgradient from the A-9 Repository, or
- 3) distant downgradient of the above-grade tailings impoundment (AGTI).

The Western Flow Regime wells listed above met the initial background selection criteria, but further evaluation suggested that inclusion within the background database might not be valid. Rationales for exclusion from the background data base are documented above. Wells that did not meet the three criteria listed above include all wells located within the site boundary and those wells located immediately downgradient (within the flow path) of mill-related contaminant sources (see Figures A.1 and A.2).

Appendix A

Attachment A-2

**Table A-2.1 Southwestern Flow Regime Analytical Results for Background Wells Sampled by Umetco
Gas Hills, Wyoming**

Monitoring Well ID	Date Sampled	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Ra- ²²⁶⁺²²⁸ (pCi/l)	Th-230 (pCi/l)	Uranium (mg/l)	Lead-210 (pCi/l)	G_Alpha (pCi/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)	Beryllium (mg/l)
LA1	9/20/96	7.6				0.085			799	1390	18.2	0.001 U	0.05 U	0.001 U	
LA1	12/12/96	7.2	6.0	13.2	-0.10	0.029	0.60	49	851	1350	17	0.001 U	0.02	0.002 U	0.01 U
LA1	9/2/97	4.7	5.3	10.0	0.00	0.013	0.00	30	893	1380	19	0.002	0.01 U	0.002 U	0.01 U
LA1	4/28/98	4.1	4.6	8.7	-0.02	0.006	-0.40	36	875	1380	18	0.001 U	0.01 U	0.002 U	0.01 U
LA1	6/24/98	2.1	1.6	3.7	0.09	0.002	-0.80	28	862	1380	17	0.006	0.01 U	0.002 U	0.01 U
LA2	3/13/96	11.0	11.0	22.0	0.20	0.074	1.80	51	770	1400	19	0.001 U	0.02	0.002 U	0.01 U
LA2	6/12/96	13.0	9.9	22.9	-0.10	0.042	0.00	67	768	1480	21	0.001 U	0.03	0.002 U	0.01 U
LA2	8/28/96	14.0	7.0	21.0	0.20	0.059	0.40	55	760	1480	22	0.001	0.03	0.002 U	0.01 U
LA2	9/17/96	16.8				0.058			793	1420	26	0.001 U	0.05 U	0.001 U	
LA2	10/28/96	11.0	11.0	22.0	-0.10	0.051	1.70	57	710	1370	22	0.001 U	0.03	0.002 U	0.01 U
LA2	2/11/97	10.0	9.6	19.6	-0.20	0.051	0.80	62	704	1460	21	0.003	0.03	0.002 U	0.01 U
LA2	6/6/97	11.0	6.0	17.0	0.00	0.110	1.90	98	788	1420	24	0.002	0.03	0.002 U	0.01 U
LA2	8/7/97	21.0	9.2	30.2	-0.30	0.008	0.50	81	812	1510	24	0.003	0.03	0.002 U	0.01 U
LA2	11/3/97	13.0	10.0	23.0	-0.10	0.096	0.60	72	780	1400	24	0.002	0.03	0.002 U	0.01 U
LA2	4/28/98	13.7	9.7	23.4	-0.20	0.078	0.10	84	818	1470	24	0.001 U	0.03	0.002 U	0.01 U
LA2	6/23/98	15.1	9.1	24.2	0.40	0.150	0.90	155	786	1500	23	0.005	0.03	0.008	0.01 U
LA2	9/1/98	14.9	9.7	24.6	0.02	0.075	0.30	84	792	1470	24	0.004	0.03	0.002 U	0.01 U
LA2	11/17/98	16.0	9.4	25.4	0.02	0.063	0.60	67	814	1490	22	0.002	0.03	0.002 U	0.01 U
LA2	1/6/99	12.7	9.6	22.3	0.05	0.073	0.40	48	834	1440	22	0.006	0.03	0.005 U	0.01 U
LA2	8/25/99	16.8	9.8	26.6	0.03	0.066	0.80	54	763	1440	21	0.003 U	0.03	0.005 U	0.01 U
LA2	2/15/00	14.0	8.8	22.8	-0.93	0.063	0.67	74	780	1500	22	0.003 U	0.04	0.005 U	0.002 U
LA3	9/19/96	1.4				0.012			312	633	6.2	0.001 U	0.05 U	0.001 U	
LA3	12/12/96	5.1	5.4	10.5	-0.10	0.017	1.80	42	790	1290	6	0.001	0.02	0.002 U	0.01 U
LA3	6/10/97	3.8	6.8	10.6	0.10	0.420	0.40	356	831	1340	5	0.002	0.01	0.002 U	0.01 U
LA3	9/2/97	5.3	6.8	12.1	-0.20	0.012	0.50	30	877	1220	6	0.002	0.01 U	0.002 U	0.01 U
LA3	11/23/97	5.0	5.8	10.8	-0.10	0.020	0.30	29	890	1560	6	0.001 U	0.01	0.002 U	0.01 U
LA3	4/21/98	6.2	6.6	12.8	-0.19	0.016	0.10	41	914	1380	6	0.002	0.02	0.002 U	0.01 U
LA3	6/23/98	7.8	7.6	15.4	0.20	0.032	0.20	46	836	1390	5	0.005	0.02 U	0.002 U	0.01 U
LA5	9/17/96	42.7				0.093			839	1460	4.7	0.001 U	0.05 U	0.001 U	
LA5	6/10/97	6.0	2.4	8.4	0.10	0.130	0.10	123	632	1120	4	0.001 U	0.01 U	0.002 U	0.01 U
LA5	8/28/97	14.0	3.5	17.5	0.10	0.040	0.10	58	677	1220	5	0.003	0.01 U	0.002 U	0.01 U
LA5	11/22/97	33.0	7.2	40.2	0.40	0.066	2.50	126	937	1670	5	0.005	0.04	0.002 U	0.01 U
LA5	4/21/98	29.1	7.1	36.2	-0.01	0.120	1.40	148	889	1610	5	0.006	0.04	0.002 U	0.01 U
LA5	6/23/98	24.3	6.9	31.2	0.10	0.091	0.90	122	905	1700	5	0.012	0.02	0.002 U	0.01 U
LA5	3/2/00	26.0	7.8	33.8	-0.49	0.073	1.40	150	890	1600	4.4	0.004	0.031	0.005 U	0.002 U

U - not detected; boxed values listed in bold are outliers that were excluded from the background evaluation.

**Table A-2.1 Southwestern Flow Regime Analytical Results for Background Wells Sampled by Umetco
Gas Hills, Wyoming**

Monitoring Well ID	Date Sampled	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Ra ²²⁶⁺²²⁸ (pCi/l)	Th-230 (pCi/l)	Uranium (mg/l)	Lead-210 (pCi/l)	G. Alpha (pCi/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)	Beryllium (mg/l)
LA6	9/17/96	32.2				0.421			1040	1600	20.4	0.009	0.05 U	0.001	
LA6	12/12/96	17.0	8.7	25.7	-0.10	0.470	2.10	551	990	1570	21	0.016	0.02	0.002 U	0.01 U
LA6	6/10/97	15.0	7.7	22.7	0.10	0.053	0.90	74	962	1480	23	0.016	0.01 U	0.002 U	0.01 U
LA6	9/2/97	12.0	7.8	19.8	0.00	0.044	1.00	97	968	1560	24	0.017	0.01 U	0.002 U	0.01 U
LA6	11/22/97	18.0	8.4	26.4	0.50	1.200	1.70	906	1100	1830	20	0.013	0.01	0.003	0.01 U
LA6	4/21/98	18.8	8.9	27.7	0.53	0.800	1.30	791	1130	1700	20	0.015	0.01 U	0.002 U	0.01 U
LA6	6/23/98	18.3	9.8	28.1	0.80	0.830	0.80	865	1090	1760	20	0.024	0.02 U	0.002 U	0.01 U
LA7	9/18/96	2.0				0.002			301	520	7.2	0.001 U	0.05 U	0.001 U	
LA7	6/10/97	1.7	3.3	5.0	-0.10	0.010	0.10	15	302	616	6.0	0.001	0.01 U	0.002 U	0.01 U
LA7	9/3/97	2.0	3.1	5.1	0.00	0.005	0.20	10	497	910	11	0.002	0.01 U	0.002 U	0.01 U
LA7	12/1/97	1.1	1.6	2.7	-0.10	0.003	0.20	8.6	308	562	7.0	0.004	0.01 U	0.002 U	0.01 U
LA7	4/29/98	2.7	2.3	5.0	0.05	0.006	0.10	14	323	604	7.0	0.001 U	0.01 U	0.002 U	0.01 U
LA7	6/25/98	0.6	1.1	1.7	0.10	0.001	-0.50	13	361	674	7.0	0.004	0.04	0.002 U	0.01 U
LA8	9/19/96	11.1				5.896			1430	2900	21.7	0.001 U	0.24	0.001 U	
LA8	12/13/96	12.0	7.3	19.3	0.40	4.400	6.40	2670	1480	2690	18	0.015	0.28	0.002 U	0.01 U
LA8	6/9/97	9.5	4.6	14.1	0.20	2.000	-0.40	1380	1400	2480	19	0.004	0.22	0.002 U	0.01 U
LA8	9/2/97	6.1	3.8	9.9	6.90	4.100	1.10	2660	1180	2120	18	0.003	0.01 U	0.002 U	0.01 U
LA8	11/21/97	16.0	6.5	22.5	1.80	4.900	1.10	2080	1500	2770	20	0.008	0.27	0.002 U	0.01 U
LA8	4/21/98	11.6	4.4	16.0	1.18	3.300	1.20	2190	1580	2730	19	0.006	0.17	0.002 U	0.01 U
LA8	6/23/98	11.2	4.8	16.0	2.30	3.500	0.70	2220	1500	2760	20	0.015	0.25	0.002 U	0.01 U
LA8	3/6/00	10.0	6.4	16.4	8.20	3.600	3.30	1300	1400	2500	18	0.003 U	0.21	0.005 U	0.002 U
PW7	3/11/96	15.0	6.8	21.8	0.20	0.660	1.60	553	830	1290	3	1.080	0.05	0.002 U	0.01 U
PW7	5/22/96	19.0	5.0	24.0	0.80	0.730	0.90	757	850	1340	3	1.260	0.04	0.002 U	0.01 U
PW7	9/4/96	17.0	5.7	22.7	1.50	0.660	1.40	558	819	1350	3	0.889	0.05	0.002 U	0.01 U
PW7	11/7/96	14.0	5.4	19.4	2.70	0.700	2.30	509	860	1300	3	0.946	0.06	0.002 U	0.01 U
PW7	3/12/97	15.0	5.0	20.0	0.00	0.710	1.90	762	860	1360	3	0.850	0.07	0.002 U	0.01 U
PW7	6/9/97	12.0	5.1	17.1	0.20	0.640	1.80	621	814	1260	4	0.513	0.06	0.002 U	0.01 U
PW7	8/5/97	16.0	-0.4	15.6	0.20	0.700	0.50	579	840	1330	3	0.862	0.08	0.002 U	0.01 U
PW7	11/3/97	15.0	5.4	20.4	0.30	0.600	0.80	638	859	1220	3	0.812	0.04	0.002 U	0.01 U
PW7	3/10/98	17.0	5.6	22.6	0.00	0.510	2.00	597	787	1310	3	0.440	0.05	0.002 U	0.01 U
PW7	6/15/98	15.0	6.5	21.5	0.30	0.560	1.70	480	692	1360	3	0.810	0.06	0.002 U	0.01 U
PW7	9/22/98	12.6	4.3	16.9	0.07	0.500	0.60	433	484	796	21	0.338	0.04	0.002 U	0.01 U
PW7	12/8/98	10.6	3.9	14.5	0.10	0.460	1.00	446	879	1200	3	0.312	0.04	0.002 U	0.01 U
PW7	3/2/99	13.2	5.2	18.4	0.05	0.490	1.30	460	764	1300	3	0.455	0.05	0.005 U	0.01 U
PW7	2/15/00	15.0	5.3	20.3	-0.48	0.500	3.50	540	820	1400	2.5	0.470	0.05	0.005 U	0.002 U

U - not detected; boxed values listed in bold are outliers that were excluded from the background evaluation.

**Table A-2.2. Southwestern Flow Regime Analytical Results for Background Wells Sampled by Others
Gas Hills, Wyoming**

Monitoring Well ID	Corresponding Colocated Wells	Colocate Well ID	PRI Mine Unit	Ore Zone Identifier	Date Sampled	Ra-226 (pCi/l)	Uranium (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)
GW11	--	--	-- TVA		9/19/96	3.75	0.1335	665.5	1440	138	0.003	0.05 U	0.014
GW11	--	--	-- TVA		11/24/96	6	0.147	685	1410	122	0.022	0.05 U	0.025
GW11	--	--	-- TVA		2/25/97	5.4	0.12	650	1350	112	0.016	0.05 U	0.027
GW11	--	--	-- TVA		4/23/97	5.9	0.139	684	1423	106	0.012	0.05 U	0.023
GW11	--	--	-- TVA		11/4/97	4.5	0.159	741	1420	122	0.01	0.05 U	0.022
GW10A	--	--	Mine Unit 5		10/20/97	9.2	0.021	1040	1760	5.2	0.009	0.05 U	0.001 U
PIXMO97-1	--	--	Mine Unit 5		10/19/97	5.5	0.0003	442	824	9.5	0.006	0.05 U	0.001 U
PIXMP97-1*	PIXMU97-1*	PIXMx97-1*	Mine Unit 5	Ore Zone	10/17/97	647	0.012	456	852	5.7	0.001 U	0.05 U	0.001 U
PIXMU97-1*	PIXMP97-1*	PIXMx97-1*	Mine Unit 5	Ore Zone	10/18/97	19.1	0.004	513	962	18	0.002	0.05 U	0.001 U
Veca 1	--	--	Mine Unit 5		9/20/96	8.4	0.0952	1580	2660	80.4	0.001 U	0.05 U	0.089
Veca 1	--	--	Mine Unit 5		11/21/96	16.6	0.058	1641	2660	97	0.002	0.05 U	0.08
Veca 1	--	--	Mine Unit 5		3/6/97	22.2	0.075	1675	2710	76	0.001	0.05 U	0.097
Veca 1	--	--	Mine Unit 5		4/28/97	9.4	0.068	1595	2682	118	0.006	0.05 U	0.04
Veca 1	--	--	Mine Unit 5		11/4/97	10.2	0.076	1600	2640	124	0.002	0.05 U	0.035
Veca 3A	--	--	Mine Unit 5		9/20/96	11.2	0.184	871	1560	55.3	0.025	0.05 U	0.001 U
Veca 3A	--	--	Mine Unit 5		11/19/96	109	0.144	893	1720	57.6	0.011	0.05 U	0.001 U
Veca 3A	--	--	Mine Unit 5		3/6/97	14	0.135	995	1580	67	0.015	0.05 U	0.001 U
Veca 3A	--	--	Mine Unit 5		4/28/97	16.3	0.202	1070	1857	74	0.076	0.05 U	0.001 U
Veca 3A	--	--	Mine Unit 5		10/29/97	12.7	0.209	1060	1950	70.9	0.027	0.05 U	0.001 U
BUMP97-1*	BUMU97-1*	BUMx97-1*	Mine Unit 4	Ore Zone	10/20/97	128	0.033	1190	1970	7.5	0.001 U	0.05 U	0.001 U
BUMU97-1*	BUMP97-1*	BUMx97-1*	Mine Unit 4	Ore Zone	10/20/97	11	0.001	823	1350	4.9	0.001 U	0.05 U	0.001 U
GW5A	--	--	Mine Unit 4		9/23/96	1	0.0012	616	1040	8.2	0.024	0.05 U	0.001 U
GW5A	--	--	Mine Unit 4		3/7/97	2.6	0.0003	621	1060	7.7	0.024	0.05 U	0.001 U
GW5A	--	--	Mine Unit 4		4/28/97	1.1	0.0003	592	1046	8.4	0.027	0.05 U	0.001 U
GW5A	--	--	Mine Unit 4		8/20/97	0.9	0.001	591	1040	7.4	0.025	0.05 U	0.001 U
GW5A	--	--	Mine Unit 4		10/29/97	1	0.0005	590	1060	7.3	0.022	0.05 U	0.001 U

PRI wells are listed according to mine unit, in order of increasing distance from the Gas Hills site. Asterisks (*) denotes those wells completed in an ore zone.

Individual wells are shaded alternately to facilitate review. Bold lines denote a change in mine unit and dashed lines separate colocated wells.

See page 4 of this table and Table A-2.3 for an explanation of the colocated PRI wells and their incorporation in the background evaluation.

U - not detected; boxed values in bold are outliers that were excluded from the background evaluation (see Appendix A, Section 3.2).

**Table A-2.2. Southwestern Flow Regime Analytical Results for Background Wells Sampled by Others
Gas Hills, Wyoming**

Monitoring Well ID	Corresponding Colocated Wells	Colocate Well ID	PRI Mine Unit	Ore Zone Identifier	Date Sampled	Ra-226 (pCi/l)	Uranium (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)
GW9	WSL96M-1	GW9,WSL	Mine Unit 4		9/20/96	2.8	0.022	99	389	3.3	0.064	0.05 U	0.001 U
GW9	WSL96M-1	GW9,WSL	Mine Unit 4		11/24/96	5.5	0.019	113	389	4.8	0.063	0.05 U	0.001
GW9	WSL96M-1	GW9,WSL	Mine Unit 4		2/28/97	2.9	0.017	93	370	4.2	0.064	0.05 U	0.003
GW9	WSL96M-1	GW9,WSL	Mine Unit 4		4/23/97	3.1	0.019	101	389	4.1	0.07	0.05 U	0.001 U
GW9	WSL96M-1	GW9,WSL	Mine Unit 4		8/25/97	5.0	0.015	103	399	4.5	0.07	0.05 U	0.001 U
GW9	WSL96M-1	GW9,WSL	Mine Unit 4		10/30/97	2.0	0.017	97.1	394	4.5	0.075	0.05 U	0.001 U
WSL96M-1	GW9	GW9,WSL	Mine Unit 4		9/27/96	10.1	0.0042	249	645	15.8	0.006	0.05 U	0.001 U
WSL96M-1	GW9	GW9,WSL	Mine Unit 4		11/13/96	8.7	0.048	247	543	16.2	0.007	0.05 U	0.001 U
WSL96M-1	GW9	GW9,WSL	Mine Unit 4		2/28/97	9.1	0.003	221	507	11.8	0.005	0.05 U	0.001 U
WSL96M-1	GW9	GW9,WSL	Mine Unit 4		4/23/97	8.2	0.003	244	523	9.3	0.006	0.05 U	0.001 U
WSL96M-1	GW9	GW9,WSL	Mine Unit 4		8/25/97	8.1	0.005	256	553	6.6	0.006	0.05 U	0.001
WSL96M-1	GW9	GW9,WSL	Mine Unit 4		10/30/97	6.5	0.0056	234	552	5.3	0.006	0.05 U	0.001 U
WSL96MP-1*	--	--	Mine Unit 4	Ore Zone	10/3/96	1200	0.0081	60.6	378	5.8	0.015	0.05 U	0.004
WSL96MP-1*	--	--	Mine Unit 4	Ore Zone	11/21/96	1310	0.016	64.4	360	6.5	0.013	0.05 U	0.006
WSL96MP-1*	--	--	Mine Unit 4	Ore Zone	3/4/97	1320	0.012	62.2	366	5.6	0.012	0.05 U	0.001 U
WSL96MP-1*	--	--	Mine Unit 4	Ore Zone	5/5/97	1240	0.012	63.9	380	1	0.011	0.05 U	0.001 U
WSL96MP-1*	--	--	Mine Unit 4	Ore Zone	8/25/97	1250	0.012	65.9	396	5.8	0.012	0.05 U	0.001 U
WSL96MP-1*	--	--	Mine Unit 4	Ore Zone	10/30/97	1050	0.012	63.3	389	5.2	0.012	0.05 U	0.001 U
BS96M-1	--	--	Mine Unit 2		9/16/96	41.1	0.0819	431	797	17.1	0.001 U	0.05 U	0.001 U
BS96M-1	--	--	Mine Unit 2		11/11/96	19.7	0.03	260	615	12.1	0.032	0.05 U	0.001 U
BS96M-1	--	--	Mine Unit 2		2/27/97	54.7	0.016	182	530	9.9	0.023	0.05 U	0.001 U
BS96M-1	--	--	Mine Unit 2		4/23/97	14.8	0.012	181	543	7.9	0.024	0.05 U	0.001 U
BS96M-1	--	--	Mine Unit 2		8/25/97	14.8	0.01	186	549	9.8	0.021	0.05 U	0.001 U
BS96M-1	--	--	Mine Unit 2		10/30/97	14.7	0.011	169	523	8.6	0.028	0.05 U	0.001 U
BSMP-1*	BSMP-2*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	9/12/96	51.3	0.283	262	601	13.9	0.056	0.05 U	0.001 U
BSMP-1*	BSMP-2*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	11/11/96	79.1	0.32	257	600	15.1	0.051	0.05 U	0.001 U
BSMP-1*	BSMP-2*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	2/27/97	93.5	0.057	257	628	14.7	0.046	0.05 U	0.003
BSMP-1*	BSMP-2*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	4/25/97	87	0.032	272	658	14.3	0.051	0.05 U	0.001 U
BSMP-1*	BSMP-2*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	8/26/97	91.4	0.051	267	659	14.9	0.054	0.05 U	0.001 U
BSMP-1*	BSMP-2*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	10/30/97	83.9	0.038	275	660	16.1	0.051	0.05 U	0.001 U

**Table A-2.2. Southwestern Flow Regime Analytical Results for Background Wells Sampled by Others
Gas Hills, Wyoming**

Monitoring Well ID	Corresponding Colocated Wells	Colocate Well ID	PRI Mine Unit	Ore Zone Identifier	Date Sampled	Ra-226 (pCi/l)	Uranium (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)
BSMP-2*	BSMP-1*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	9/13/96	35.5	0.01	206	502	9.6	0.009	0.05 U	0.001 U
BSMP-2*	BSMP-1*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	11/11/96	37.7	0.0077	183	545	10.4	0.016	0.05 U	0.001 U
BSMP-2*	BSMP-1*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	2/28/97	35.9	0.013	182	546	9.3	0.016	0.05 U	0.001 U
BSMP-2*	BSMP-1*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	4/25/97	30.7	0.009	195	562	9.4	0.02	0.05 U	0.001 U
BSMP-2*	BSMP-1*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	8/26/97	40.4	0.012	195	573	9.3	0.027	0.05 U	0.001 U
BSMP-2*	BSMP-1*, BSMP-3*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	11/3/97	33.6	0.011	195	526	9.7	0.021	0.05 U	0.001 U
BSMP-3*	BSMP-1*, BSMP-2*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	9/16/96	150	0.033	219	459	8.6	0.045	0.05 U	0.001 U
BSMP-3*	BSMP-1*, BSMP-2*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	11/11/96	156	0.056	188	515	9.1	0.011	0.05 U	0.001 U
BSMP-3*	BSMP-1*, BSMP-2*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	2/28/97	82	0.019	181	547	9.3	0.002	0.05 U	0.001 U
BSMP-3*	BSMP-1*, BSMP-2*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	4/25/97	163.7	0.058	196	559	9.2	0.015	0.05 U	0.001 U
BSMP-3*	BSMP-1*, BSMP-2*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	8/26/97	155	0.054	198	585	10.1	0.012	0.05 U	0.001 U
BSMP-3*	BSMP-1*, BSMP-2*, BSPW-1*	BS-ore*	Mine Unit 2	Ore Zone	10/28/97	143	0.056	194	588	9	0.012	0.05 U	0.001 U
BSPW-1*	BSMP-1*, BSMP-2*, BSMP-3*	BS-ore*	Mine Unit 2	Ore Zone	9/16/96	140	0.0585	199	500	9.3	0.009	0.05 U	0.001 U
BSPW-1*	BSMP-1*, BSMP-2*, BSMP-3*	BS-ore*	Mine Unit 2	Ore Zone	11/11/96	305	0.032	202	538	7.7	0.047	0.05 U	0.001 U
BSPW-1*	BSMP-1*, BSMP-2*, BSMP-3*	BS-ore*	Mine Unit 2	Ore Zone	2/27/97	353	0.042	203	570	8.2	0.043	0.05 U	0.002
BSPW-1*	BSMP-1*, BSMP-2*, BSMP-3*	BS-ore*	Mine Unit 2	Ore Zone	4/23/97	308	0.036	220	581	7.7	0.052	0.05 U	0.001 U
BSPW-1*	BSMP-1*, BSMP-2*, BSMP-3*	BS-ore*	Mine Unit 2	Ore Zone	8/26/97	325	0.038	214	587	8.1	0.047	0.05 U	0.001 U
BSPW-1*	BSMP-1*, BSMP-2*, BSMP-3*	BS-ore*	Mine Unit 2	Ore Zone	11/3/97	272	0.035	215	542	7.7	0.045	0.05 U	0.001 U
MP-1*	P-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	2/27/97	958	0.027	187	515	12.9	0.015	0.05 U	0.001 U
MP-1*	P-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	4/23/97	911	0.024	197	545	11.2	0.014	0.05 U	0.001 U
MP-1*	P-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	8/20/97	572	0.023	191	542	11.9	0.013	0.05 U	0.001 U
MP-1*	P-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	10/30/97	1000	0.026	189	539	11.8	0.015	0.05 U	0.001 U
P-1*	MP-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	2/27/97	2059	0.02	237	590	13.5	0.003	0.05 U	0.002
P-1*	MP-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	4/23/97	1715	0.019	250	622	12.5	0.002	0.05 U	0.001 U
P-1*	MP-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	8/20/97	1100	0.017	249	630	13.5	0.002	0.05 U	0.001 U
P-1*	MP-1*	MP-1, P-1*	Mine Unit 1	Ore Zone	10/30/97	1650	0.021	244	630	12.3	0.002	0.05 U	0.001 U
MU96M-2	--	--	Mine Unit 1		4/23/97	36.8	0.002	290	677	21.5	0.001 U	0.05 U	0.001 U
MU96M-2	--	--	Mine Unit 1		9/22/97	37.4	0.002	308	689	24.6	0.001 U	0.05 U	0.001 U
MU96M-2	--	--	Mine Unit 1		11/3/97	33.4	0.001	294	640	20.5	0.001 U	0.05 U	0.052
MUMP97-1*	--	--	Mine Unit 1	Ore Zone	10/18/97	898	0.052	229	596	12.7	0.032	0.05 U	0.001 U

**Table A-2.2. Southwestern Flow Regime Analytical Results for Background Wells Sampled by Others
Gas Hills, Wyoming**

Monitoring Well ID	Corresponding Colocated Wells	Colocate Well ID	PRI Mine Unit	Ore Zone Identifier	Date Sampled	Ra-226 (pCi/l)	Uranium (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)
PC	--	--	Mine Unit 3		8/24/96	8.6	0.0019	420	846	10.8	0.001 U	0.05 U	0.001 U
PC	--	--	Mine Unit 3		11/13/96	8.7	0.0032	425	822	11.3	0.002	0.05 U	0.001 U
PCHMP97-1*	--	--	Mine Unit 3	Ore Zone	10/17/97	444	0.033	459	826	18	0.001 U	0.05 U	0.001 U
PEACHM-1	--	--	Mine Unit 3		9/25/96	12.7	0.0026	447	842	12.7	0.001 U	0.05 U	0.001 U
PEACHM-1	--	--	Mine Unit 3		11/13/96	11.7	0.0038	460	824.5	12.35	0.001 U	0.05 U	0.001 U
PEACHM-1	--	--	Mine Unit 3		3/3/97	19.3	0.003	420	842	10.7	0.001 U	0.05 U	0.001 U
PEACHM-1	--	--	Mine Unit 3		6/20/97	11.2	0.002	457	834	10.5	0.001 U	0.05 U	0.004
PEACHM-1	--	--	Mine Unit 3		8/26/97	13.9	0.002	452	874	11.4	0.001 U	0.05 U	0.001 U
PEACHM-2	--	--	Mine Unit 3		9/25/96	22.1	0.0082	529	1130	116	0.005	0.05 U	0.001 U
PEACHM-2	--	--	Mine Unit 3		11/13/96	19.5	0.038	442	860	4	0.005	0.05 U	0.001 U
PEACHM-2	--	--	Mine Unit 3		3/3/97	25	0.032	463	893	37.9	0.01	0.05 U	0.001 U
PEACHM-2	--	--	Mine Unit 3		6/20/97	19.2	0.02	504	882	29.2	0.003	0.05 U	0.001 U
PEACHMP-1*	--	--	Mine Unit 3	Ore Zone	9/25/96	416	0.307	461	890	23.2	0.001 U	0.05 U	0.001 U
PEACHMP-1*	--	--	Mine Unit 3	Ore Zone	10/3/96	525	0.065	421	861	14.7	0.001 U	0.05 U	0.001
PEACHMP-1*	--	--	Mine Unit 3	Ore Zone	11/13/96	37.4	0.04	419	823	30.7	0.001 U	0.05 U	0.001
PEACHMP-1*	--	--	Mine Unit 3	Ore Zone	3/3/97	536	0.153	421	838	16.2	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	--	Mine Unit 3		9/25/96	38.2	0.0247	432	859	17.4	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	--	Mine Unit 3		2/28/97	48.4	0.033	406	817	14.9	0.001 U	0.05 U	0.003
PEACHMP-2	--	--	Mine Unit 3		6/20/97	45.9	0.025	438	827	13.7	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	--	Mine Unit 3		8/26/97	43	0.029	421	821	15	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	--	Mine Unit 3		10/31/97	39.6	0.028	403	805	14.6	0.001 U	0.05 U	0.001 U

Note

As discussed in Table A.1 of the text (Note 4), a large number of PRI wells (n=28) were included in the background database. Some wells have only one data point, and several wells are colocated (see Figure A.1). To account for the colocated wells, all non-radium results for colocated wells were averaged for each monitoring period. This approach was taken so as to not weight the background database, and to facilitate review of the graphical plots presented later in this report. The colocated wells are highlighted above, and assigned a corresponding collocate well ID, as reflected in the parameter-box plots shown in Figures A.5 through A.16. The reason that radium (Ra-226) results were not treated similarly is due to the variability in radium concentrations exhibited within even the colocated well clusters. As indicated above, PRI well samples were not analyzed for Th-230, Lead-210, gross alpha, or beryllium.

Table A-2.3. Southwestern Flow Regime Background Database for all Non-Radium Parameters Reflecting Averaging of Results for Colocated Wells, Gas Hills, Wyoming

Well ID	Corresponding Colocated Wells	PRI Mine Unit	Ore Zone Identifier	Date Sampled	Uranium (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)
GW11	--	-- TVA		Sep-96	0.1335	665.5	1440	138	0.003	0.05 U	0.014
GW11	--	-- TVA		Nov-96	0.147	685	1410	122	0.022	0.05 U	0.025
GW11	--	-- TVA		Feb-97	0.12	650	1350	112	0.016	0.05 U	0.027
GW11	--	-- TVA		Apr-97	0.139	684	1423	106	0.012	0.05 U	0.023
GW11	--	-- TVA		Nov-97	0.159	741	1420	122	0.01	0.05 U	0.022
GW10A	--	Mine Unit 5		Oct-97	0.021	1040	1760	5.2	0.009	0.05 U	0.001 U
PIXMO97-1	--	Mine Unit 5		Oct-97	0.0003	442	824	9.5	0.006	0.05 U	0.001 U
PIXMx97-1*	PIXMP97-1*, PIXMU97-1*	Mine Unit 5	Ore Zone	Oct-97	0.008	484.5	907	11.9	0.002	0.05 U	0.001 U
Veca MW-1	--	Mine Unit 5		Sep-96	0.0952	1580	2660	80.4	0.001 U	0.05 U	0.089
Veca MW-1	--	Mine Unit 5		Nov-96	0.058	1641	2660	97	0.002	0.05 U	0.08
Veca MW-1	--	Mine Unit 5		Mar-97	0.075	1675	2710	76	0.001	0.05 U	0.097
Veca MW-1	--	Mine Unit 5		Apr-97	0.068	1595	2682	118	0.006	0.05 U	0.04
Veca MW-1	--	Mine Unit 5		Nov-97	0.076	1600	2640	124	0.002	0.05 U	0.035
Veca MW-3A	--	Mine Unit 5		Sep-96	0.184	871	1560	55.3	0.025	0.05 U	0.001 U
Veca MW-3A	--	Mine Unit 5		Nov-96	0.144	893	1720	57.6	0.011	0.05 U	0.001 U
Veca MW-3A	--	Mine Unit 5		Mar-97	0.135	995	1580	67	0.015	0.05 U	0.001 U
Veca MW-3A	--	Mine Unit 5		Apr-97	0.202	1070	1857	74	0.076	0.05 U	0.001 U
Veca MW-3A	--	Mine Unit 5		Oct-97	0.209	1060	1950	70.9	0.027	0.05 U	0.001 U
BUMx97-1*	BUMP97-1*, BUMU97-1*	Mine Unit 4	Ore Zone	Oct-97	0.017	1006.5	1660	6.2	0.001 U	0.05 U	0.001 U
GW5A	--	Mine Unit 4		Sep-96	0.0012	616	1040	8.2	0.024	0.05 U	0.001 U
GW5A	--	Mine Unit 4		Mar-97	0.0003	621	1060	7.7	0.024	0.05 U	0.001 U
GW5A	--	Mine Unit 4		Apr-97	0.0003	592	1046	8.4	0.027	0.05 U	0.001 U
GW5A	--	Mine Unit 4		Aug-97	0.001	591	1040	7.4	0.025	0.05 U	0.001 U
GW5A	--	Mine Unit 4		Oct-97	0.0005	590	1060	7.3	0.022	0.05 U	0.001 U
GW9,WSL	GW-9, WSL96M-1	Mine Unit 4		Sep-96	0.0131	174	517	9.55	0.035	0.05 U	0.001 U
GW9,WSL	GW-9, WSL96M-1	Mine Unit 4		Nov-96	0.0335	180	466	10.5	0.035	0.05 U	0.001
GW9,WSL	GW-9, WSL96M-1	Mine Unit 4		Feb-97	0.010	157	439	8.0	0.0345	0.05 U	0.003
GW9,WSL	GW-9, WSL96M-1	Mine Unit 4		Apr-97	0.011	172.5	456	6.7	0.038	0.05 U	0.001 U
GW9,WSL	GW-9, WSL96M-1	Mine Unit 4		Aug-97	0.01	179.5	476	5.55	0.038	0.05 U	0.001
GW9,WSL	GW-9, WSL96M-1	Mine Unit 4		Oct-97	0.0113	165.55	473	4.9	0.0405	0.05 U	0.001 U

See notes on Table A-2.2. U - not detected.

Table A-2.3. Southwestern Flow Regime Background Database for all Non-Radium Parameters Reflecting Averaging of Results for Colocated Wells, Gas Hills, Wyoming

Well ID	Corresponding Colocated Wells	PRI Mine Unit	Ore Zone Identifier	Date Sampled	Uranium (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)
WSL96MP-1*	--	Mine Unit 4	Ore Zone	Oct-96	0.0081	60.6	378	5.8	0.015	0.05 U	0.004
WSL96MP-1*	--	Mine Unit 4	Ore Zone	Nov-96	0.016	64.4	360	6.5	0.013	0.05 U	0.006
WSL96MP-1*	--	Mine Unit 4	Ore Zone	Mar-97	0.012	62.2	366	5.6	0.012	0.05 U	0.001 U
WSL96MP-1*	--	Mine Unit 4	Ore Zone	May-97	0.012	63.9	380	1	0.011	0.05 U	0.001 U
WSL96MP-1*	--	Mine Unit 4	Ore Zone	Aug-97	0.012	65.9	396	5.8	0.012	0.05 U	0.001 U
WSL96MP-1*	--	Mine Unit 4	Ore Zone	Oct-97	0.012	63.3	389	5.2	0.012	0.05 U	0.001 U
BS96M-1	--	Mine Unit 2		Sep-96	0.0819	431	797	17.1	0.001 U	0.05 U	0.001 U
BS96M-1	--	Mine Unit 2		Nov-96	0.03	260	615	12.1	0.032	0.05 U	0.001 U
BS96M-1	--	Mine Unit 2		Feb-97	0.016	182	530	9.9	0.023	0.05 U	0.001 U
BS96M-1	--	Mine Unit 2		Apr-97	0.012	181	543	7.9	0.024	0.05 U	0.001 U
BS96M-1	--	Mine Unit 2		Aug-97	0.01	186	549	9.8	0.021	0.05 U	0.001 U
BS96M-1	--	Mine Unit 2		Oct-97	0.011	169	523	8.6	0.028	0.05 U	0.001 U
BS-ore*	BSMP-1*, BSMP-2*, BSMP-3*, BSPW-1*	Mine Unit 2	Ore Zone	Sep-96	0.096	221.5	515.5	10.35	0.030	0.05 U	0.001 U
BS-ore*	BSMP-1*, BSMP-2*, BSMP-3*, BSPW-1*	Mine Unit 2	Ore Zone	Nov-96	0.104	207.5	550	10.6	0.031	0.05 U	0.001 U
BS-ore*	BSMP-1*, BSMP-2*, BSMP-3*, BSPW-1*	Mine Unit 2	Ore Zone	Feb-97	0.033	205.75	573	10.4	0.027	0.05 U	0.002
BS-ore*	BSMP-1*, BSMP-2*, BSMP-3*, BSPW-1*	Mine Unit 2	Ore Zone	Apr-97	0.034	220.75	590	10.2	0.035	0.05 U	0.001 U
BS-ore*	BSMP-1*, BSMP-2*, BSMP-3*, BSPW-1*	Mine Unit 2	Ore Zone	Aug-97	0.039	218.5	601	10.6	0.035	0.05 U	0.001 U
BS-ore*	BSMP-1*, BSMP-2*, BSMP-3*, BSPW-1*	Mine Unit 2	Ore Zone	Oct-97	0.035	219.75	579	10.6	0.032	0.05 U	0.001 U
MP-1, P-1*	MP-1*, P-1*	Mine Unit 1	Ore Zone	Feb-97	0.024	212	553	13.2	0.009	0.05 U	0.002
MP-1, P-1*	MP-1*, P-1*	Mine Unit 1	Ore Zone	Apr-97	0.022	224	584	11.9	0.008	0.05 U	0.001 U
MP-1, P-1*	MP-1*, P-1*	Mine Unit 1	Ore Zone	Aug-97	0.020	220	586	12.7	0.0075	0.05 U	0.001 U
MP-1, P-1*	MP-1*, P-1*	Mine Unit 1	Ore Zone	Oct-97	0.0235	216.5	584.5	12.05	0.0085	0.05 U	0.001 U
MU96M-2	--	Mine Unit 1		Apr-97	0.002	290	677	21.5	0.001 U	0.05 U	0.001 U
MU96M-2	--	Mine Unit 1		Sep-97	0.002	308	689	24.6	0.001 U	0.05 U	0.001 U
MU96M-2	--	Mine Unit 1		Nov-97	0.001	294	640	20.5	0.001 U	0.05 U	0.052
MUMP97-1*	--	Mine Unit 1	Ore Zone	Oct-97	0.052	229	596	12.7	0.032	0.05 U	0.001 U
PC	--	Mine Unit 3		Aug-96	0.0019	420	846	10.8	0.001 U	0.05 U	0.001 U
PC	--	Mine Unit 3		Nov-96	0.0032	425	822	11.3	0.002	0.05 U	0.001 U
PCHMP97-1*	--	Mine Unit 3	Ore Zone	Oct-97	0.033	459	826	18	0.001 U	0.05 U	0.001 U

Table A-2.3. Southwestern Flow Regime Background Database for all Non-Radium Parameters Reflecting Averaging of Results for Colocated Wells, Gas Hills, Wyoming

Well ID	Corresponding Colocated Wells	PRI Mine Unit	Ore Zone Identifier	Date Sampled	Uranium (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Selenium (mg/l)
PEACHM-1	--	Mine Unit 3		Sep-96	0.0026	447	842	12.7	0.001 U	0.05 U	0.001 U
PEACHM-1	--	Mine Unit 3		Nov-96	0.0038	460	824.5	12.35	0.001 U	0.05 U	0.001 U
PEACHM-1	--	Mine Unit 3		Mar-97	0.003	420	842	10.7	0.001 U	0.05 U	0.001 U
PEACHM-1	--	Mine Unit 3		Jun-97	0.002	457	834	10.5	0.001 U	0.05 U	0.004
PEACHM-1	--	Mine Unit 3		Aug-97	0.002	452	874	11.4	0.001 U	0.05 U	0.001 U
PEACHM-2	--	Mine Unit 3		Sep-96	0.0082	529	1130	116	0.005	0.05 U	0.001 U
PEACHM-2	--	Mine Unit 3		Nov-96	0.038	442	860	4	0.005	0.05 U	0.001 U
PEACHM-2	--	Mine Unit 3		Mar-97	0.032	463	893	37.9	0.01	0.05 U	0.001 U
PEACHM-2	--	Mine Unit 3		Jun-97	0.02	504	882	29.2	0.003	0.05 U	0.001 U
PEACHMP-1*	--	Mine Unit 3	Ore Zone	Sep-96	0.307	461	890	23.2	0.001 U	0.05 U	0.001 U
PEACHMP-1*	--	Mine Unit 3	Ore Zone	Oct-96	0.065	421	861	14.7	0.001 U	0.05 U	0.001
PEACHMP-1*	--	Mine Unit 3	Ore Zone	Nov-96	0.04	419	823	30.7	0.001 U	0.05 U	0.001
PEACHMP-1*	--	Mine Unit 3	Ore Zone	Mar-97	0.153	421	838	16.2	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	Mine Unit 3		Sep-96	0.0247	432	859	17.4	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	Mine Unit 3		Feb-97	0.033	406	817	14.9	0.001 U	0.05 U	0.003
PEACHMP-2	--	Mine Unit 3		Jun-97	0.025	438	827	13.7	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	Mine Unit 3		Aug-97	0.029	421	821	15	0.001 U	0.05 U	0.001 U
PEACHMP-2	--	Mine Unit 3		Oct-97	0.028	403	805	14.6	0.001 U	0.05 U	0.001 U

**Table A-2.4 Western Flow Regime Background Sample Results
Gas Hills, Wyoming**

Monitoring Well ID	Date Sampled	226 (pCi/l)	Ra-228 (pCi/l)	Ra ^{226,228} (pCi/l)	Th-230 (pCi/l)	Uranium (mg/l)	Lead-210 (pCi/l)	G. Alpha (pCi/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Selenium (mg/l)
Adobe 4	6/5/90	4.1				0.0075			581	1018	3.1	0.05		0.01 U	0.005 U
Adobe 4	9/25/90	3.3				0.0117			610	1024	2.5	0.05		0.01	0.005 U
Adobe 4	3/20/91	3.4				0.0025			662	975	3.8	0.03	0.01 U	0.01 U	0.005 U
Adobe 4	6/26/91	2.3				0.0037			640	976	3.1	0.07		0.03	0.005 U
Adobe 4	9/11/91	3.3				0.0046			630	1037	8.3	0.055		0.05 U	0.005 U
Adobe 4	12/18/91	2.9				0.0586			601	1002	5	0.04		0.03	0.005 U
Adobe 4	3/25/92	3.6				0.0300			632	986	4.35	0.069		0.05 U	0.005 U
Adobe 4	6/24/92	4.1				0.0040			582	1058	3.1	0.095		0.04	0.005 U
Adobe 4	9/23/92	3				0.0038			591	947	3.9	0.04		0.04 U	0.005 U
Adobe 4	5/12/93	3.3				0.0060			578	996	3.6	0.05		0.01	0.005 U
Adobe 4	11/16/93	3.1				0.0052			546	966	1.8	0.043		0.05 U	
A8	7/8/96	72	7.3	79.3	(0.10)	0.018	6.1	161	647	1160	8	0.006	0.01 U	0.03	0.002 U
A8	9/19/96	40	2.6	42.60	0.00	0.023	-0.2	96	796	1210	11	0.001	0.01 U	0.03	0.002 U
A8	9/8/97	29	2.7	31.70	0.20	0.047	0.1	101	865	1370	13	0.005	0.01 U	0.02	0.002 U
A8	10/14/98	26	3.8	29.90	0.20	0.067	0.6	94	900	1420	14	0.002	0.01 U	0.03	0.002 U
DOMW1	3/23/94	1.3				0.0115		9.3	146	458	7.7	0.01 U	0.01 U	0.01 U	0.005 U
DOMW1	6/13/94	0.6				0.0096		7.5 U	130	426	4.4	0.01 U	0.01 U	0.01 U	0.005 U
DOMW1	12/28/94	0.2 U				0.0053		3.4	137	454	5.1	0.002	0.01 U	0.01 U	0.005 U
DOMW1	3/20/95	0.5	1 U	1.50	0.20 U	0.0061	1.3	1 U	133	441	4.6	0.01 U	0.01 U	0.01 U	0.005 U
DOMW1	6/29/95	1.0	2.2	3.20	0.50	0.6204	1 U	1.6	388	857	33	0.01 U	0.01 U	0.01 U	0.010
DOMW1	8/23/95	0.2	0.9	1.10	0.20	0.032	0.1	33	152	366	5	0.001 U	0.01 U	0.01 U	0.002 U
DOMW1	12/14/95	7.1	0.6	7.70	0.00	0.006	1.4	11	145	452	4	0.002	0.01 U	0.01 U	0.002 U
DOMW1	3/22/96	0.4	1.5	1.90	0.00	0.004	-0.3	6.6	130	414	4	0.001 U	0.01 U	0.01 U	0.002 U
DOMW1	7/1/96	0.3	0.4	0.70	0.00	0.004	0.3	5.7	128	398	4	0.001 U	0.01 U	0.01 U	0.002 U
DOMW1	11/11/96	0.4	2	2.40	0.00	0.003	1.2	6.9	137	418	4	0.001 U	0.01 U	0.01 U	0.002 U

U - not detected. Blank spaces indicate that parameter not analyzed for.

Boxed values listed in bold are outliers that were excluded from the background evaluation.

Table A-2.4 Western Flow Regime Background Sample Results
Gas Hills, Wyoming

Monitoring Well ID	Date Sampled	226 (pCi/l)	Ra-228 (pCi/l)	Ra ²²⁶⁺²²⁸ (pCi/l)	Th-230 (pCi/l)	Uranium (mg/l)	Lead-210 (pCi/l)	G. Alpha (pCi/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Selenium (mg/l)
MW27	3/13/96	8.1	6.2	14.30	0.00	0.004	2.9	20	450	738	6	0.007	0.01 U	0.06	0.002 U
MW27	6/11/96	8.5	4	12.50	(0.10)	0.005	1	23	438	780	6	0.005	0.01 U	0.06	0.002 U
MW27	8/22/96	8.5	3.1	11.60	0.90	0.005	0.5	18	433	702	6	0.008	0.01 U	0.06	0.002 U
MW27	10/11/96	7.6	1.9	9.50	(0.10)	0.001	1.6	26	431	758	6	0.008	0.01 U	0.07	0.005 U
MW27	5/7/97	7.4	4	11.40	0.00	0.003	1	24	398	726	5	0.01	0.01 U	0.06	0.002 U
MW27	7/28/97	8.3	2.5	10.80	(0.10)	0.005	1.6	26	424	806	6	0.012	0.01 U	0.07	0.002 U
MW27	10/13/97	6.3	4.2	10.50	(0.10)	0.004	1.1	22	408	746	5	0.008	0.01 U	0.06	0.002 U
MW27	2/4/98	7.1	3.6	10.70	(0.10)	0.002	1.6	21	411	720	5	0.006	0.01 U	0.04	0.002 U
MW27	5/6/98	8.7	3.9	12.60	(0.04)	0.004	1.4	19	407	746	9	0.008	0.01 U	0.05	0.002 U
MW27	7/29/98	8.3	4.2	12.50	(0.02)	0.003	1.4	22	415	762	5	0.011	0.01 U	0.07	0.002 U
MW27	10/21/98	7.0	3.8	10.80	(0.09)	0.004	2.6	9.6	390	728	5	0.009	0.01 U	0.06	0.005 U
MW27	1/6/99	6.4	4.7	11.10	(0.01)	0.001	1.3	22	428	746	5	0.012	0.01 U	0.05	0.005 U
MW27	8/9/99	5.1	3.3	8.40	(0.06)	0.001 U	1.5	17	378	760	5	0.008	0.01 U	0.06	0.005 U
MW27	1/20/00	6.3	3.1	9.40	(0.33)	0.001 U	2.7	37	390	710	3.8	0.0065	0.002 U	0.051	0.005 U
MW28	3/29/96	9.2	5.8	15.00	0.00	0.003	1.2	26	380	688	5	0.01	0.01 U	0.03	0.002 U
MW28	6/5/96	8.7	5	13.70	(0.10)	0.003	2.4	24	358	656	5	0.008	0.01 U	0.05	0.002 U
MW28	8/14/96	7.5	3.8	11.30	0.00	0.001	0.5	29	386	670	5	0.007	0.01 U	0.04	0.002 U
MW28	10/28/96	11	6.4	17.40	(0.10)	0.001	0.9	19	381	636	5	0.006	0.01 U	0.05	0.002 U
MW28	2/3/97	11	3.8	14.80	(0.20)	0.004	1.4	51	359	678	4	0.009	0.01 U	0.05	0.002 U
MW28	4/30/97	11	4.6	15.60	0.10	0.002	1.4	33	388	692	6	0.009	0.01 U	0.05	0.002 U
MW28	7/25/97	6.6	4.4	11.00	(0.10)	0.003	1.1	20	374	688	5	0.006	0.01 U	0.03	0.002 U
MW28	10/8/97	9.6	4.2	13.80	(0.10)	0.002	-2.8	33	407	678	6	0.009	0.01 U	0.05	0.002 U
MW28	1/28/98	10	4.5	14.50	0.20	0.002	1	30	435	748	6	0.007	0.01 U	0.05	0.002 U
MW28	4/28/98	10.4	5.4	15.80	0.07	0.001 U	1.1	41	432	732	6	0.004	0.01 U	0.05	0.002 U
MW28	7/29/98	12.3	7.1	19.40	0.01	0.002	0.2	32	445	798	6	0.009	0.01 U	0.06	0.002 U
MW28	10/20/98	10.7	5	15.70	(0.10)	0.003	1	23	435	782	5	0.01	0.01 U	0.05	0.005 U
MW28	1/19/99	10.3	4	14.30	0.10	0.004	1.2	27	479	818	6	0.008	0.01 U	0.05	0.005 U
MW28	1/20/00	12	4.9	16.90	(2.90)	0.001 U	3.7	46	500	810	5.8	0.0078	0.002 U	0.051	0.005 U
MW30	3/20/96	15	1.7	16.70	0.00	0.056	2	60	250	540	3	0.001 U	0.01 U	0.01 U	0.002 U
MW30	6/17/96	14	2.6	16.60	(0.10)	0.090	2	40	252	538	4	0.005	0.01 U	0.01 U	0.002 U
MW30	8/26/96	18	2.3	20.30	0.20	0.053	1.8	73	264	478	4	0.004	0.01 U	0.01 U	0.002 U
MW30	10/29/96	22	1.6	23.60	0.00	0.060	3.3	105	260	533	4	0.004	0.01 U	0.01 U	0.002 U

Table A-2.4 Western Flow Regime Background Sample Results
Gas Hills, Wyoming

Monitoring Well ID	Date Sampled	226 (pCi/l)	Ra-228 (pCi/l)	Ra ²²⁶⁺²²⁸ (pCi/l)	Th-230 (pCi/l)	Uranium (mg/l)	Lead-210 (pCi/l)	G_Alpha (pCi/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Selenium (mg/l)
MW30	2/13/97	31	3	34.00	0.00	0.062	3.9	69	256	590	6	0.002	0.01 U	0.01 U	0.002 U
MW30	5/7/97	24	2.5	26.50	(0.10)	0.059	3.8	94	272	540	5	0.006	0.01 U	0.01 U	0.002 U
MW30	7/29/97	12	4	16.00	0.00	0.019	1.5	58	284	606	2	0.009	0.01 U	0.01 U	0.002 U
MW30	10/22/97	30	1.7	31.70	0.00	0.066	4.2	91	278	584	6	0.005	0.01 U	0.01 U	0.002 U
MW30	2/3/98	14	4	18.00	0.10	0.061	1.9	50	283	610	5	0.004	0.01 U	0.01 U	0.002 U
MW30	6/16/98	32.3	3.4	35.70	0.04	0.067	3.8	95	271	612	6	0.007	0.01 U	0.01 U	0.002 U
MW30	8/13/98	25.6	2.8	28.40	(0.02)	0.063	2.1	94	288	614	6	0.005	0.01 U	0.01 U	0.002 U
MW30	11/11/98	35.1	2.3	37.40	(0.10)	0.075	3.4	114	259	618	8	0.009	0.01 U	0.01 U	0.005 U
MW30	1/7/99	20.4	2.6	23.00	0.10	0.056	2.8	63	306	574	6	0.008	0.01 U	0.01 U	0.005 U
MW30	8/17/99	20.3	3.5	23.80	(0.06)	0.070	4.1	142	1840	602	39	0.003 U	0.01 U	0.01 U	0.005 U
MW30	1/24/00	28	3.5	31.50	(2.00)	0.065	4.6	180	310	620	6.5	0.0073	0.002 U	0.01 U	0.005 U
MW76	6/6/97	42	12	54.00	0.10	0.240	2.2	276	1710	2480	7	0.068	0.01 U	2.08	0.002 U
MW76	8/4/97	35	9.8	44.80	0.00	0.200	2.2	380	1860	2570	8	0.078	0.01 U	2.22	0.002 U
MW76	11/4/97	42	11	53.00	0.10	0.250	3.1	161	1830	2510	16	0.083	0.01 U	2.09	0.01 U
MW76	2/4/98	36	11	47.00	0.10	0.260	3	355	1830	2610	7	0.082	0.01 U	1.84	0.002 U
MW76	5/5/98	36	12	48.00	0.08	0.250	2	255	1880	2360	8	0.089	0.01 U	1.9	0.002 U
MW76	8/10/98	42.8	9.8	52.60	(0.20)	0.230	1.7	220	1870	2710	7	0.089	0.01 U	1.8	0.002 U
MW76	10/14/98	54.2	11	65.20	(0.20)	0.220	2	209	1780	2640	7	0.092	0.01 U	1.62	0.002 U
MW76	1/6/99	39	11	50.00	(0.20)	0.220	2.3	249	1920	2600	6	0.099	0.01 U	1.82	0.005 U
MW76	1/24/00	35	8.9	43.90	(1.50)	0.240	3.8	210	1900	2600	6.1	0.074	0.004 U	1.9	0.005 U
MW77	3/20/97	4.2	5.4	9.60	(0.10)	0.003	0.9	16	444	730	1 U	0.003	0.01 U	0.22	0.002 U
MW77	6/6/97	5.5	5	10.50	0.00	0.018	0.4	21	437	740	4	0.005	0.01 U	0.17	0.002 U
MW77	8/4/97	5.7	4.9	10.60	0.00	0.010	0.8	24	442	714	4	0.007	0.01 U	0.16	0.002 U
MW77	11/4/97	5.3	4.8	10.10	(0.20)	0.004	0.8	22	507	780	4	0.008	0.01 U	0.24	0.002 U
MW77	1/28/98	6.3	5.4	11.70	0.00	0.001	0.6	11	511	798	4	0.006	0.01	0.25	0.002 U
MW77	4/29/98	5.6	5.7	11.30	(0.10)	0.001 U	1	28	558	812	4	0.005	0.01	0.26	0.002 U
MW77	8/11/98	6.8	5.6	12.40	(0.04)	0.005	0.3	26	573	876	4	0.008	0.01	0.25	0.002 U
MW77	11/3/98	6.3	5.7	12.00	(0.10)	0.001 U	0	41	531	866	4	0.007	0.01	0.25	0.002 U
MW77	1/26/99	5.2	6.4	11.60	0.04	0.001 U	0.7	30	560	878	4	0.01	0.01 U	0.23	0.005 U
MW77	8/9/99	7.5	5.6	13.10	(0.10)	0.001 U	0.8	17	520	868	4	0.007	0.01	0.26	0.005 U
MW77	1/19/00	6.7	5.4	12.10	6.20	0.001 U	1.2	43	590	900	3.2	0.0059	0.013	0.27	0.005 U

Table A-2.4 Western Flow Regime Background Sample Results
Gas Hills, Wyoming

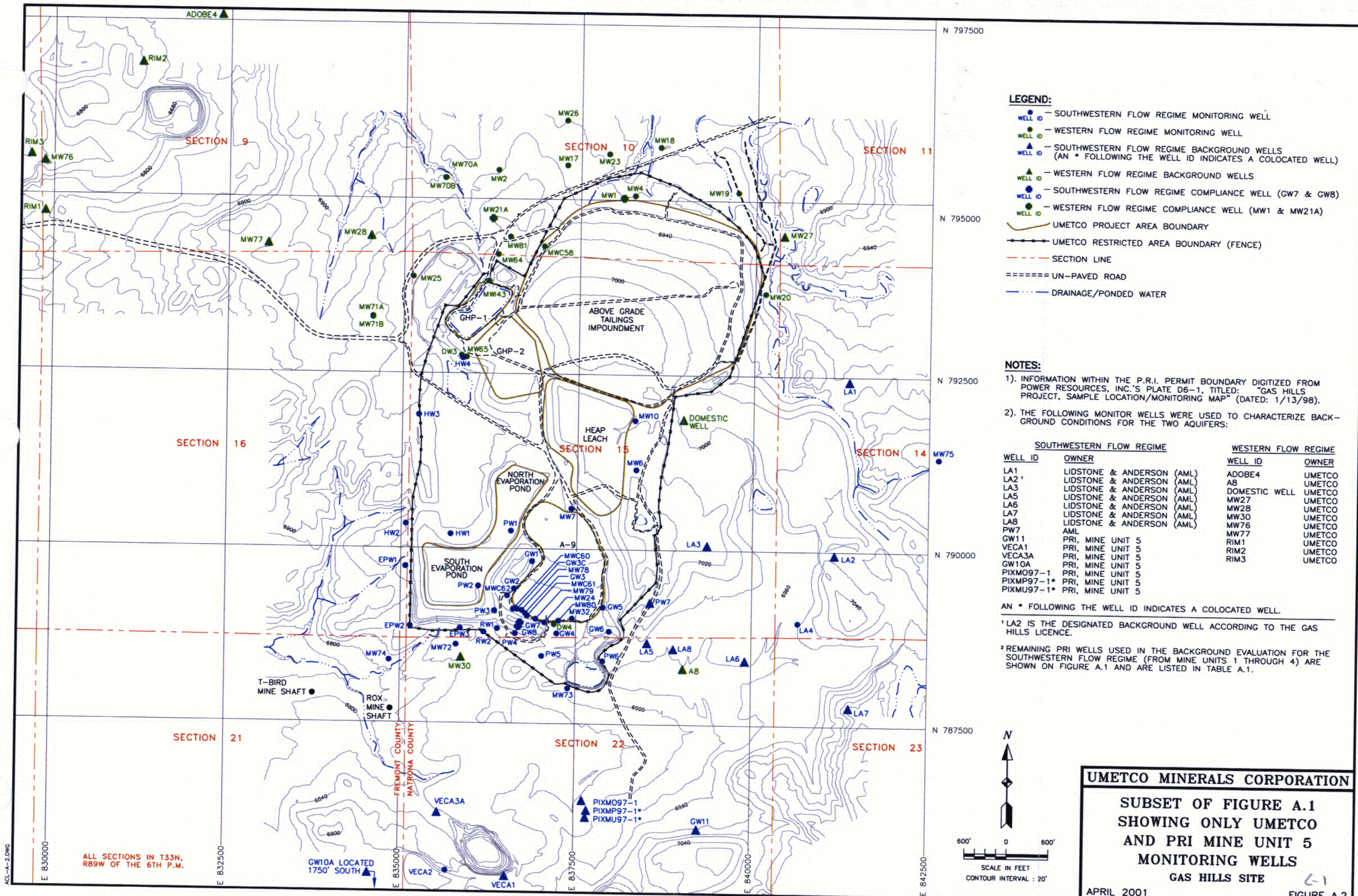
Monitoring Well ID	Date Sampled	226 (pCi/l)	Ra-228 (pCi/l)	Ra ²²⁶⁺²²⁸ (pCi/l)	Th-230 (pCi/l)	Uranium (mg/l)	Lead-210 (pCi/l)	G. Alpha (pCi/l)	Sulfate (mg/l)	TDS (mg/l)	Chloride (mg/l)	Arsenic (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Selenium (mg/l)
RIM1	6/5/90	26.9				0.0250			799	1361	4.3	0.08		0.24	0.005 U
RIM1	9/25/90	23.1				0.0465			847	1442	4	0.07		0.21	0.005 U
RIM1	3/20/91	16.5				0.0191			924	1410	5.6	0.06	0.01 U	0.25	0.005 U
RIM1	6/26/91	19.6				0.0109			812	1392	6.4	0.06		0.18	0.005 U
RIM1	9/11/91	17.1				0.0493			910	1555	8.9	0.172		0.2	0.005 U
RIM1	3/25/92	17.3				0.0270			935	1526	10	0.094		0.2	0.005 U
RIM1	6/24/92	15.4				0.0453			928	1717	6.6	0.101		0.17	0.005 U
RIM1	9/22/92	12.4				0.0278			988	1619	4.5	0.03	0.01 U	0.11	0.005 U
RIM1	5/12/93	14				0.0330			1015	1670	5.7	0.05		0.19	0.005 U
RIM1	11/16/93	30.7				0.0405			1038	1783	3.7	0.066		0.17	0.001 U
RIM2	6/5/90	8.9				0.0484			126	410	6.5	0.01 U		0.01 U	0.005 U
RIM2	9/25/90	8.1				0.0097			156	412	6.2	0.01 U		0.01 U	0.005 U
RIM2	3/20/91	4.5				0.0050			147	382	7	0.01 U	0.01 U	0.01 U	0.005 U
RIM2	6/26/91	6.9				0.0099			133	403	6	0.01 U		0.03	0.005 U
RIM2	9/11/91	6				0.0092			125	418	9.4	0.0000		0.05 U	0.005 U
RIM2	3/25/92	4.4				0.0060			129	397	7.12	0.001		0.05 U	0.005 U
RIM2	6/24/92	4.1				0.0081			135	547	6.7	0.002		0.01 U	0.005 U
RIM2	9/23/92	3.6				0.0059			136	454	6.6	0.01 U		0.01 U	0.005 U
RIM2	5/12/93	4.1				0.0087			126	390	7.9	0.01 U		0.01	0.005 U
RIM2	11/16/93	5.8				0.0078			128	393	5.8	0.001 U		0.05 U	0.001 U
RIM3	6/5/90	42.8				0.0479			1771	2906	5.7	0.04		0.04	0.005 U
RIM3	9/25/90	31.1				0.0582			1902	2923	6.5	0.04		0.37	0.005 U
RIM3	3/20/91	22.4				0.0464			1772	2891	7.3	0.01 U	0.01 U	0.23	0.005 U
RIM3	6/26/91	21				0.0480			1613	2941	6.8	0.04		0.19	0.005 U
RIM3	9/11/91	25				0.0548			1823	3046	11.5	0.034		0.17	0.005 U
RIM3	12/18/91	19.8				0.0437			1889	2981	9.9	0.04		0.2	0.005 U
RIM3	3/25/92	17.7				0.0460			1787	3046	5.34	0.043		0.16	0.005 U
RIM3	6/24/92	22.1				0.0675			1755	3097	6.3	0.056		0.16	0.005 U
RIM3	9/22/92	16				0.0451			1804	2966	6.6	0.03	0.01 U	0.13	0.005 U
RIM3	5/12/93	17.9				0.0541			1744	3042	7.9	0.03		0.1	0.005 U
RIM3	11/16/93	22.6				0.0521			1795	3031	5.6	0.027		0.08	0.001 U

**THIS PAGE IS AN
OVERSIZED DRAWING
OR FIGURE,
THAT CAN BE VIEWED AT
THE RECORD TITLED:**

**FIGURE A.1:
BACKGROUND WELL DESIGNATIONS FOR
SOUTHWESTERN AND WESTERN FLOW
REGIMES
GAS HILLS SITE**

**WITHIN THIS PACKAGE...OR,
BY SEARCHING USING THE DRAWING
NUMBER:
FIGURE A.1**

NOTE: Because of this page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.



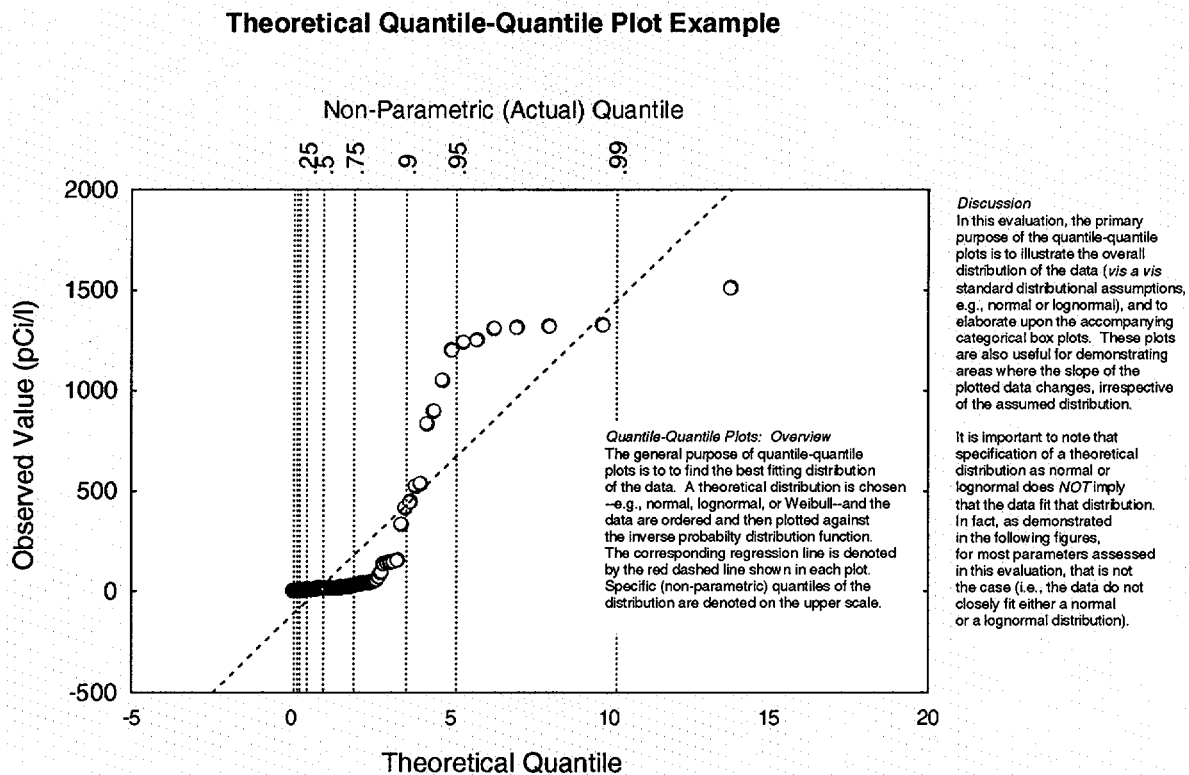
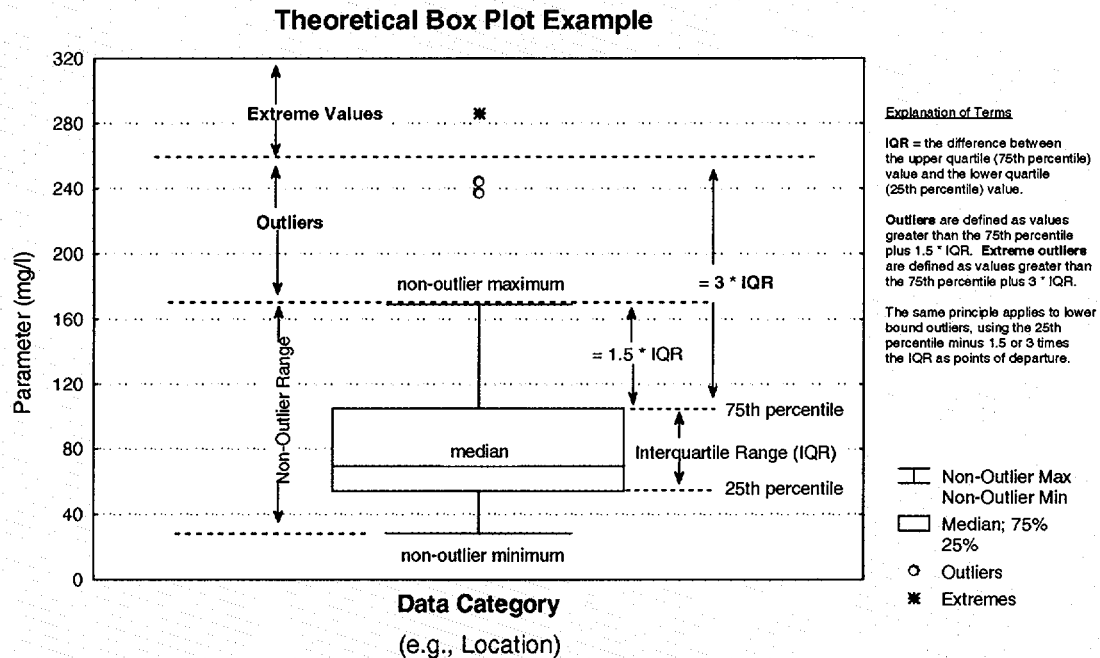
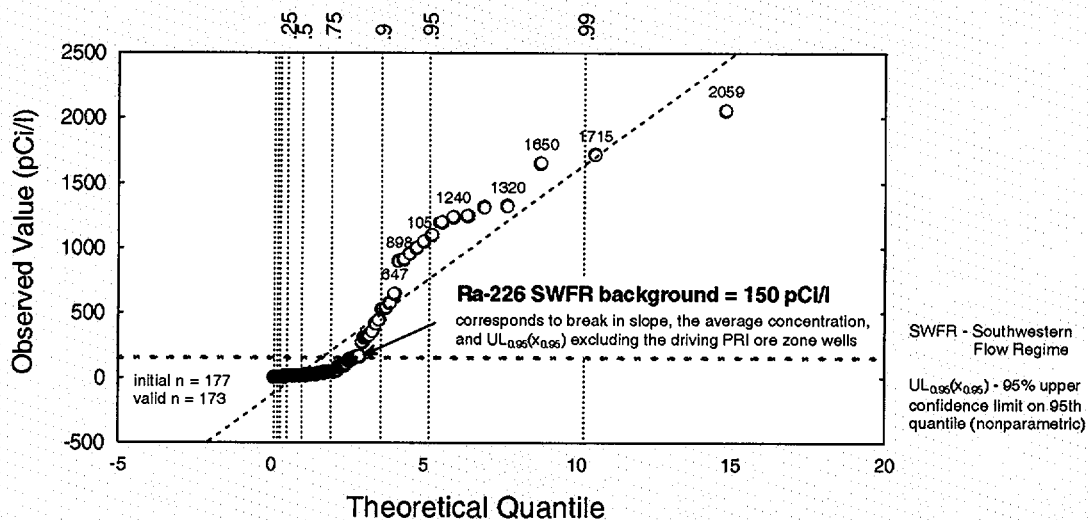


Figure A.3. Explanation of the Use of Box Plots and Quantile-Quantile Plots in Examining Statistical Trends

Quantile-Quantile Plot of Ra-226

Theoretical Distribution: Lognormal



Box Plot of Ra-226: All Wells

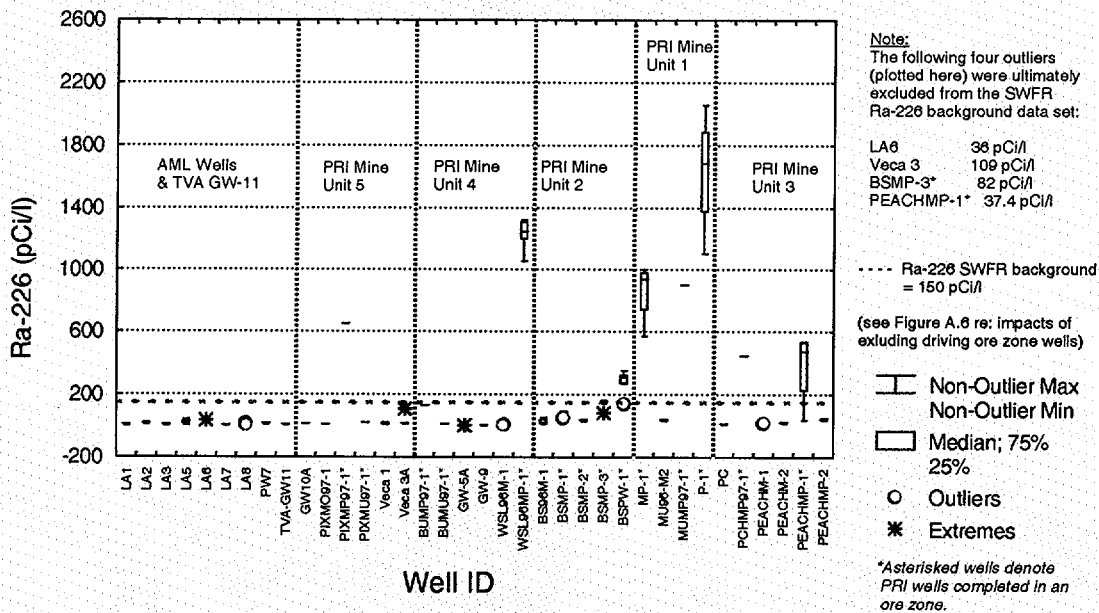
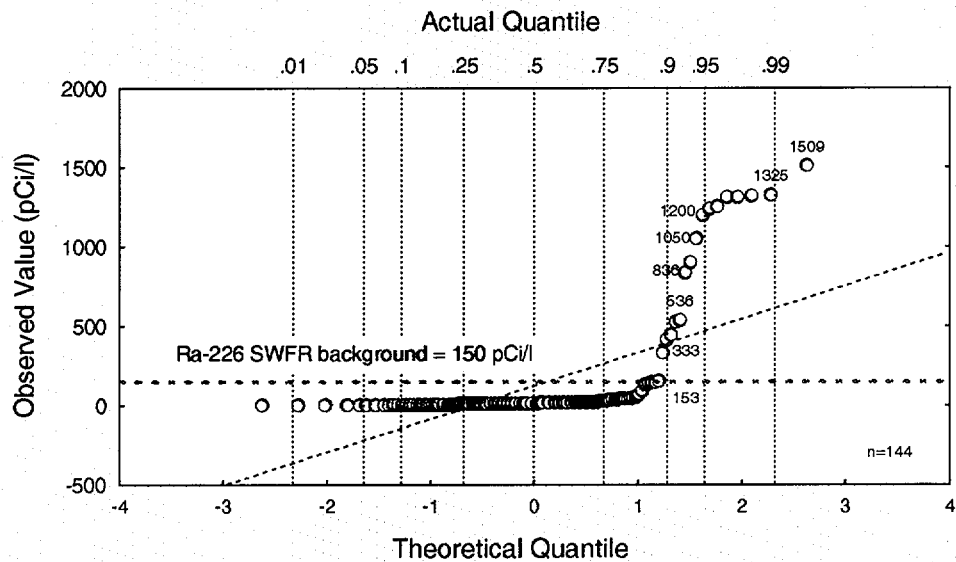


Figure A.4. Distribution of Radium-226 in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

Quantile-Quantile Plot for Theoretical Normal Distribution



Quantile-Quantile Plot for Theoretical Lognormal Distribution

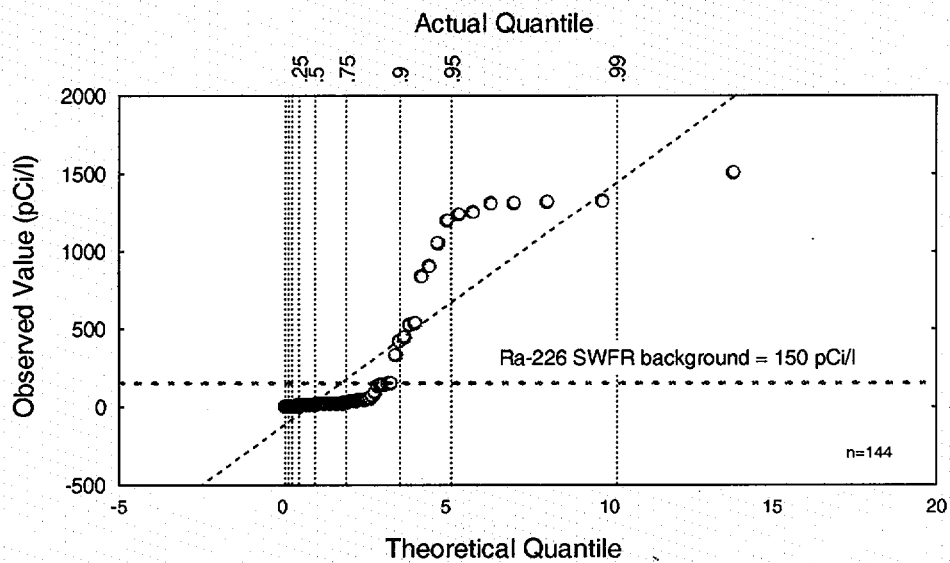


Figure A.5. Distribution of Radium-226 in Southwestern Flow Regime Background Samples: PRI Colocates Averaged, Outliers Excluded Gas Hills, Wyoming

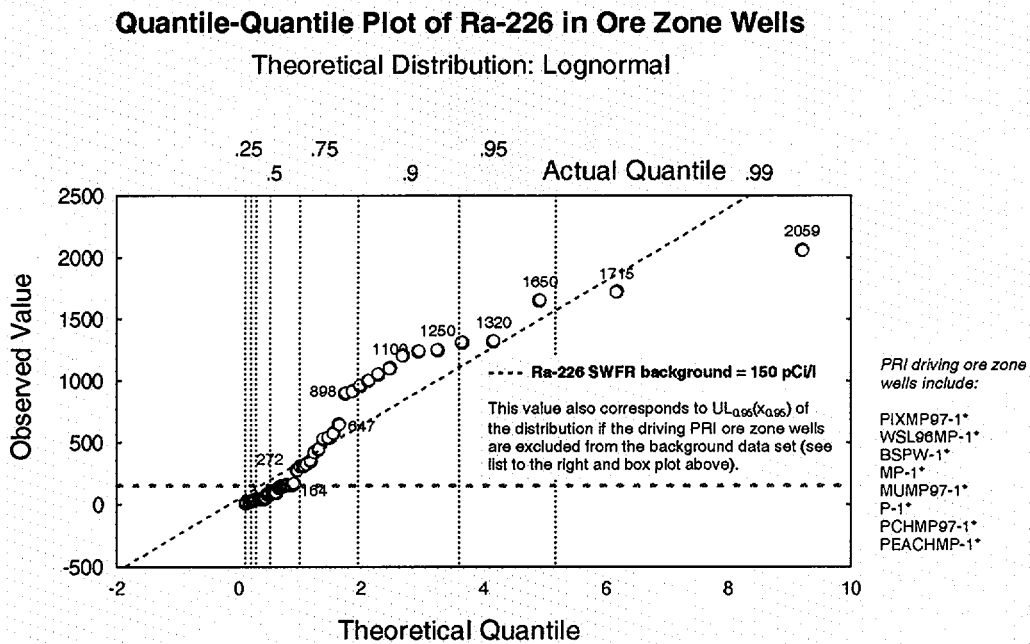
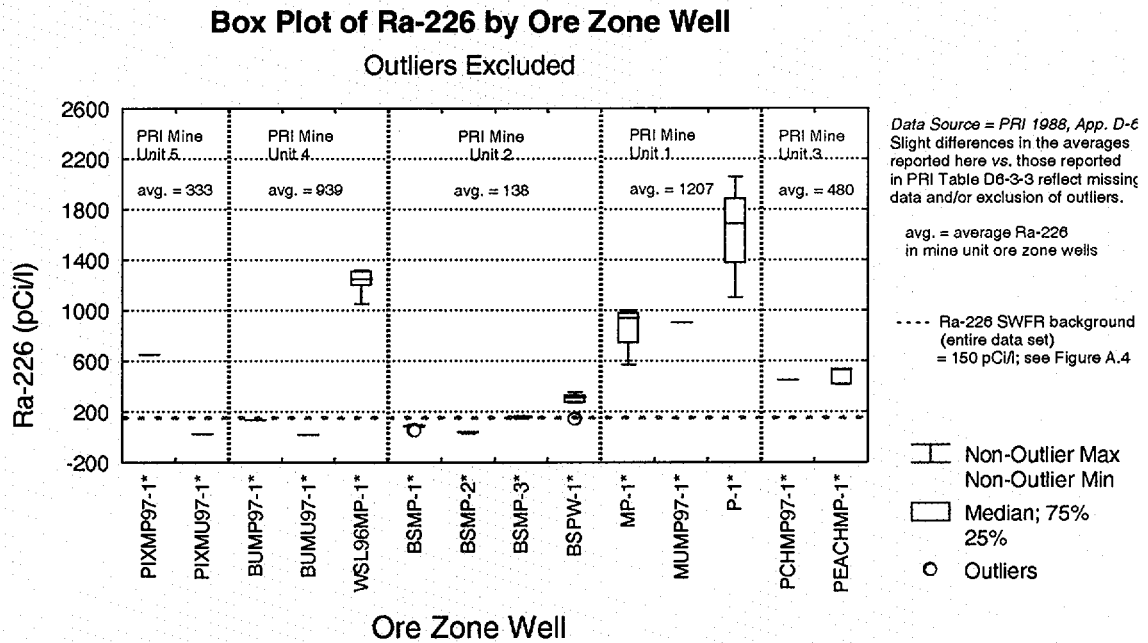


Figure A.6. Distribution of Radium-226 in PRI Ore Zone Wells
Gas Hills, Wyoming

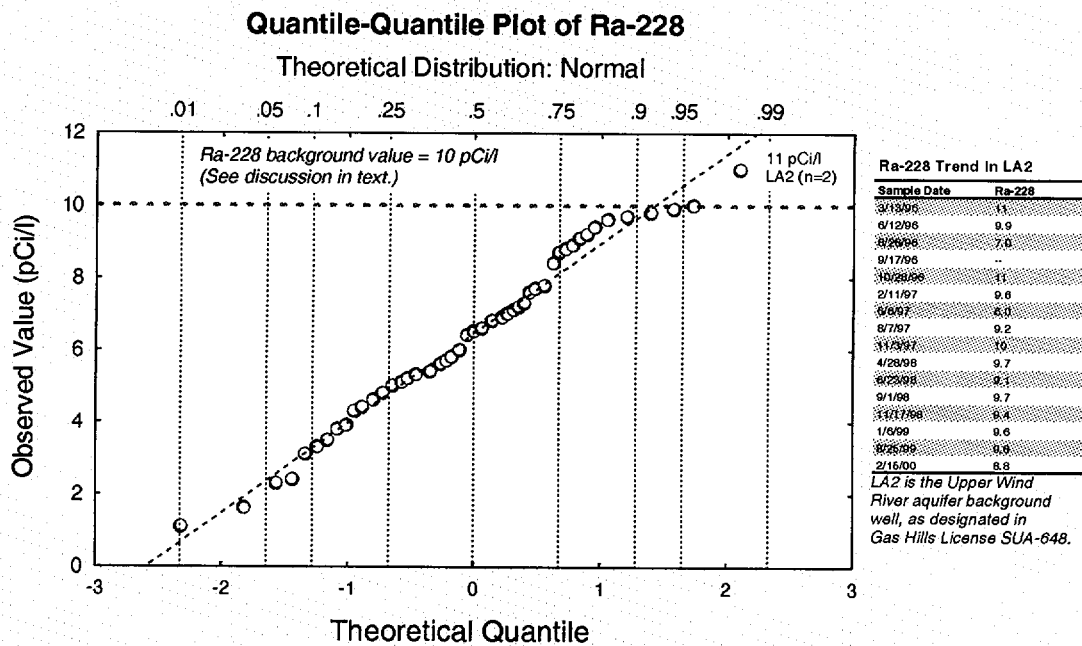
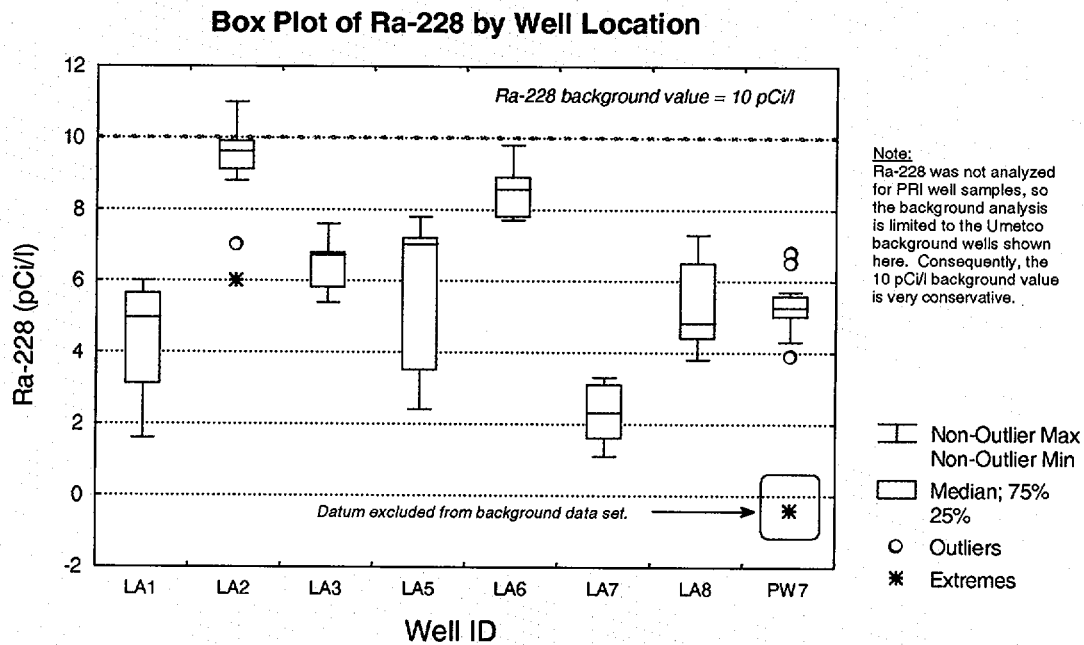


Figure A.7. Distribution of Radium-228 in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

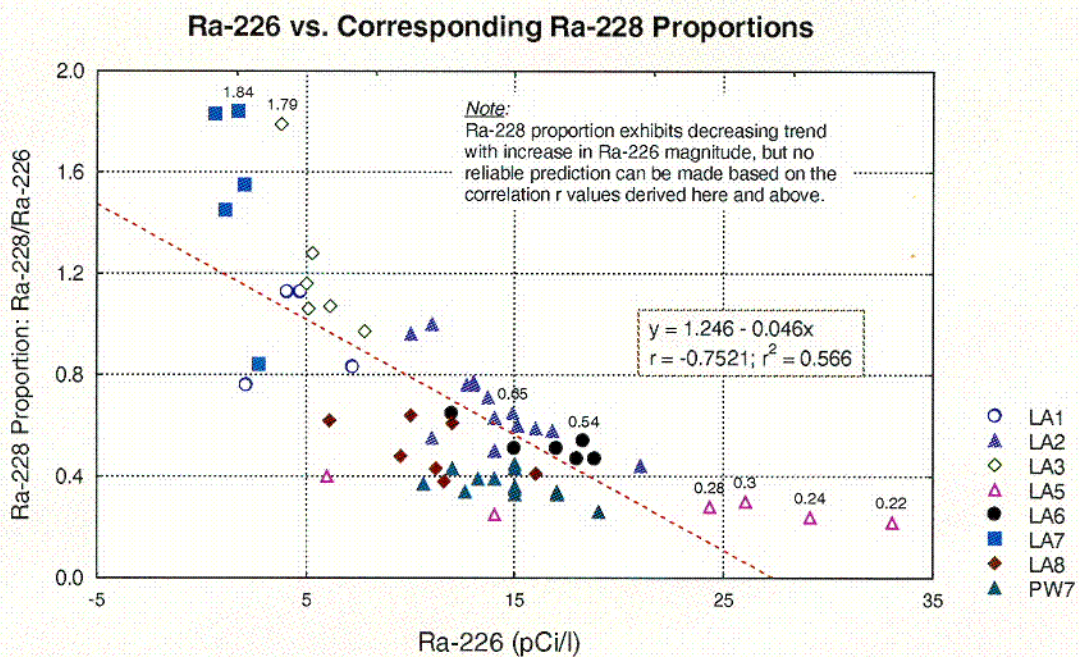
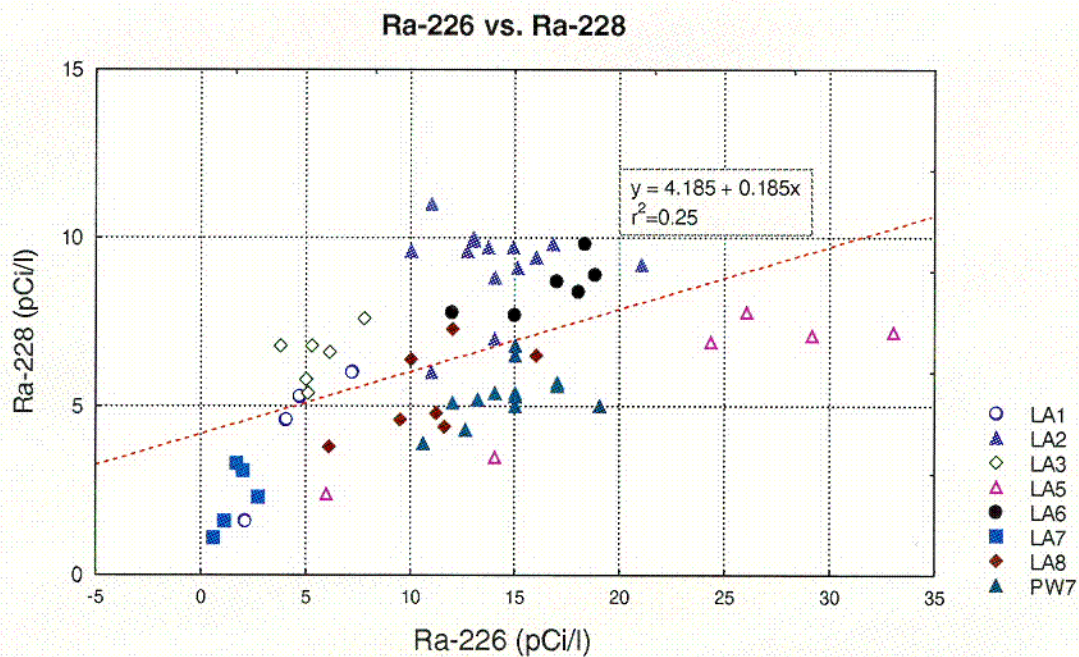


Figure A.8. Radium-226 vs. Radium-228 in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

C.2

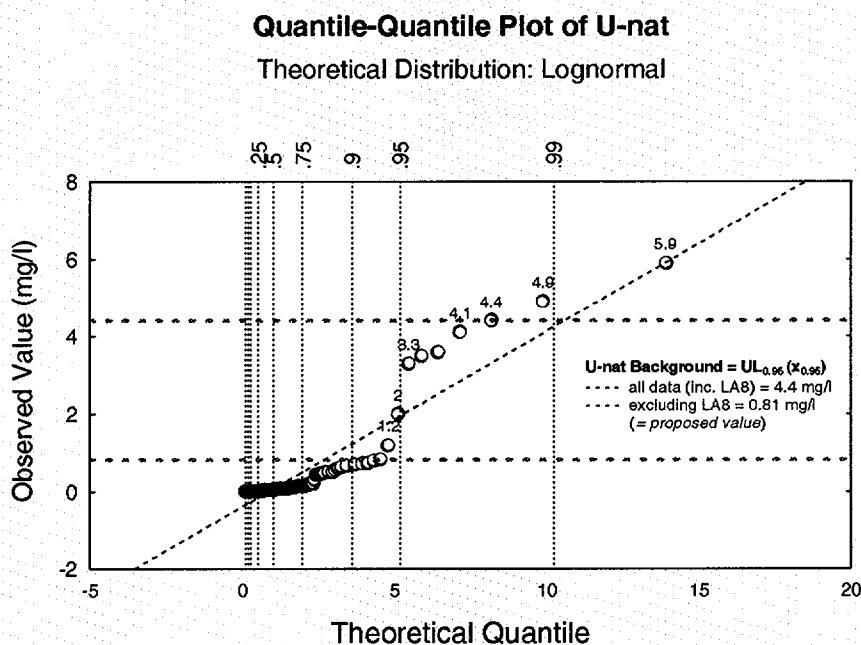
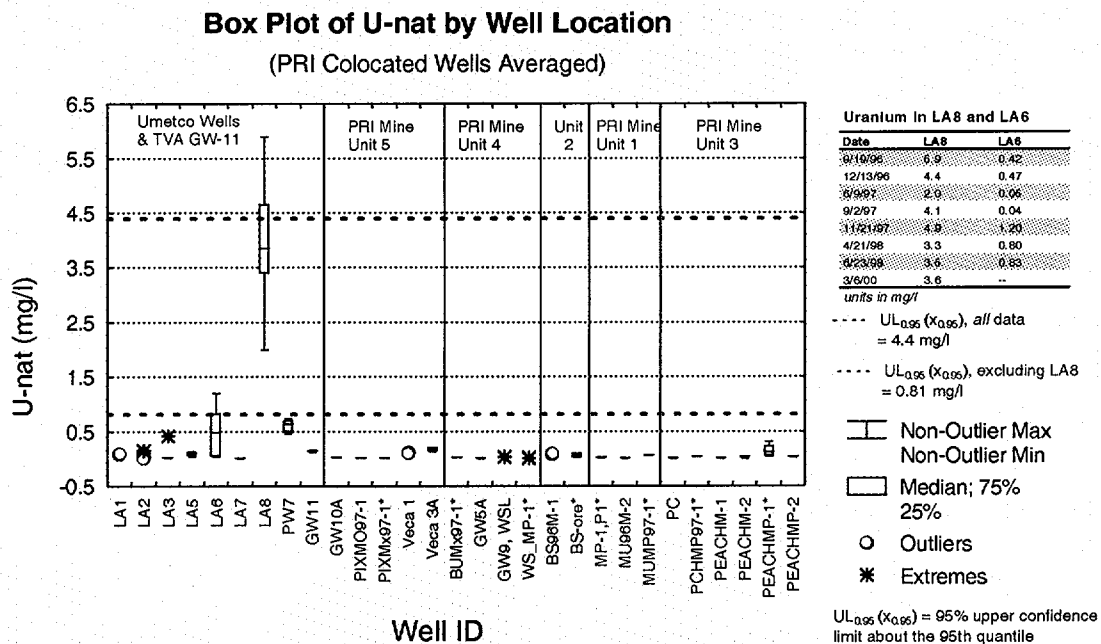


Figure A.9. Distribution of Uranium in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

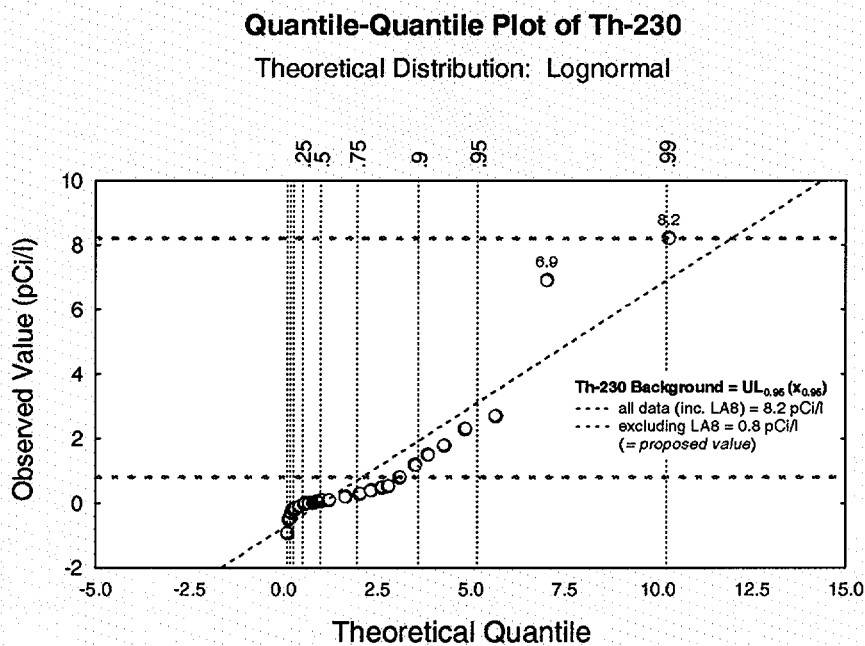
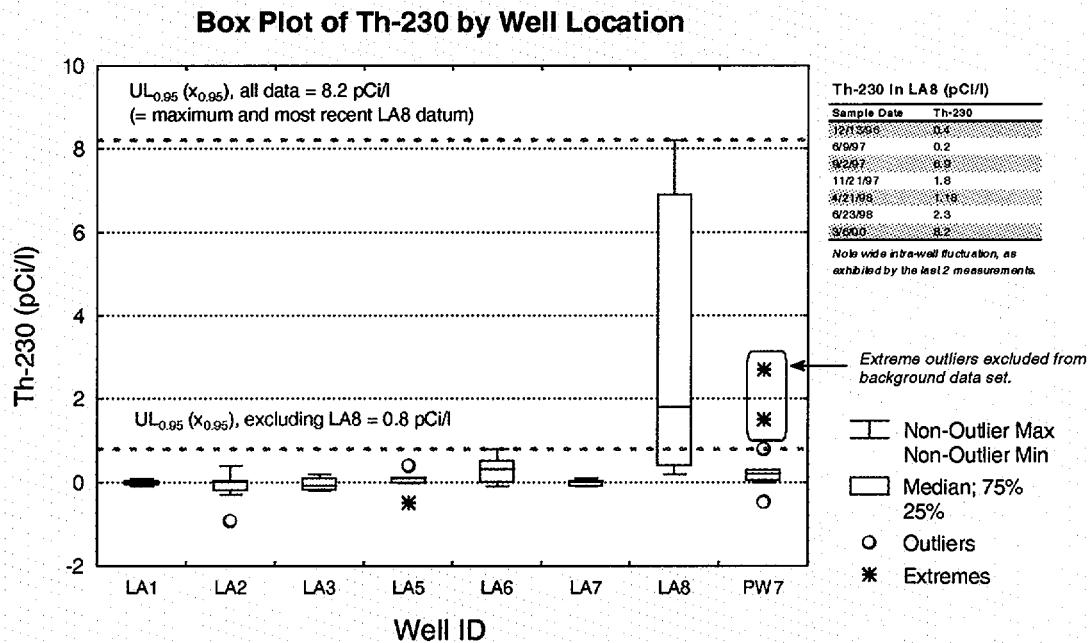


Figure A.10. Distribution of Th-230 in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

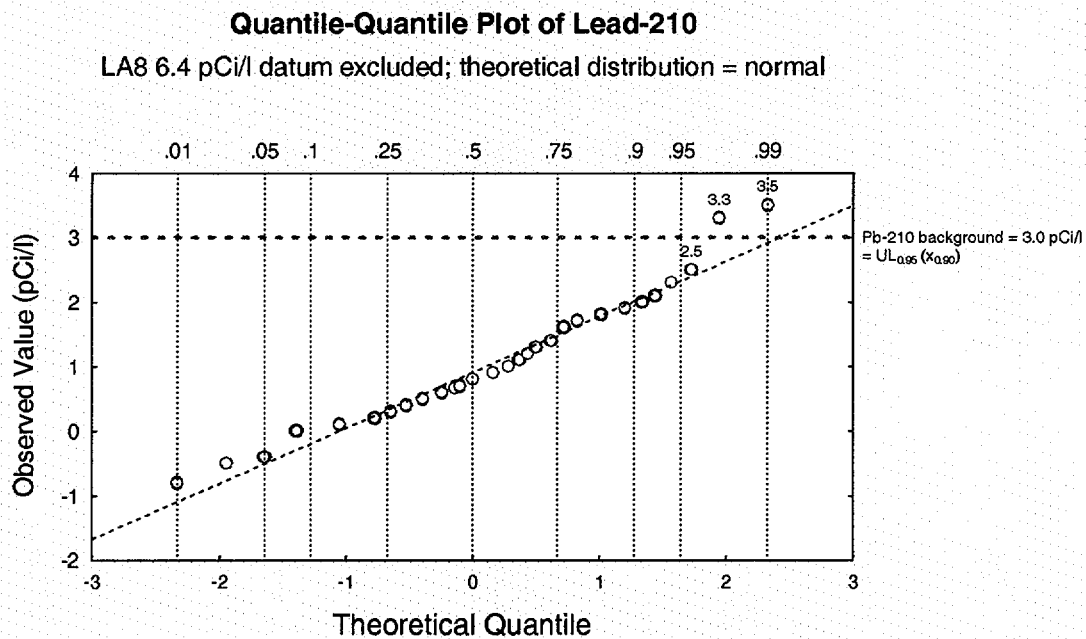
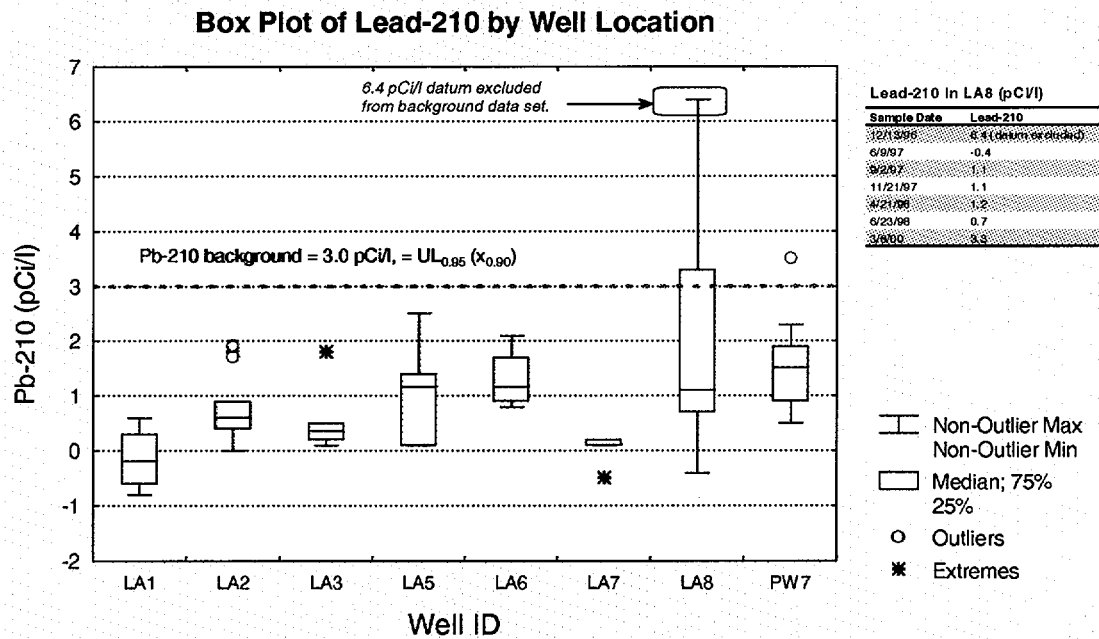


Figure A.11. Distribution of Lead-210 in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

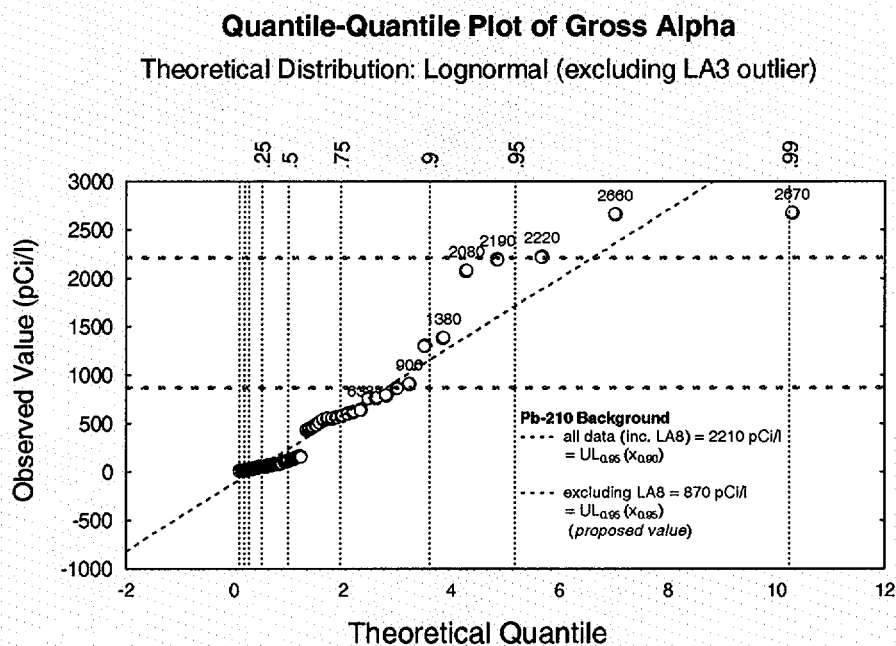
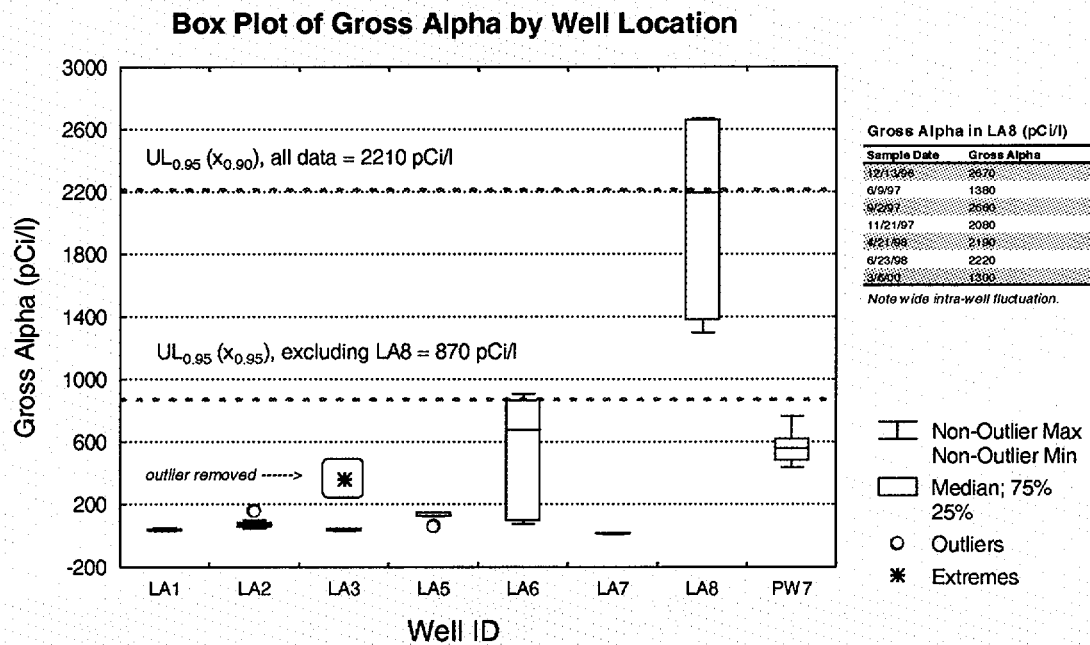


Figure A.12. Distribution of Gross Alpha in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

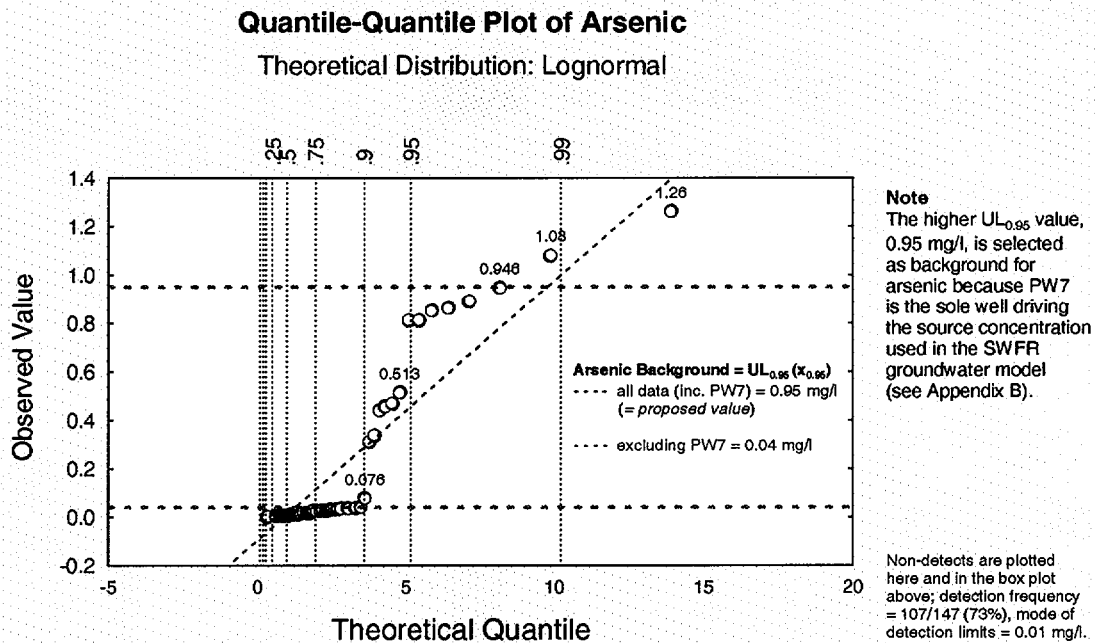
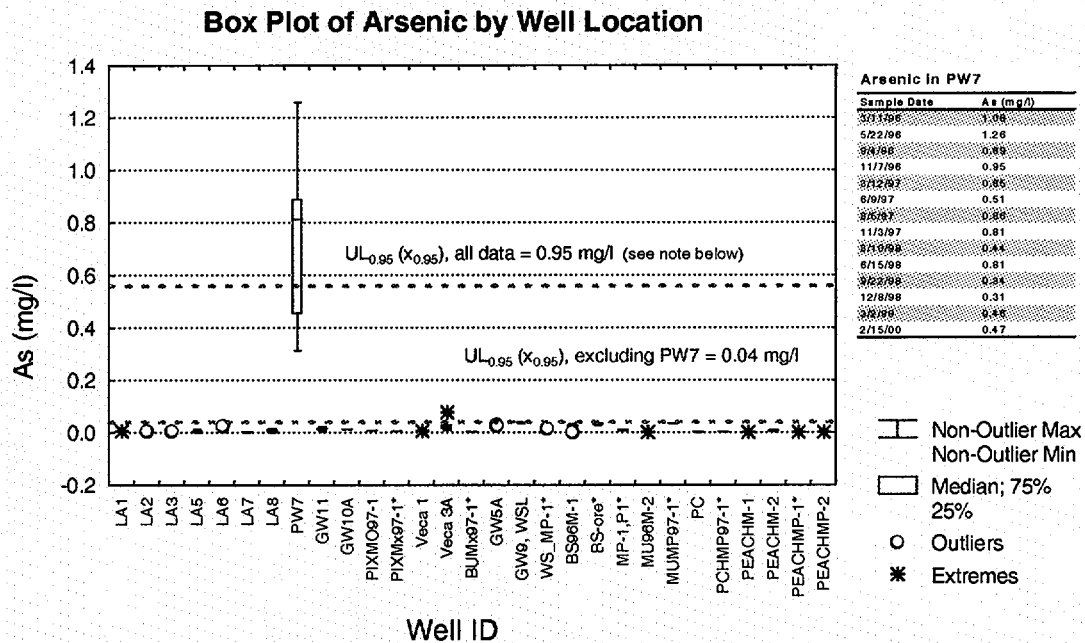


Figure A.13. Distribution of Arsenic in Southwestern Flow Regime Background Wells. Gas Hills, Wyoming

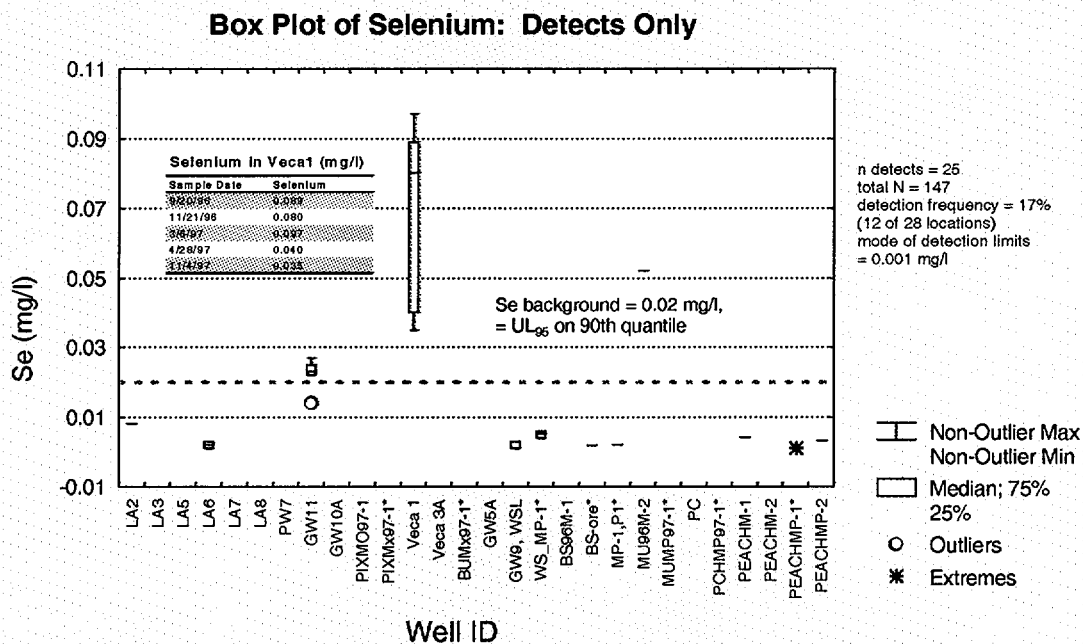
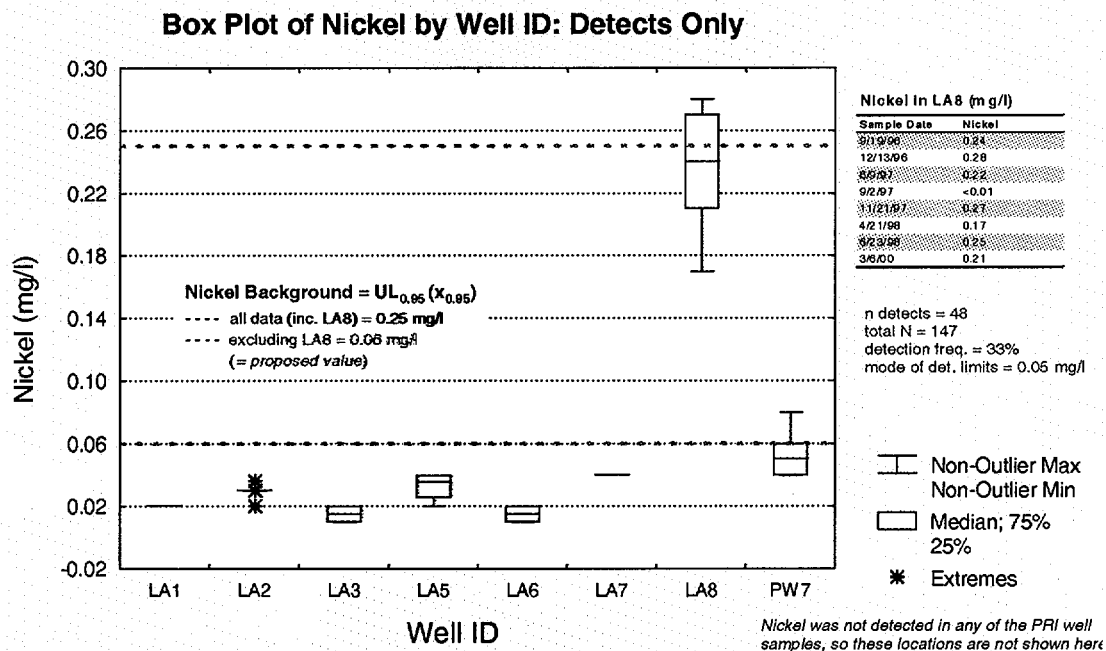


Figure A.14. Distribution of Nickel and Selenium in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

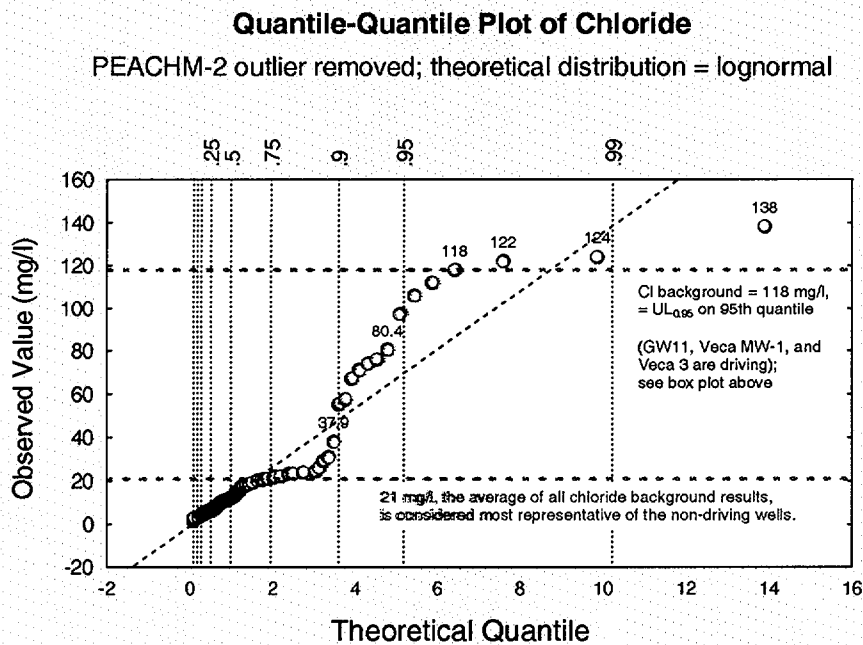
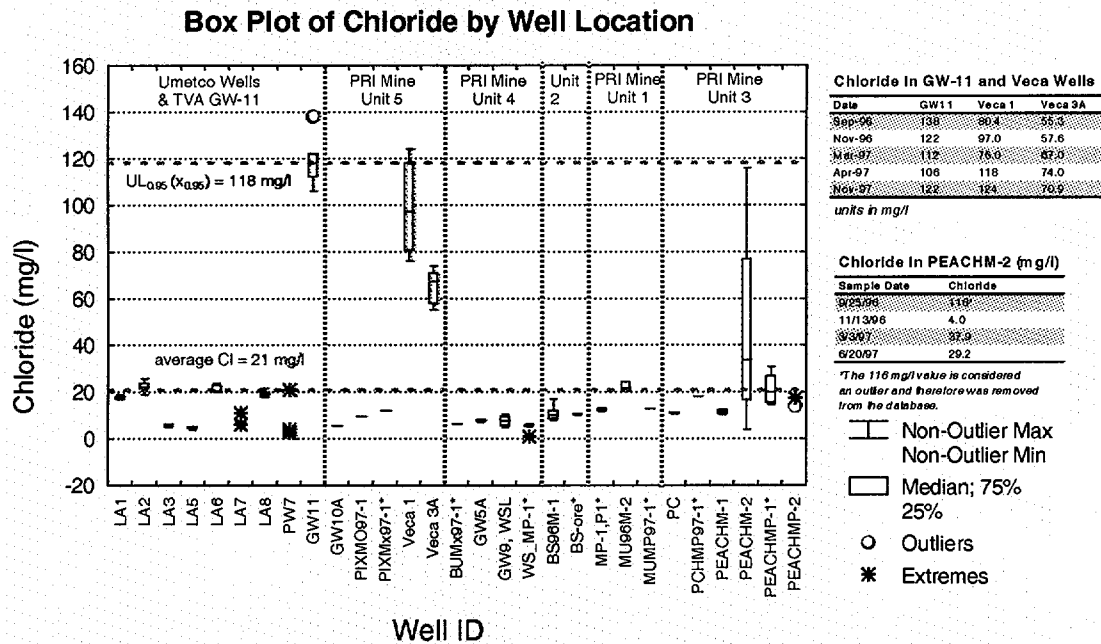
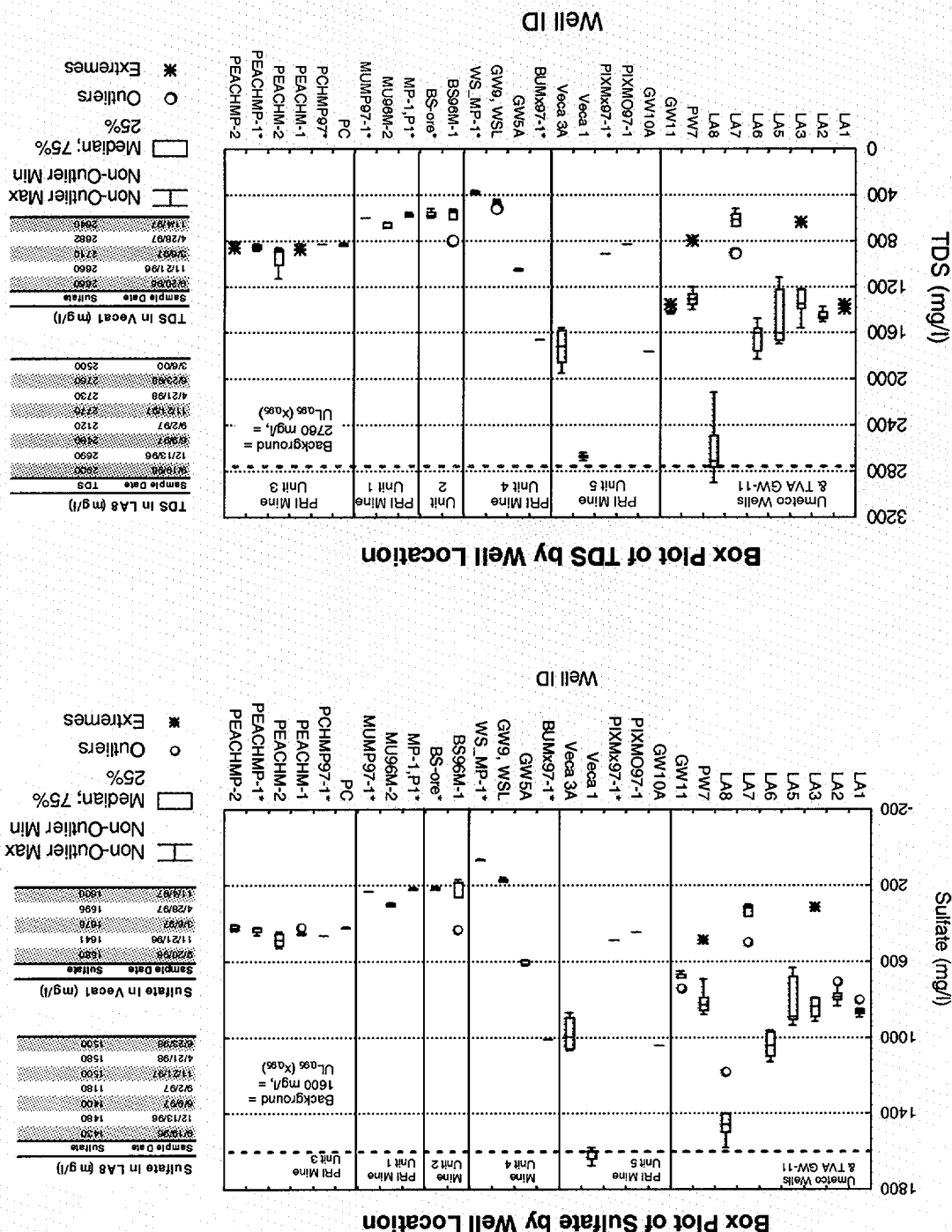
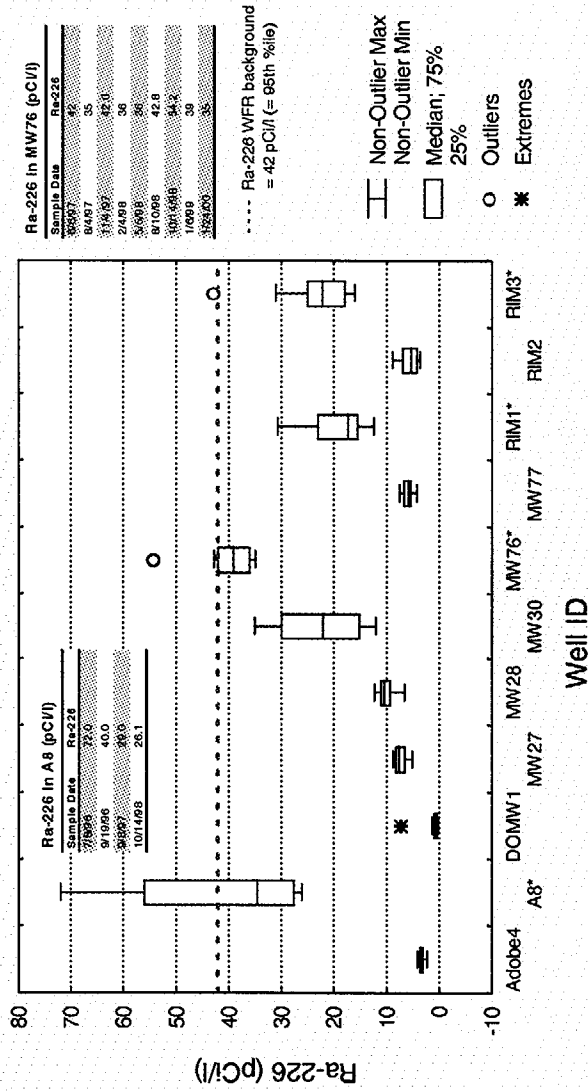


Figure A.15. Distribution of Chloride in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming

Figure A.16. Distribution of Sulfate and TDS in Southwestern Flow Regime Background Wells, Gas Hills, Wyoming



Box Plot of Ra-226 by Well Location



Quantile-Quantile Plot of Ra-226

Theoretical Distribution: Weibull

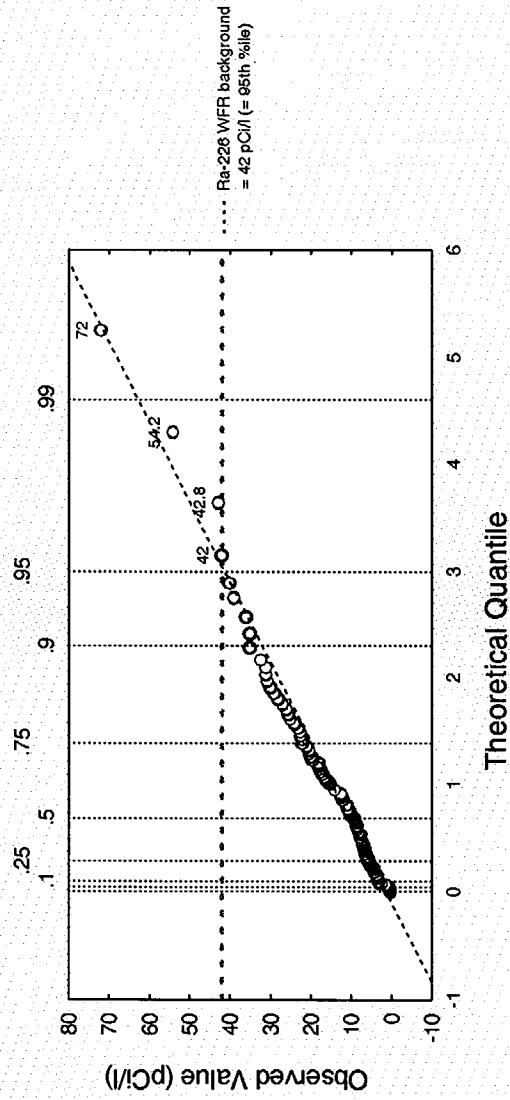


Figure A.17. Distribution of Ra-226 in Western Flow Regime Background Wells, Gas Hills, Wyoming

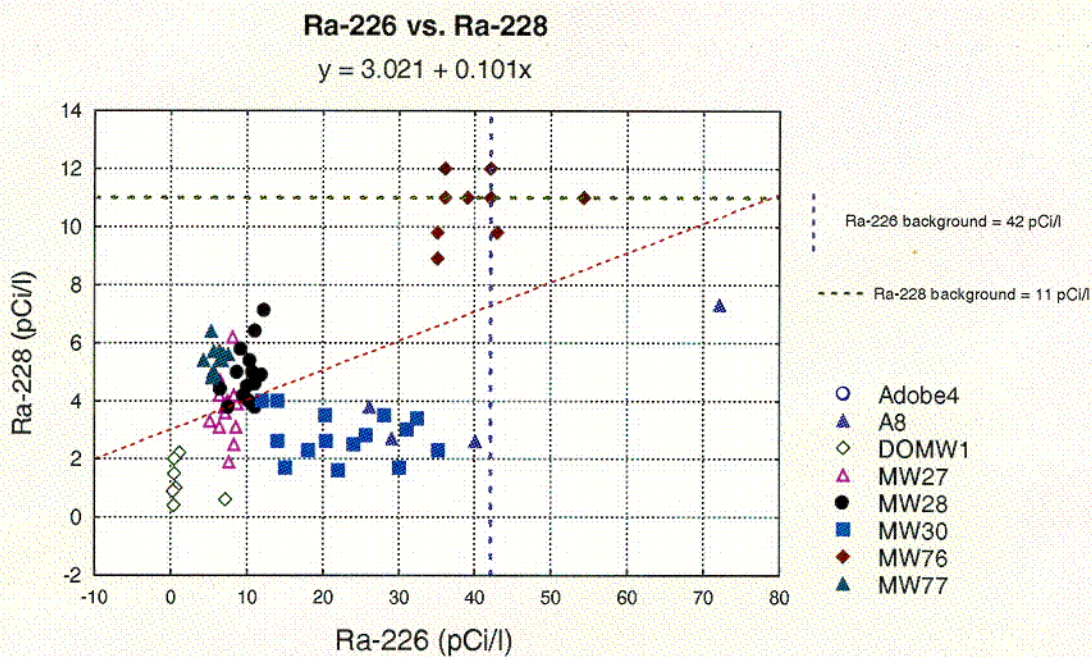
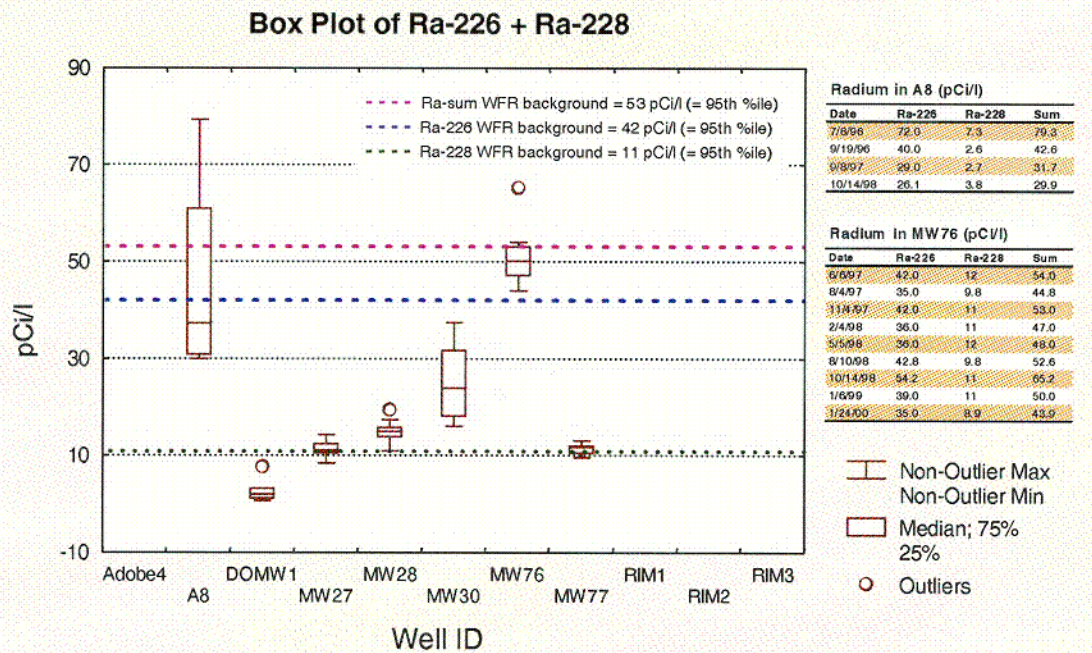


Figure A.18. Distribution of Ra-226 + Ra-228 in Western Flow Regime Background Wells, Gas Hills, Wyoming

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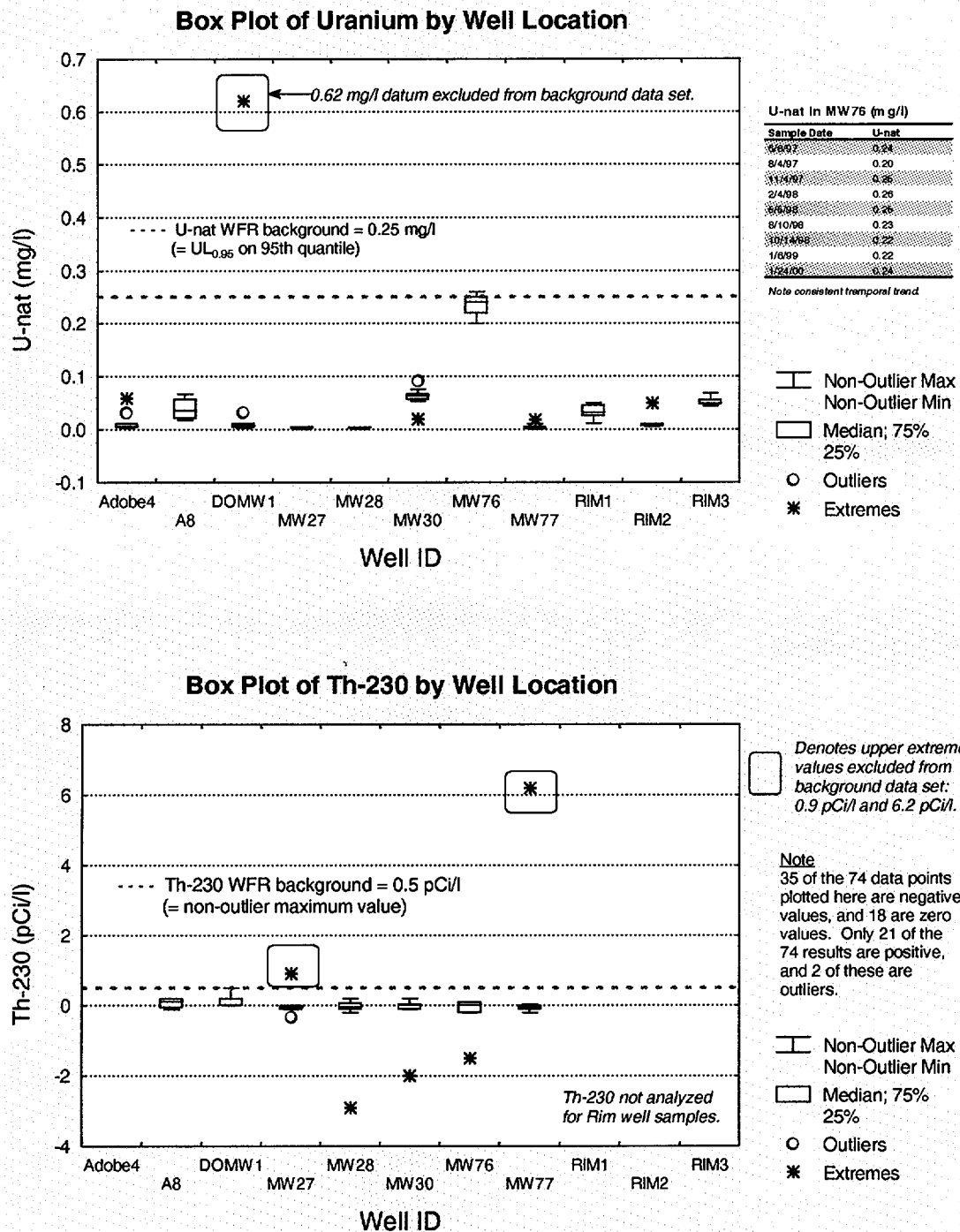


Figure A.19. Distribution of Uranium and Thorium-230 in Western Flow Regime Background Wells, Gas Hills, Wyoming

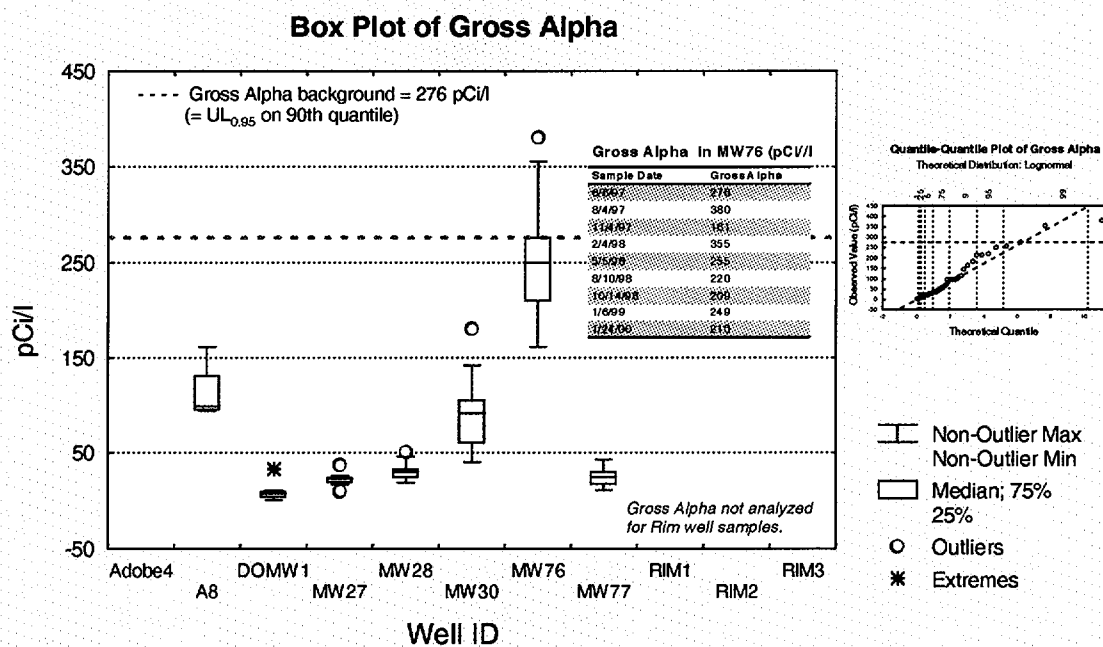
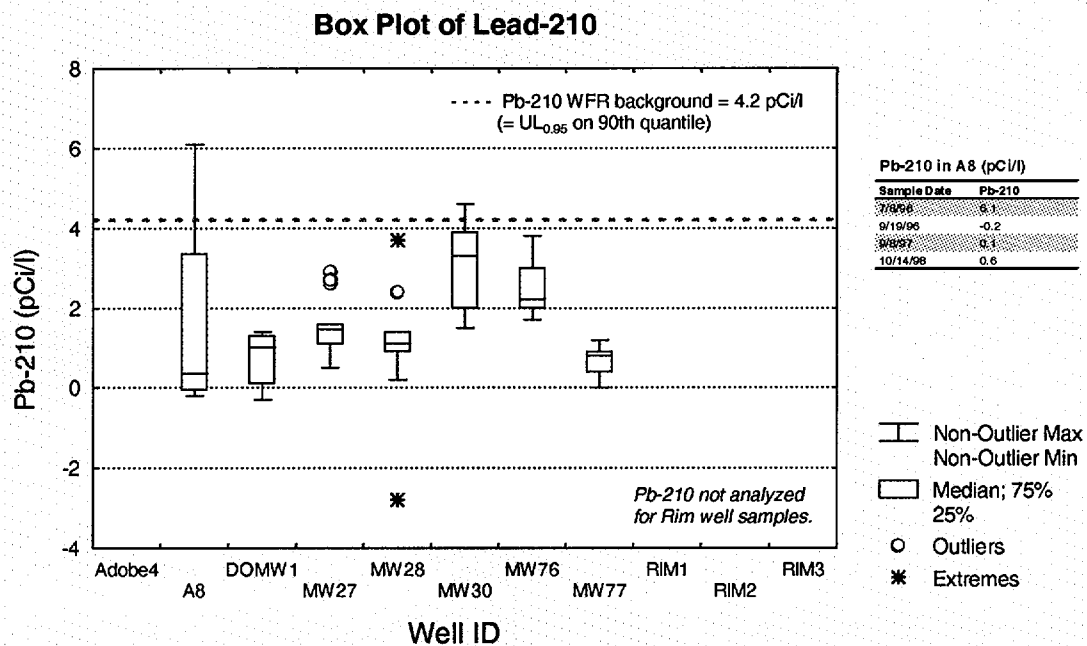


Figure A.20. Distribution of Lead-210 and Gross Alpha in Western Flow Regime Background Wells, Gas Hills, Wyoming

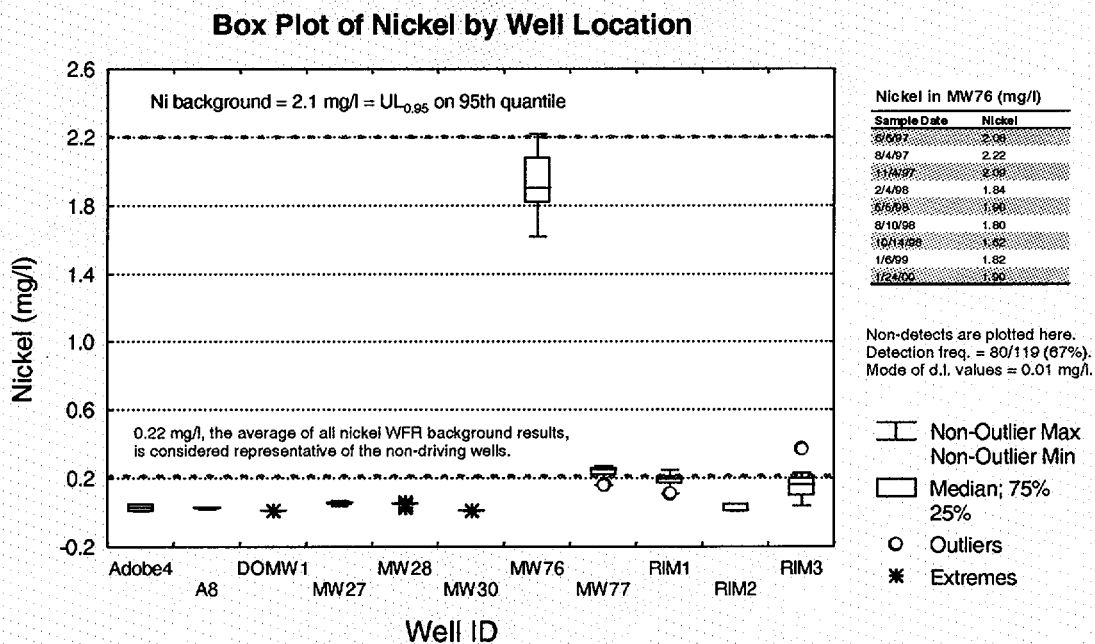
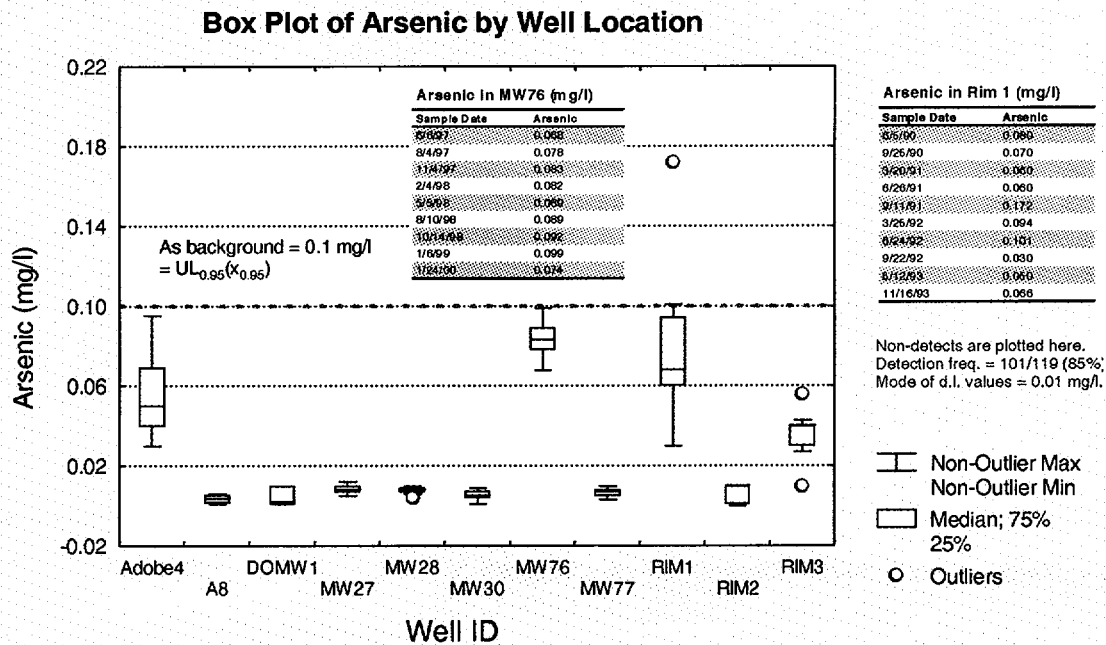


Figure A.21. Distribution of Arsenic and Nickel in Western Flow Regime Background Wells, Gas Hills, Wyoming

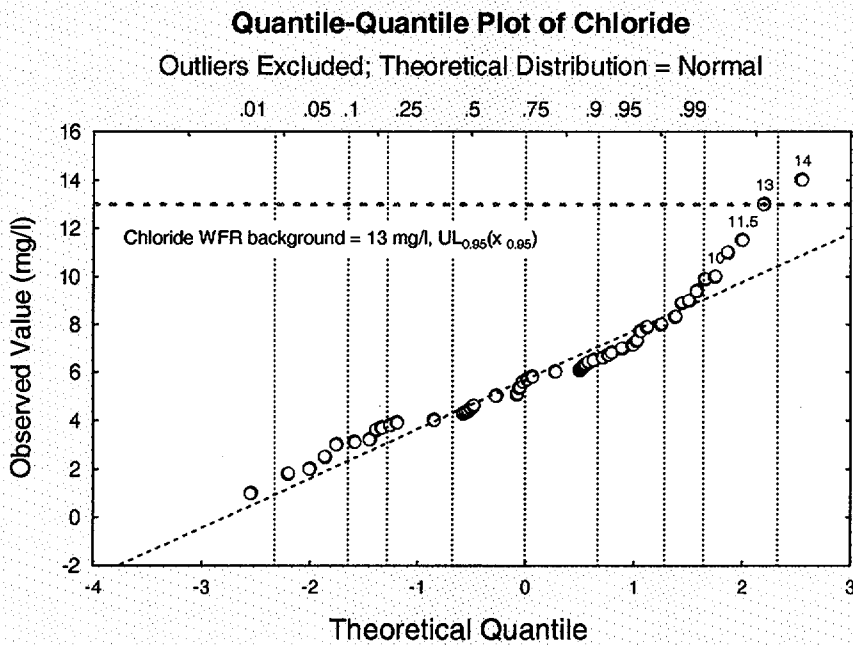
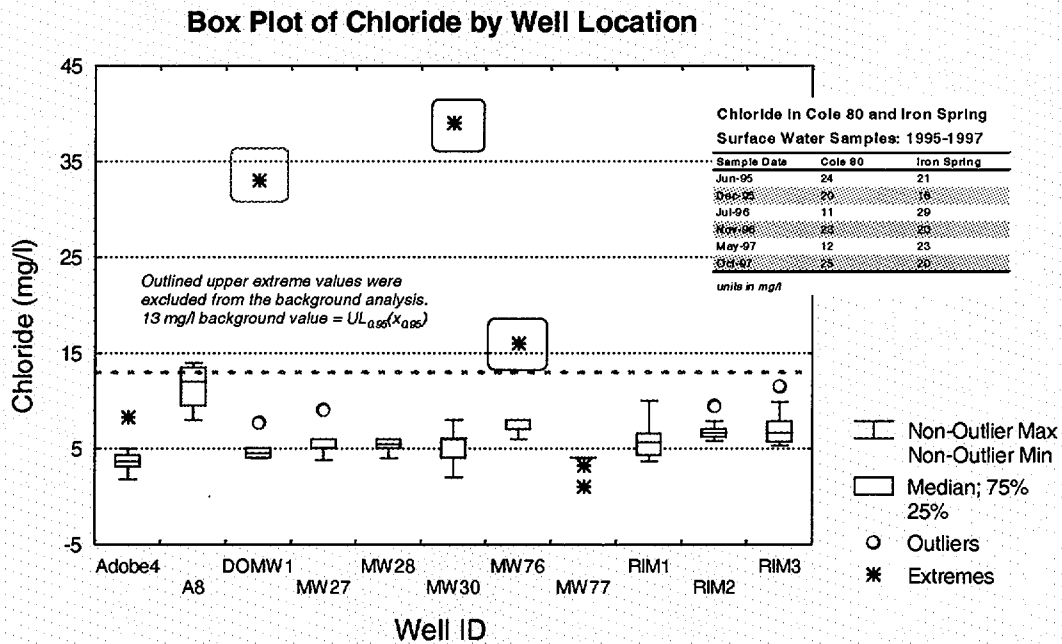


Figure A.22. Distribution of Chloride in Western Flow Regime Background Wells, Gas Hills, Wyoming

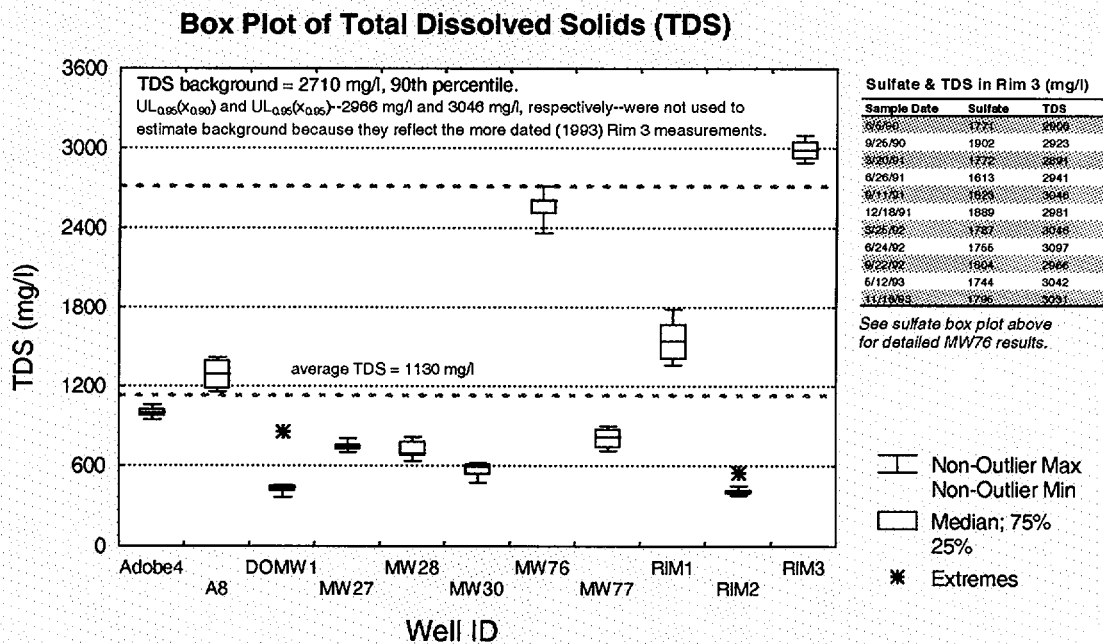
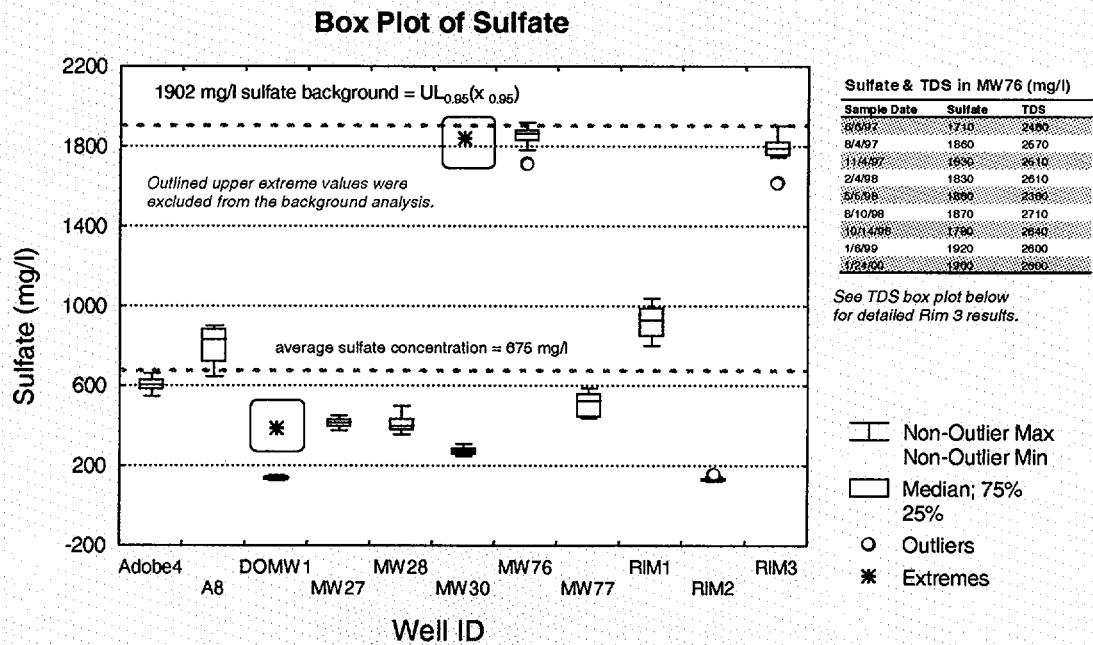


Figure A.23. Distribution of Sulfate and TDS in Western Flow Regime Background Wells, Gas Hills, Wyoming

Appendix B

Geochemical Model Umetco Gas Hills Site Fremont and Natrona Counties, Wyoming

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ACRONYMS AND ABBREVIATIONS

ACL	Alternate Concentration Limit
AGTI	Above Grade Tailings Impoundment
As(III)	Arsenite
As(V)	Arsenate
Ba ²⁺	Barium Ion
Ca ²⁺	Calcium Ion
Calcite	CaCO ₃ (s)
CEC	Cation Exchange Capacity
Coffinite	USiO ₄ (s)
Eh	Oxidation/Reduction Potential Relative to Standard Hydrogen Electrode
Fe(OH) ₃	Ferrihydrite
FeSe ₂	Ferroselite
Ft/d	Feet per Day
Gypsum	CaSO ₄ •2H ₂ O
HFO	Hydrous Ferric Oxide
ΔH°	Standard Enthalpy of Reaction
K	Dissociation or Formation Constant
K _{sp}	Solubility Product
Kcal/mol	KiloCalories per Mole
MCL	Maximum Contaminant Level
MnO ₂	Manganese Dioxide
Na ⁺	Sodium Ion
NaOCl ₃	Sodium Chlorate
NiSe	Nickel Selenide
PbX ₂	Exchangeable Lead
pE	Negative Logarithm of Free Electron Activity, -log(e ⁻)
pH	-log (H ⁺)
POC	Point of Compliance
POE	Point of Exposure
PV	Pore Volume
Pyrite	FeS ₂ (s)

ACRONYMS AND ABBREVIATIONS

Ra ²⁺	Radium Ion
RaX2	Exchangeable Radium
Redox	Reduction/Oxidation
SO ₄ ²⁻	Sulfate Ion
Sur_sAsO4-2	Respective Arsenic (V) Species Adsorbed to Type 1 Sites
Sur_sH2AsO3	Respective Arsenic (III) Species Adsorbed to Type 1 Sites
Sur_sHAsO4-	Respective Arsenic (V) Species Adsorbed to Type 1 Sites
Sur_sH2AsO4	Respective Arsenic (V) Species Adsorbed to Type 1 Sites
Sur_sOBe+	Beryllium Adsorbed to Type 1 Sites
Sur_sOHAsO4-3	Respective Arsenic (V) Species Adsorbed to Type 1 Sites
Sur_sOHRa+2	Radium Adsorbed to Type 1 Sites
Sur_sOHUO2+2	Respective Uranium (IV) Species Adsorbed to Type 1 Sites
Sur_sONi+	Nickel Adsorbed to Type 1 Sites
Sur_sOPb+	Lead Adsorbed to Type 1 Sites
Sur_wAsO4-2	Respective Arsenic (V) Species Adsorbed to Type 2 Sites
Sur_wHAsO4-	Respective Arsenic (V) Species Adsorbed to Type 2 Sites
Sur_wH2AsO3	Respective Arsenic (III) Species Adsorbed to Type 2 Sites
Sur_wH2AsO4	Respective Arsenic (V) Species Adsorbed to Type 2 Sites
Sur_wOBe+	Beryllium Adsorbed to Type 2 Sites
Sur_wOHAsO4-3	Respective Arsenic (V) Species Adsorbed to Type 2 Sites
Sur_wOHSeO3-	Respective Selenium (III) Species Adsorbed to Type 2 Sites
Sur_wOHSeO4-	Respective Selenium (VI) Species Adsorbed to Type 2 Sites
Sur_wONi+	Nickel Adsorbed to Type 2 Sites
Sur_wOPb+	Lead Adsorbed to Type 2 Sites
Sur_wORa+	Radium Adsorbed to Type 2 Sites
Sur_wOTh+3	Respective Thorium Species Adsorbed to Type 2 Sites
Sur_wOTh(OH)2+	Respective Thorium Species Adsorbed to Type 2 Sites
Sur_wOTh(OH)3	Respective Thorium Species Adsorbed to Type 2 Sites
Sur_wOTh(OH)4-	Respective Thorium Species Adsorbed to Type 2 Sites
Sur_wOUO2+2	Respective U(IV) Species Adsorbed to Type 2 Sites
Sur_wSeO4-	Respective Selenium (VI) Species Adsorbed to Type 2 Sites

ACRONYMS AND ABBREVIATIONS

Sur_wTh(OH)+2	Respective Thorium Species Adsorbed to Type 2 Sites
Uraninite	UO ₂ (s)

1.0 INTRODUCTION

The purpose of this geochemical model is to demonstrate that applying a dynamic geochemical model at the Gas Hills site predicts that the proposed Alternate Concentration Limits (ACLs) are protective of human health and the environment at the Point of Exposure (POE). The model is based on knowledge of groundwater compositions and geochemically reactive aquifer components present at Gas Hills, and utilizes geochemical principles based on the site conceptual geochemical model (Geraghty & Miller, Inc. 1996). The results of the geochemical model are used to predict the 1,000-year concentrations of constituents in the Wind River Aquifer as a function of distance between the Point of Compliance (POC) wells and the POE.

The Umetco Gas Hills site is located in Fremont and Natrona Counties, Wyoming, approximately 60 miles east of Riverton in a remote area of central Wyoming, in the Gas Hills Uranium District of the Wind River Basin. The site consists of approximately 542 acres, including tailings disposal and heap leach areas. Open pit mining occurred within and around the Umetco site from the late 1950s until 1984. The Gas Hills mill was constructed in 1959 and uranium oxide was produced until the mill was decommissioned in 1987. Tailings from the milling process were stored in the Above Grade Tailings Impoundment (AGTI) and the A-9 Repository.

The Wind River Formation lies beneath the facility and is characterized by a network of oxidation-reduction (redox) fronts that contain uranium mineralization. This network is extensive in both the vertical and horizontal directions throughout the stratigraphic section. Open pit and underground mining along the redox fronts exposed ore bodies within the Wind River Formation to oxidizing conditions. Surface water infiltration through the pits and mine spoils produced acidic drainage which subsequently migrated into the shallow aquifer system. Natural uranium mineralization, open pit mines, and mine spoil piles are present throughout and surrounding the site.

2.0 CONCEPTUAL GEOCHEMICAL MODEL

Geochemical conditions within the Wind River Aquifer have been characterized through government and private scientific studies and from Umetco exploration, development, and reclamation activities. The data collected during these studies were used to create the geochemical model to assist in projecting future concentrations of constituents along groundwater flow paths.

The Wind River Formation is differentiated into an upper unit and a lower unit separated by a mudstone aquitard. The majority of the Wind River Aquifer is reducing and has a high neutralization capacity as a result of CaCO_3 (calcite) present in the aquifer. The aquifer materials also contain reactive mineral surfaces capable of adsorbing constituents. Therefore, natural attenuation processes associated with the initial geochemical conditions that produced uranium mineralization limit the mobility of constituents from all sources. Thus, elevated concentrations of constituents near source areas do not persist in downgradient areas. The following sections describe the groundwater flow regimes, geochemical conditions, and conceptual geochemical model.

2.1 Groundwater Flow Regime

The regional groundwater flow pattern is northwest toward the Wind River. In the northern portion of the site, local groundwater flow is to the west (Western Flow Regime) and in the southern portion, local flow is to the southwest (Southwestern Flow Regime). Groundwater flowing to the west discharges at seeps and springs located along West Canyon Creek. Groundwater flowing to the southwest continues until reaching the area of the Lucky Mc site (approximately five miles away) where the flow turns north and eventually discharges at seeps and springs along Fraser Draw and Willow Springs Draw.

2.2 Uranium Mineralization

Historically, the Gas Hills district in Central Wyoming has been one of the major uranium-producing regions of the United States. Based on past production and established reserves, the district accounts for about 12 percent of the United States' total uranium reserves (Anderson 1969). Uranium mineralization occurs in an area about five miles wide and 20 miles long, in three north-trending belts known as the East, Central, and West Gas Hills (Figure 2.1). The uranium solution front can be traced for miles along each of these belts and may be mineralized to ore grade continuously for thousands of feet along the front. The thickness of an ore body is constrained by the thickness of the permeable sandstone unit, which is bounded by less-permeable strata. Uranium ore bodies in the Gas Hills can be extensive as seen in the Lucky Mc ore trend that is approximately 2,300 feet long, 600 feet wide, and contains nine ore zones averaging 5 feet in thickness distributed throughout a stratigraphic interval 150 feet thick (USAEC 1959).

2.3 Geochemical Conditions within the Wind River Aquifer

Wyoming roll-front uranium deposits have been comprehensively studied and Gas Hills has been used as a type location for these deposits (King and Austin 1966; Harshman 1974; DeVoto 1978). These studies provided site-specific information on mineral phases found upgradient,

downgradient, and within the ore zone. Existing mineral phases control the solubility of constituents and, therefore, their concentrations in the groundwater. Figure 1.15 depicts a cross-section of an idealized roll-front uranium deposit typical of the Gas Hills and the characteristic mineralogy across an ore deposit.

Above the mudstone aquitard in the vicinity of the AGTI and the A-9 Repository, the Wind River Formation is an oxidizing environment. Roll-front uranium ore deposits are located above the mudstone unit along a redox boundary downgradient of the AGTI and A-9 Repository. Geochemical conditions at the ore deposits and in areas farther downgradient (west of the AGTI and southwest of the A-9 Repository) are pervasively reducing. Beneath the mudstone unit, the Wind River Formation is generally a reducing geochemical environment. Uranium is likely to be enriched in the aquifer matrix as UO_2 (uraninite), USiO_4 (coffinite), or other reduced uranium minerals because of the reducing conditions within the aquifer. Based on the model of a Wyoming roll-front uranium deposit, the portion of the Wind River Formation below the local mudstone corresponds to the downgradient, regionally reduced portion of the aquifer that is in equilibrium with FeS_2 (pyrite) and calcite.

Previous Umetco studies at Gas Hills provided information on specific pH and redox conditions in the vicinity of ore deposits. These parameters vary widely across an ore deposit and influence the transport of constituents in groundwater. For example, many constituents that are mobile in acidic-oxidizing environments, are immobile in more neutral and reducing environments. Figure 2.18 summarizes conditions determined by Harshman (1966) for ore deposits at Gas Hills and Shirley Basin, Wyoming. The oxidation-reduction potential (Eh) ranges from near +300 to -300 millivolts. The pH ranges from approximately 8 to less than 4, depending on the location relative to ore deposits.

2.4 Sources of Mill-Related Constituents and Interaction with Aquifer Components

The AGTI and the A-9 Repository are the primary sources of mill-related constituents. Mine pits and spoils are also sources of constituents to groundwater. The source fluids that transport mill-related constituents are oxidizing and acidic. Reagents such as NaClO_3 (sodium chlorate) and MnO_2 (manganese dioxide) were added during the milling process as oxidizing agents to bring the process solution to an Eh between +400 and +425 millivolts (Merriott 1971). The pH of the process solution was generally less than two due to additions of sulfuric acid (H_2SO_4) during milling.

In the vicinity of the AGTI, the water table occurs beneath the mudstone unit. Seepage from the AGTI is impeded by the low permeability of the mudstone unit, resulting in localized perched conditions. The geochemical environment of the Wind River Formation directly beneath the AGTI and above the mudstone unit is characterized as oxidized and calcite-depleted and corresponds to the hematitic core shown in the idealized cross-section in Figure 1.15. The mill-affected groundwater migrates west into the regionally reduced portion of the Wind River Aquifer. Attenuation of the milling-related constituents occurs through reactions with groundwater and aquifer components.

In the area of the A-9 Repository, the water table occurs above the mudstone unit and tailings seepage mixing with groundwater is restricted to the area above the mudstone, typically less than 50 feet thick. The A-9 Repository was formerly a mine pit. Milling-related constituents in the

vicinity of the A-9 Repository mix with constituents derived from mining and ore deposits. Constituents from these commingled sources migrate to the southwest and encounter reducing conditions. When the constituents, regardless of source, encounter reducing conditions, they are attenuated through reactions with groundwater and aquifer components.

3.0 GEOCHEMICAL COMPUTER CODE - PHREEQC

The Wind River groundwater beneath the Gas Hills contains complex chemical compositions and the aquifer materials include diverse reactive minerals and adsorbing surfaces. To predict changes in solution speciation and mineralogical controls on dissolved constituent concentrations as mill-affected water moves through the aquifer, the computer code used must be capable of solution speciation, mass transfer, and mass transport. PHREEQC (Parkhurst 1995) was chosen because it is a well-established code applicable to a wide range of geochemical conditions. PHREEQC was derived from the original PHREEQE code (Parkhurst and others 1980) in use for 20 years. PHREEQC is capable of performing a variety of aqueous geochemical calculations, such as (1) speciation and saturation index calculations; (2) reaction-path and advective-transport calculations involving specified irreversible reactions, mixing of solutions, mineral and gas equilibria, surface complexation reactions, and ion exchange reactions; and (3) inverse modeling to account for chemical changes that occur along a groundwater flow path. Construction of the PHREEQC database and input files is discussed in the following sections, (these files are supplied on disk; see key in Section 7.0).

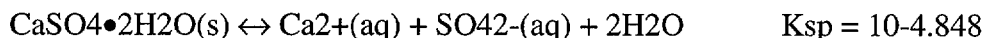
3.1 PHREEQC Model Database

Three different databases are included in the PHREEQC model package: (1) the PHREEQE database (Parkhurst and others 1980), (2) the WATEQ4F database (Ball and Nordstrom 1991), and (3) the MINTEQ database (Allison and others 1991). The MINTEQ database was used for this study because it is an extensive thermodynamic compilation that is adequate for addressing a broad range of geochemical conditions involving metals. While the User Guide to PHREEQC (Parkhurst 1995) states that one limitation of the aqueous model is a lack of internal consistency in the database, this is an inherent property of any geochemical database. The lack of internal consistency results from those equilibrium constants and enthalpies of reaction that are compiled from various literature sources. In fact, no geochemical database exists that contains thermodynamic data derived from a single source. The databases used in contemporary geochemical models (MINTEQ, WATEQ4F, EQ3/6, SOLMNEQ, GEOCHEM) contain thermodynamic data that were compiled from various sources because it would not be feasible for an individual to generate equilibrium constants for the hundreds of reactions contained within any geochemical database.

The original MINTEQ model was developed at Batelle Pacific Northwest Laboratories. Research contributing to the continued development of MINTEQ was supported in part by the Office of Solid Waste at the U. S. Environmental Protection Agency. The current MINTEQ database originated from the "...well-developed thermodynamic database of the U. S. Geological Survey's WATEQ3 model" (Ball and others 1981) (Allison and others 1991). The following sections describe the modifications made to the MINTEQ database for the site-specific Gas Hills conceptual geochemical model. The modified database is included on the disk provided in Section 7.0.

3.1.1 Correction of the Gypsum Solubility Constant in the MINTEQ Database

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ is an important mineral that controls the concentration of sulfate in soil solutions and aquifer systems. Therefore, the sulfate concentrations modeled using PHREEQC are strongly dependent on the gypsum solubility constant used in the MINTEQ database. The gypsum solubility expression and corresponding solubility constant (K_{sp}) provided in the MINTEQ database are shown below:



Nordstrom and others (1990) presented a revised summary of equilibrium constants for aqueous ion associations and mineral solubilities, and proposed a revised gypsum solubility constant of $10^{-4.58}$. This revised gypsum solubility product is used by both the PHREEQC (Parkhurst 1995) and WATEQ4F (Ball and Nordstrom 1991) databases, and is known with high precision based on measurements by previous investigators cited in Nordstrom and others (1990). Therefore, the revised gypsum solubility constant of $10^{-4.58}$ was added to the MINTEQ database and used for the Gas Hills modeling. The revised gypsum solubility constant increases the modeled solubility of gypsum and results in a higher, more conservative estimate for the predicted radium concentrations because radium is largely controlled by co-precipitation with gypsum (see Section B5.1.6).

3.1.2 MINTEQ Database Modification to Include Radium Thermodynamic Data

Thermodynamic data for radium complexes and solid phases were obtained from Langmuir and Riese (1985) and added to the MINTEQ database. These authors used a comprehensive thermodynamic model based on similarities among calcium, strontium, and barium aqueous complexes and solid compounds to extrapolate the equilibrium constants (K) and standard enthalpies of reaction (ΔH°) for radium solids and solution species. Given the chemical similarities between the radium (Ra^{2+}) and barium (Ba^{2+}) ions, surface complexation constants for barium are assumed to be valid for radium (Langmuir 1997). Therefore, a surface complexation constant for adsorption of radium by hydrous ferric oxide (HFO) was added by using the well-established barium surface complexation data provided by Dzombak and Morel (1990). The radium thermodynamic data added to the MINTEQ database are given in Table B3.1. The values for K indicate that RaSO_4° is the most stable form of the listed aqueous species.

Table B3.1 Relevant Thermodynamic Equations for Radium.

Reaction	log K or log K _{sp}	ΔH° (kcal/mol)
$\text{Ra}^{2+} + \text{OH}^- = \text{Ra}(\text{OH})^+$	0.5	1.1
$\text{Ra}^{2+} + \text{Cl}^- = \text{RaCl}^+$	-0.10	0.50
$\text{Ra}^{2+} + \text{CO}_3^{2-} = \text{RaCO}_3^\circ$	2.5	1.07
$\text{Ra}^{2+} + \text{SO}_4^{2-} = \text{RaSO}_4^\circ$	2.75	1.3
$\text{RaCO}_3(\text{c}) = \text{Ra}^{2+} + \text{CO}_3^{2-}$	-8.3	-2.8
$\text{RaSO}_4(\text{c}) = \text{Ra}^{2+} + \text{SO}_4^{2-}$	-10.26	-9.4
$\text{Hfo_wOH} + \text{Ra}^{2+} = \text{Hfo_wORa}^{2+} + \text{H}^+$	-7.2	-----
$\text{Hfo_sOH} + \text{Ra}^{2+} = \text{Hfo_sOH}\text{Ra}^{2+}$	5.46	-----

Source: Langmuir and Riese (1985)

3.1.3 MINTEQ Database Modification to Include Thorium Thermodynamic Data

The thermodynamic data for the aqueous thorium complexes and solid phases are those used in the database of the chemical equilibrium model EQ3/6 developed at Lawrence Livermore National Laboratory (Wolery 1992). Surface complexation constants to describe thorium adsorption onto HFO were obtained from LaFlamme and Murray (1987). Relevant thorium thermodynamic equations for solution species, solid phases, and surface complexes are given in Table B3.2. The data indicate that the aqueous thorium sulfate solution species are the most stable species relative to the other listed complexes.

3.2 Surface Complexation Modeling

A commonly used surface complexation model was used to represent the attenuation of calcium, sulfate, beryllium, nickel, arsenic, selenium, 226+228radium, 230thorium, 210lead, and uranium. Many studies have shown adsorption models based on double-layer theory to be successful in predicting the composition of complex solutions in contact with an adsorbing surface (Langmuir 1997). Westall and Hohl (1980) demonstrated that any of five electrostatic models can describe the same set of experimental data equally well. The PHREEQC geochemical model incorporates the Dzombak and Morel (1990) diffuse double-layer and a non-electrostatic surface-complexation model (Davis and Kent 1990). Of the three adsorption models commonly used, (constant capacitance, diffuse double-layer, and triple-layer), the diffuse double-layer model requires the least number of input parameters.

The modeling exercise assumes that the adsorbing surface is HFO. HFO is a naturally dominant adsorbent because of its tendency to be finely dispersed and to exist as both ubiquitous coatings on mineral particles and as discrete oxide particles (Jenne 1968; Dzombak and Morel 1990). The reactive properties of HFO are well characterized. The three most important properties of the adsorbing phase that are used as input to the model are (1) the surface area, (2) the mass of the adsorbing material, and (3) the surface site density.

Table B3.2 Relevant Thermodynamic Equations for Thorium

Reaction	log K or log K _{sp}	ΔH° (kcal/mol)	Source
$\text{Th}^{+4} + \text{H}_2\text{O} = \text{ThOH}^{+3} + \text{H}^+$	-3.887	-246.2	Wagman and others (1982)
$\text{Th}^{+4} + 2\text{H}_2\text{O} = \text{Th}(\text{OH})_2^{+2} + 2\text{H}^+$	-7.11	-306.5	Langmuir and Herman (1980)
$\text{Th}^{+4} + 3\text{H}_2\text{O} = \text{Th}(\text{OH})_3^{+1} + 3\text{H}^+$	-11.86	-368.4	Langmuir and Herman (1980)
$\text{Th}^{+4} + 4\text{H}_2\text{O} = \text{Th}(\text{OH})_4 + 4\text{H}^+$	-16.03	-438.4	Langmuir and Herman (1980)
$2\text{Th}^{+4} + 2\text{H}_2\text{O} = \text{Th}_2(\text{OH})_2^{+6} + 2\text{H}^+$	-6.46	-489.4	Langmuir and Herman (1980)
$4\text{Th}^{+4} + 8\text{H}_2\text{O} = \text{Th}_4(\text{OH})_8^{+8} + 8\text{H}^+$	-21.76	-1224.0	Langmuir and Herman (1980)
$6\text{Th}^{+4} + 15\text{H}_2\text{O} = \text{Th}_6(\text{OH})_{15}^{+9} + 15\text{H}^+$	-37.70	-2019.0	Langmuir and Herman (1980)
$\text{Th}^{+4} + \text{Cl}^- = \text{ThCl}^{+3}$	0.954	-223.7	Langmuir and Herman (1980)
$\text{Th}^{+4} + 2\text{Cl}^- = \text{ThCl}_2^{+2}$	0.676	NR	Langmuir and Herman (1980)
$\text{Th}^{+4} + 3\text{Cl}^- = \text{ThCl}_3^{+1}$	1.498	NR	Langmuir and Herman (1980)
$\text{Th}^{+4} + 4\text{Cl}^- = \text{ThCl}_4$	1.073	NR	Langmuir and Herman (1980)
$\text{Th}^{+4} + \text{SO}_4^{-2} = \text{ThSO}_4^{+2}$	5.31	-397.2	Langmuir and Herman (1980)
$\text{Th}^{+4} + 2\text{SO}_4^{-2} = \text{Th}(\text{SO}_4)_2$	9.62	-611.0	Langmuir and Herman (1980)
$\text{Th}^{+4} + 3\text{SO}_4^{-2} = \text{Th}(\text{SO}_4)_3^{-2}$	10.40	NR	Langmuir and Herman (1980)
$\text{Th}^{+4} + 4\text{SO}_4^{-2} = \text{Th}(\text{SO}_4)_4^{-4}$	8.44	NR	Langmuir and Herman (1980)
$\text{Th}(\text{SO}_4)_2(\text{c}) = \text{Th}^{+4} + 2\text{SO}_4^{-2}$	-20.3	-607.7	Wagman and others (1982)
$\text{Th}(\text{OH})_4(\text{c}) + 4\text{H}^+ = \text{Th}^{+4} + 4\text{H}_2\text{O}$	9.65	-423.6	Naumov and others (1974) ¹
$\text{ThO}_2(\text{c}) + 4\text{H}^+ = \text{Th}^{+4} + 2\text{H}_2\text{O}$	1.86	-293.1	Cox and others (1989)
$\text{Hfo_wOH} + \text{Th}^{+4} = \text{Hfo_wOTh}^{+3} + \text{H}^+$	3.5	NR	LaFlamme and Murray (1987)
$\text{Hfo_wOH} + \text{Th}^{+4} + \text{H}_2\text{O} = \text{Hfo_wOTh}(\text{OH})^{+2} + 2\text{H}^+$	0.20	NR	LaFlamme and Murray (1987)
$\text{Hfo_wOH} + \text{Th}^{+4} + 2\text{H}_2\text{O} = \text{Hfo_wOTh}(\text{OH})_2^{+1} + 3\text{H}^+$	-6.38	NR	LaFlamme and Murray (1987)
$\text{Hfo_wOH} + \text{Th}^{+4} + 3\text{H}_2\text{O} = \text{Hfo_wOTh}(\text{OH})_3 + 4\text{H}^+$	-6.3	NR	LaFlamme and Murray (1987)
$\text{Hfo_wOH} + \text{Th}^{+4} + 4\text{H}_2\text{O} = \text{Hfo_wOTh}(\text{OH})_4^{-1} + 5\text{H}^+$	-16.32	NR	LaFlamme and Murray (1987)

NR not reported.

¹ log K for $\text{Th}(\text{OH})_4(\text{c})$ reported by Naumov and others (1974) is consistent with Langmuir and Herman (1980).

3.2.1 Surface Area

Laboratory experiments demonstrate that measured surface areas depend on the HFO aging after it is prepared and the specific method used to measure surface area. Tabulating measured surface areas for HFO (21 determinations) shows a range of 159 to 720 square meters per gram (m²/g). However, the values at the low end of this range are considered to be underestimates due to difficulties in measuring the surface area of HFO with the commonly used nitrogen gas adsorption methods (Dzombak and Morel 1990). The Gas Hills geochemical model used the estimate of 600 m²/g recommended by Davis and co-workers (Davis 1977; Davis and Leckie 1978; Luoma and Davis 1983) and is consistent with the work by Dzombak and Morel (1990).

3.2.2 Mass of the Adsorbing Surface

Analyses of aquifer materials in the Gas Hills area show that iron concentrations in the sediments commonly range from two to three percent (Lidstone & Anderson, Inc. 1989). The modeling exercise is conservative, assuming that the aquifer sediments contain two percent total iron, and that 10 percent of the total iron exists as HFO. The model was shown to be insensitive to total iron concentration when the results were compared using one, two, and three percent total iron.

The mass of HFO used in PHREEQC must be expressed on a per liter basis and was calculated by assuming that the sediments contain 0.2 percent HFO, and by using an estimated aquifer porosity of 15 percent (5.7 L soil/ L H₂O), a bulk density of 2.1 g/cm³ (Umetco Minerals Corporation 1997), and a molecular weight of 107 g/mole for HFO [Fe(OH)₃ (ferrihydrite)]. The resulting value is 45.9 g HFO/L and was calculated as follows:

$$\frac{g \text{ HFO}}{L} = \left(\frac{5.7 \text{ L rock}}{L \text{ H}_2\text{O}} \right) \left(\frac{1000 \text{ cm}^3 \text{ rock}}{L \text{ rock}} \right) \left(\frac{2.1 \text{ g rock}}{\text{cm}^3 \text{ rock}} \right) \left(\frac{0.2 \text{ g Fe as HFO}}{100 \text{ g rock}} \right) \left(\frac{107 \text{ g HFO}}{55.85 \text{ g Fe}} \right) = \frac{45.9 \text{ g HFO}}{L \text{ H}_2\text{O}}$$

3.2.3 Surface Site Density

Using PHREEQC adsorption model assumes that the number of active sites on the adsorbing surface (surface site density) is known. Surface densities for sorption sites are divided into two types, both used in the model. Type 1 sites are a small set of high-energy binding sites. Type 2 sites are determined from experimental sorption maxima. Previous studies showed that measured densities of Type 1 sites on HFO are sufficiently close to justify the use of a single Type 1 site density (0.005 mole/mole Fe) (Dzombak and Morel 1990). The range of estimates for Type 2 site densities on HFO is small (from 0.1 to 0.3 mole/mole Fe) and use of an approximate median Type 2 site density of 0.20 mole/mole Fe is shown to be successful when describing the sorption behavior of HFO (Dzombak and Morel 1990). To calculate the number of adsorption sites, the moles of iron per liter of water must first be calculated from the mass of HFO:

$$\frac{\text{moles Fe}}{L \text{ H}_2\text{O}} = \left(\frac{45.9 \text{ g HFO}}{L \text{ H}_2\text{O}} \right) \left(\frac{\text{mole HFO}}{107 \text{ g HFO}} \right) \left(\frac{1 \text{ mole Fe}}{\text{mole HFO}} \right) = \frac{0.429 \text{ moles Fe}}{L \text{ H}_2\text{O}}$$

Based on this result, it follows that the number of Type 1 and Type 2 sites can be calculated as follows:

$$\frac{\text{moles Type 1 sites}}{L \text{ H}_2\text{O}} = \left(\frac{0.429 \text{ moles Fe}}{L \text{ H}_2\text{O}} \right) \left(\frac{0.005 \text{ moles sites}}{\text{mole Fe}} \right) = \frac{0.002 \text{ moles Type 1 sites}}{L \text{ H}_2\text{O}}$$

$$\frac{\text{moles Type 2 sites}}{L \text{ H}_2\text{O}} = \left(\frac{0.429 \text{ moles Fe}}{L \text{ H}_2\text{O}} \right) \left(\frac{0.2 \text{ moles sites}}{\text{mole Fe}} \right) = \frac{0.086 \text{ moles Type 2 sites}}{L \text{ H}_2\text{O}}$$

3.3 Ion Exchange Modeling

Ion exchange equilibria were included in PHREEQC to model the exchange of calcium, sodium, potassium, magnesium, 210lead, 226+228radium, and iron (II). Ion exchange equilibria are included in PHREEQC through heterogeneous mass-action and mole-balance equations for exchange sites, with mass-action expressions based on half-reactions between aqueous species and unoccupied exchange sites. Values for the exchange coefficients were taken from Appelo and Postma (1993), where the exchange coefficients are expressed using Na⁺ (sodium) as the

reference cation, and using equivalent fractions for activities of the exchange species (Gaines-Thomas convention, Gaines and Thomas 1953).

A range in measured cation exchange capacity (CEC) values (3.9 to 14.1 cmole/kg) has been reported for the Wind River Aquifer (Umetco Minerals Corporation 1997). The number of exchange sites (moles X) specified in PHREEQC must be expressed on a per liter of water basis and was calculated using a representative CEC value of 10 cmole/kg, an aquifer porosity of 15 percent (5.7 L soil/ L H₂O), and a bulk density of 2.1 g/cm³ (Umetco Minerals Corporation 1997).

$$\frac{\text{moles X}}{\text{L H}_2\text{O}} = \left(\frac{5.7 \text{ L rock}}{\text{L H}_2\text{O}} \right) \left(\frac{1000 \text{ cm}^3 \text{ rock}}{\text{L rock}} \right) \left(\frac{2.1 \text{ g rock}}{\text{cm}^3 \text{ rock}} \right) \left(\frac{10 \text{ cmol}}{1000 \text{ g rock}} \right) \left(\frac{\text{mol}}{100 \text{ cmol}} \right) = \frac{1.2 \text{ moles X}}{\text{L H}_2\text{O}}$$

4.0 PHREEQC MODEL CONSTRUCTION

The groundwater flow regime at the Gas Hills site has two distinct components: (1) a southwestern flow in the vicinity of the A-9 Repository, and (2) a deeper, western flow in the vicinity of the AGTI. A mudstone unit separates the two flow regimes. Because unique conditions are present in the two flow regimes, each was modeled separately. Both models used an assumed aquifer porosity of 15 percent, a hydraulic conductivity of 1 foot/day (ft/d) and a hydraulic gradient of 0.025, resulting in a representative groundwater velocity of 0.167 ft/d. The model was constructed based upon several conservative assumptions:

- The model was also run using conservative velocities of 0.33 ft/d for the Western Flow Regime and 0.28 ft/d for the Southwestern Flow Regime. These values are upper limits derived from the stochastic groundwater flow modeling effort described in Appendix C.
- The model assumes that there is a constant source of mill-affected water from the tailing impoundments, when in reality this source will diminish with time.
- Transport of hazardous constituents is modeled using advective flow and ignores the effects of dispersion that further reduce the concentrations of mill-affected constituents.
- Minimum values are used for the masses of pyrite and calcite.

4.1 Model Grid for the Western Flow Regime

The model grid for the Western Flow Regime is one-dimensional, extending from the edge of the AGTI through the POC well MW21A and monitoring well MW28 to the POE, approximately 4,600 feet from the edge of the impoundment (Figure 2.20). The model grid consists of a single row of 46 cells, each representing an aquifer unit 100 feet long. Key features considered in model construction were the regionally reduced character of the Wind River Formation in this area and the presence of an oxidized, carbonate depleted halo downgradient of the AGTI.

4.1.1 Initial Solutions for the Western Flow Regime

The initial solution represents the source of constituents entering the Western Flow Regime. The model conservatively assumes that the source is constant. An additional degree of conservatism

with respect to mass loading onto the minerals of the aquifer is also inherent in the model. That is, the model simulates transport of constituents that are in complete contact with the aquifer matrix. In reality, based on results associated with wells screened in discrete intervals within the Western Flow Regime, the constituents have impacted only the upper portion of the aquifer. Therefore, the model over-predicts mass loading to solid phases in the aquifer.

For the source term, the model conservatively incorporated the 95 percent upper confidence limit of the upper 95th quantile concentration of the hazardous constituents from data sets collected from monitoring wells located within or close to the AGTI. Elevated levels of the hazardous constituents are consistently reported at these locations. Selection for input values is described in Appendix E. For the major ions, the input concentrations from the original ACL application were used (99th percentile of concentrations in first quarter 1997 through fourth quarter 1998 data from MW1 or MW21A, whichever was higher).

The oxidation-reduction potential measured in POC Well MW21A corresponded to a negative logarithm of free electron activity (pE) of 5.8. As mentioned earlier, sodium chlorate and manganese dioxide were added to the milling process as oxidizers to bring the solution to an Eh of between +400 and +425 millivolts (Merritt 1971) which corresponds to a pE of 6.8 to 7.2. Assuming only minor reaction with redox sensitive materials through the thick unsaturated zone beneath the AGTI, the oxidation-reduction potential of the initial solution was therefore set at a pE of 6.

4.1.2 Solutions That Occupy Model Cells for the Western Flow Regime

The solutions in the first 15 cells of the Western Flow Regime model use concentrations (including pH, temperature, and oxidation-reduction potential measurements) measured during the 4th quarter 1998 in POC Well MW21A located immediately downgradient of the AGTI. Based on analytical data and field measurements, MW21A is within the oxidized, carbonate-depleted halo downgradient of the AGTI. The basis of this is:

- Elevated total dissolved solids (TDS) concentrations (typically ranging between 1,500 to 2,000 mg/L).
- pH values (approximately 6.0) that are transitional between the average pH at the edge of the cell (5.5) and those from Well MW28 (> 6.5), which is located outside of the depleted halo.

The solutions in cells 16-46 of the Western Flow Regime model are also concentrations (including pH, temperature, and oxidation-reduction potential measurements) measured during the 4th quarter 1998 in monitor Well MW28. Well MW28 appears to be outside the influence of the AGTI since tritium measurements indicate the water in this well is older than uranium milling at Gas Hills (SMI 1998), as well as consistently low levels (<10 mg/L) of chloride.

4.1.3 Simulating Advective Transport for the Western Flow Regime

Advective transport simulation is conservative because transport is modeled based on simple "plug flow" without accounting for the effects of dispersion or diffusion. Advective transport occurs through a number of "shifts", which is the number of times the solution in each cell will be shifted to the next higher numbered cell. Two flow rates were modeled for the Western Flow

Regime: 0.167 ft/d and 0.33 ft/d. For these two flow rates, the model was assigned 644 and 1,242 shifts, respectively. For example, at a flow rate of 0.167 ft/d along the Western Flow Regime, 14 pore volumes (PV) will have moved from the POC to the POE (4,600 feet) in 1,000 years. Therefore, (14 PV) x (46 cells) = 644 shifts.

4.2 Model Grid for the Southwestern Flow Regime

The model grid for the Southwestern Flow Regime (Figure 2.21) begins at the toe of the A-9 Repository and extends for 5,400 feet downgradient to the POE. The model grid consists of a single row of 54 cells each representing an aquifer unit 100 feet long.

4.2.1 Initial Solutions for the Southwestern Flow Regime

The initial solution composition for the Southwestern Flow Regime incorporated the 95 percent upper confidence limit of the upper 95th quantile concentration of constituents from data sets collected from monitoring wells screened within the upper portion of the Wind River Aquifer that contain consistently elevated levels of the hazardous constituents. The only exception was the value for Thorium-230, which was the maximum value observed at POC Well GW7. The selection of input values is presented in Appendix E. As for the Western Flow Regime, the Southwestern Flow Regime model is conservative because it uses the 95 percent upper confidence limit of the upper 95th quantile concentration of constituents, and because it also assumes that the source is constant. For the major ions, the input concentrations from the original ACL application were used (99th percentile of concentrations in first quarter 1997 through fourth quarter 1998 data from GW7 or GW8, whichever was higher). A calculated pE of 9, based on site-specific measurements of the Fe²⁺/Fe³⁺ couple collected from POC Well GW7 in August 1998, was used in the model input.

4.2.2 Solutions That Occupy Model Cells for the Southwestern Flow Regime

The solutions in the first five cells of the Southwestern Flow Regime model used concentrations (including pH, temperature, and oxidation-reduction measurements) measured during the 4th quarter of 1998 in POC Well GW8. It is assumed that as groundwater approaches the PRI ore body, conditions closely resemble those found in the ore body. Well MW74 appears to be outside the influence of the A-9 Repository based on low concentrations of chloride, sulfate, and licensed constituents. Therefore, the solutions in the remaining cells, 6-54, are those from 4th quarter 1998 measured in Well MW74.

4.2.3 Simulating Advective Transport for the Southwestern Flow Regime

As was done for the Western Flow Regime, the transport simulations for the Southwestern Flow Regime were also conservatively modeled using simple advective transport without the modeled effects of dispersion or diffusion on constituent concentrations. Two flow rates were modeled for the Southwestern Flow Regime: 0.167 ft/d and 0.28 ft/d. For these two flow rates, the model was assigned 648 and 1,026 shifts, respectively. For example, at a flow rate of 0.167 ft/d along the Southwestern Flow Regime, 12 PV will have moved from the POC to the POE (5,400 feet) in 1,000 years. Therefore, (12 PV) x (54 cells) = 648 shifts.

4.3 Reactive Minerals in the Geochemical Modeling

Two different attenuation mechanisms exist for metals and metalloids in the Wind River Aquifer. Oxidation/reduction reactions cause redox-sensitive constituents to be removed as either oxides or sulfides. Pyrite in the aquifer matrix acts as a reductant for incoming solutions. In addition, neutralization of low pH solutions by calcite causes many metals to be removed from groundwater. Both the Southwestern and the Western Flow Regimes contain pyrite and calcite in the aquifer matrix that react with constituents in groundwater.

4.3.1 Calcite

Anderson (1969) described the Wind River Formation as cemented with calcite and limonite. Calcite tends to be more abundant on the reduced, downgradient side of the redox front than in the oxidized core. Samples analyzed from the hematitic core, just south of the AGTI, indicate a calcite equivalent of 3.92 tons per 1,000 tons of matrix material (Umetco Minerals Corporation 1997), yielding an estimate of approximately 0.4 percent calcite in the hematitic core. This was taken as a minimum value for the Wind River Formation because calcite is known to occur at much higher concentrations in roll-front uranium deposits (Granger and Warren 1974). Therefore, a concentration of 0.40 percent calcite was assigned to all cells in both models with the exception of the first 15 cells of the Western Flow Regime as described below.

Assuming that a calcite depleted halo exists in the aquifer around the AGTI, the first 15 cells of the western flow model were assigned a value of 0.2 percent calcite by weight. This model configuration is conservative because the assumed halo is unlikely to extend for 1,500 feet at the lowest calcite value. There may be less than 0.2 percent calcite in the Wind River Formation directly adjacent to the AGTI, but it is also likely that calcite percentages in the aquifer matrix increase as distance from the AGTI increases. The pH and associated model calculations for all wells used to establish the source at the edge of the AGTI indicates equilibrium with calcite (except Well MWC56), and therefore the remaining cells 16 through 46 were assigned the higher concentration (0.4 percent) of calcite.

4.3.2 Pyrite

Pyrite occurs in the hematitic core, in uranium roll fronts, and in the regionally reduced portions of the Wind River Formation (Harshman 1974, Granger and Warren 1974, King and Austin 1966). Although sparse, pyrite found in the hematitic core is very fine-grained, shiny, and euhedral, with no limonitic specks. Pyrite found in the roll fronts is even finer-grained, and present in clusters that are less shiny and associated with limonitic specks (King and Austin 1966). Harshman (1974) analyzed samples of Wind River Formation at Gas Hills for pyrite and a suite of chemical constituents typically present in uranium mineralization. These samples were taken on close-spaced centers (no more than two meters apart) and extended from the hematitic core, across a roll front and into unaltered, regionally reduced sandstone. Measured pyrite abundance ranged from approximately two percent by weight in the hematitic core to over 20 percent in the roll front and more than five percent in the regionally reduced sandstone.

Pyrite has been noted in mining records and during monitoring wells drilling at the site. Very fine-grained pyrite is defined petrographically as being from 0.125 to 0.05 mm in diameter (Williams and others 1982). Particles in this size range are difficult to see with the human eye. Typically, if a mineral in this size range is visible, it is probably present at more than two

percent. The drilling log for MW77 describes “abundant” pyrite at and below the water table (U.S. Environmental Services 1996). Assuming that “abundant” refers to two percent or more, the amount of pyrite included in the model in the region of MW77 was conservatively estimated as two percent. Pyrite was not noted in the drilling of MW28 and MW21A, and therefore supports the model assumption that an oxidized halo exists around the AGTI. Therefore, no pyrite was assumed in the first 15 cells of the model, but was defined at a concentration of two percent in the remaining cells.

As noted above, pyrite ranges from two to twenty percent across a uranium roll front. The area downgradient of the A-9 Repository is located within roll front uranium mineralization. The corrective action program has impacted the Wind River Aquifer at POC well GW7. However, falling pH and rising iron concentrations in this well are evidence that pyrite is present and is reacting with oxidizing solutions. In order to ensure that the model makes conservative predictions of attenuation by reaction with pyrite along the remainder of the flow path, all cells in the model were assigned two percent pyrite by weight.

4.3.3 Precipitating Minerals and Equilibrium Phases

A number of minerals are identified as being associated with Wyoming roll front uranium deposits in general and at Gas Hills specifically (Granger and Warren 1974; Harshman 1974; DeVoto 1978; Ludwig and Grauch 1980; U.S. Environmental Services 1996). Of these minerals, only pyrite, calcite, and ferrihydrite are initially present in the cells of the model. These minerals are allowed to dissolve or precipitate during model simulations based on thermodynamic data in the model database. In addition, the following minerals were allowed to precipitate to equilibrium upon saturation:

- anglesite [PbSO₄]
- nickel carbonate [NiCO₃]
- selenium (elemental) [Se(a)]
- nickel selenide [NiSe]
- calcite [CaCO₃]
- nickel sulfide [NiS]
- coffinite [USiO₄]
- pyrite [FeS₂]
- ferrihydrite [Fe(OH)₃]
- radium sulfate [RaSO₄(c)]
- ferroselite [FeSe₂]
- thorium hydroxide [Th(OH)₄(a)]
- gypsum [CaSO₄•2H₂O]
- uraninite [UO₂]

4.4 Summary of Site-Specific Input Used in the Geochemical Model

Site-specific data from the Gas Hills Site were used in the geochemical model to define properties of groundwaters, reactive mineral phases, adsorption surfaces, and cation exchange sites. The site-specific data used with the PHREEQC data blocks are summarized in Table B4.1

Table B4.1 Site-Specific Data Defined in PHREEQC Modeling

Keyword Data Block ¹	Site-Specific Parameter(s)	Comments
SOLUTION	<p><u>Source Water</u> 95% UCL of the 95th quantile from site wells</p> <p><u>Native Groundwater</u> Well MW28 (W Flow Regime) Well MW74 (SW Flow Regime)</p>	<p>The compositions for these wells can be found in the attached PHREEQC input files. Data include chemical composition, temperature, and measured redox potential.</p>
EQUILIBRIUM_PHASES	<p>Potential controlling solid phases are CaSO₄•2H₂O, FeS₂, USiO₄, UO₂, CaCO₃, FeSe₂, Fe(OH)₃, Se(a), RaSO₄, Th(OH)₄, NiSe, PbSO₄, NiCO₃, NiS.</p>	<p>CaCO₃, FeS₂, and Fe(OH)₃ were added at initial concentrations based on observations in drill cores.² CaSO₄•2H₂O, USiO₄, UO₂, FeSe₂, Fe(OH)₃, and Se(a) are known to occur in the Wind River Formation.</p>
SURFACE	<p>A total iron concentration of two percent (Lidstone & Anderson 1989) was used to calculate the mass of the adsorbing phase (45.9 g/L).²</p>	<p>The value of two percent is a conservative value since some samples contained three percent total iron.</p>
EXCHANGE	<p>A cation exchange capacity of 10 cmole/kg was used to calculate an exchanger concentration of 1.68 moles/L.²</p>	<p>Measured CEC values ranged from 4 to 14 cmole/kg (Umetco 1997). The value of 10 cmole/kg is within the measured range, and is a typical value for chlorite identified in the Wind River Aquifer.</p>

¹ See the attached PHREEQC input files key in Section 7.0.

² An average bulk density of 2.1 g/cm³ was used to calculate the moles of solid phase per liter of water. Sandstone bulk density was 2.15 g/cm³ and mudstone was 2.00 g/cm³ (Umetco 1997).

5.0 PREDICTIVE SIMULATION RESULTS

The Western Flow Regime model was run using two flow rates across 46 cells (0.167 ft/d or 644 shifts and 0.33 ft/d or 1,242 shifts). These two flow rates correspond to 14 and 27 PV, respectively, and represent 1,000 years of transport time. Results are shown in Table B5.1 and profiles of concentrations for each constituent along the flow path at 1,000 years of transport are shown in Figures B.1 through B.8. Figures B.9 through B.16 depict the concentrations of the various constituents as a function of time at the POE.

The Southwestern Flow Regime model was also run using two flow rates across 54 cells (0.167 ft/d or 648 shifts and 0.28 ft/d or 1,026 shifts). These two flow rates correspond to 12 and 19 PV, respectively, and represent 1,000 years of transport time. Results are shown in Table B5.2 and profiles of concentrations for each constituent along the flow path at 1,000 years of transport are shown in Figures B.17 through B.24. Figures B.25 through B.32 depict the concentrations of the various constituents as a function of time at the POE.

5.1 Reactions Controlling the Attenuation of the Constituents of Concern

Attenuation was represented by geochemical reactions defined by the user and then specified in the PHREEQC model input files. Three important geochemical processes were considered for the various constituents in the model: (1) precipitation-dissolution of mineral phases, (2) cation exchange on the surfaces of clay minerals, and (3) adsorption-desorption interactions with HFO. Precipitation and dissolution reactions are the dominant mechanisms controlling the major ion composition of the ground water. The model results show that as the mill-affected water moves through the aquifer, calcite dissolves, pH increases, and gypsum precipitates; pyrite remains unreactive, however, because reducing conditions are maintained within the aquifer, regardless of the mixing of relatively oxidizing tailings fluid with the natural ground water (see results for mineral masses in the selected output files). Therefore, dissolution of other naturally occurring sulfide minerals, such as arsenopyrite, is not predicted to occur due to the persistence of reducing conditions downgradient.

Ion exchange and adsorption to HFO are the dominant mechanisms controlling the mobility of the hazardous constituents. The specific reactions corresponding to these geochemical processes can be examined by reviewing the modified MINEQ database provided on the disk in Section 7.0. The following sections describe the dominant attenuation mechanisms for the hazardous constituents predicted by the geochemical model. Because geochemical conditions differ between the Western and Southwestern Flow Regimes, there are differences in the types of phases predicted to form between the two flow regimes. The types of phases formed are independent of flow rate, however, and therefore only the results for the 0.167 ft/day flow rate are presented for the Western (Figure B.33 through B.40) and Southwestern (B.41 through B.48) Flow Regimes.

5.1.1 Arsenic

Under oxidizing and mildly reducing conditions such as those encountered in the Western and Southwestern Flow Regimes, dissolved arsenic concentrations are typically controlled by adsorption rather than mineral precipitation (Clement and Faust 1981). The model does not consider arsenic minerals to be initially present nor are any arsenic minerals allowed to

precipitate. Rather, the model calculates the distribution of aqueous arsenic species according to the equations in the MINTEQA database, and then allows for arsenic concentrations to be controlled by adsorption to HFO. Surface complexation constants for arsenic(V) (arsenate) and arsenic(III) (arsenite) were taken from Dzombak and Morel (1990). The model predicts that adsorption of arsenite will be the dominant attenuation mechanism for arsenic within the Western (Figure B.33) and Southwestern (Figure B.41) Flow Regimes.

5.1.2 Beryllium

Beryllium is strongly bound by organic matter and clays and therefore is relatively immobile in soils and sediments (Kabata-Pendias and Pendias 1992). No thermodynamic data were available in the MINTEQA database to allow for precipitation of discrete beryllium mineral phases. However, beryllium is an alkaline earth metal whose chemical behavior in groundwater systems is similar to calcium, magnesium, barium, strontium, and radium. Therefore, attenuation of beryllium was modeled by allowing for adsorption to the surface of HFO. Beryllium surface complexation constants were obtained from Dzombak and Morel (1990). Consequently, the modeled beryllium attenuation for the Western (Figure B.34) and Southwestern (Figure B.42) Flow Regimes result from adsorption to HFO.

5.1.3 Lead

Aqueous speciation of lead is generally dominated by the free lead ion (Pb^{2+}) in neutral to acidic solutions with lead carbonate solution species becoming important at higher pH values (Rai and others 1987). Under these conditions, lead will form adsorbed surface complexes with available clay minerals and iron hydroxide. Therefore, lead attenuation was modeled using ion-exchange (Appelo and Postma 1993) and surface-complexation equilibria (Dzombak and Morel 1990). The mineral $PbSO_4$ (anglesite) was also specified as a potential solid phase due to its low solubility, but anglesite was not predicted to precipitate along either flow path. The model predicts that adsorption, and to a lesser extent ion exchange, will be the attenuation mechanisms for lead along the Western (Figure B.35) and Southwestern (Figure B.43) Flow Regimes.

5.1.4 Uranium

Distribution of uranium solution species was calculated according to the equations in the MINTEQA database that allow for the formation of aqueous complexes with carbonate, hydroxide, and sulfate ions. Uraninite and coffinite are the important uranium minerals in the Gas Hills ore, and the model allowed for precipitation of these minerals upon saturation. Precipitation of these minerals depends, however, on the effect of redox conditions on the relative concentration of uranium(IV) $[U(IV)]$ compared to uranium(VI) $[U(VI)]$. The redox conditions that were used as input to the PHREEQC model were measured using a platinum electrode with a silver/silver chloride reference. Under the measured redox conditions, the uranium solution species are dominated by U(IV), allowing for precipitation of uraninite and coffinite. Although U(VI) is a small component of the dissolved uranium species, the surface complexation constants for U(VI) were included in the model for completeness (Langmuir 1997). The geochemical model predicts that precipitation of uraninite, and to a lesser extent adsorption to HFO, are the primary attenuation mechanisms for uranium in both the Western (Figure B.36) and Southwestern (Figure B.44) Flow Regimes.

5.1.5 Nickel

Dissolved nickel species in groundwater are typically dominated by the free nickel ion $[\text{Ni}^{2+}(\text{aq})]$ and by association with sulfate to form $\text{NiSO}_4^0(\text{aq})$. In most groundwater systems, adsorption is the primary mechanism of nickel attenuation. Therefore, nickel attenuation was modeled using established surface complexation constants for HFO (Dzombak and Morel 1990). Nickel was also allowed to precipitate as NiSe (nickel selenide) (Masscheleyn and others 1991), NiCO_3 (nickel carbonate), and NiS (millerite). Attenuation results from both precipitation of nickel selenide and adsorption to HFO for the Western (Figure B.37) and Southwestern (Figure B.45) Flow Regimes.

5.1.6 Radium

Distribution of solution radium species was calculated according to the equations given in Table B3.1 (Langmuir and Riese 1985). Radium concentrations in groundwater are generally limited by adsorption or solid solution formation, because radium concentrations in both natural waters and waters associated with uranium mining are usually not high enough to reach saturation with $\text{RaSO}_4(\text{c})$ (Langmuir and Riese 1985). Results of the modeling indicated that the modeled groundwaters were undersaturated with respect to $\text{RaCO}_3(\text{c})$ (radium carbonate) and the less soluble $\text{RaSO}_4(\text{c})$ (radium sulfate). Barium surface-complexation (Dzombak and Morel 1990) and ion-exchange (Appelo and Postma 1993) constants for HFO were used to model radium attenuation because these constants are considered to be valid for radium (Langmuir 1997).

Radium co-precipitation with gypsum was conservatively modeled by using the lowest radium:calcium ratio (2.5×10^{-11}) observed in a series of laboratory experiments by Gnanapragasam and Lewis (1995). At the end of the modeling run, the amount of radium co-precipitation with gypsum was calculated. Since the model also allows for ion exchange and surface complexation along both the Western (Figure B.38) and Southwestern (Figure B.46) Flow Regimes, negative values were obtained for some cells in the transport calculations. This is because the partition coefficients for radium in gypsum (Gnanapragasam and Lewis 1995) were measured in a pure system where gypsum co-precipitation was the only removal mechanism in the system. Therefore, when negative values were obtained for radium concentrations, they were plotted as zero in all figures. Radium co-precipitation with gypsum was the dominant radium attenuation mechanism within cells where gypsum oversaturation and precipitation occurred. In cells where gypsum undersaturation occurred, ion exchange of radium was the dominant attenuation mechanism.

5.1.7 Selenium

Distribution of dissolved selenium species was calculated based on both the equations for selenium aqueous complex formation in the MINTEQ database and also according to a set of redox conditions that are defined in the PHREEQC input files. The Se(III) (selenite) species are strongly adsorbed by HFO, while the Se(VI) (selenate) species are also adsorbed, but to a lesser extent (Neal 1990). The reduction of selenate and selenite species to Se(a) (amorphous selenium) is usually microbially mediated and occurs under anaerobic conditions; with further reduction and in the presence of iron, Se(-II) (selenide) can precipitate as ferroselite (Weres and others 1989; Garbisu and others 1996). The model input files allowed for precipitation of ferroselite, elemental selenium, and nickel selenide if these phases became oversaturated. In

addition, selenium adsorption was modeled using the surface complexation constants for selenite and selenate taken from Dzombak and Morel (1990). Nickel selenide precipitation and adsorption of selenite onto HFO are predicted to be the dominant attenuation mechanisms for the Western Flow Regime (Figure B.39). For the Southwestern Flow Regime (Figure B.47), the model predicts that precipitation of nickel selenide and ferroselite will be the dominant attenuation mechanism.

5.1.8 Thorium

Distribution of thorium species was calculated according to the equations given in Table B3.2. Results indicated that the modeled groundwaters were undersaturated with minerals that might be expected to control thorium concentrations in groundwaters, namely $\text{Th}(\text{OH})_4$ (thorium hydroxide) and ThO_2 (thorium oxide) (Langmuir 1997). However, thorium concentrations in groundwater are also controlled by adsorption. Complete adsorption of thorium has been observed in laboratory studies on FeOOH (goethite) when carbonate alkalinities are low enough (<100 meq/L) to prevent both complexation with, and desorption of, thorium by carbonate (LaFlamme and Murray 1987). Because the modeled groundwaters contain carbonate alkalinities ≤ 3 meq/L, thorium attenuation was modeled with adsorption using the surface complexation constants for aqueous Th^{4+} (without carbonate complexes) provided by LaFlamme and Murray (1987). The model results indicated that thorium attenuation will occur as a result of surface complexation in both the Western (Figure B.40) and Southwestern (Figure B.48) Flow Regimes.

The modeled thorium results are consistent with observed adsorption characteristics of thorium in natural systems. Maximum thorium adsorption occurs above pH values of 5.5 to 6.5, and the tendency of thorium to be strongly adsorbed by clays and oxyhydroxides in neutral to alkaline solutions causes thorium to be naturally concentrated in sediments. Thorium-230 activities up to 22,000 pCi/L have been measured in acidic waste milling solutions discharged from the Highland Uranium Mill in Wyoming, which may be contrasted with a thorium-230 activity of 110 pCi/L in alkaline ($\text{pH} \geq 10$) leach solutions discharged from the Humeca Uranium Mill (Langmuir and Herman 1980).

5.2 Gross Alpha Calculations at the Point of Exposure

The gross alpha concentrations at the POE were calculated using the 1,000 year geochemical modeling simulations for the Western and Southwestern Flow Regimes (Tables B5.1 and B5.2). The gross alpha concentration at the POE is the sum of the activity concentrations of the individual alpha emitters. The calculations for the projected specific radionuclide concentrations at the Western and Southwestern POEs, attributable to the Gas Hills Facility, are given in Table B5.3. Radon-222, Radon-220, and their short-lived decay products were not included in the calculations because the gross alpha maximum contaminant level (MCL) for drinking water specifically excludes radon. Since it is a noble gas, radon would be lost in the preparation of samples for gross alpha analysis. In addition, radon and its decay products do not contribute significantly to radiation dose when they are ingested.

The calculated gross alpha concentrations at the POE for the Western Flow Regime were <0.6 and <0.4 pCi/L for modeled flow rates of 0.167 ft/d and 0.33 ft/d, respectively. For the Southwestern Flow Regime, the calculated gross alpha concentrations at the POEs were 79 and

<2 pCi/L for modeled flow rates of 0.167 ft/d and 0.28 ft/d, respectively. In comparison, the gross alpha MCL for drinking water is 15 pCi/L, excluding uranium and radon. In this case, the uranium does not contribute to the calculated gross alpha concentration.

It is inappropriate to evaluate health and safety impacts on the basis of gross alpha concentrations since the tap water ingestion risk coefficient is different for each of the radionuclides. The mortality risk coefficients in lifetime risk per unit activity ingested (Bq-1) from Federal Guidance Report No. 13 (USEPA, 1999) are given below for each of the radionuclides listed:

U-238:	1.13 E-9 Bq ⁻¹	Th-228:	1.82 E-9 Bq ⁻¹
U-235:	1.21 E-9 Bq ⁻¹	Ra-228:	2.00 E-8 Bq ⁻¹
U-234:	1.24 E-9 Bq ⁻¹	Ra-224:	2.74 E-9 Bq ⁻¹
Th-230:	1.67 E-9 Bq ⁻¹	Po-210:	3.53 E-8 Bq ⁻¹

The risk coefficients vary by more than an order of magnitude. Therefore, health risk evaluations should be performed only on the basis of specific radionuclide activity concentrations. Uranium decay products Th-234, Pa-234m, and Bi-210 were not considered in this analysis since they are beta emitters. Polonium-210, the alpha-emitting decay product of Bi-210, is accounted for in the analysis by assuming that the decay of Pb-210 results in the emission of one alpha particle.

Table B5.1 Geochemical Model Results for Western Flow Regime

Parameter	Source Concentration (ACL)	Modeled Flow Rate 0.167 ft/d	Modeled Flow Rate 0.33 ft/d
Licensed Constituents			
Arsenic (mg/L)	1.8	0.10	0.11
Beryllium (mg/L)	1.6	3×10^{-4}	2.3×10^{-4}
Selenium (mg/L)	0.16	2×10^{-13}	1.8×10^{-13}
Nickel (mg/L)	13	0.005	0.004
Uranium (mg/L)	12	3.7×10^{-5}	5.2×10^{-5}
²¹⁰ Pb (pCi/L)	35	0.23	0.18
²²⁶⁺²²⁸ Radium (pCi/L)	250	<0.14	<0.35
²³⁰ Th (pCi/L)	57	$<2.6 \times 10^{-19}$	$<1.8 \times 10^{-15}$
Non-Licensed Constituents			
Calcium (mg/L)	460	400	400
Magnesium (mg/L)	110	94	120
Sodium (mg/L)	180	180	180
Potassium (mg/L)	24	16	18
Bicarbonate (mg/L)	3.1	22	16
Chloride ¹ (mg/L)	270	13	13
Sulfate ¹ (mg/L)	3,480	1,902	1,902
TDS (mg/L)	4,500	2,600	2,600

¹ Results are derived from Appendix C, Numerical Groundwater Flow Model.

Table B5.2 Geochemical Model Results for Southwestern Flow Regime

Parameter	Source Concentration (ACL)	Modeled Flow Rate 0.167 ft/d	Modeled Flow Rate 0.28 ft/d
Licensed Constituents			
Arsenic (mg/L)	1.4	0.109	0.092
Beryllium (mg/L)	1.7	1.3×10^{-4}	1.7×10^{-4}
Selenium (mg/L)	0.53	1.9×10^{-8}	1.0×10^{-8}
Nickel (mg/L)	9.3	2.2×10^{-8}	7.6×10^{-8}
Uranium (mg/L)	34	4.7×10^{-5}	2.7×10^{-5}
²¹⁰ Pb (pCi/L)	47	0.005	0.008
²²⁶⁺²²⁸ Ra (pCi/L)	353	79.4	<1.33
²³⁰ Th (pCi/L)	44.8	0.004	0.003
Non-Licensed Constituents			
Calcium (mg/L)	660	510	180
Magnesium (mg/L)	140	80	270
Sodium (mg/L)	60	60	63
Potassium (mg/L)	15	30	22
Bicarbonate (mg/L)	2.4	10	680
Chloride ¹ (mg/L)	160	120	120
Sulfate ¹ (mg/L)	2,650	1,600	1,600
TDS (mg/L)	3,690	2,400	2,940

¹ Results are derived from Appendix C, Numerical Groundwater Flow Model.

Table B5.3: Projected Radionuclide Activity Concentrations at the Point of Exposure

Radionuclide	ACL Western Flow Regime (pCi/L)	1,000 yr Western POE (pCi/L)	1,000 yr Western POE (pCi/L)	ACL Southwestern Flow Regime (pCi/L)	1,000 yr Southwestern POE (pCi/L)	1,000 yr Southwestern POE (pCi/L)
Modeled Flow Rate	-----	0.167 ft/d	0.33 ft/d	-----	0.167 ft/d	0.33 ft/d
U-238 ¹ mg/l pCi/L	12 3,960	3.7×10^{-5} 0.012	5.2×10^{-5} 0.017	34 11,220	4.7×10^{-5} 0.015	2.7×10^{-5} 0.009
U-235	178	<0.001	<0.001	505	<0.001	<0.001
U-234	3,960	0.012	0.017	11,220	0.015	0.009
Th-230	57	<0.0001	<0.0001	27	0.004	0.003
Ra-226+228 ²	250	<0.35	<0.14	353	79.4	<1.33
Pb-210 ³	35	0.23	0.18	47	0.005	0.008
Total	NA	<0.6	<0.4	NA	79	<2
Total excluding uranium	NA	<0.6	<0.4	NA	79	<2

¹ The ACL for uranium is 12 mg/L for the Western Flow Regime and 34 mg/L for the Southwestern Flow Regime. The U-238 concentrations for the ACLs and the POEs in pCi/L were calculated from the mass concentrations in mg/L as follows:

$$[U-238 \text{ (pCi/L)}] = [U-238 \text{ (mg/L)}](330 \text{ pCi/mg})$$

Western Flow Regime

$$\text{ACL} = (12 \text{ mg/L})(330 \text{ pCi/mg}) = 3,960 \text{ pCi/L}$$

$$\text{POE [0.167 ft/d]} = (3.7 \times 10^{-5} \text{ mg/L})(330 \text{ pCi/mg}) = 0.012 \text{ pCi/L}$$

$$\text{POE [0.33 ft/d]} = (5.2 \times 10^{-5} \text{ mg/L})(330 \text{ pCi/mg}) = 0.017 \text{ pCi/L}$$

Southwestern POE

$$\text{ACL} = (34 \text{ mg/L})(330 \text{ pCi/mg}) = 1.12 \times 10^4 \text{ pCi/L}$$

$$\text{POE [0.167 ft/d]} = (4.7 \times 10^{-5} \text{ mg/L})(330 \text{ pCi/mg}) = 0.015 \text{ pCi/L}$$

$$\text{POE [0.28 ft/d]} = (2.7 \times 10^{-5} \text{ mg/L})(330 \text{ pCi/mg}) = 0.009 \text{ pCi/L}$$

¹The uranium isotopes were assumed to be in equilibrium in the groundwater so that the activity concentration of U-234 is equal to the activity concentration of U-238. The activity concentration of U-235 is 4.5 percent of the U-238.

² Ra-228 is a beta emitter; however, its shorter-lived decay products, Th-228 (1.9 years) and Ra-224 (3.7 days), are alpha emitters and could be in equilibrium with the Ra-228 depending on the residence time. Therefore, the gross alpha concentration for the combined Ra-226+228 activity concentration would be somewhat greater than the factor of one times the combined activity concentration. The Ra-226 was assumed to comprise nearly all of the combined activity. Therefore, the relative error in assuming one alpha per disintegration of the combined Ra-226+228 would be small.

activity. Therefore, the relative error in assuming one alpha per disintegration of the combined Ra-226+228 would be small.

³ Pb-210 is a beta emitter but decays to Po-210 which is an alpha emitter. Therefore, the Pb-210 was assumed to emit one alpha per disintegration.

Modeled Flow Rates are derived from Appendix C, Numerical Groundwater Flow Model.

6.0 REFERENCES

- Allison, J.D., D.S. Brown, and K.J. Novo-Gradac. 1991. "MINTEQA2/PRODEFA2, A Geochemical Assessment Model for Environmental Systems," Version 3.0 *User's Manual*. Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia. 106 pages.
- Anderson, D.A. 1969. "Uranium Deposits of the Gas Hills," *Contributions to Geology of Wyoming*, Uranium Issue, Volume 8, Number 2, page 93.
- Appelo, C.A.J. and D. Postma. 1993. *Geochemistry, Groundwater, and Pollution*. A.A. Balkema, Rotterdam. 536 pages.
- Ball, J.W., E.A. Jenne, and M.W. Cantrell. 1981. "WATEQ3: A Geochemical Model with Uranium Added". *U.S. Geological Survey Open File Report 81-1183*. Washington, D.C.
- Ball, J.W. and D.K. Nordstrom. 1991. "WATEQ4F – User's Manual with Revised Thermodynamic Database and Test Cases for Calculating Speciation of Major, Trace, and Redox Elements in Natural Waters". *U.S. Geological Survey Open-File Report 90-129*. 185 pages.
- Clement, W.H. and S.D. Faust. 1981. "The Release of Arsenic from Contaminated Muds and Sediments." *Journal of Environmental Science and Health*, A16:87-122.
- Cox, J.D., D.D. Wagman, and V.A. Medvedev. 1989. *Codata Key Values for Thermodynamics*. Hemisphere Publications, New York. 271 pages.
- Davis, J.A. 1977. *Adsorption of Trace Metals and Complexing Ligands at the Oxide/Water Interface*. Ph.D. Thesis, Stanford University, Stanford, California.
- Davis, J.A. and D.B. Kent. 1990. "Surface Complexation Modeling in Aqueous Chemistry," in M.F. Hochella and A.F. White (eds.), *Mineral-Water Interface Geochemistry, Reviews in Mineralogy*, Volume 23, Chapter 5, pages 177-260. Mineralogical Society of America, Washington, D.C.
- Davis, J.A. and J.O. Leckie. 1978. "Surface Ionization and Complexation at the Oxide/Water Interface. II, Surface Properties of Amorphous Iron Oxyhydroxide and Adsorption of Metal Ions," *Journal of Colloid and Interface Science*, 67:90-107.
- DeVoto, R.H. 1978. *Uranium Geology and Exploration*, Lecture Notes and References. Colorado School of Mines, Golden, Colorado. 396 pages.
- Dzombak, D.A. and F.M.M. Morel. 1990. *Surface Complexation Modeling-Hydrous Ferric Oxide*. John Wiley & Sons, New York. 393 pages.
- Gaines, G.L. and H.C. Thomas. 1953. "Adsorption studies on clay minerals II, A formulation of the thermodynamics of exchange adsorption." *Journal of Chemical Physics*, 21:714-718.

- Garbisu, C., T. Ishii, T. Leighton, and B.B. Buchanan. 1996. "Bacterial Reduction of Selenite to Elemental Selenium." *Chemical Geology*, Volume 132, pages 199-204.
- Geraghty & Miller, Inc. 1996. *Preliminary Site Conceptual Model and Proposed Groundwater Compliance Program, Umetco Uranium Mill Site, Gas Hills, Wyoming*. Prepared for Umetco Minerals Corporation, Grand Junction, Colorado, by Geraghty & Miller, Inc., Albuquerque, NM.
- Gnanapragasam, E.K. and B.G. Lewis. 1995. "Elastic strain energy and the distribution coefficient of radium in solid solutions with calcium salts." *Geochimica et Cosmochimica Acta*, 59:5103-5111.
- Granger, H.C. and C.G. Warren. 1974. *Zoning in the Altered Tongue Associated With Uranium Deposits, in Formation Of Uranium Ore Deposits*, proceedings of a symposium, Athens, 6-10 May 1974. International Atomic Energy Agency, Vienna. 748 pages.
- Harshman, E.N. 1966. *Genetic Implications of Some Elements Associated with Uranium Deposits, Shirley Basin, Wyoming*. U.S. Geological Survey Professional Paper 550-C.
- Harshman, E.N. 1974. *Distribution of Elements in Some Roll-type Uranium Deposits, in Formation of Uranium Ore Deposits*, proceedings of a symposium, Athens, 6-10 May 1974. International Atomic Energy Agency, Vienna. 748 pages.
- Jenne, E.A. 1968. "Controls on Mn, Fe, Co, Ni, Cu, and Zn Concentrations in Soils and Water: The Significant Role of Hydrous Mn and Fe Oxides." *American Chemical Society Advances in Chemistry Series*, 73:337-387.
- Kabata-Pendias and Pendias. 1992. *Trace Elements in Soils and Plants*, Second Edition. CRC Press, Boca Raton. 365 pages.
- King, J.W. and S.R. Austin. 1966. "Some Characteristics of Roll-type Uranium Deposits at Gas Hills, Wyoming." *Mining Engineering*, Volume 18, Number 5, pages 73-80.
- LaFlamme, B.D. and J.M. Murray. 1987. "Solid/Solution Interaction: The Effect of Carbonate Alkalinity on Adsorbed Thorium." *Geochimica et Cosmochimica Acta*, 51:243-250.
- Langmuir, D. and J.S. Herman. 1980. "The Mobility of Thorium in Natural Waters at Low Temperatures." *Geochimica et Cosmochimica Acta*, 44:1753-1766.
- Langmuir, D. and A.C. Riese. 1985. "The Thermodynamic Properties of Radium." *Geochimica et Cosmochimica Acta*, 49:1593-1601.
- Langmuir, D. 1997. *Aqueous Environmental Chemistry*. Prentice-Hall, Inc., New Jersey. 599 pages.
- Lidstone & Anderson, Inc. 1989. *Ground-Water Investigation of the East Gas Hills. AML 16-E*. Prepared for Worthington, Lenhart, & Carpenter, Casper, Wyoming, by Lidstone & Anderson, Inc., Fort Collins, Colorado.

- Luoma, S.N. and J.A. Davis. 1983. "Requirements for Modeling Trace Metal Partitioning in Oxidized Estuarine Sediments." *Marine Chemistry*, 12:159-181.
- Ludwig, K.R. and R.I. Grauch. 1980. "Coexisting Coffinite and Uraninite in Some Sandstone-host Uranium Ores of Wyoming." *Economic Geology*, Volume 75, pages 296-302.
- Masscheleyn, P.H., R.D. Delaune, and W.H. Patrick, Jr. 1991. "Arsenic and selenium chemistry as affected by sediment redox potential and pH." *Journal of Environmental Quality*, 20:522-527.
- Merritt, R.C. 1971. *The Extractive Metallurgy of Uranium*. Prepared Under Contract with the U.S. Atomic Energy Commission by the Colorado School of Mines Research Institute.
- Naumov, G.B., B.N. Ryzhenko, and I.L. Khodakovsky. 1974. *Handbook of Thermodynamic Data*. U.S.G.S. WRD-74-001. 328 pages.
- Neal, R.H. 1990. "Selenium," pages 237-260, in B.J. Alloway (ed.) *Heavy Metals in Soils*. John Wiley & Sons, Inc. New York. 339 pages.
- Nordstrom, D.K., L.N. Plummer, D. Langmuir, E. Busenberg, H.M. May, B.F. Jones, and D.L. Parkhurst. 1990. "Revised chemical equilibrium data for major water-mineral reactions and their limitations," pages 398-413, in D.C. Melchior and R.L. Bassett (eds.) *Chemical Modeling of Aqueous Systems II*. American Chemical Society, Washington, D.C.
- Parkhurst, D.L. 1995. "User's Guide to PHREEQC - A Computer Program for Speciation, Reaction-Path, Advective-Transport, and Inverse Geochemical Calculations." *U.S. Geological Survey Water-Resources Investigations Report 95-4227*.
- Parkhurst, D.L., D.C. Thorstenson, and L.N. Plummer. 1980. "PHREEQE - A Computer Program For Geochemical Calculations." *U.S. Geological Survey Water-Resources Investigations Report 80-96*. Revised and Reprinted August, 1990.
- Rai, D., C.C. Ainsworth, L.E. Eary, S.V. Mattigod, and D.R. Jackson. 1987. *Inorganic and Organic Constituents in Fossil Fuel Combustion Residues, Volume 1: A Critical Review*. EA-5176, Electric Power Research Institute, Palo Alto, California.
- SMI. 1998. *Evaluation of Background Groundwater Quality for the Umetco Gas Hills Uranium Mill Site, Fremont and Natrona Counties, Wyoming*. Prepared for Umetco Minerals Corporation, Grand Junction, Colorado, by Shepherd Miller, Inc., Fort Collins, Colorado.
- Umetco Minerals Corporation. 1997. *Site Characterization Report, East Gas Hills Reclamation Project, Gas Hills, Wyoming*.
- USAEC (Atomic Energy Commission). 1959. *Guidebook to Uranium Deposits of the Western United States*. Prepared by the Production Evaluation Division of the Grand Junction Operations Office.

- USEPA (Environmental Protection Agency). 1999. "Cancer Risk Coefficients for Environmental Exposure to Radionuclides." *Federal Guidance Report Number 13*. EPA 402-R-99-001.
- U.S. Environmental Services. 1996. *Drilling and Construction of Monitoring Wells MW75, MW76, and MW77, East Gas Hills, Wyoming*, unpublished report prepared for Umetco Minerals Corporation, May, 1997.
- Wagman, D.D., W.H. Evans, V.B. Parker, R.H. Schumm, I. Halow, S.M. Bailey, K.L. Churney, and R.L. Nutall. 1982. "The NBS Tables of Chemical Thermodynamic Properties. Selected Values for Inorganic and C1 and C2 Organic Substances in SI Units." *Journal of Physical and Chemical Reference Data*. Volume 11, Supplement Number 2. 392 pages.
- Weres, O., A.R. Jaouni, and L. Tsao. 1989. "The Distribution, Speciation and Geochemical Cycling of Selenium in a Sedimentary Environment, Kesterson Reservoir, California, U.S.A." *Applied Geochemistry*, Volume 4, pages 543-563.
- Westall, J.C. and H. Hohl. 1980. "A Comparison of Electrostatic Models for the Oxide/Solution Interface." *Advanced Colloid Interface Science*, 12:265-294.
- Wolery, T.J. 1992. *EQ3/6. A Software Package for Geochemical Modeling of Aqueous Systems: Package Overview and Installation Guide*, Version 7. UCRL-MA-11062 Part I, Lawrence Livermore National Laboratory.
- Williams, H., F.J. Turner, and C.M. Gilbert. 1982. *Petrography: An Introduction to the Study of Rocks in Thin Section*. W.H. Freeman and Company, San Francisco, California.

7.0 ATTACHMENTS

The PHREEQC input files and the modified MINTEQ database used for the Gas Hills geochemical model are on the disk included with this attachment. A key to the filenames on the disk is provided below.

Southwestern Flow Regime

- OSWACL1.IN Southwestern Flow Regime (0.167 ft/d). Concentration vs Distance (1000 yr)
- OSWACL2.IN Southwestern Flow Regime (0.280 ft/d). Concentration vs Distance (1000 yr)
- OSWACL1t.IN Southwestern Flow Regime (0.167 ft/d). Concentration vs Time at the POE
- OSWACL2t.IN Southwestern Flow Regime (0.280 ft/d). Concentration vs Time at the POE

Western Flow Regime

- OWACL1.IN Western Flow Regime (0.167 ft/d). Concentration vs Distance (1000 yr)
- OWACL2.IN Western Flow Regime (0.330 ft/d). Concentration vs Distance (1000 yr)
- OWACL1t.IN Western Flow Regime (0.167 ft/d). Concentration vs Time at the POE
- OWACL2t.IN Western Flow Regime (0.330 ft/d). Concentration vs Time at the POE

Modeling Data

- Umetco.dat Modified MINTEQ Database Used in the Gas Hills Modeling

UMETCO MINERALS CORPORATION

GEOCHEMICAL MODEL INPUT FILES

GAS HILLS SITE

APRIL 2001

Geochemical Model Input Files

Figure B.1 1000-Year Arsenic Concentrations Between the Western Flow Regime POC and POE.

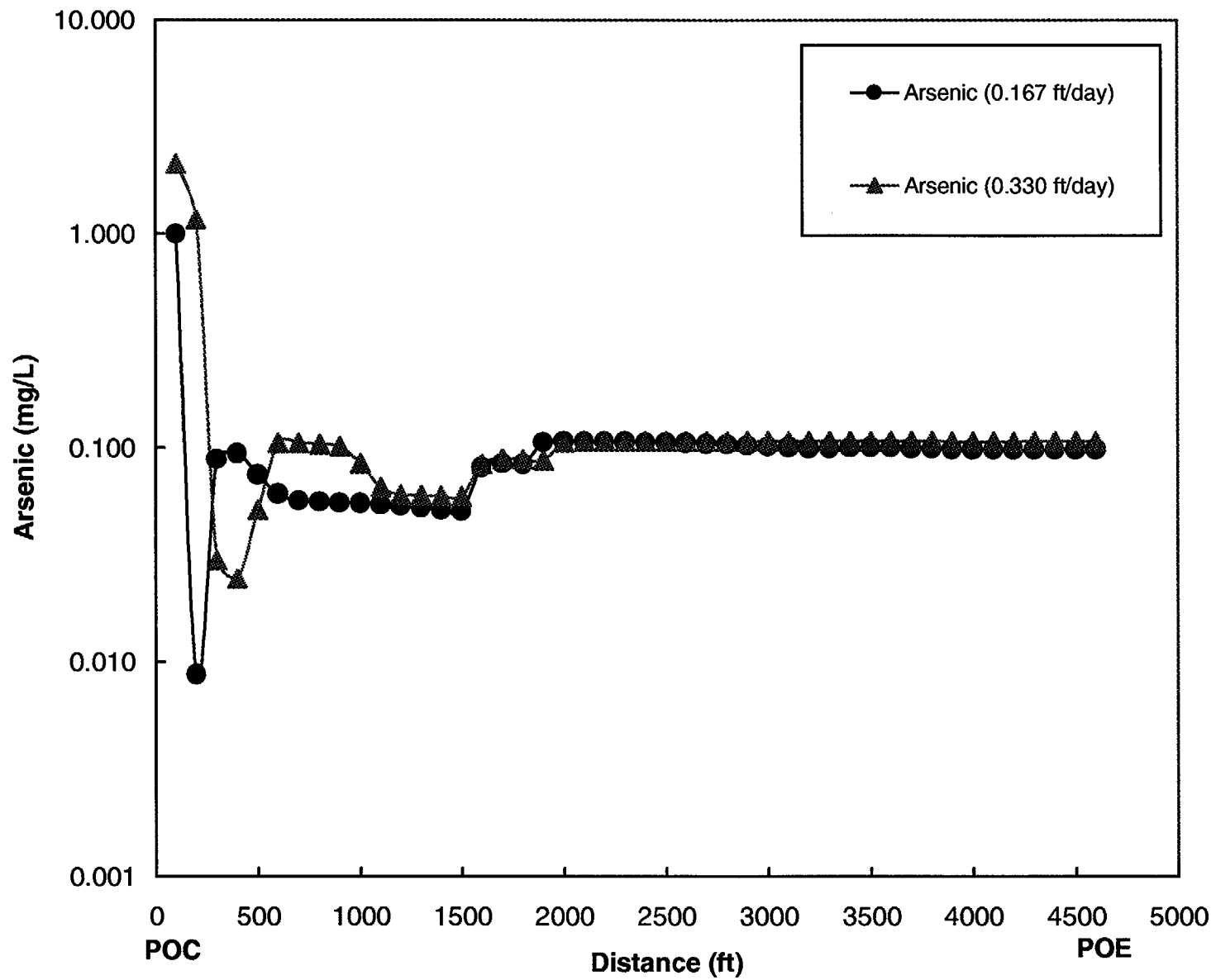


Figure B.2 1000-Year Beryllium Concentrations Between the Western Flow Regime POC and POE.

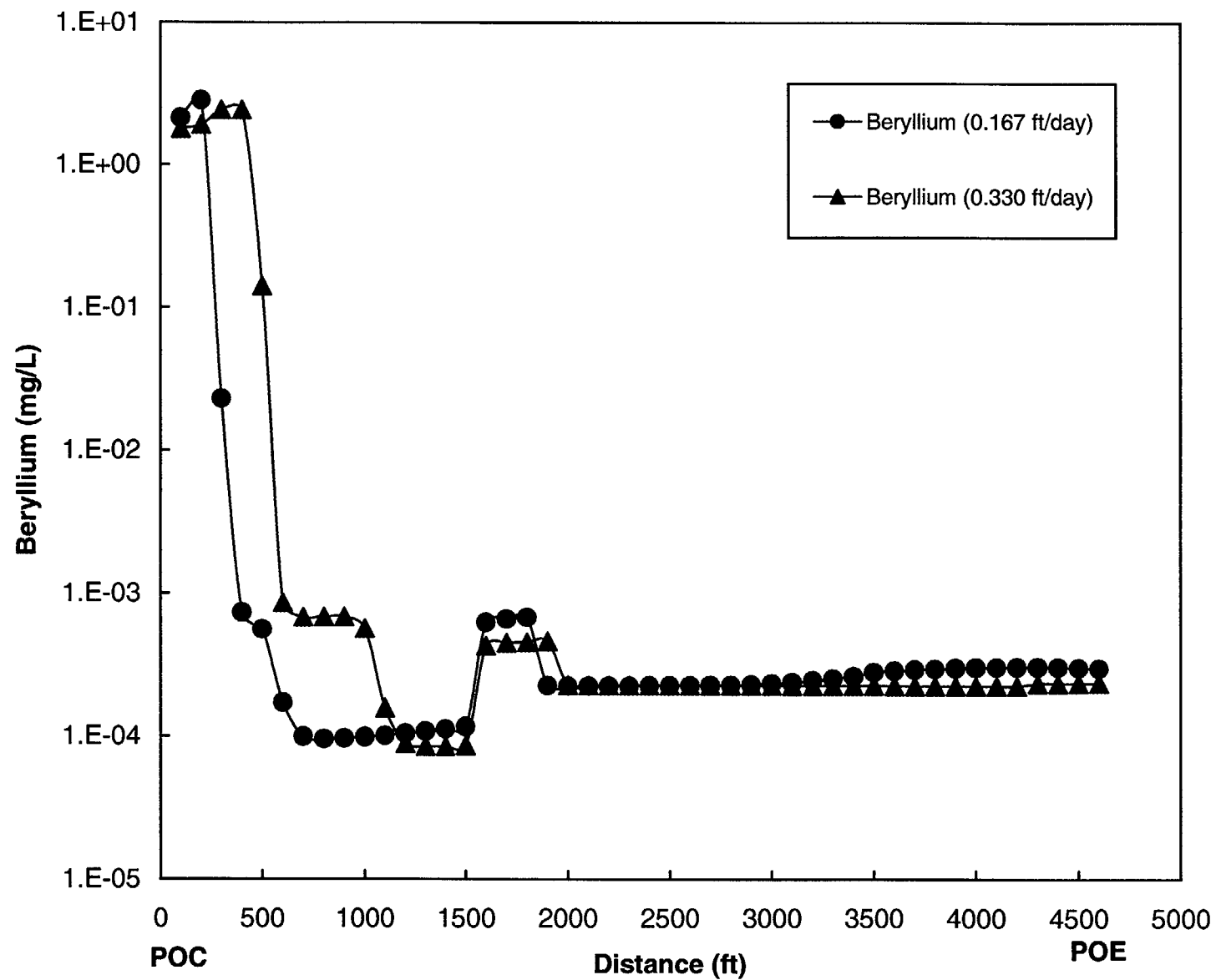


Figure B.3 1000-Year Lead-210 Concentrations Between the Western Flow Regime POC and POE.

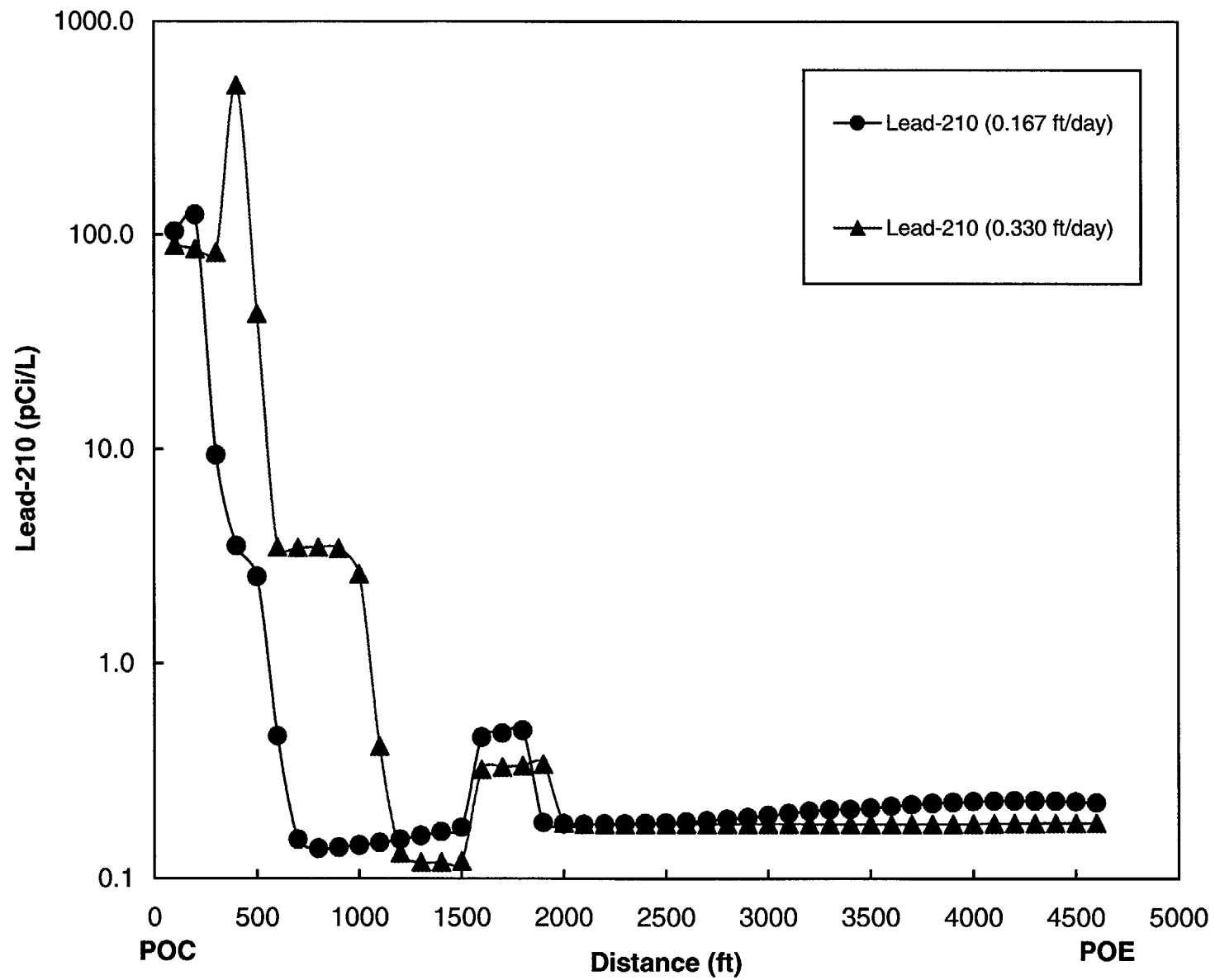


Figure B.4 1000-Year Uranium Concentrations Between the Western Flow Regime POC and POE.

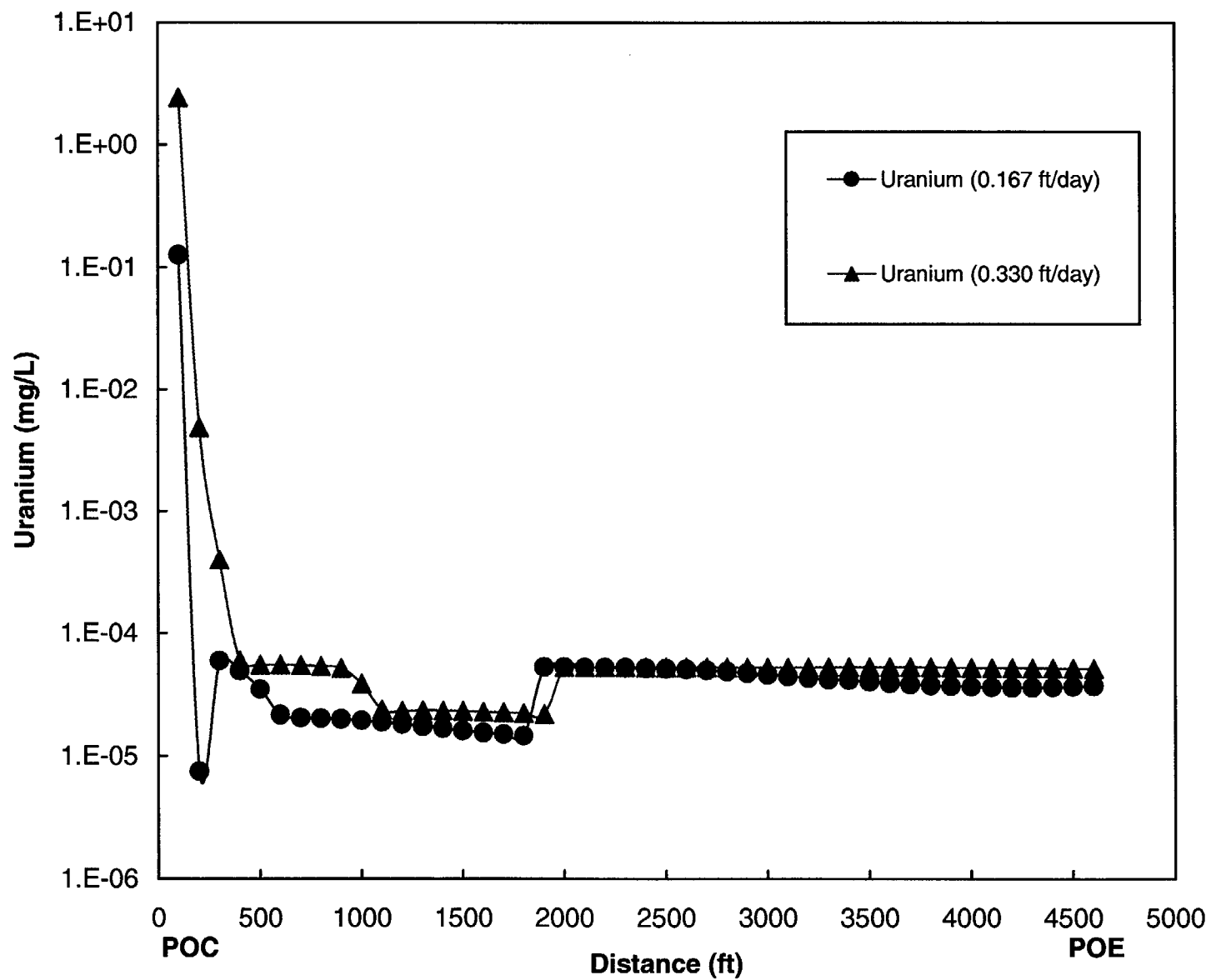


Figure B.5 1000-Year Nickel Concentrations Between the Western Flow Regime POC and POE.

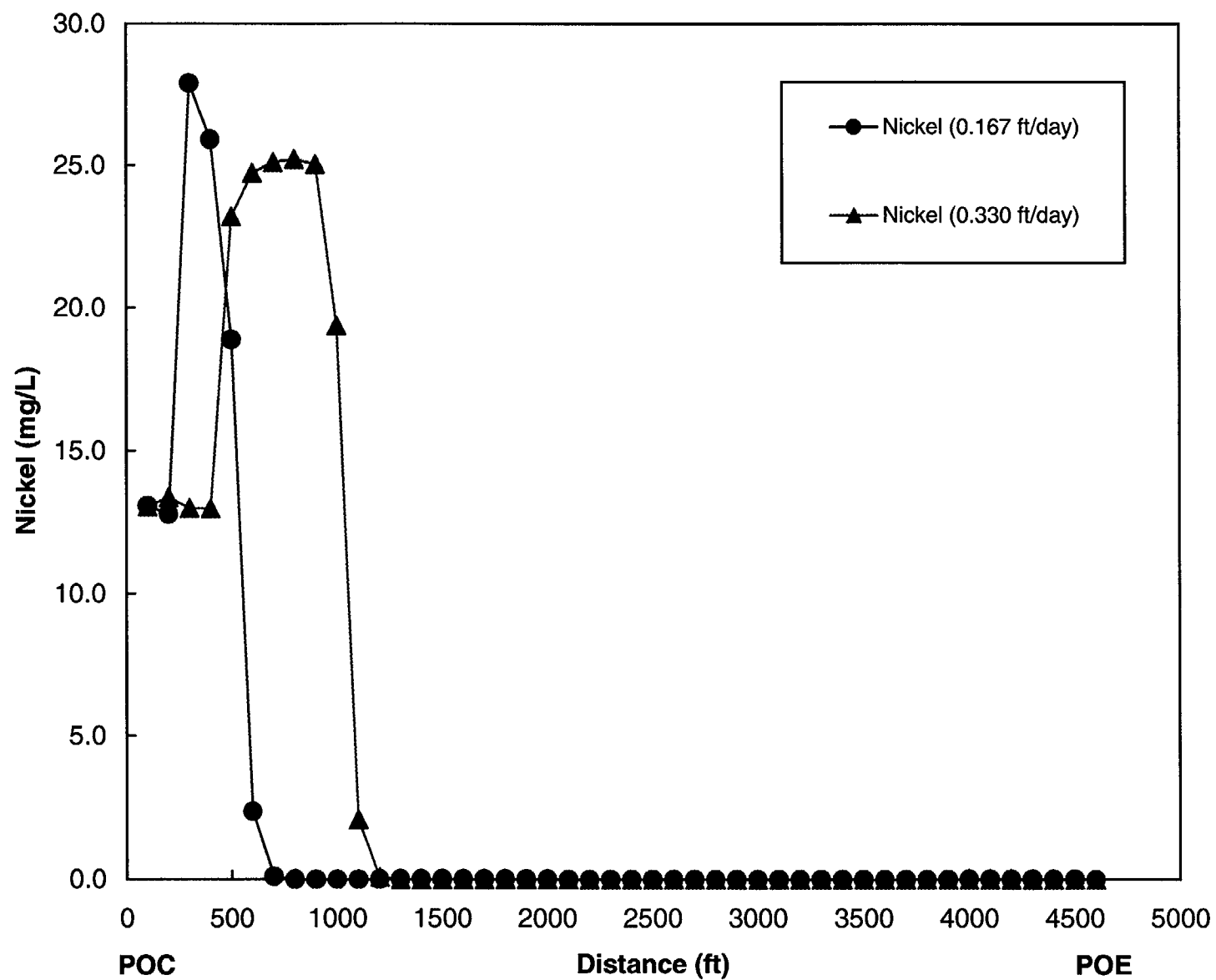


Figure B.6 1000-Year Radium-226+228 Concentrations Between the Western Flow Regime POC and POE.

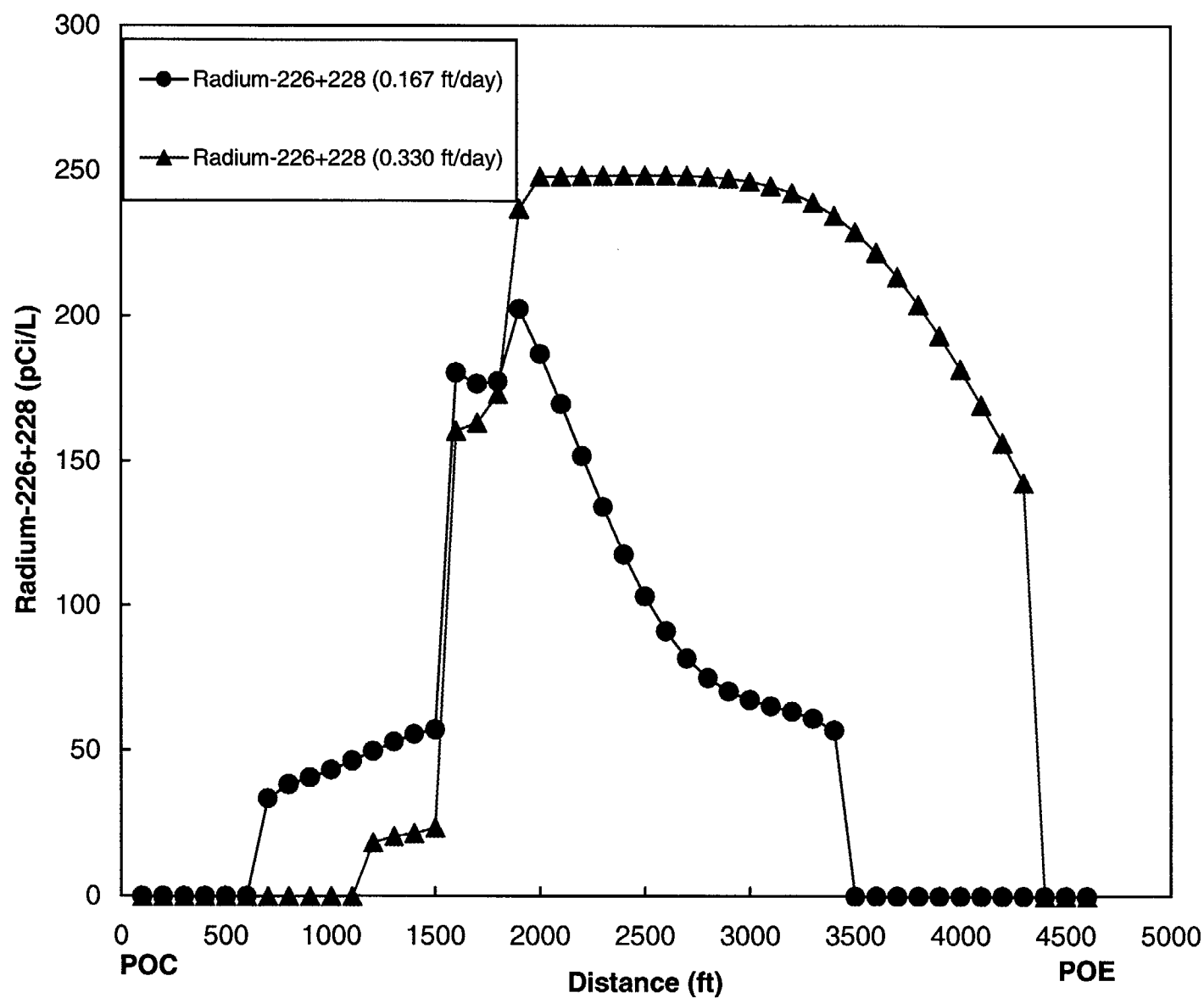


Figure B.7 1000-Year Selenium Concentrations Between the Western Flow Regime POC and POE.

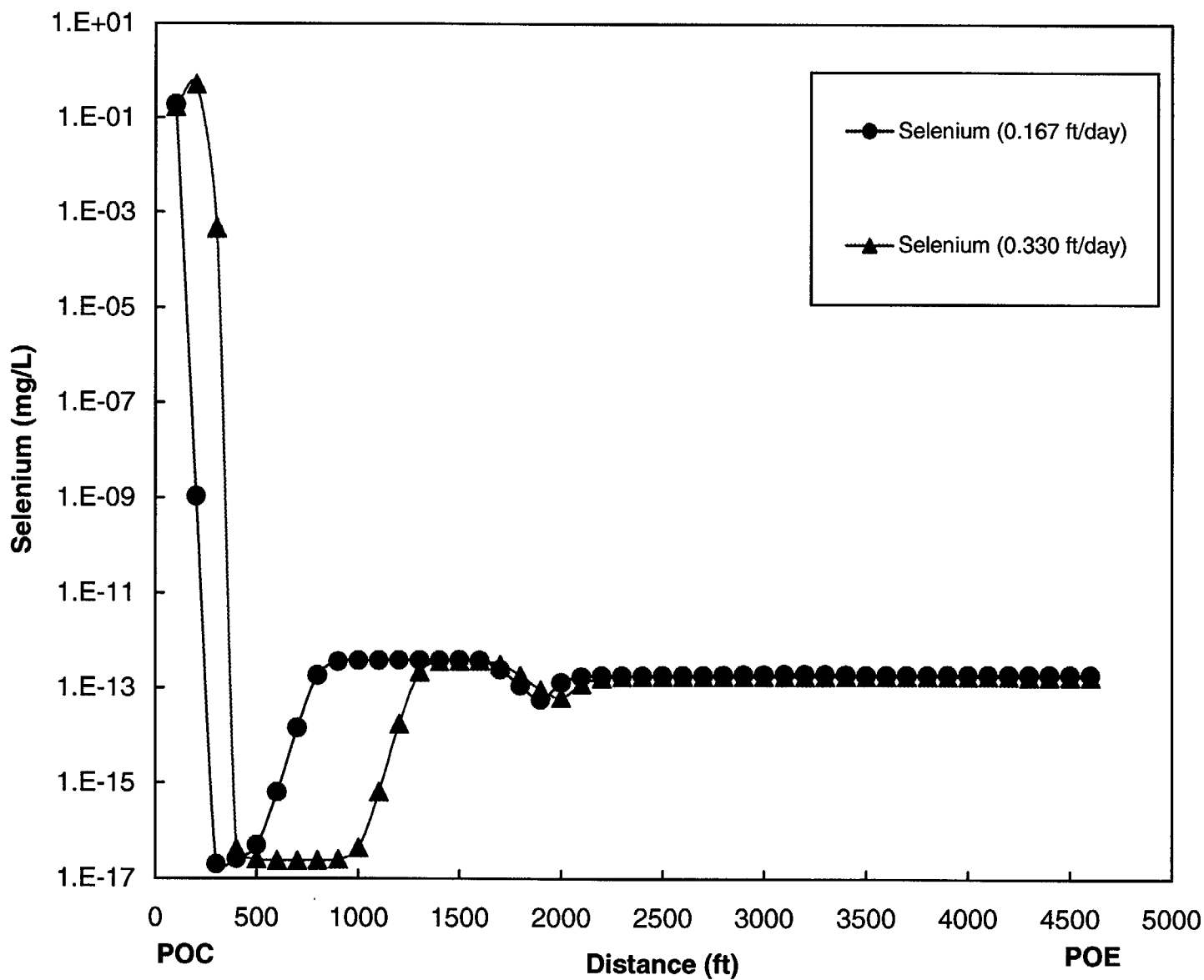


Figure B.8 1000-Year Thorium-230 Concentrations Between the Western Flow Regime POC and POE.

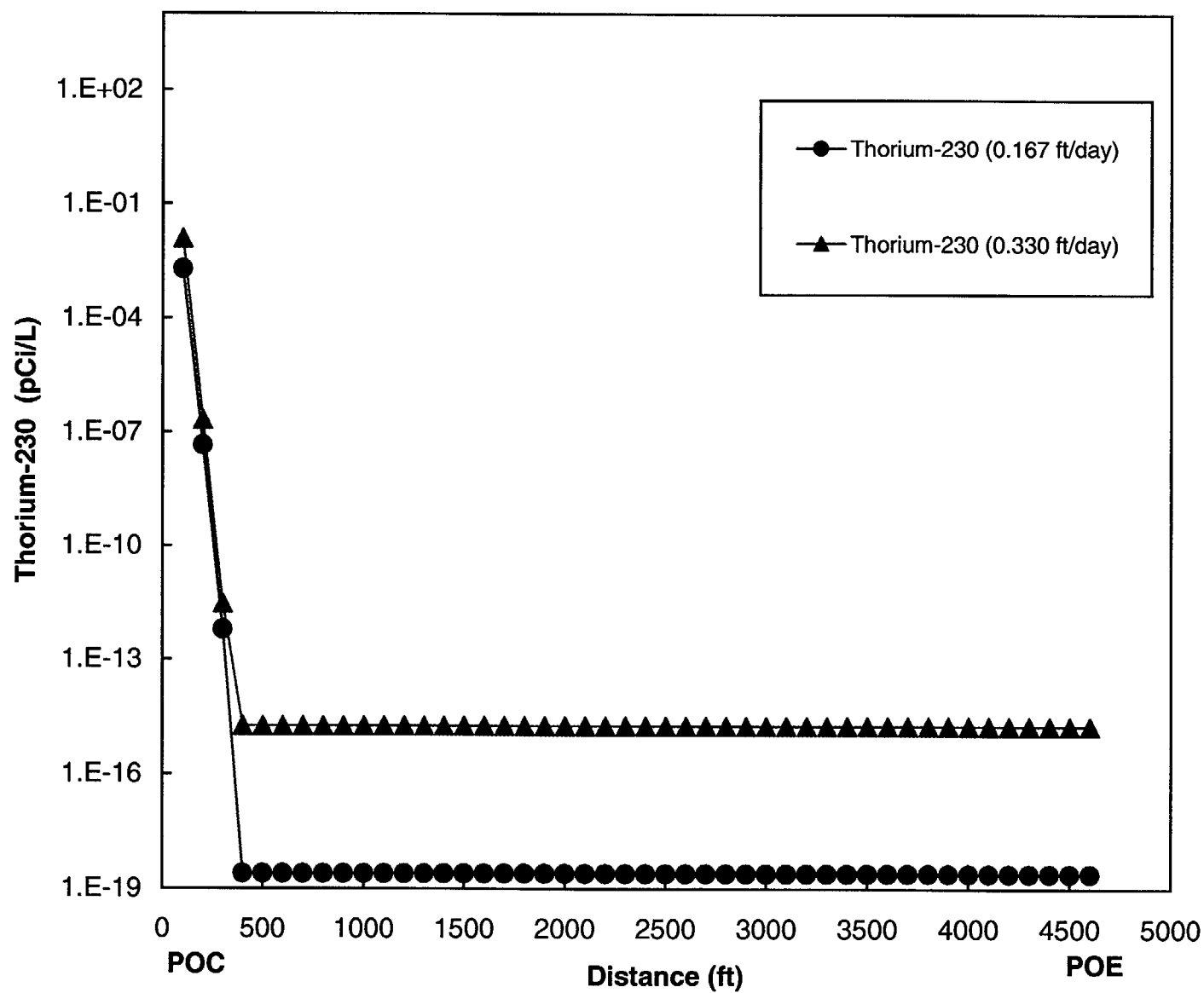


Figure B.9 Arsenic Concentrations at the POE for the Western Flow Regime With Time.

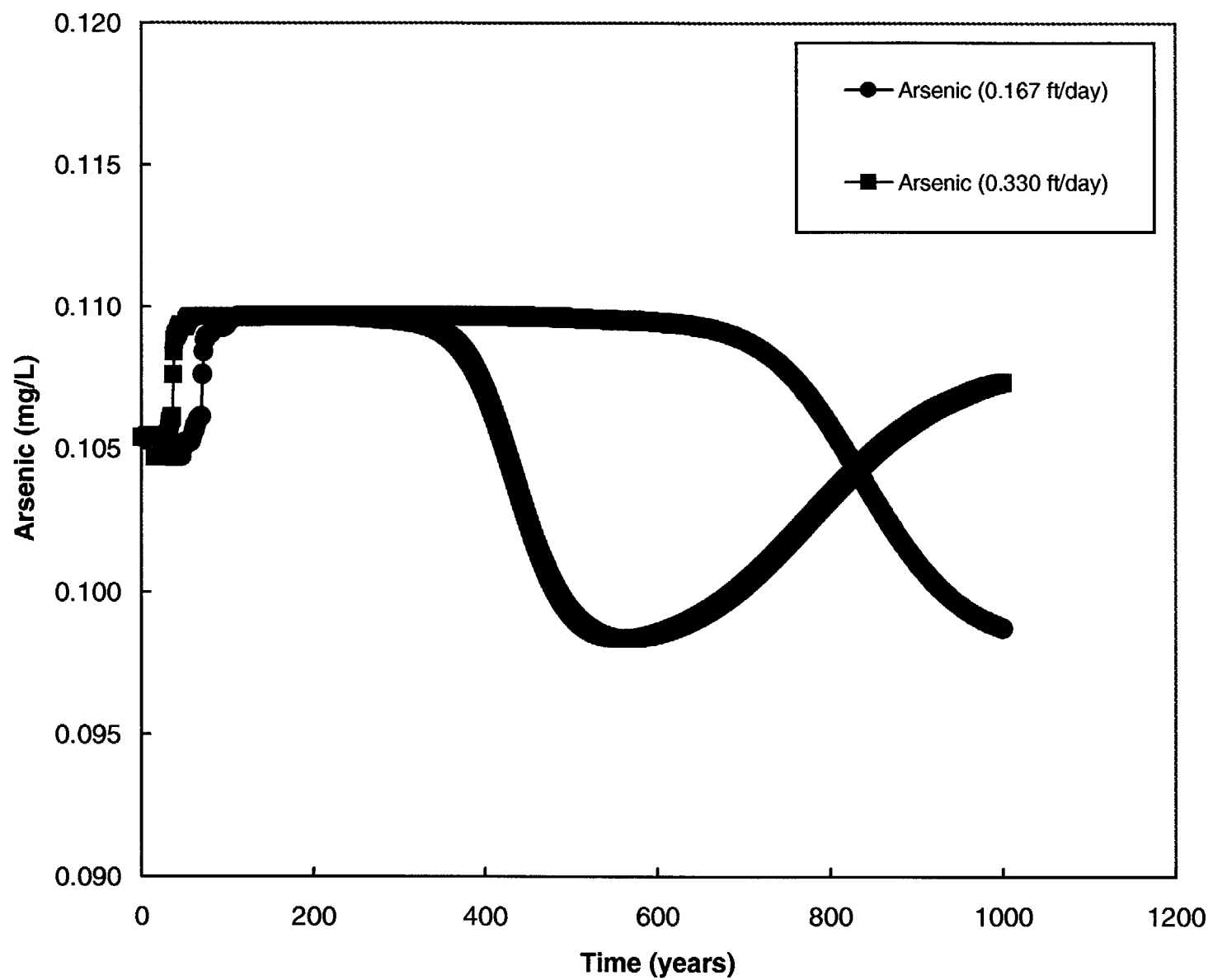


Figure B.10 Beryllium Concentrations at the POE for the Western Flow Regime With Time.

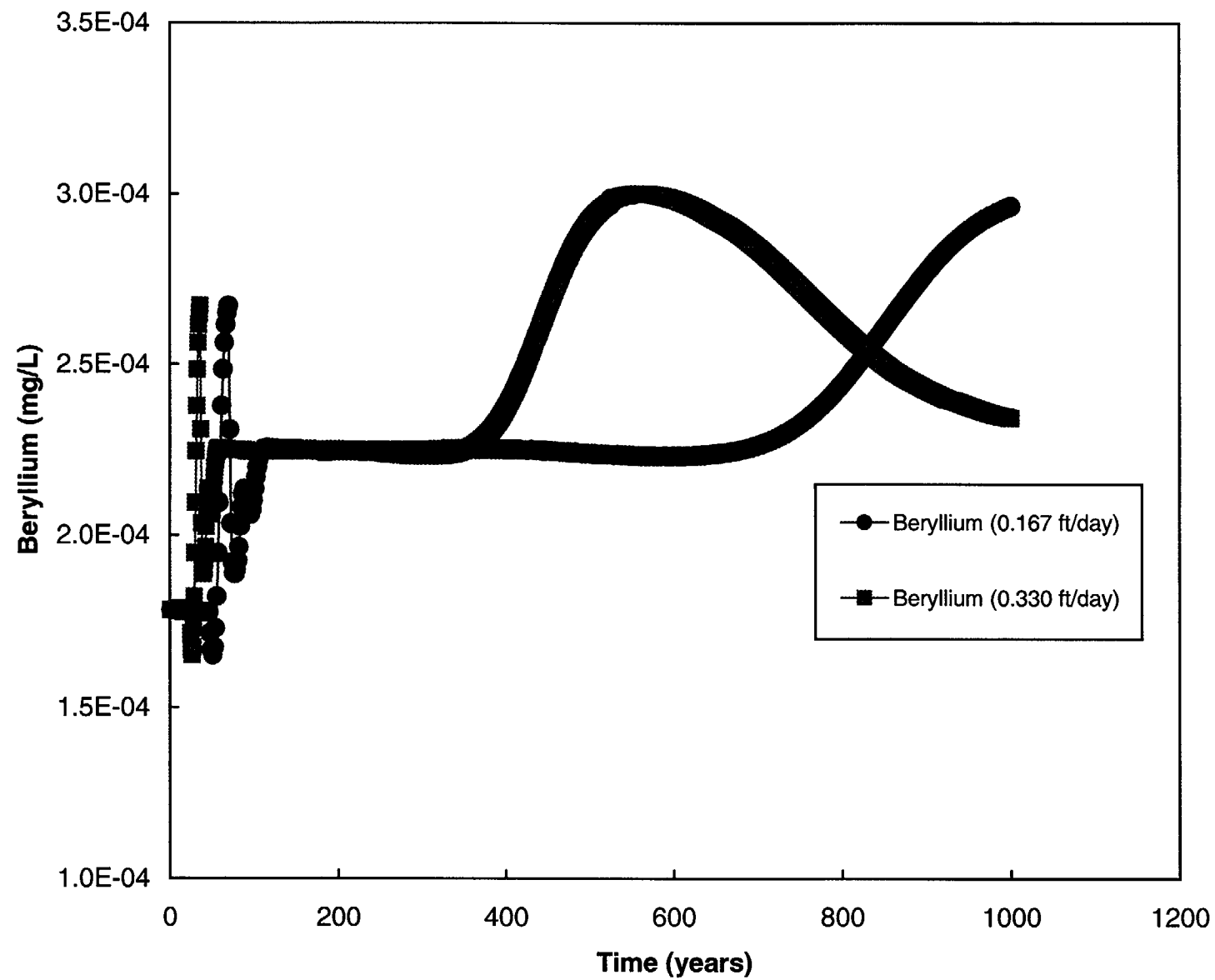


Figure B.11 Lead-210 Concentrations at the POE for the Western Flow Regime With Time.

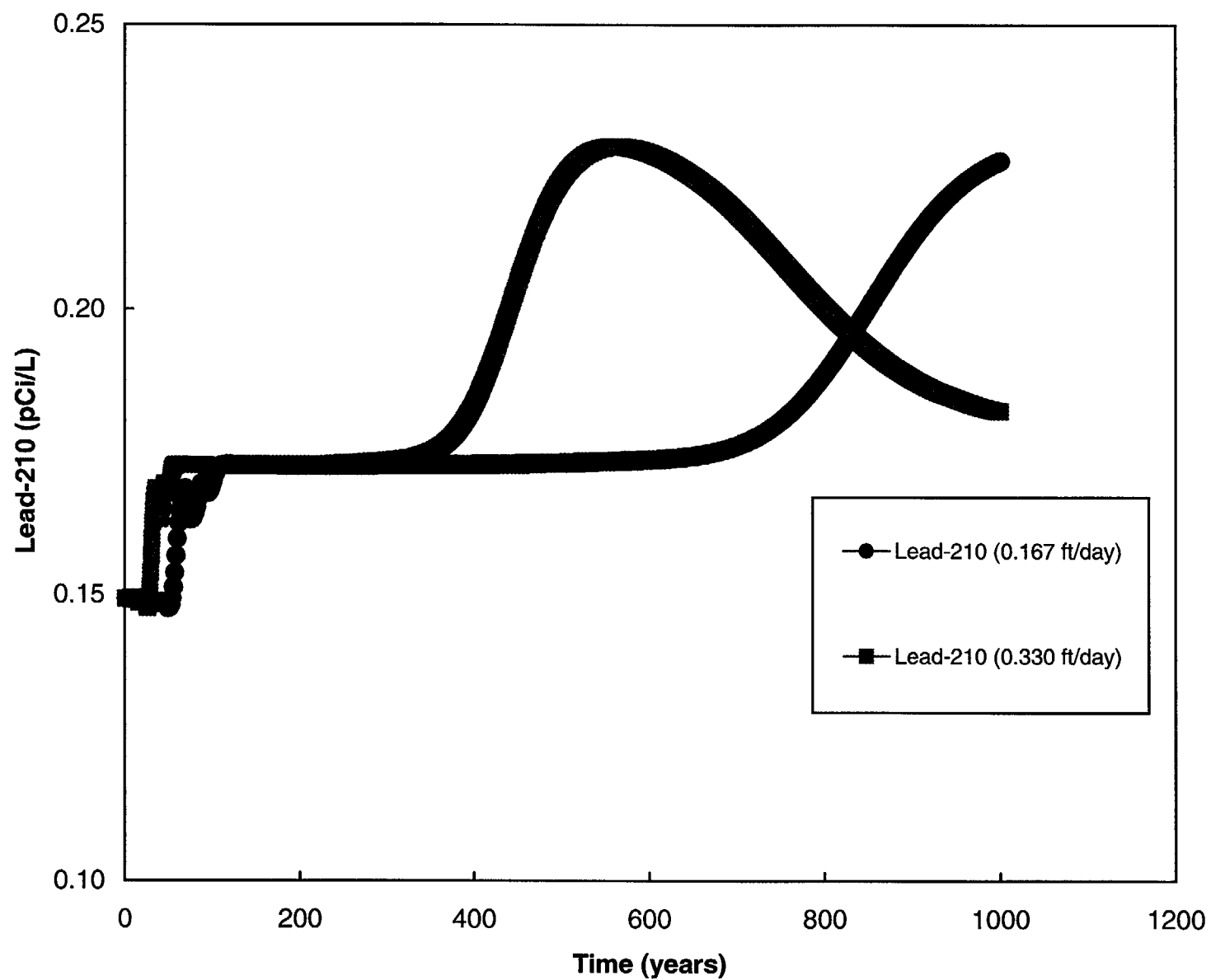


Figure B.12 Uranium Concentrations at the POE for the Western Flow Regime With Time.

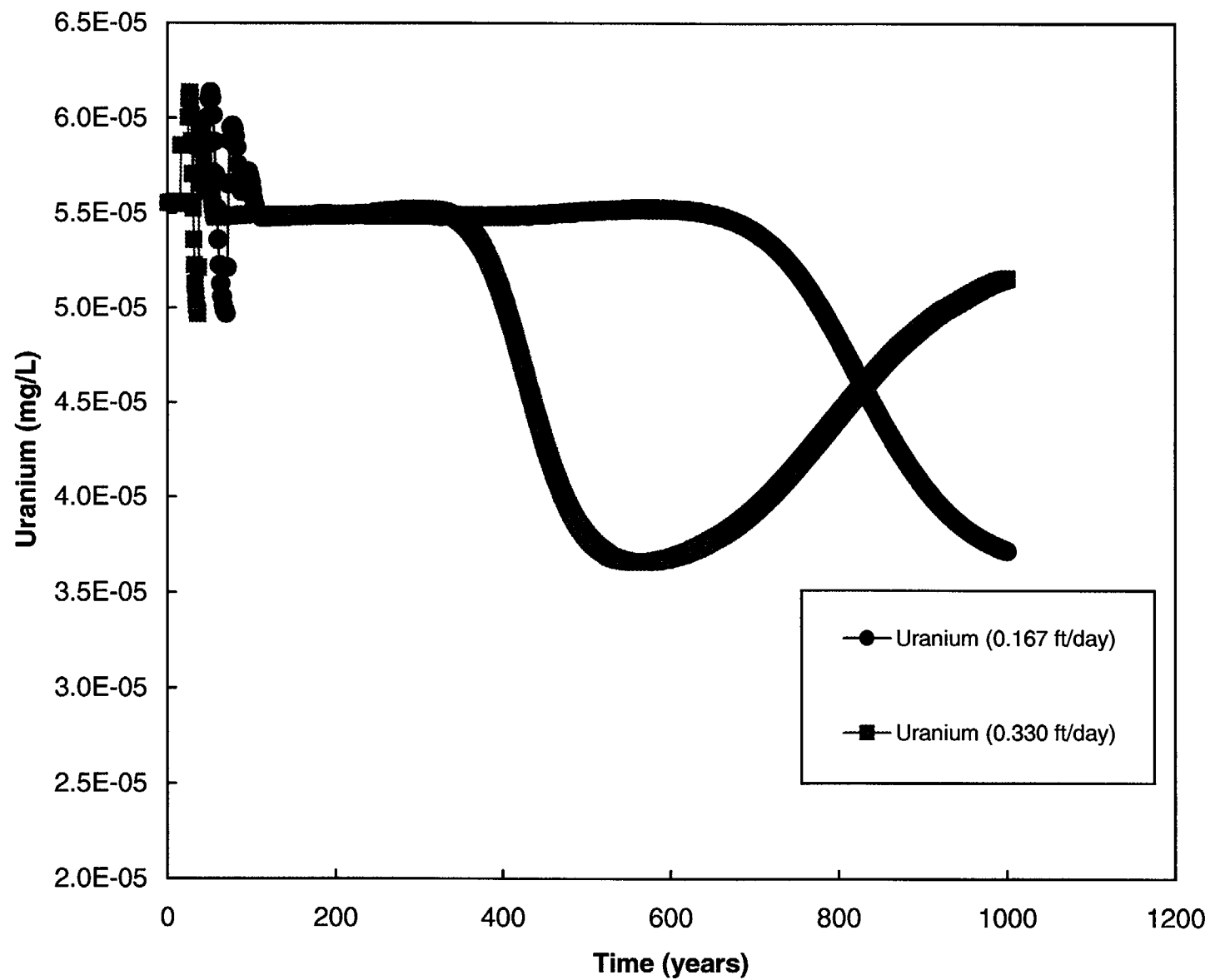


Figure B.13 Nickel Concentrations at the POE for the Western Flow Regime With Time.

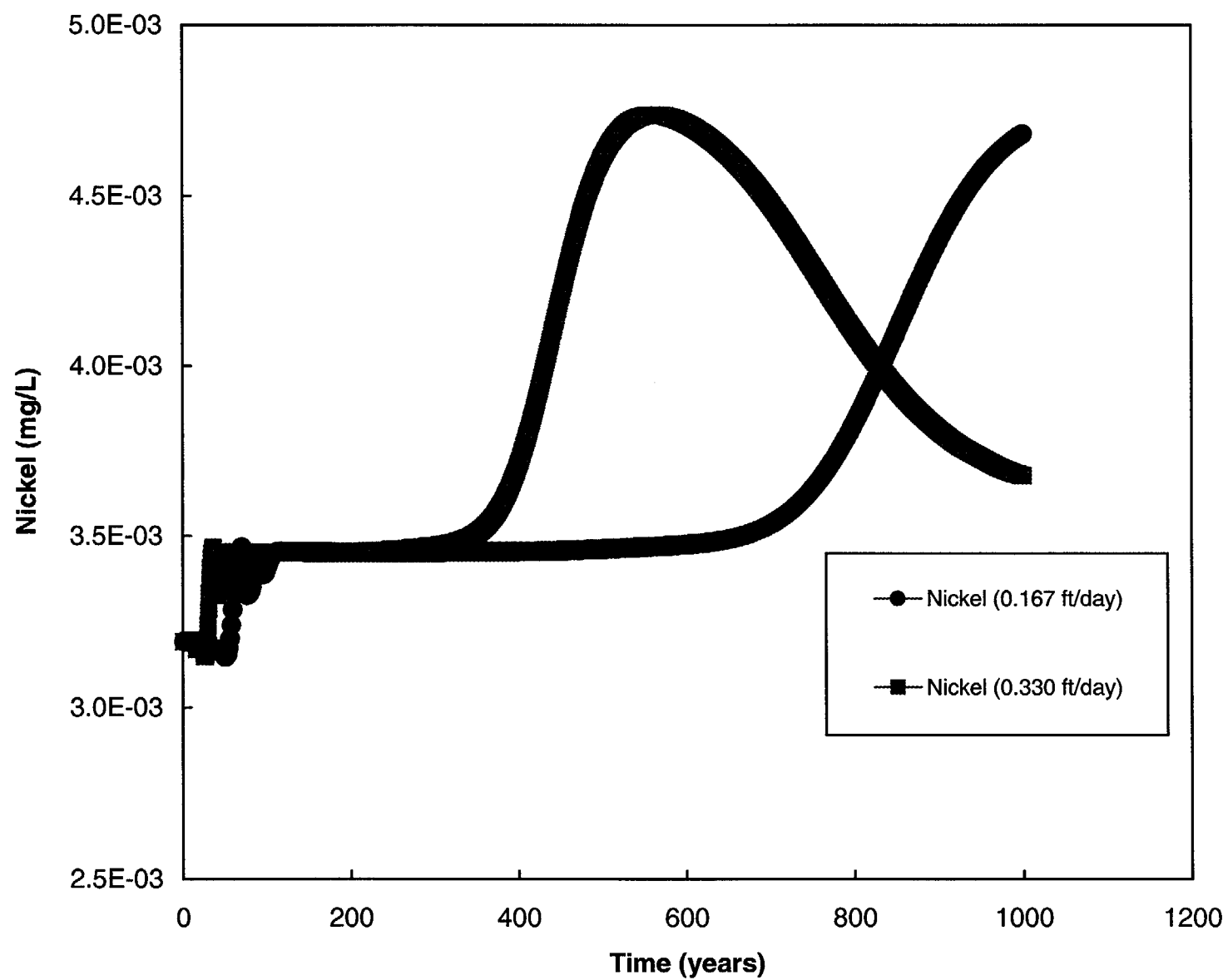


Figure B.14 Radium-226+228 Concentrations at the POE for the Western Flow Regime With Time.

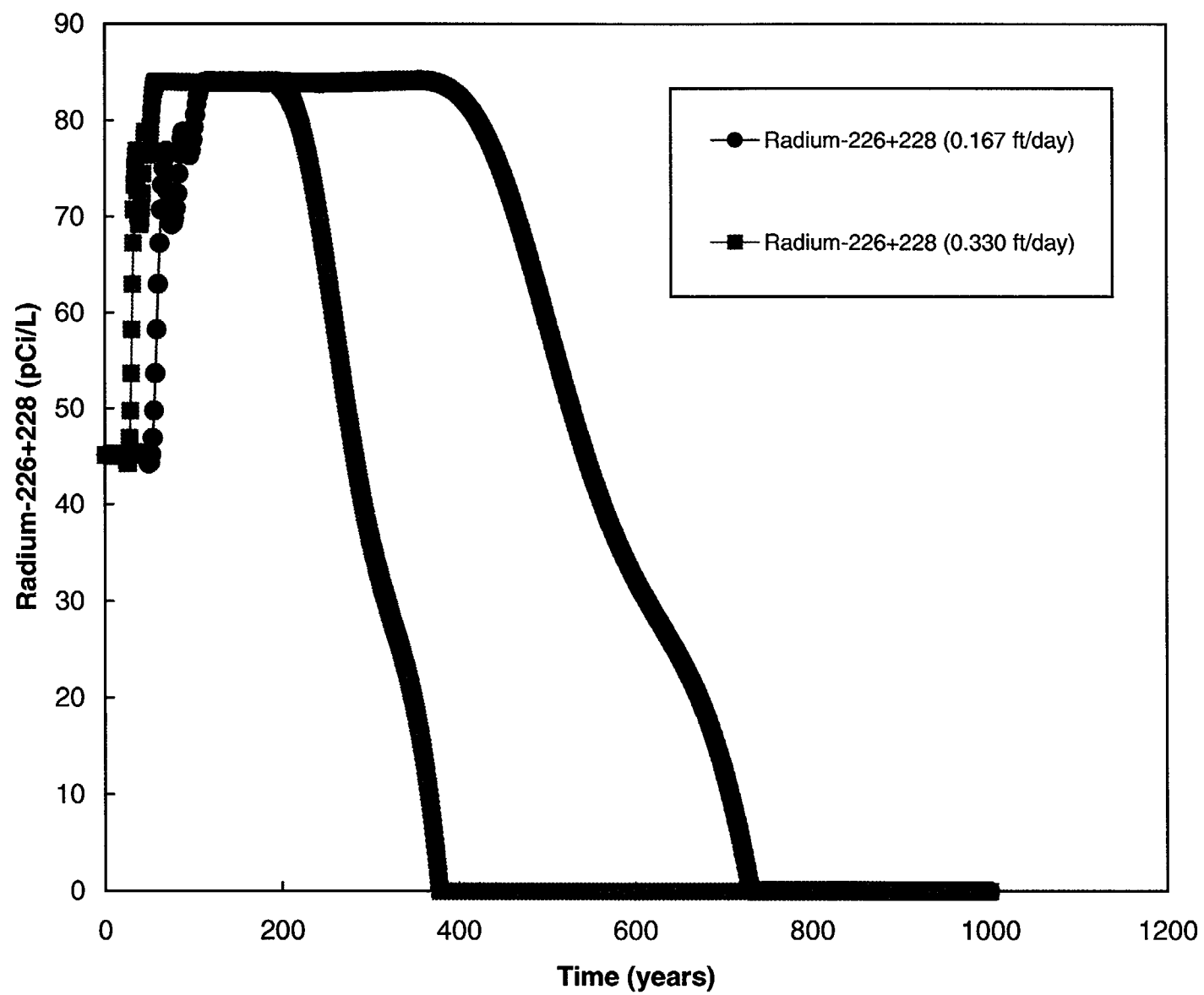


Figure B.15 Selenium Concentrations at the POE for the Western Flow Regime With Time.

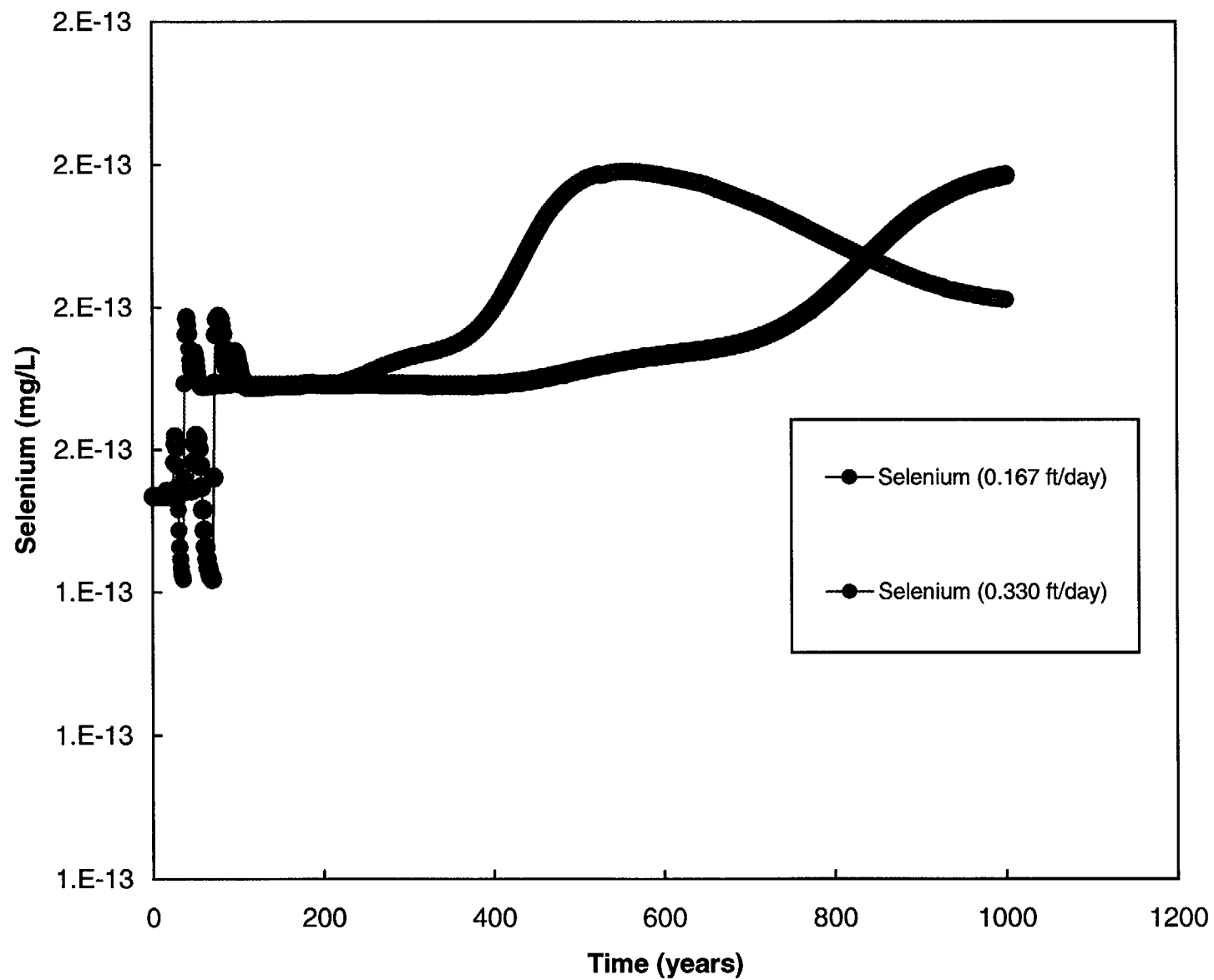


Figure B.16 Thorium-230 Concentrations at the POE for the Western Flow Regime With Time.

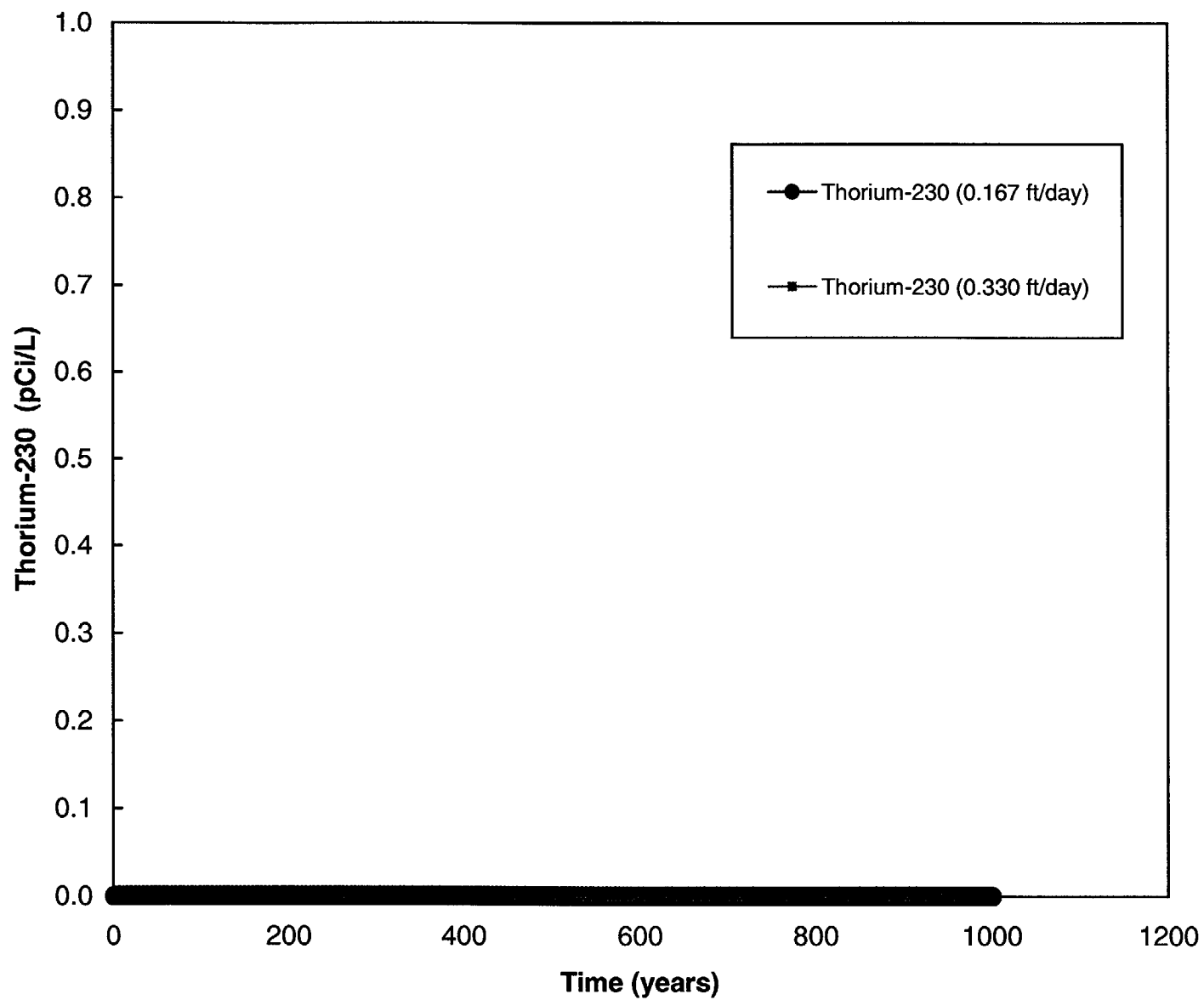


Figure B.17 1000-Year Arsenic Concentrations Between the Southwestern Flow Regime POC and POE.

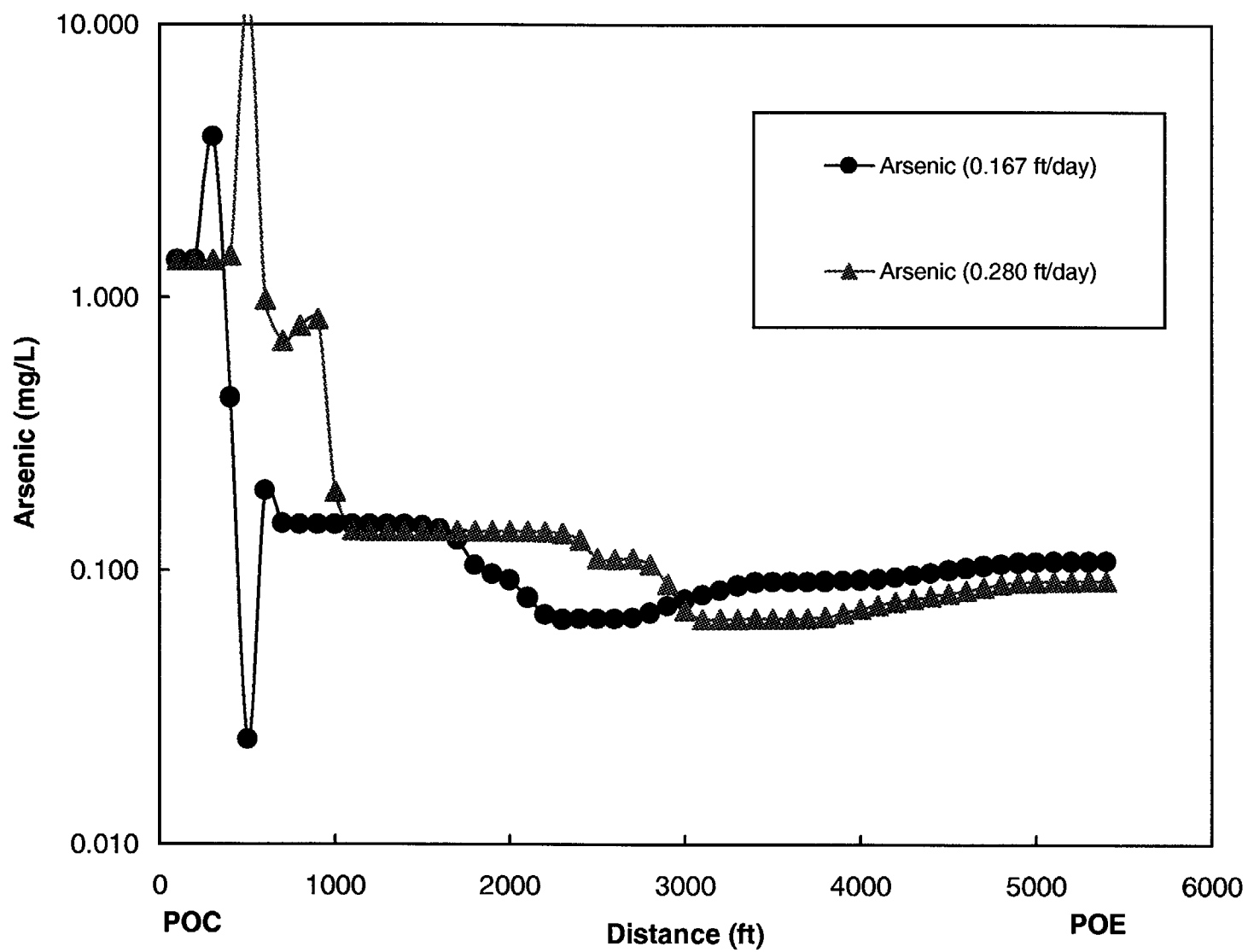


Figure B.18 1000-Year Beryllium Concentrations Between the Southwestern Flow Regime POC and POE.

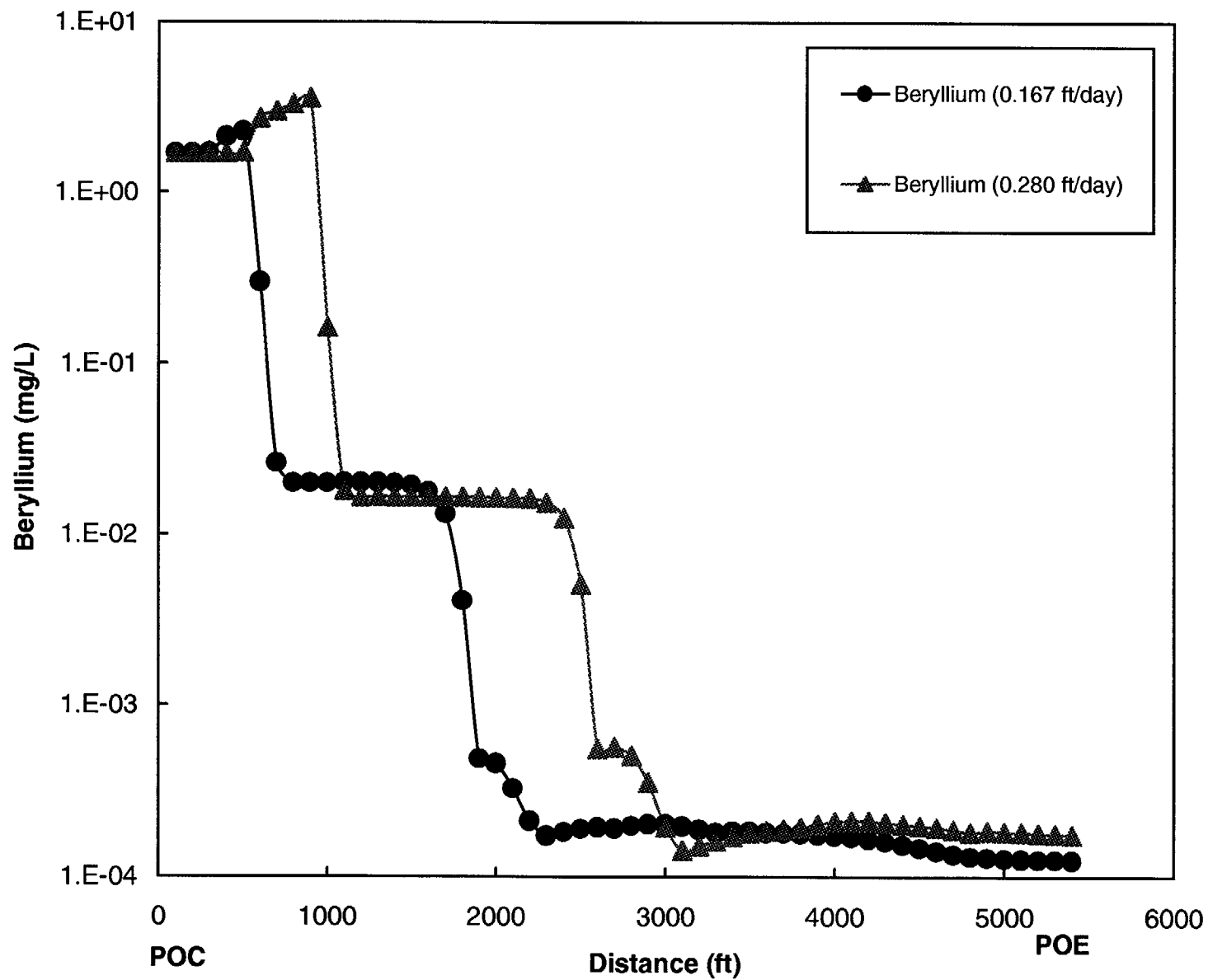


Figure B.19 1000-Year Lead-210 Concentrations Between the Southwestern Flow Regime POC and POE.

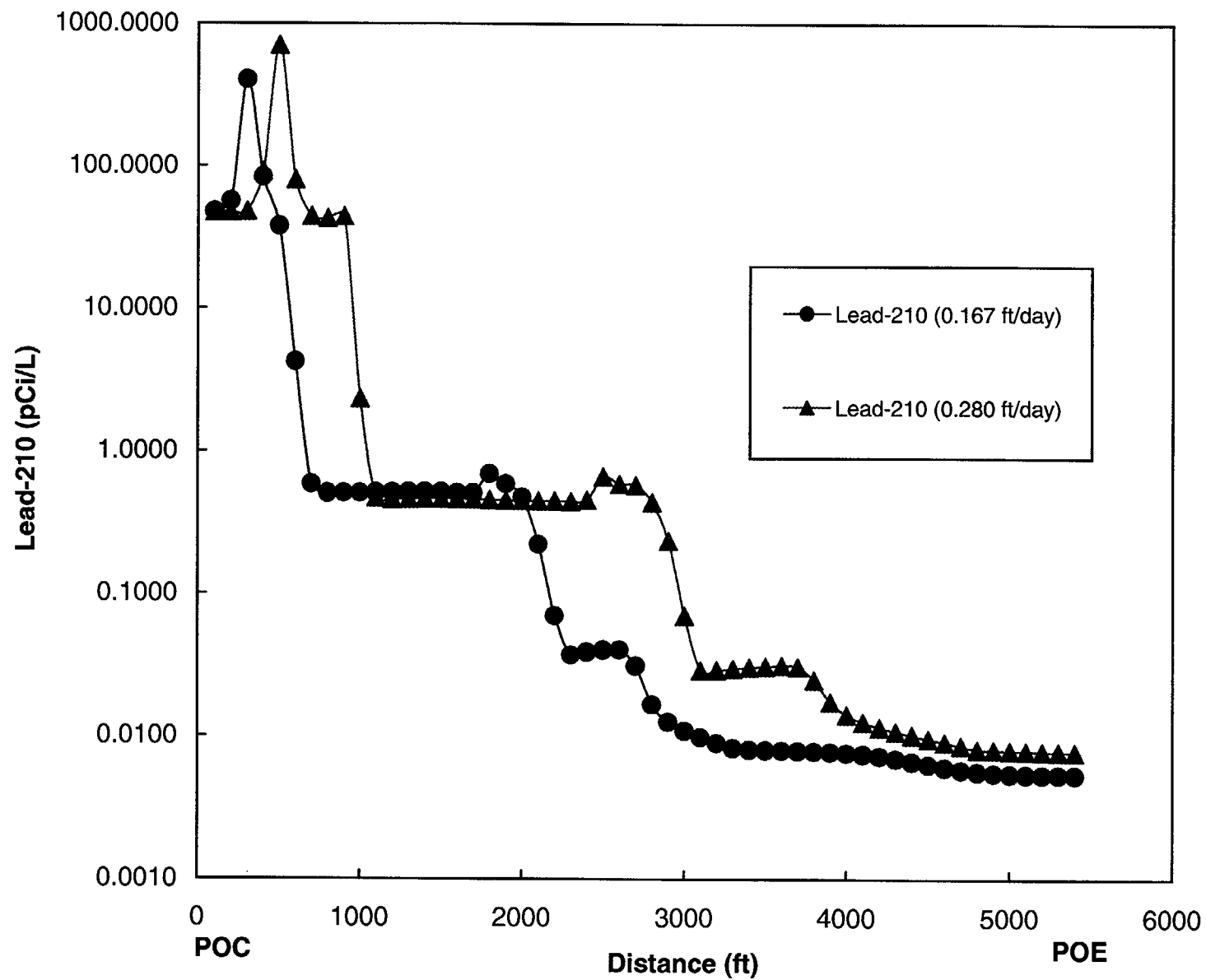


Figure B.20 1000-Year Uranium Concentrations Between the Southwestern Flow Regime POC and POE.

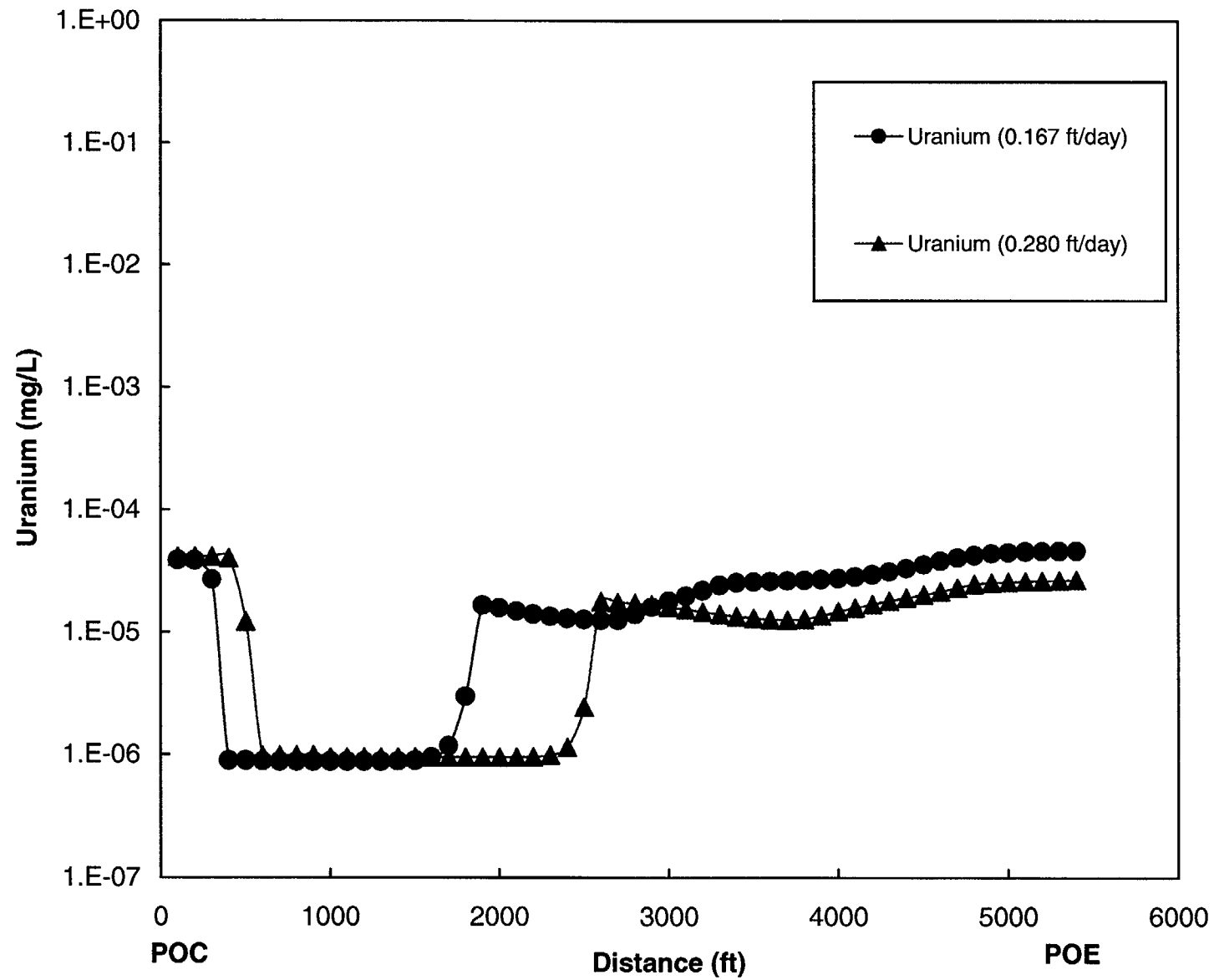


Figure B.21 1000-Year Nickel Concentrations Between the Southwestern Flow Regime POC and POE.

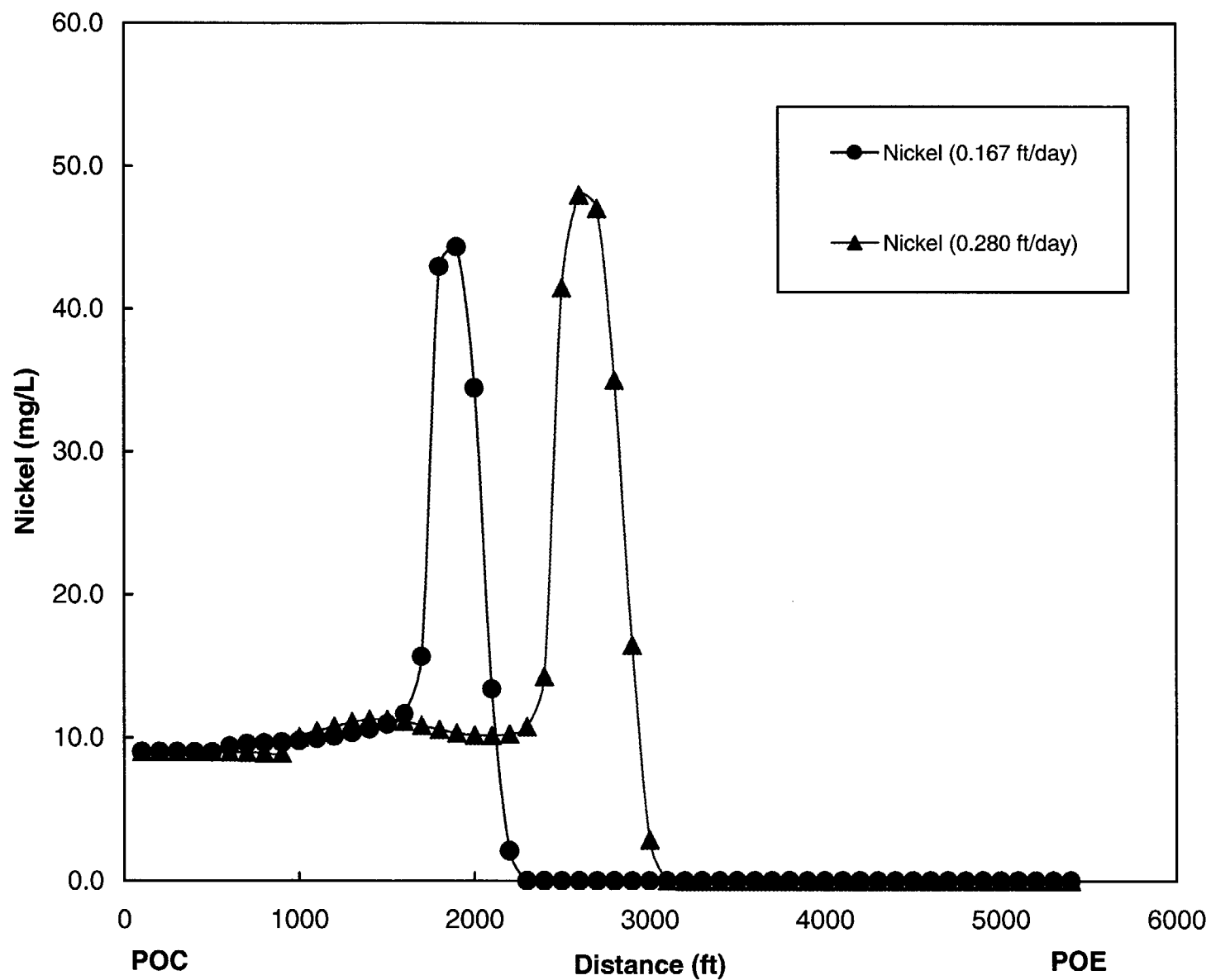


Figure B.22 1000-Year Radium-226+228 Concentrations Between the Southwestern Flow Regime POC and POE.

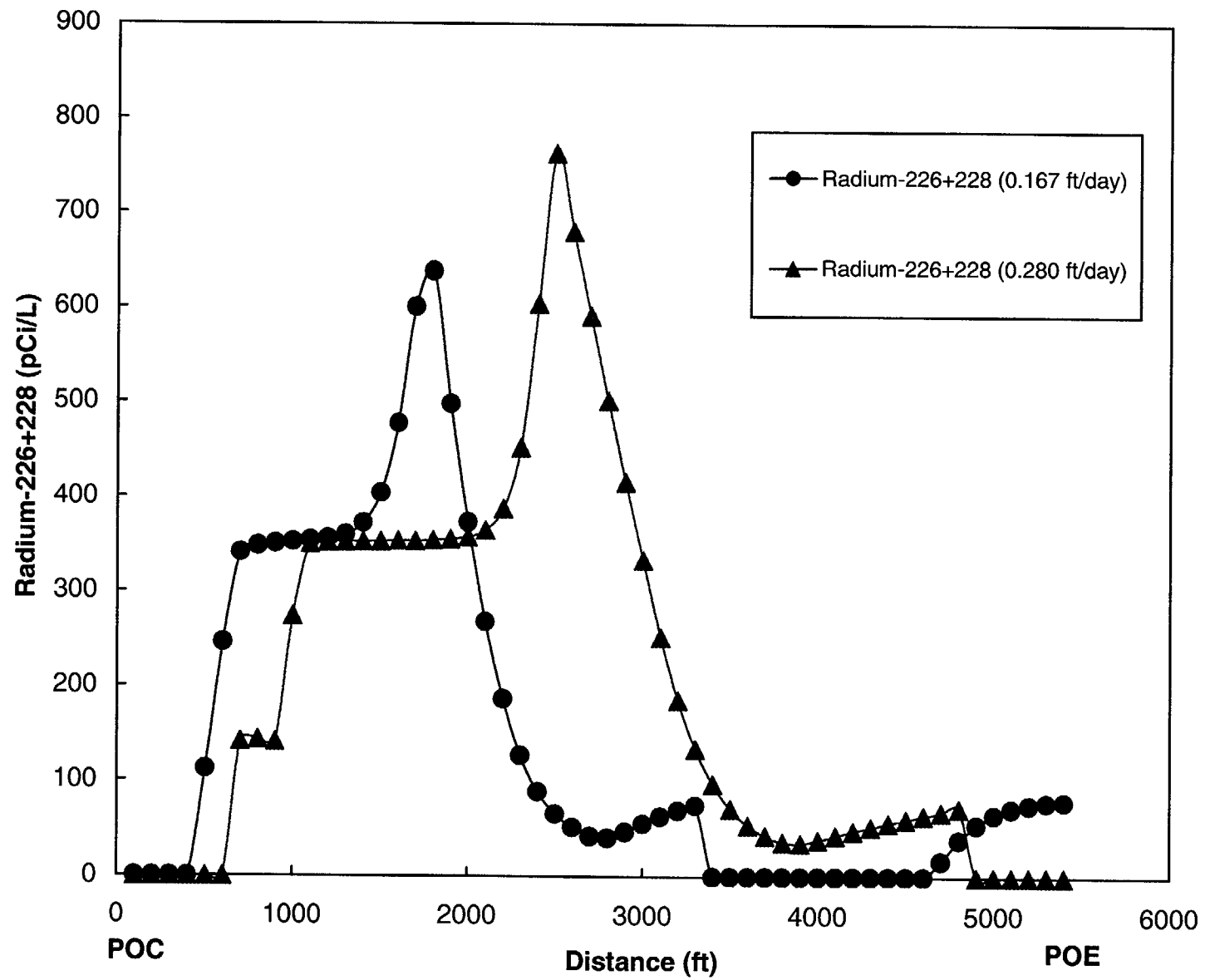


Figure B.23 1000-Year Selenium Concentrations Between the Southwestern Flow Regime POC and POE.

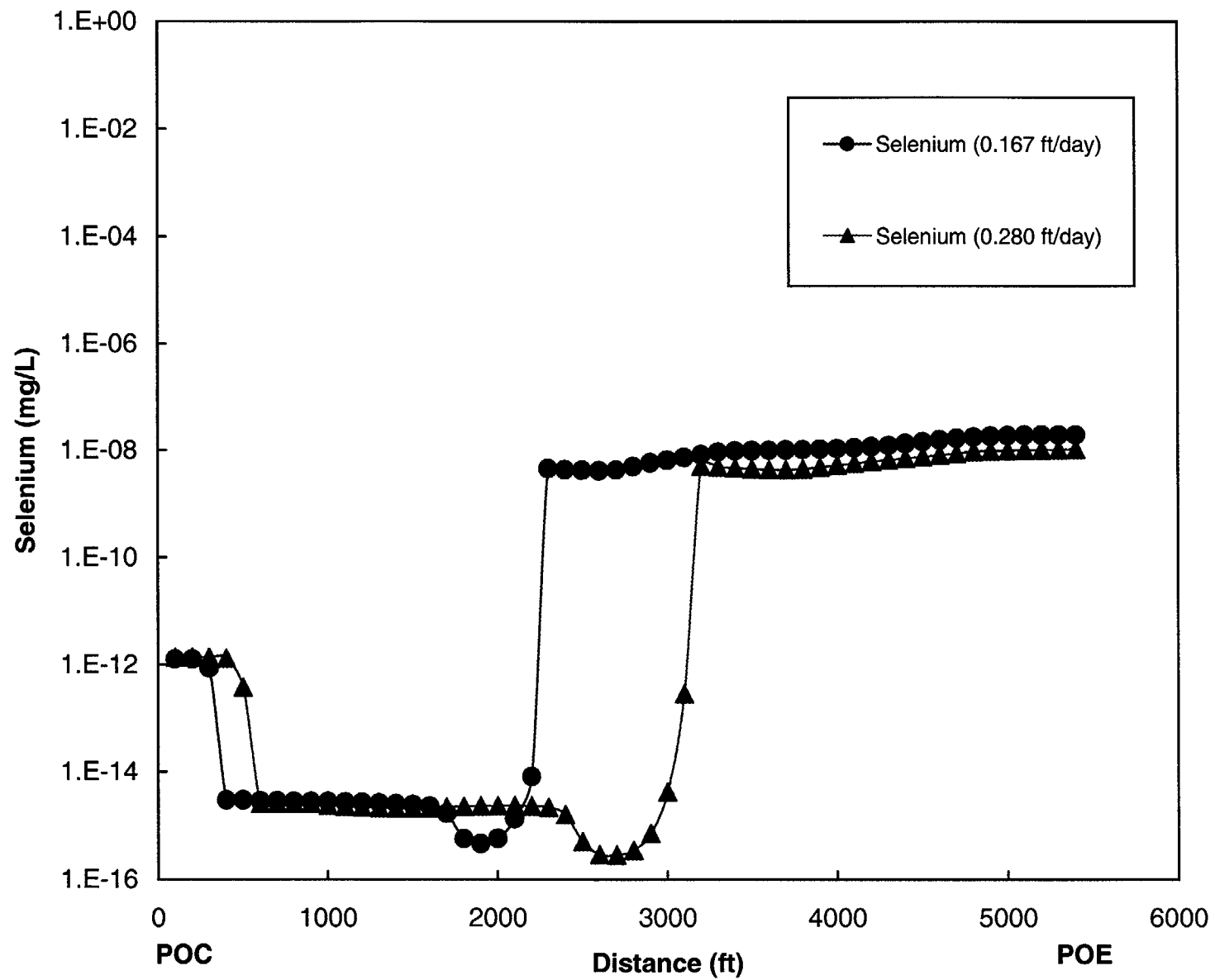


Figure B.24 1000-Year Thorium-230 Concentrations Between the Southwestern Flow Regime POC and POE.

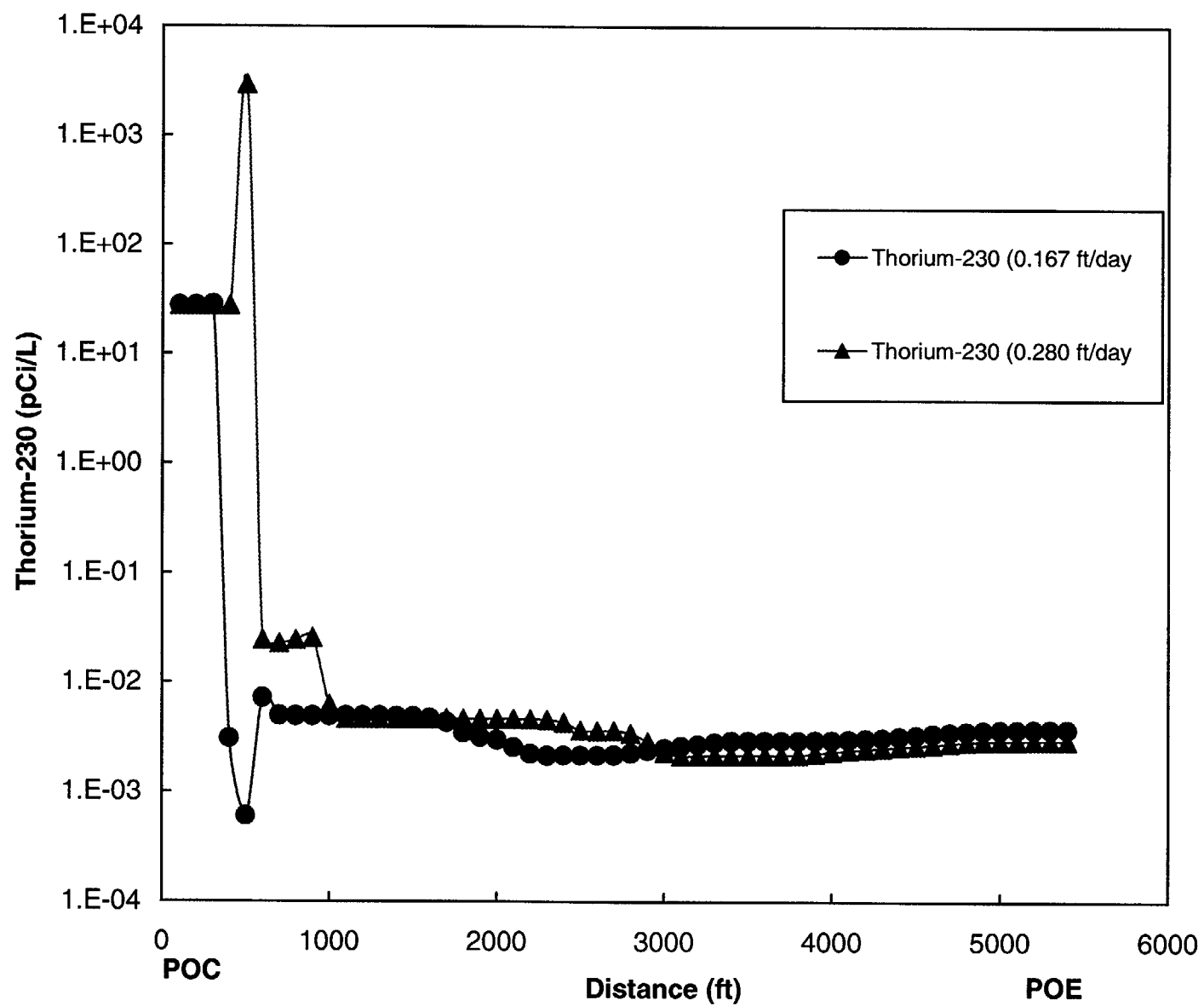


Figure B.25 Arsenic Concentrations at the POE for the Southwestern Flow Regime With Time.

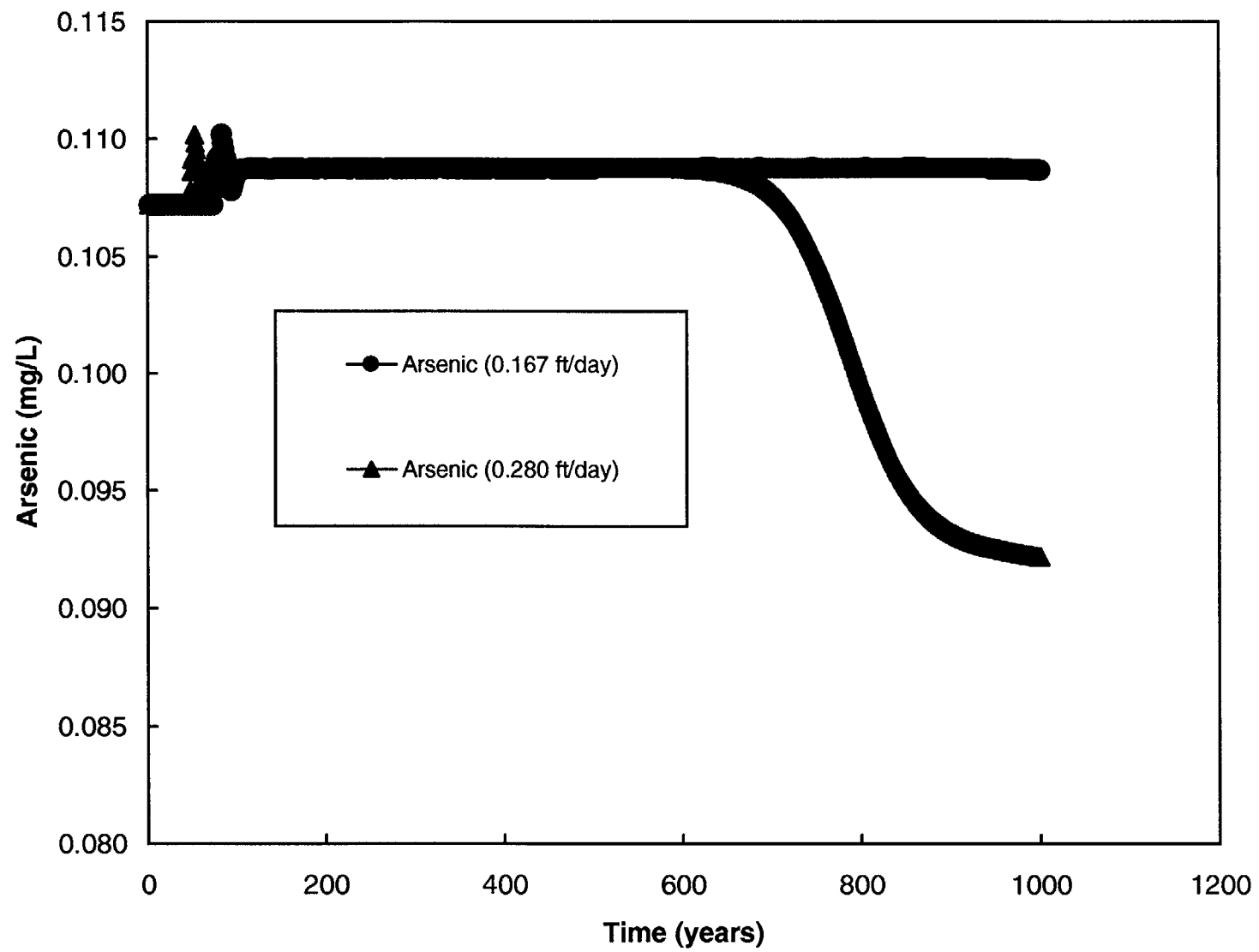


Figure B.26 Beryllium Concentrations at the POE for the Southwestern Flow Regime With Time.

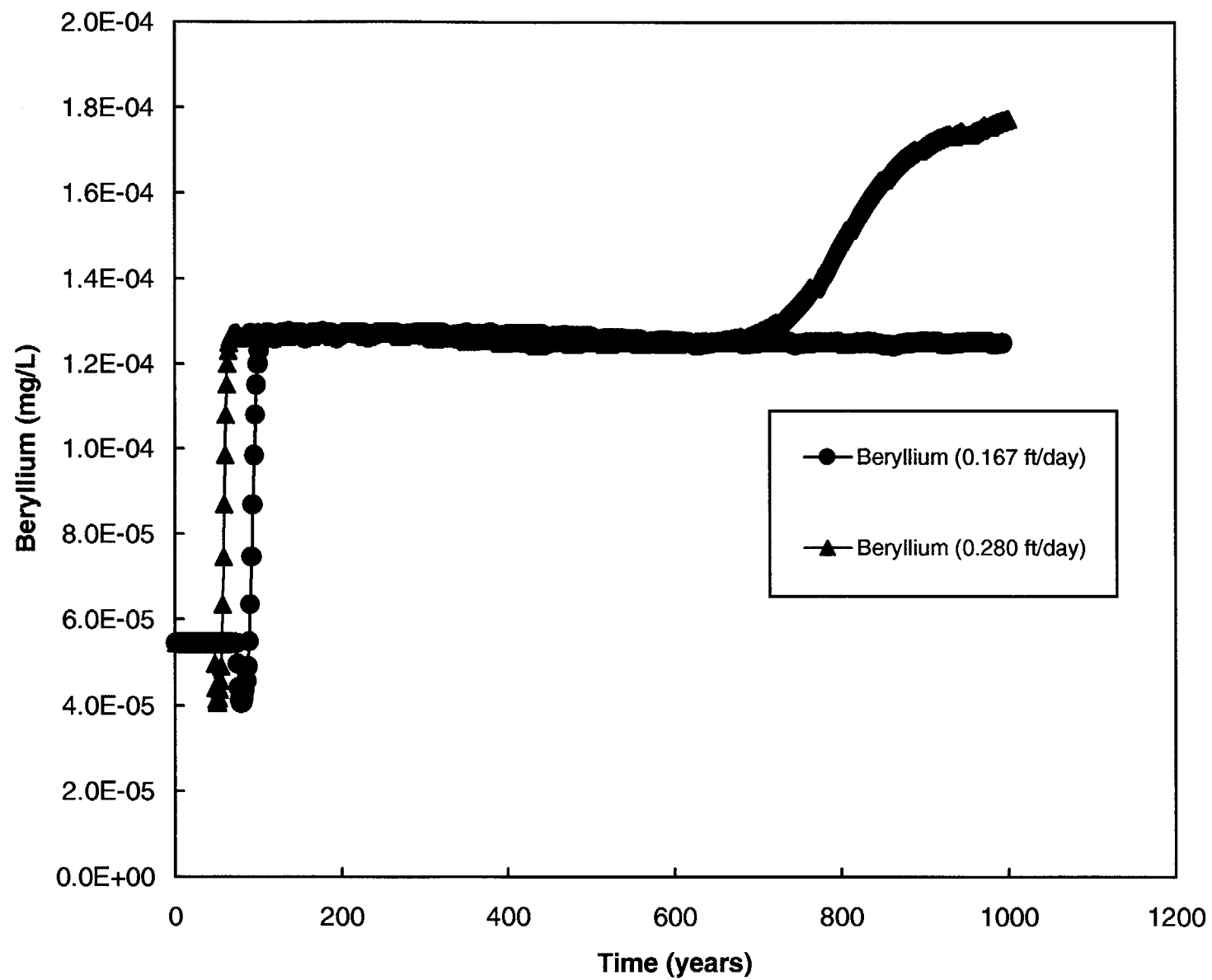


Figure B.27 Lead-210 Concentrations at the POE for the Southwestern Flow Regime With Time.

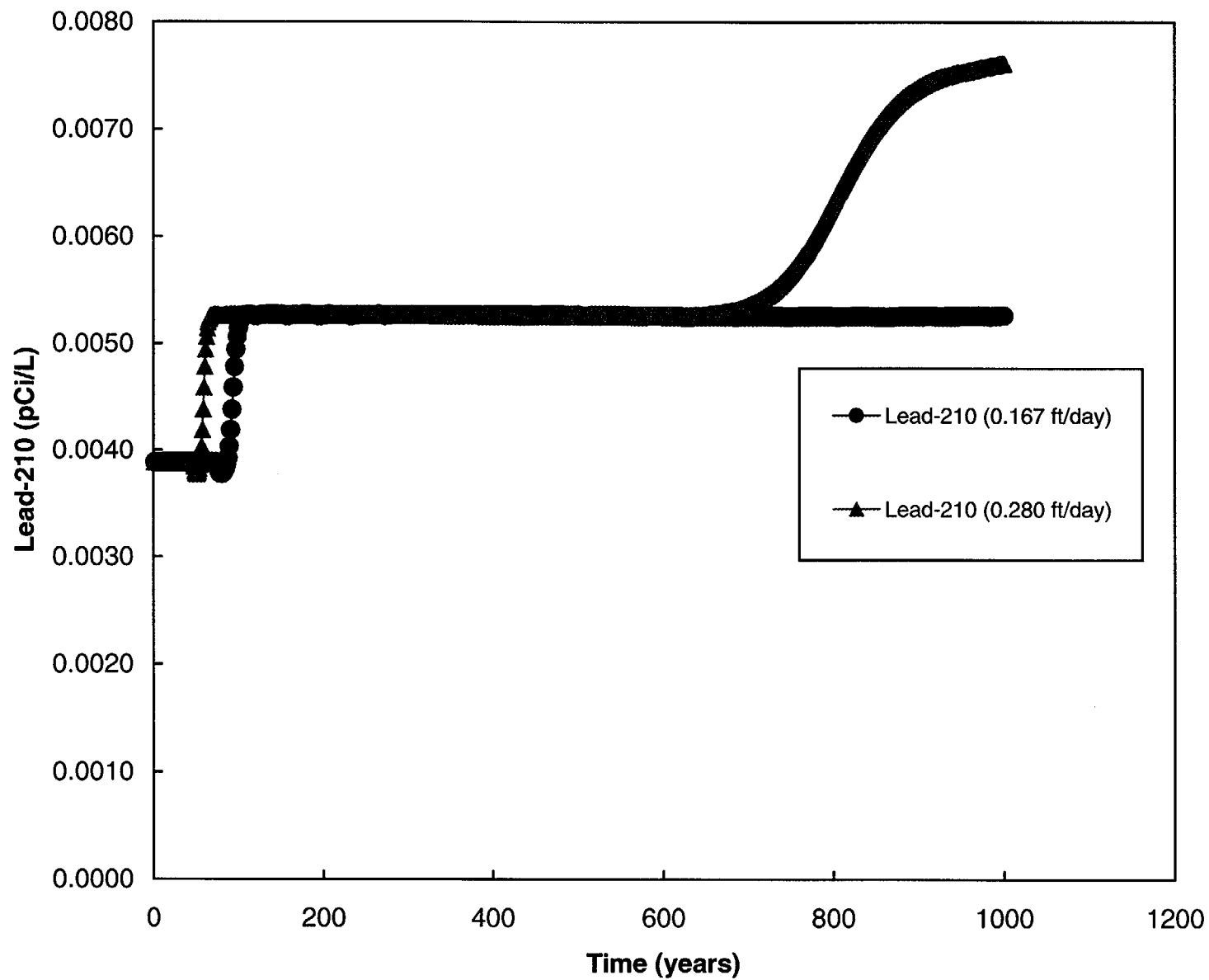


Figure B.28 Uranium Concentrations at the POE for the Southwestern Flow Regime With Time.

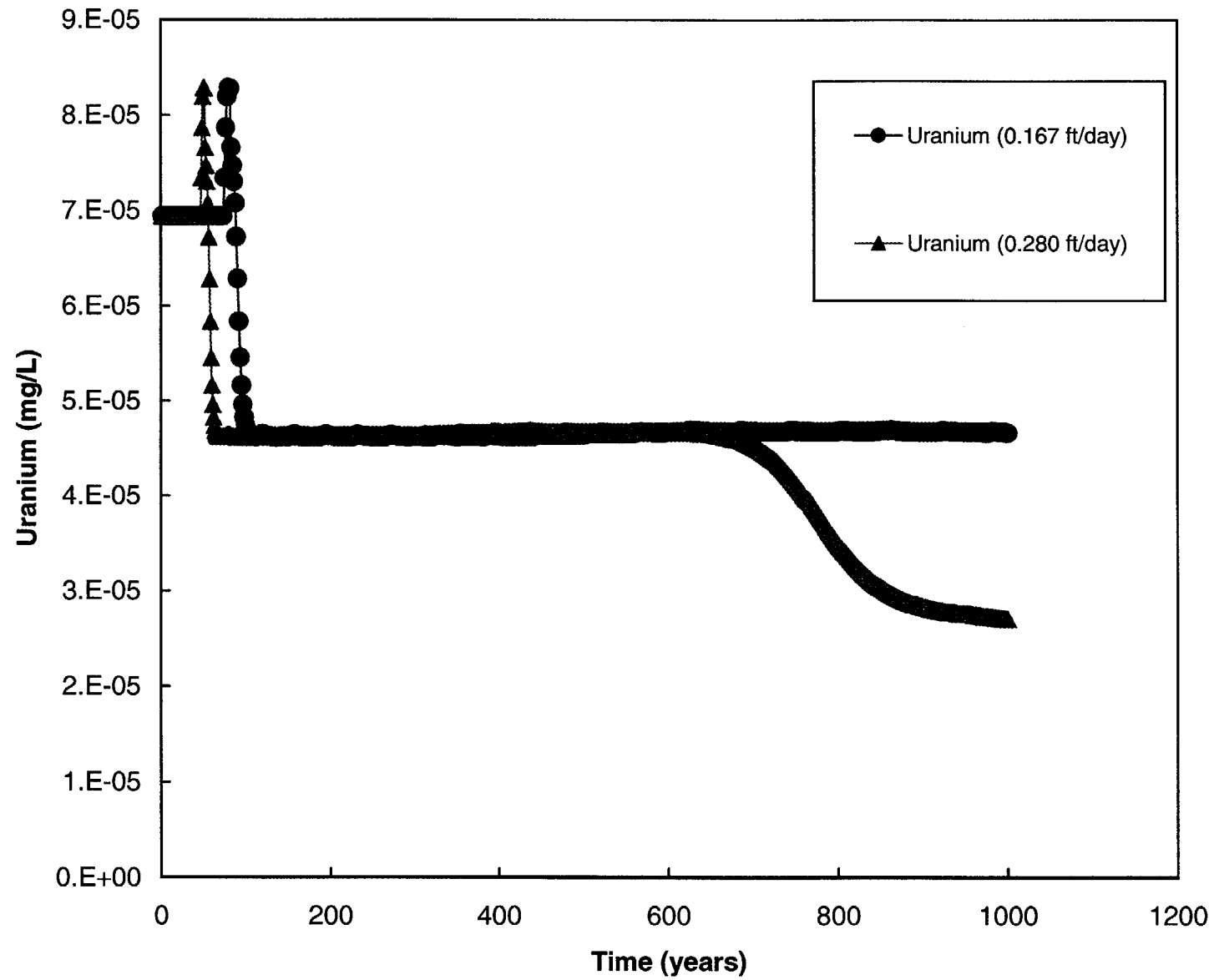


Figure B.29 Nickel Concentrations at the POE for the Southwestern Flow Regime with Time.

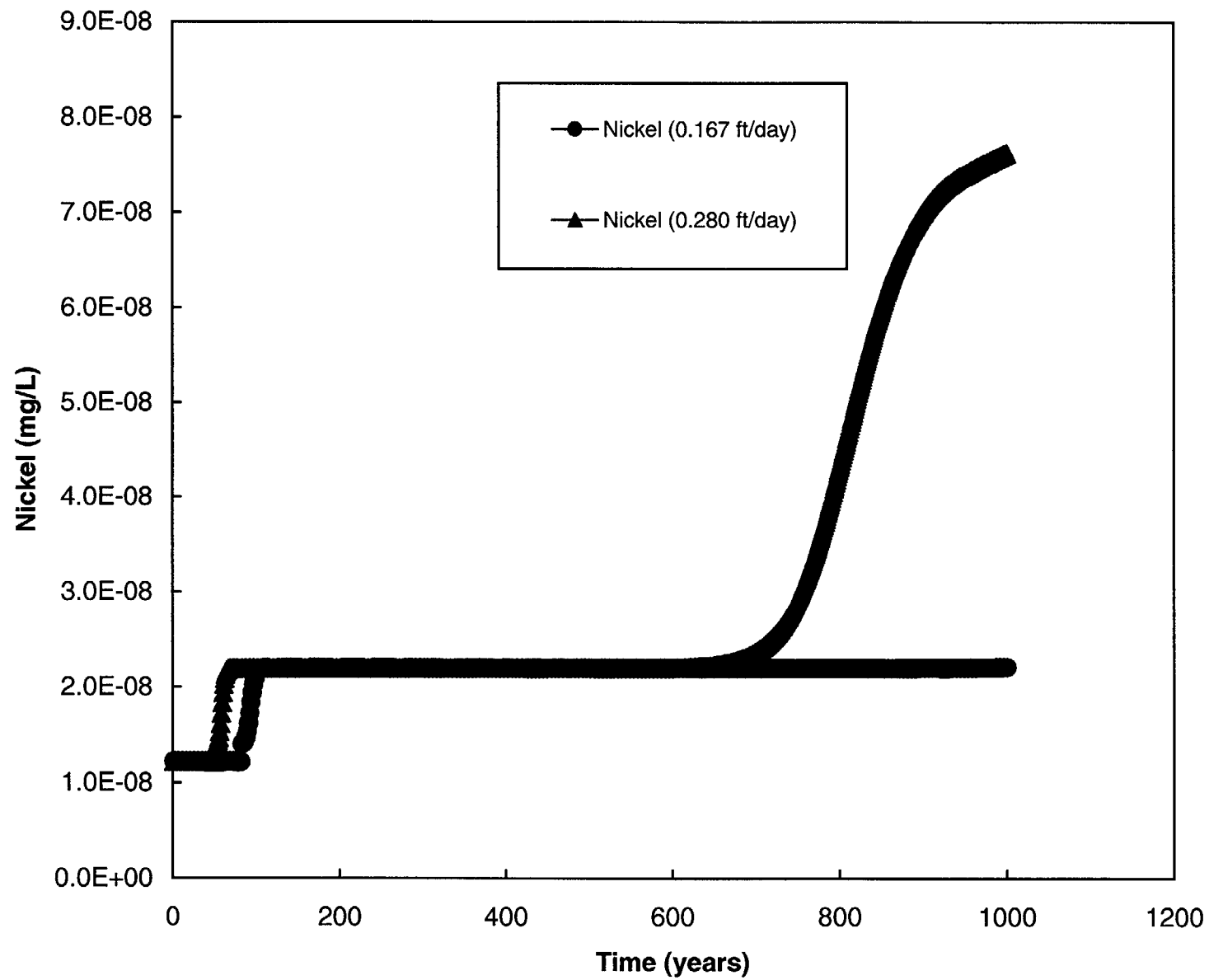


Figure B.30 Radium-226+228 Concentrations at the POE for the Southwestern Flow Regime With Time.

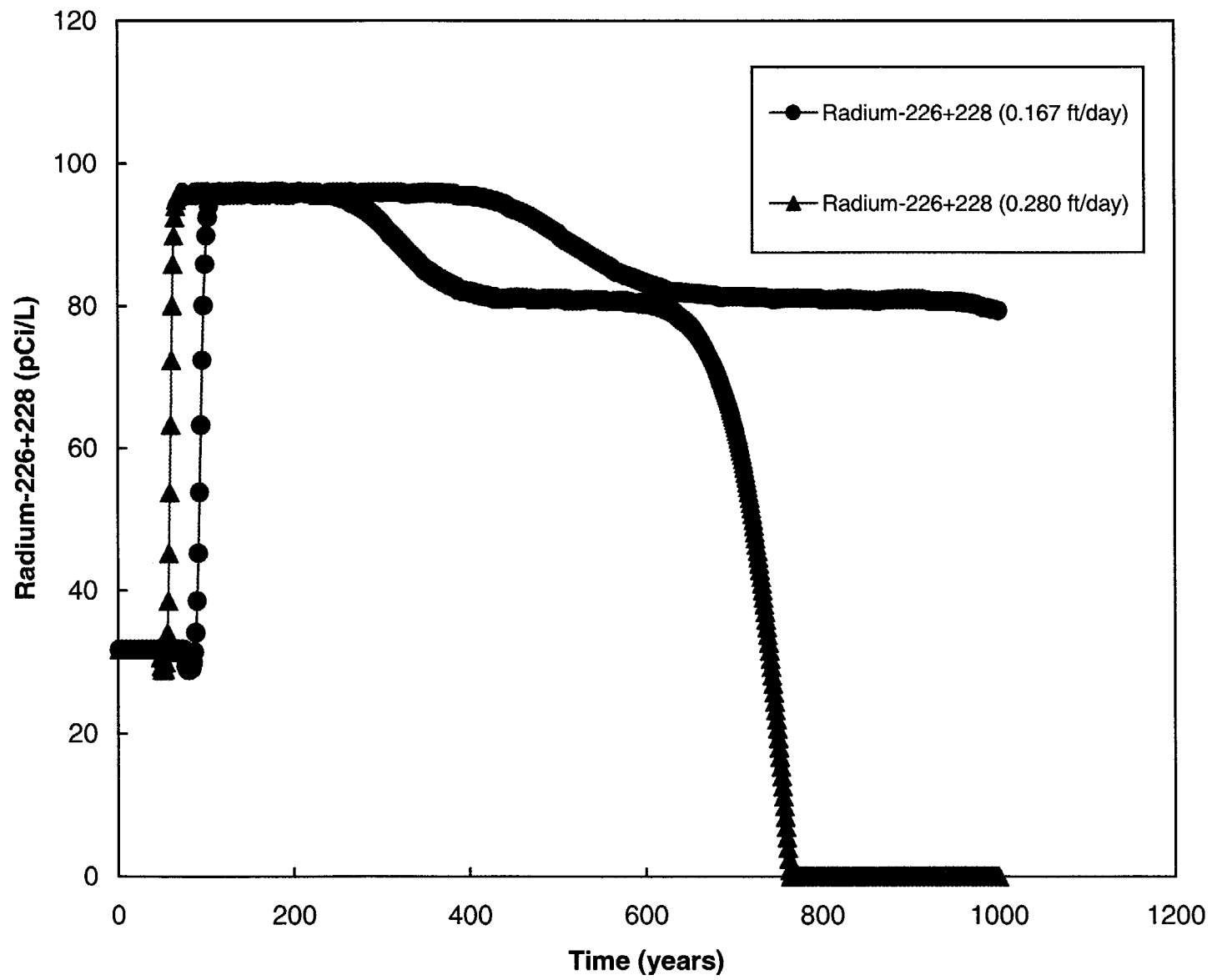


Figure B.31 Selenium Concentrations at the POE for the Southwestern Flow Regime With Time.

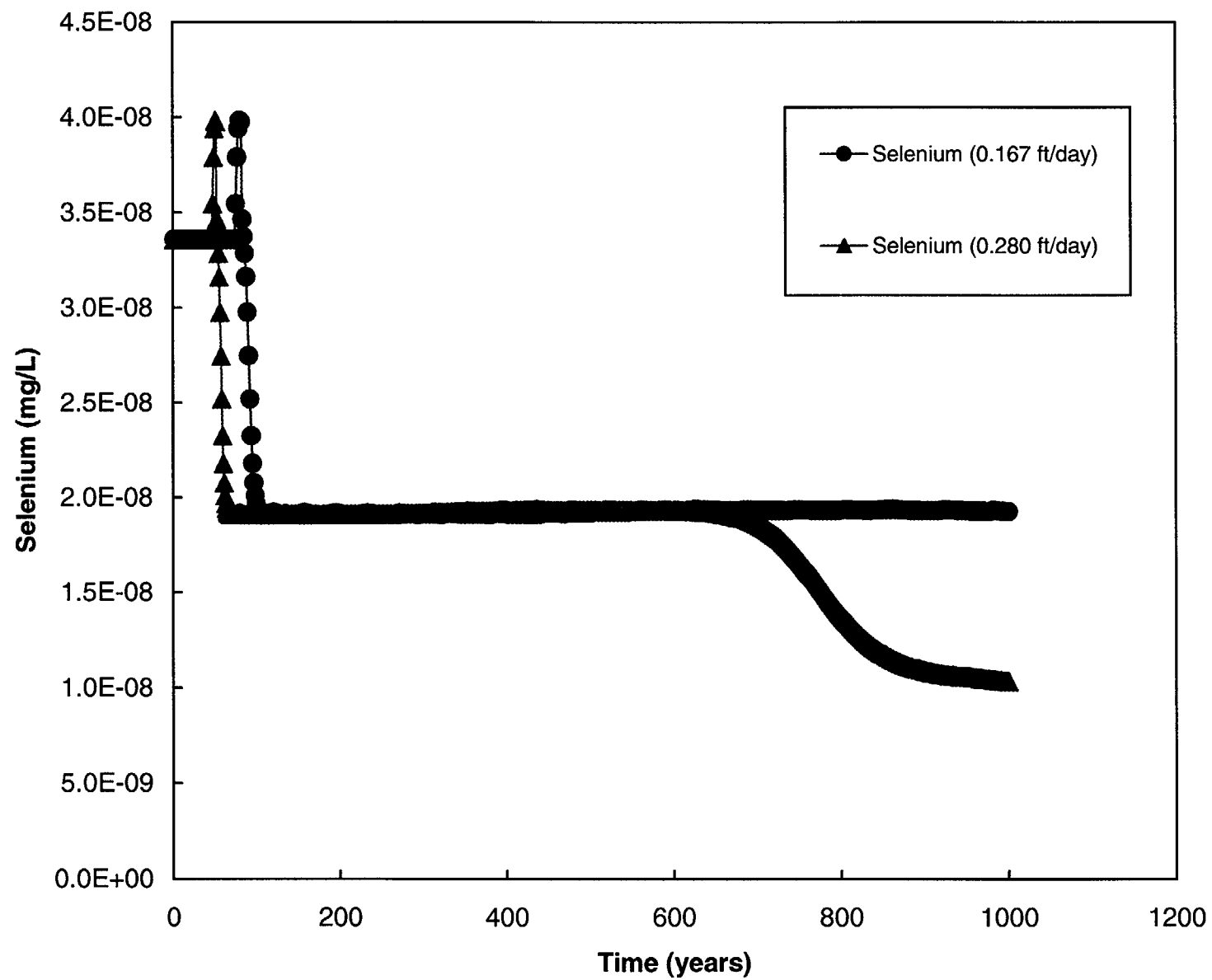


Figure B.32 Thorium-230 Concentrations at the POE for the Southwestern Flow Regime With Time.

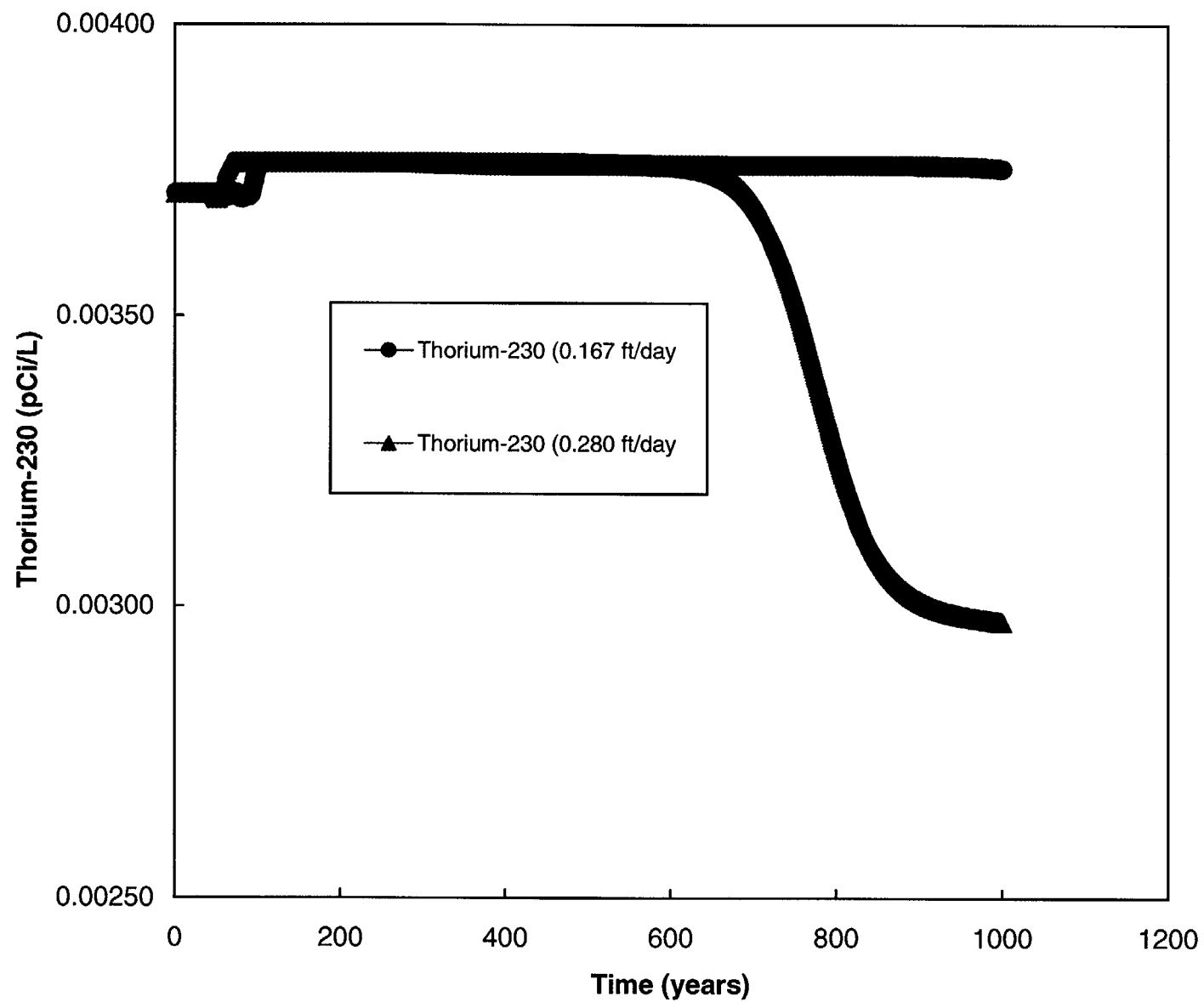


Figure B.33: Concentration of Adsorbed Arsenic Phases for the Western Flow Regime (0.167 ft/d).

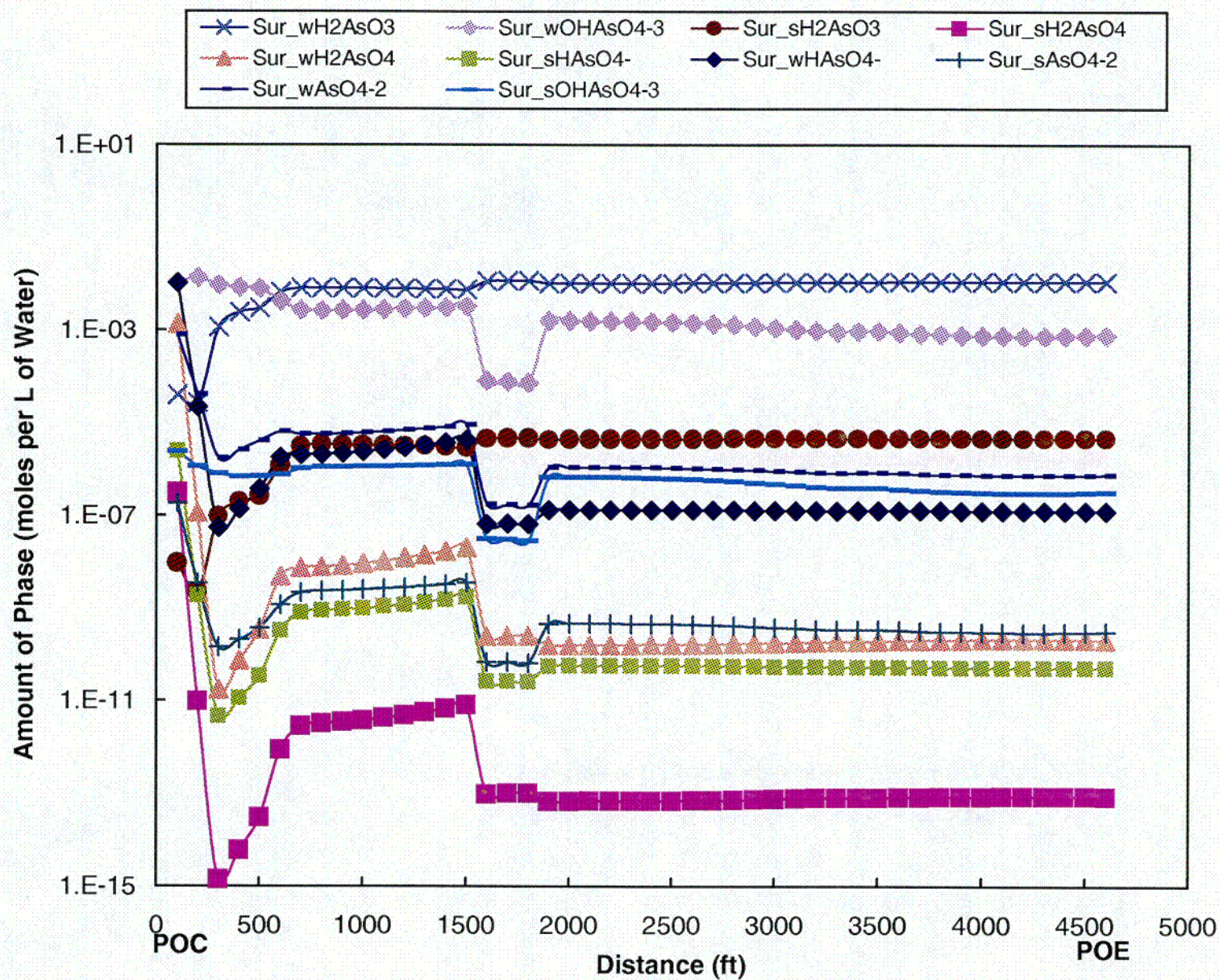


Figure B.34 Concentration of Adsorbed Beryllium Phases for the Western Flow Regime (0.167 ft/d).

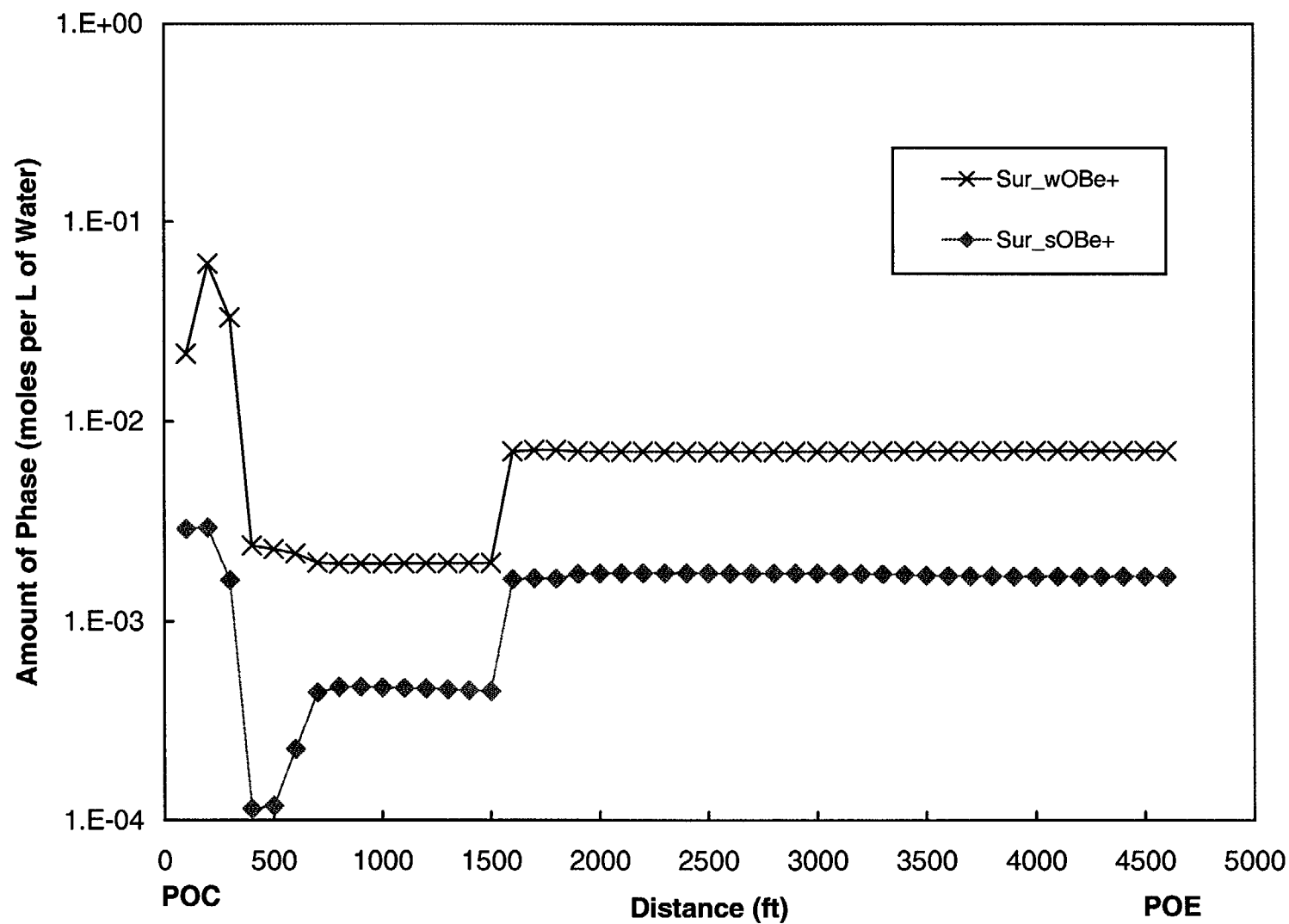


Figure B.35 Concentrations of Adsorbed and Exchangeable Lead-210 Phases for the Western Flow Path (0.167 ft/d).

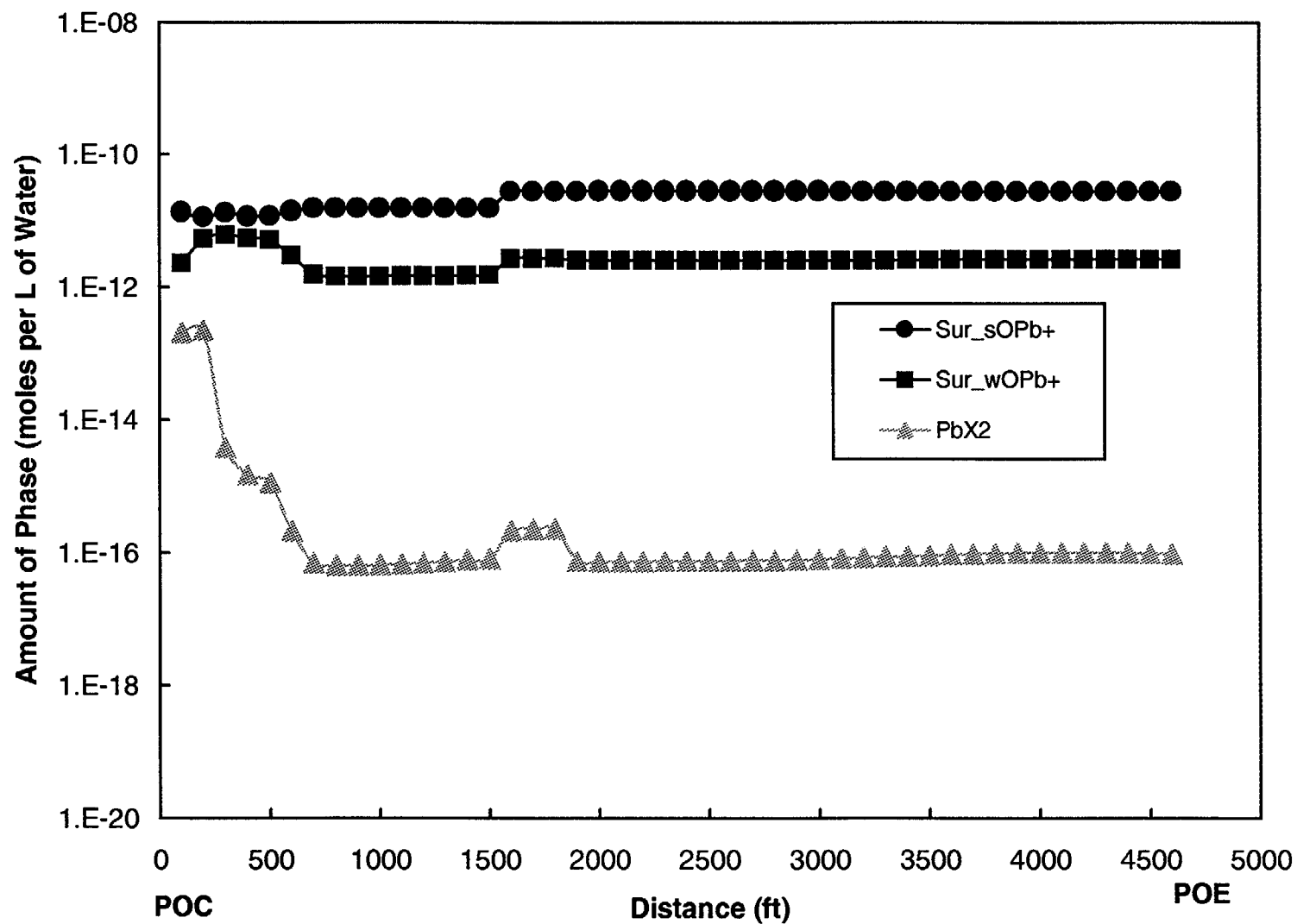


Figure B.36 Concentration of Precipitated and Adsorbed Uranium Phases for the Western Flow Path (0.167 ft/d).

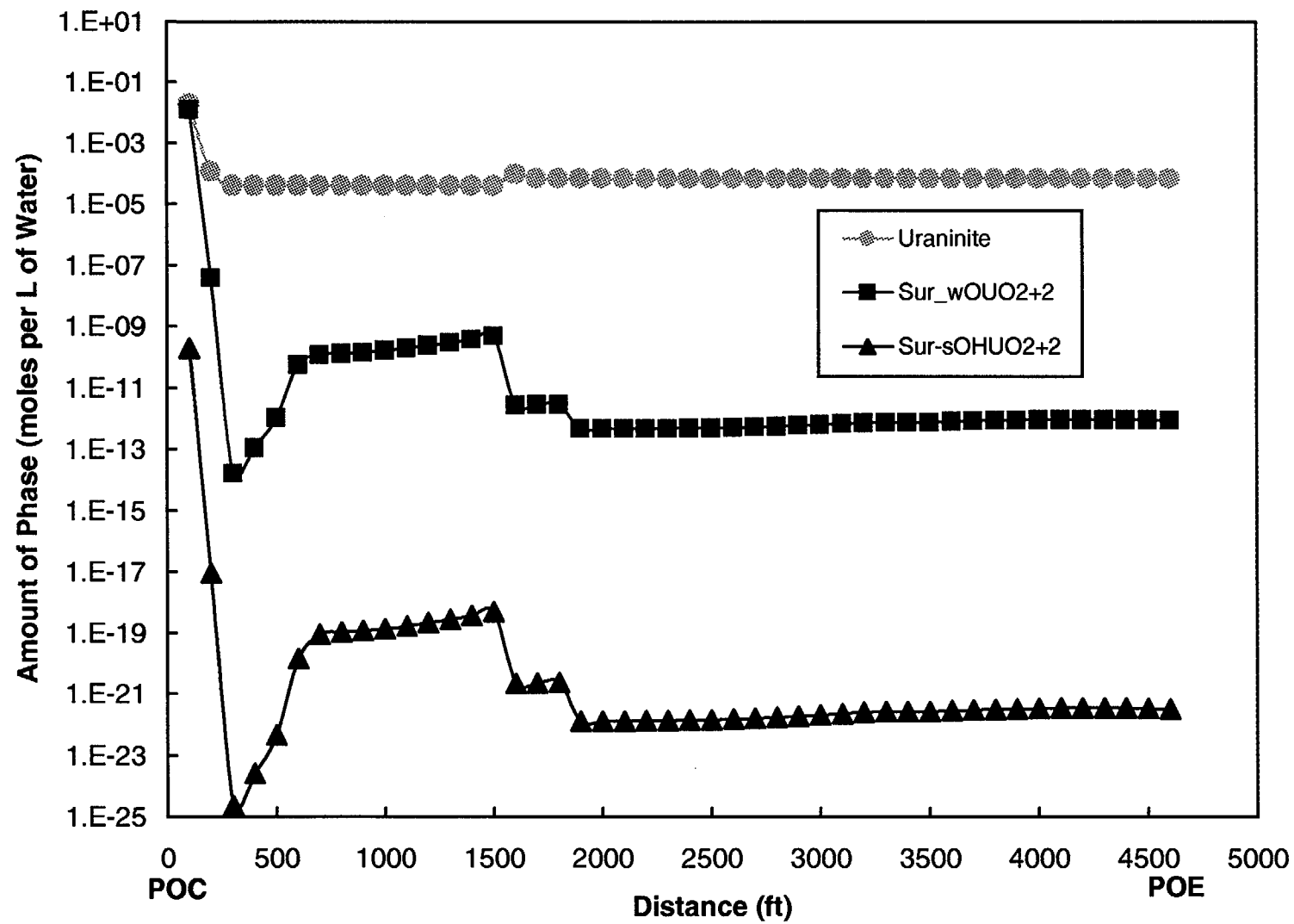


Figure B.37 Concentration of Adsorbed and Precipitated Nickel Phases for the Western Flow Path (0.167 ft/d).

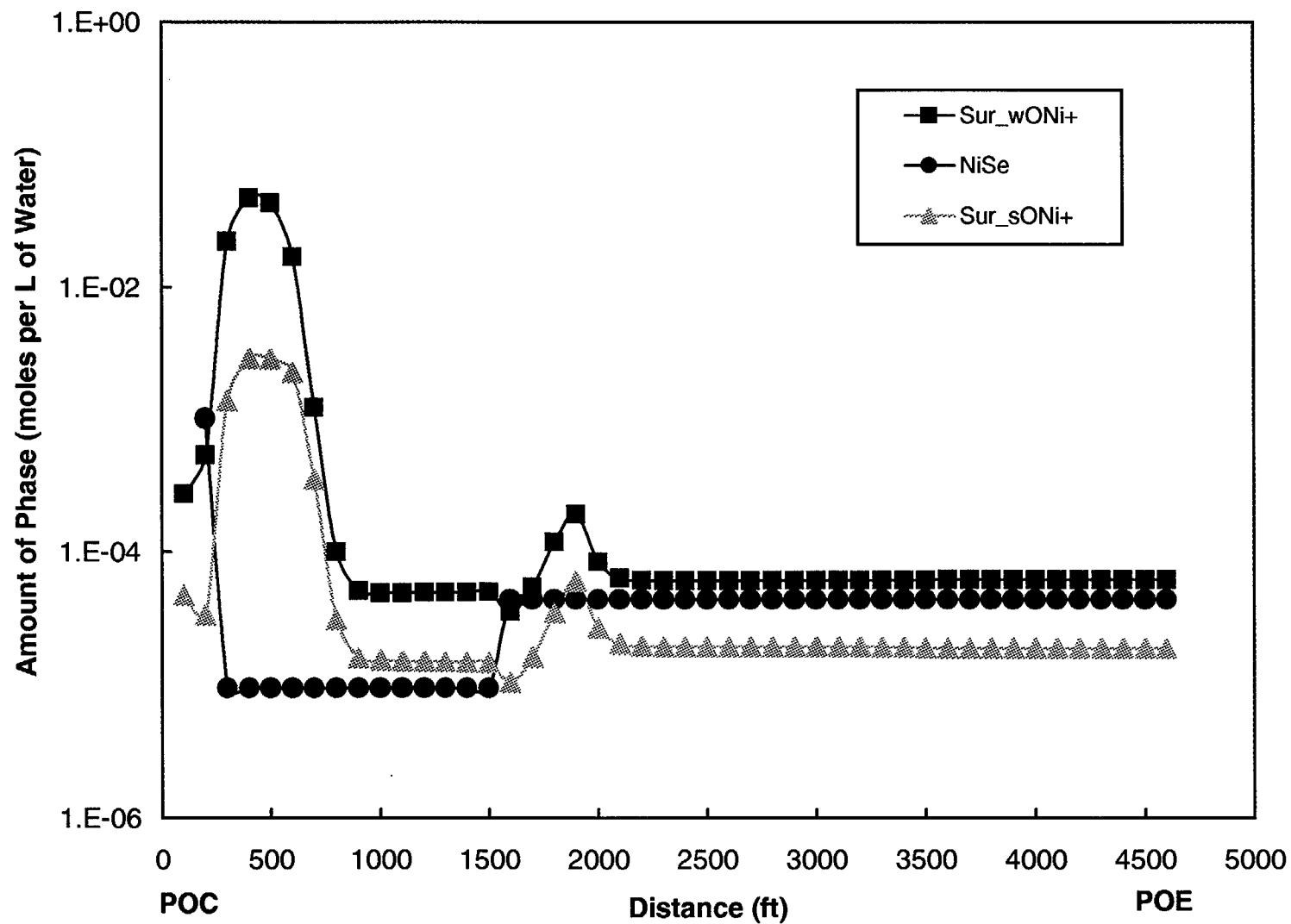


Figure B.38 Concentration of Exchangeable and Adsorbed Radium Phases for the Western Flow Path (0.167 ft/d).

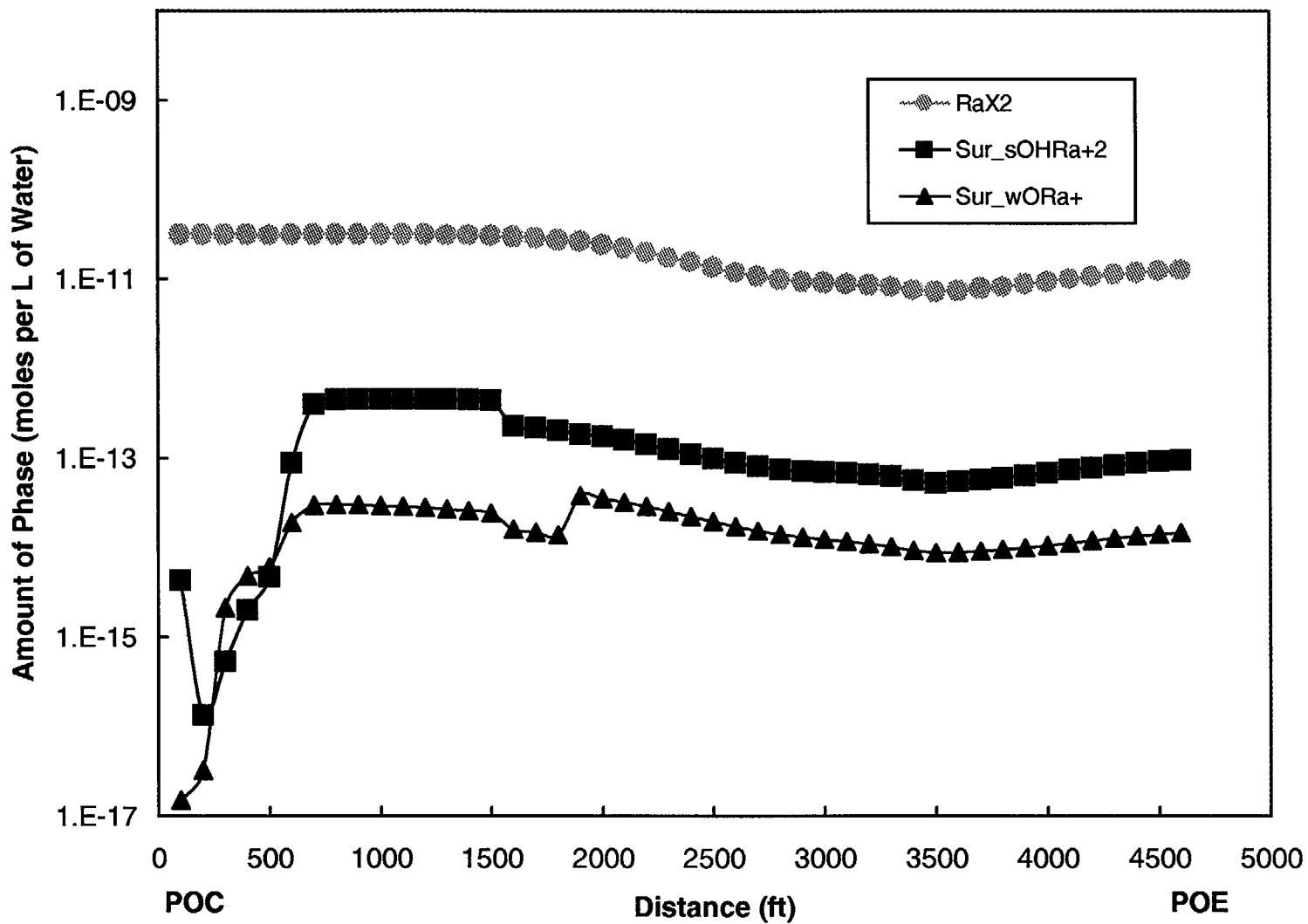


Figure B.39 Concentration of Precipitated and Adsorbed Selenium Phases for the Western Flow Path (0.167 ft/d).

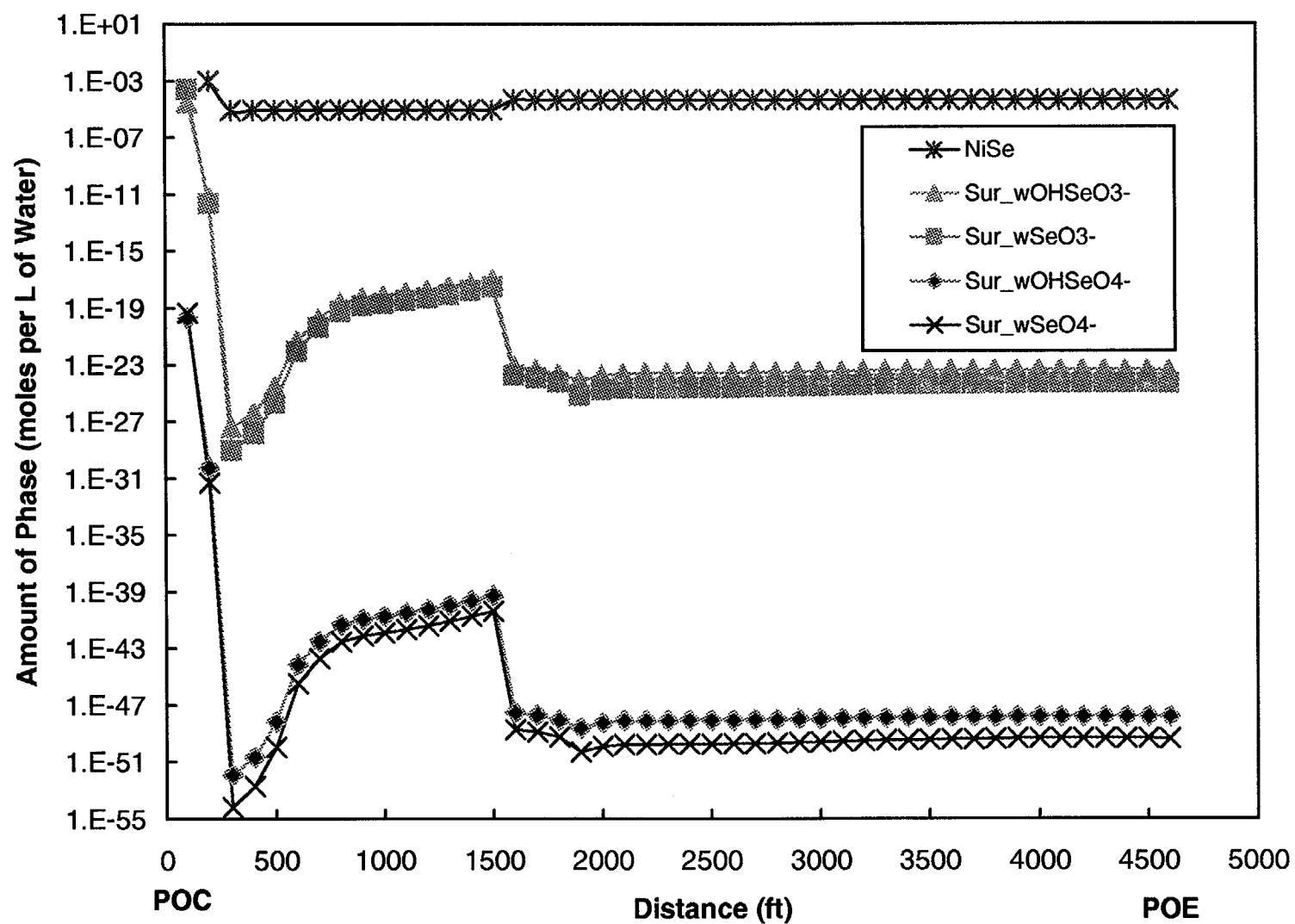


Figure B.40 Concentration of Adsorbed Thorium-230 Phases for the Western Flow Path (0.167 ft/d).

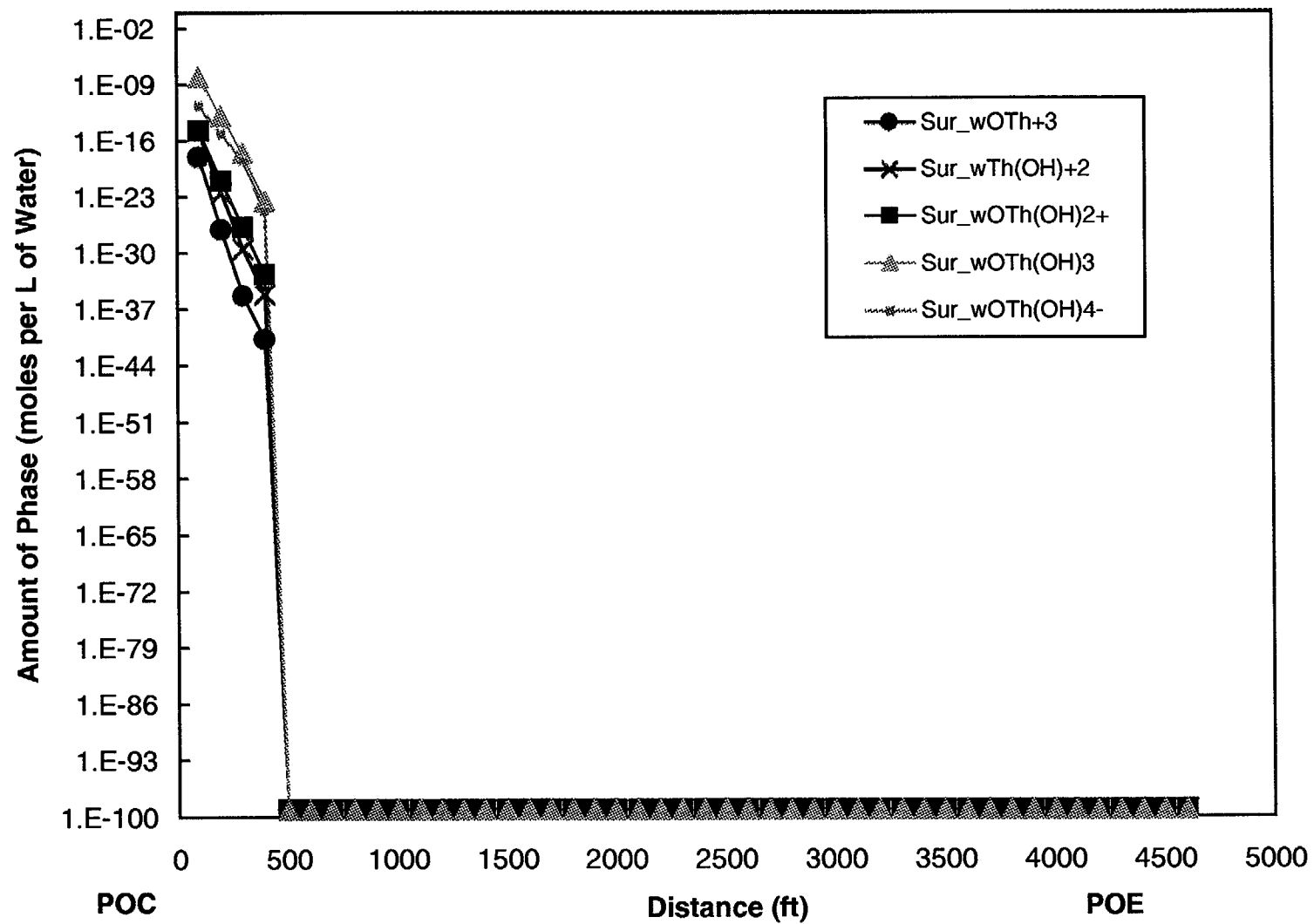


Figure B.41 Concentration of Adsorbed Arsenic Phases for the Southwestern Flow Path (0.167 ft/d).

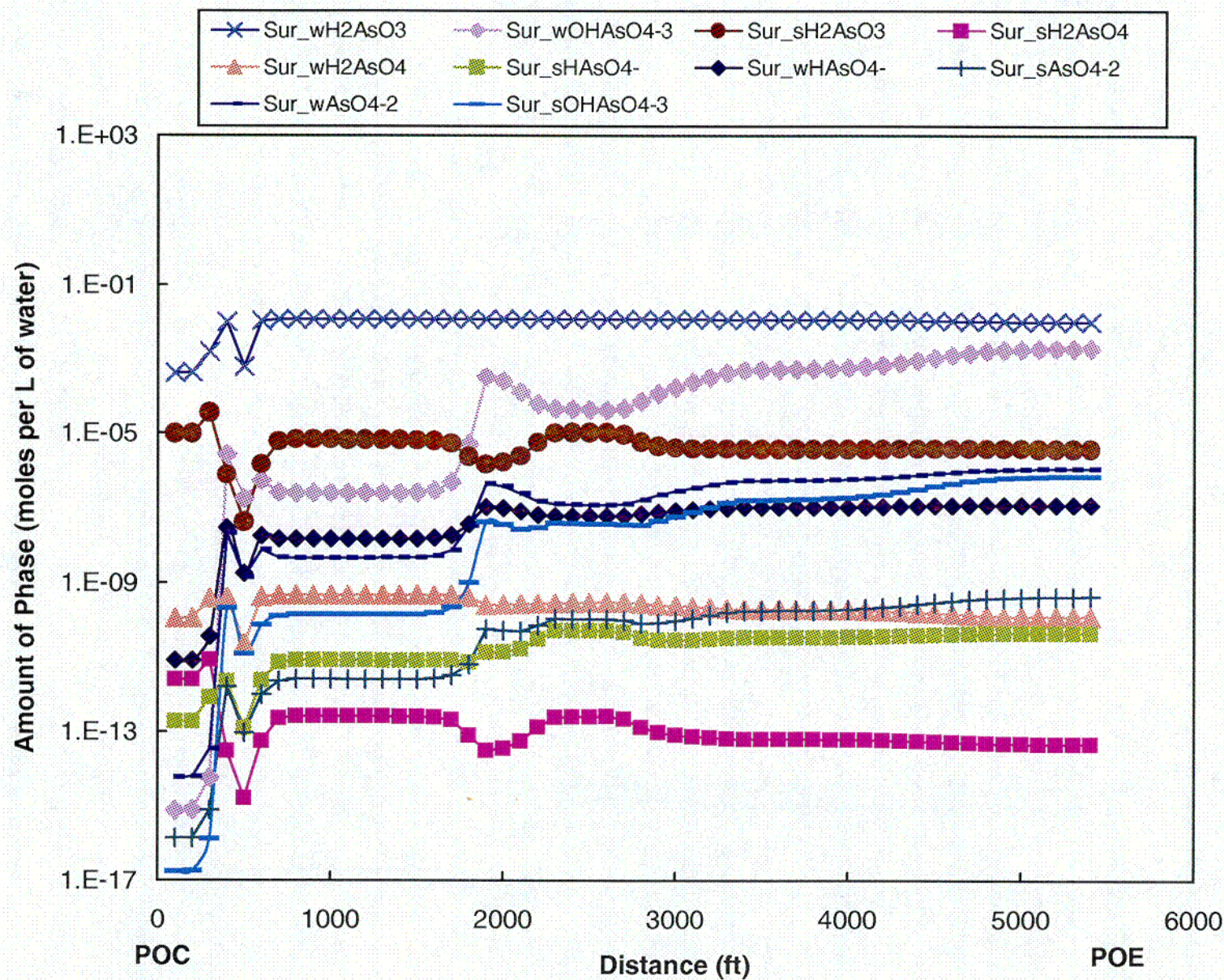


Figure B.42 Concentration of Adsorbed Beryllium Phases for the Southwestern Flow Path (0.167 ft/d).

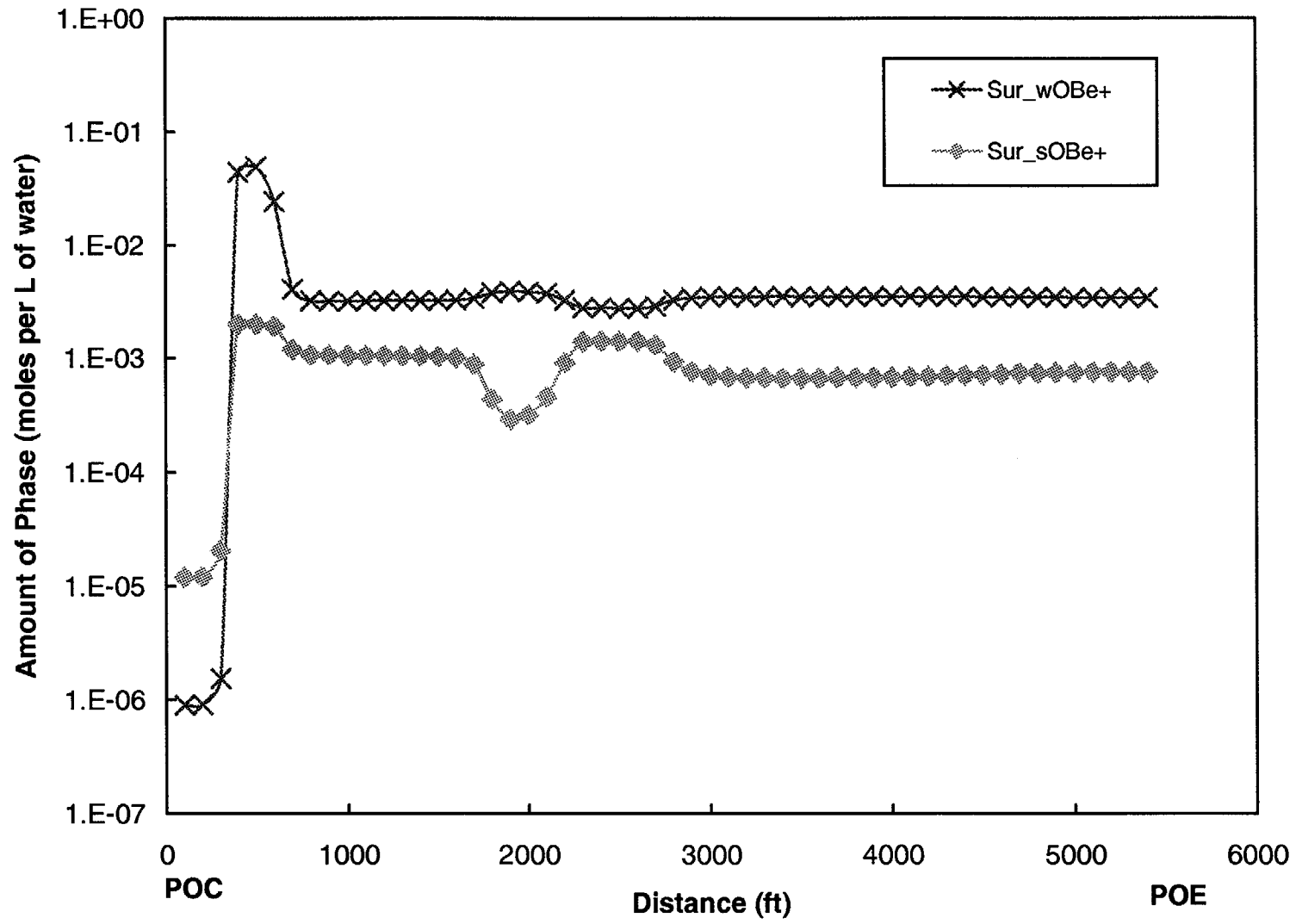


Figure B.43 Concentration of Adsorbed and Exchangeable Lead Phases for the Southwestern Flow Path (0.167 ft/d).

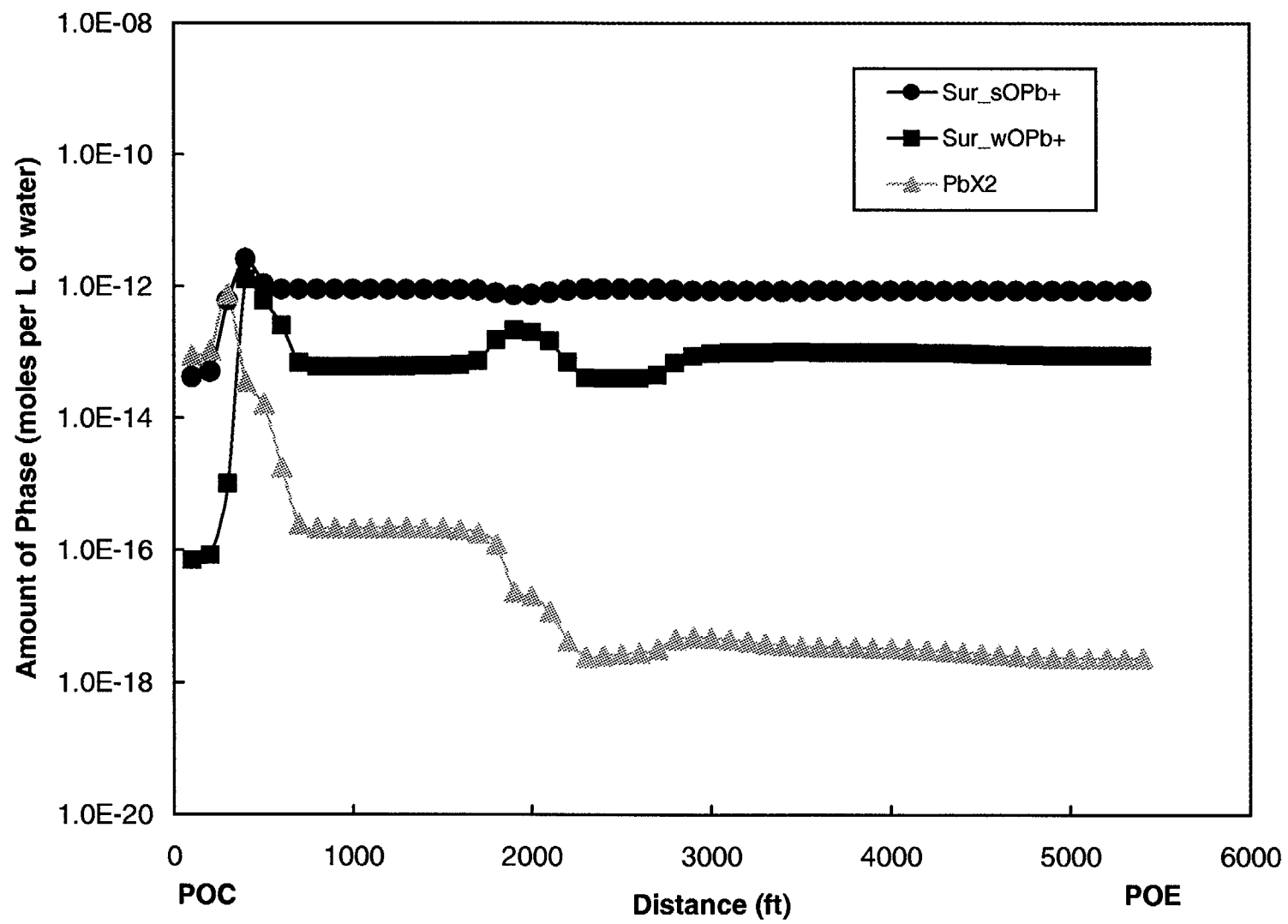


Figure B.44 Concentration of Precipitated and Adsorbed Uranium Phases for the Southwestern Flow Path (0.167 ft/d).

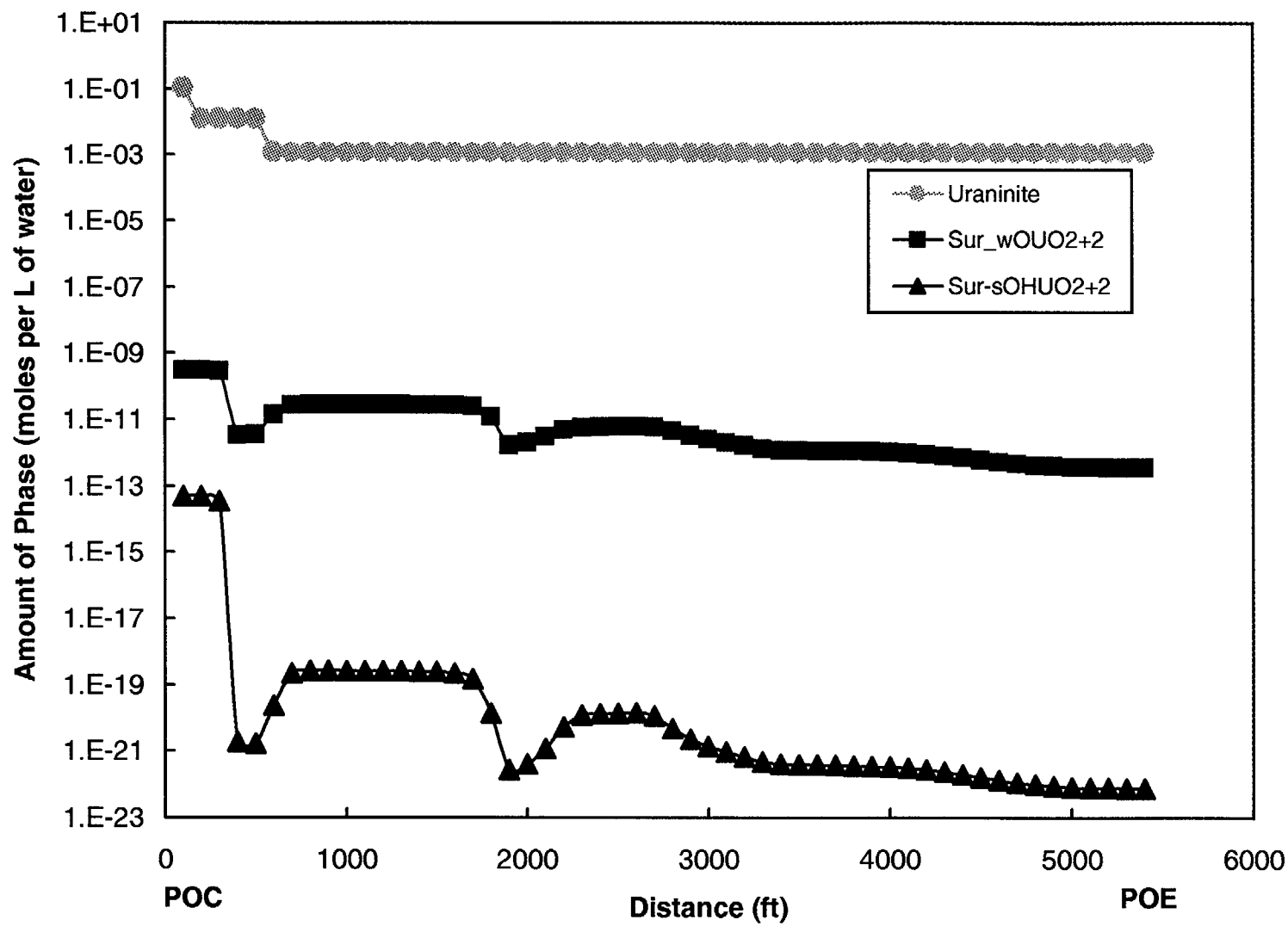
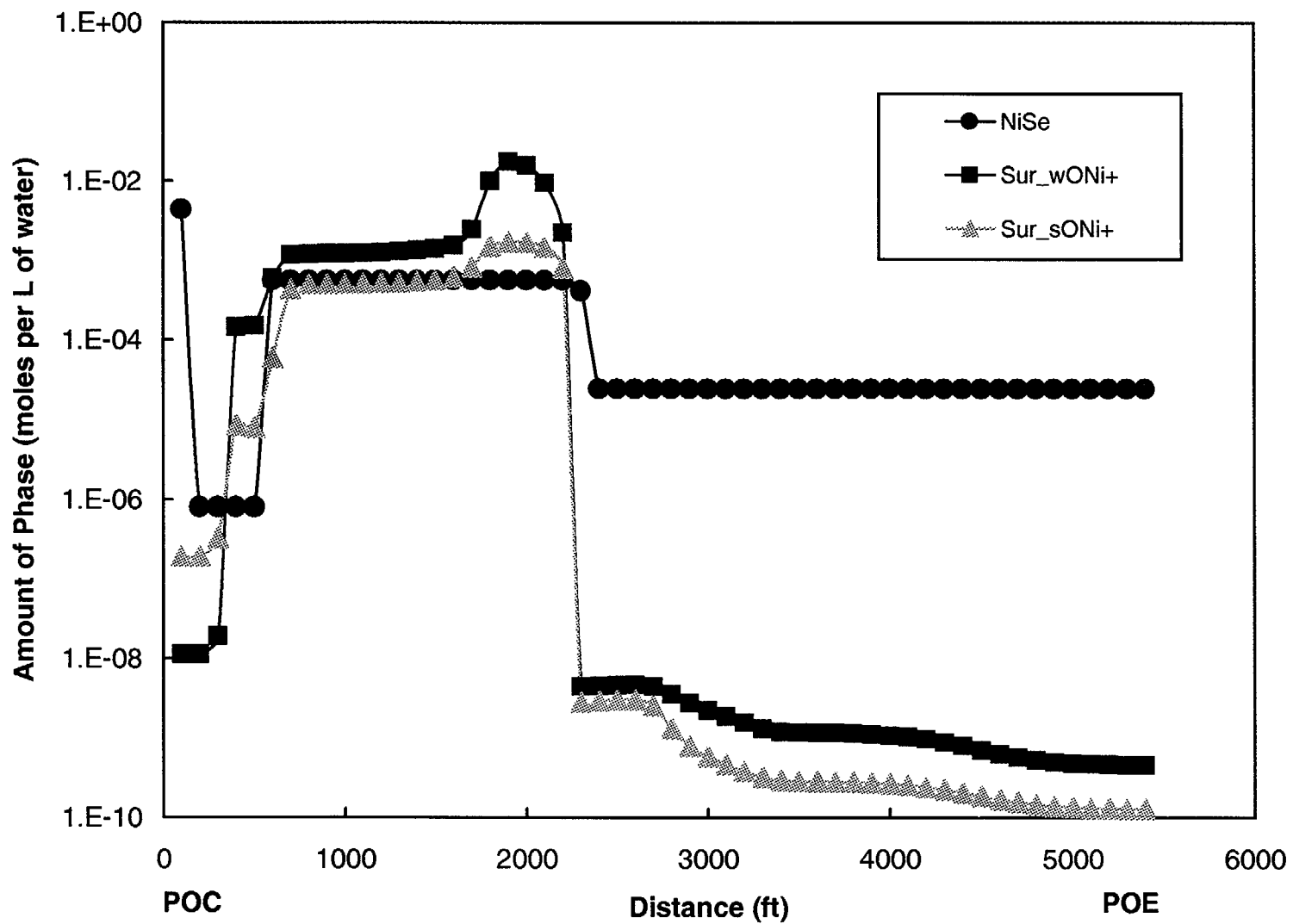


Figure B.45 Concentrations of Precipitated and Adsorbed Nickel Phases for the Southwestern Flow Path (0.167 ft/d).



**Figure B.46 Concentration of Exchangeable and Adsorbed Radium Phases for the Southwestern Flow Path
(0.167 ft/d)**

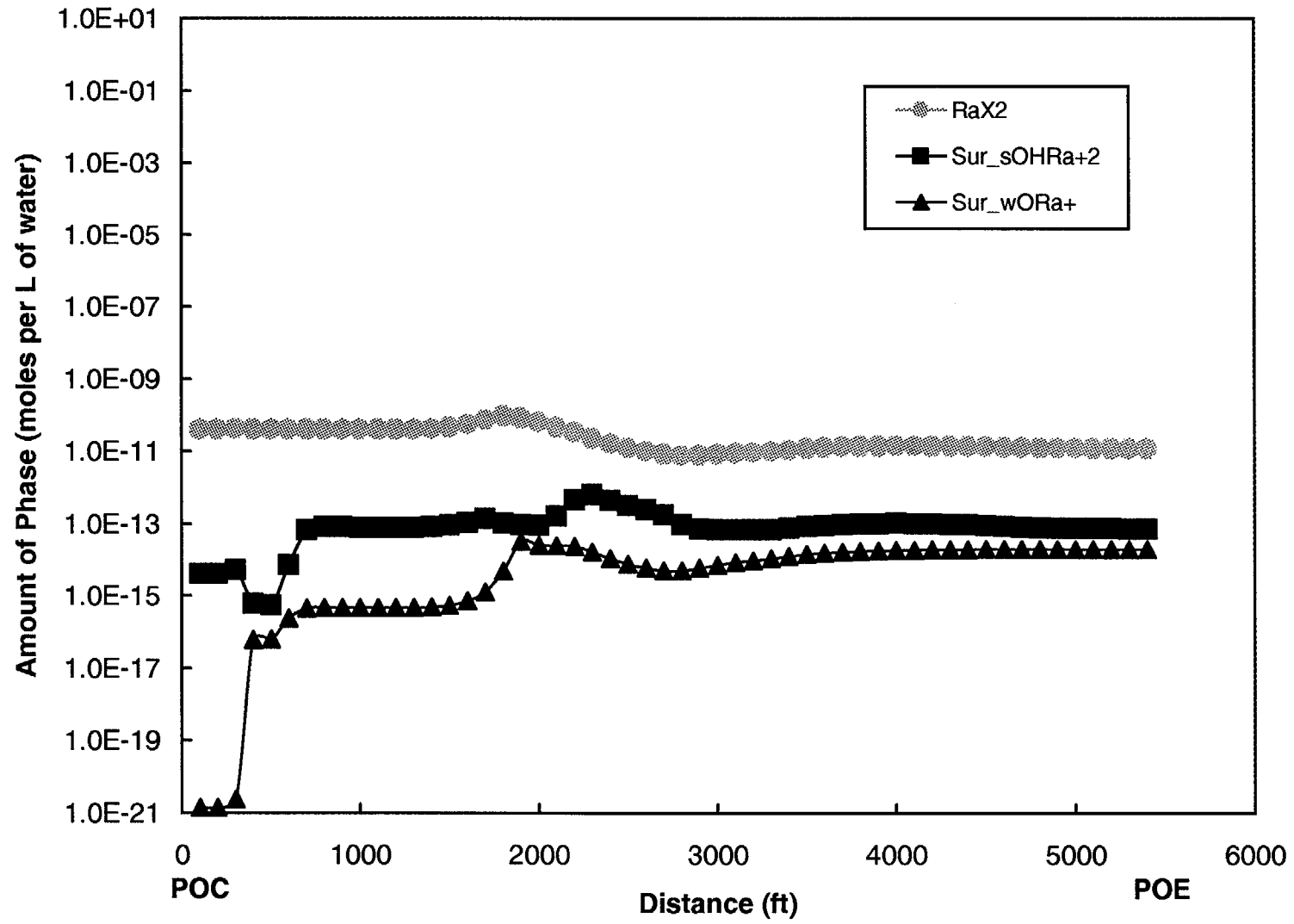


Figure B.47 Concentration of Precipitated and Adsorbed Selenium Phases for the Southwestern Flow Path (0.167 ft/d)

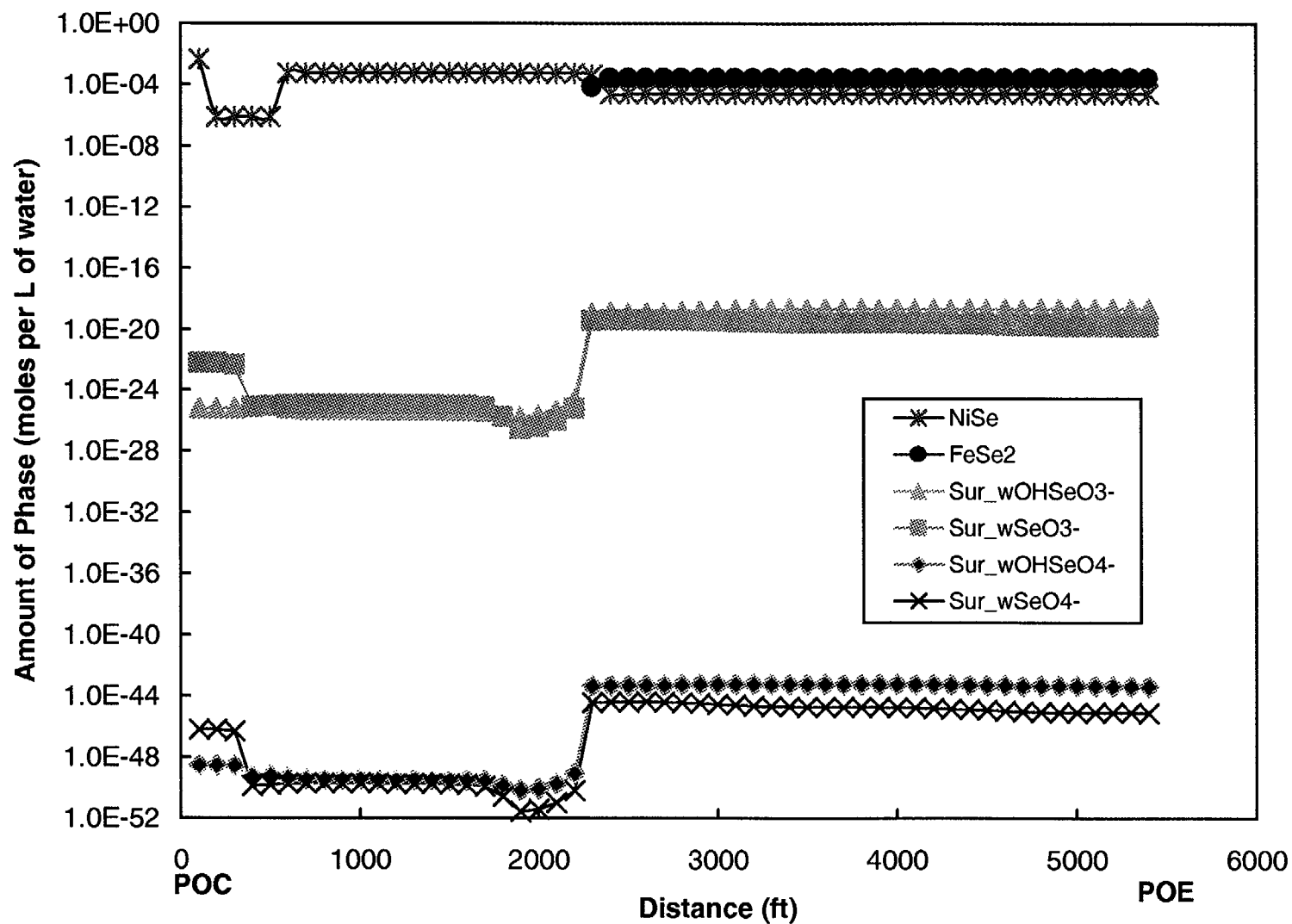


Figure B.48 Concentration of Adsorbed Thorium-230 Phases for the Southwestern Flow Path (0.167 ft/d).

