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June 1994

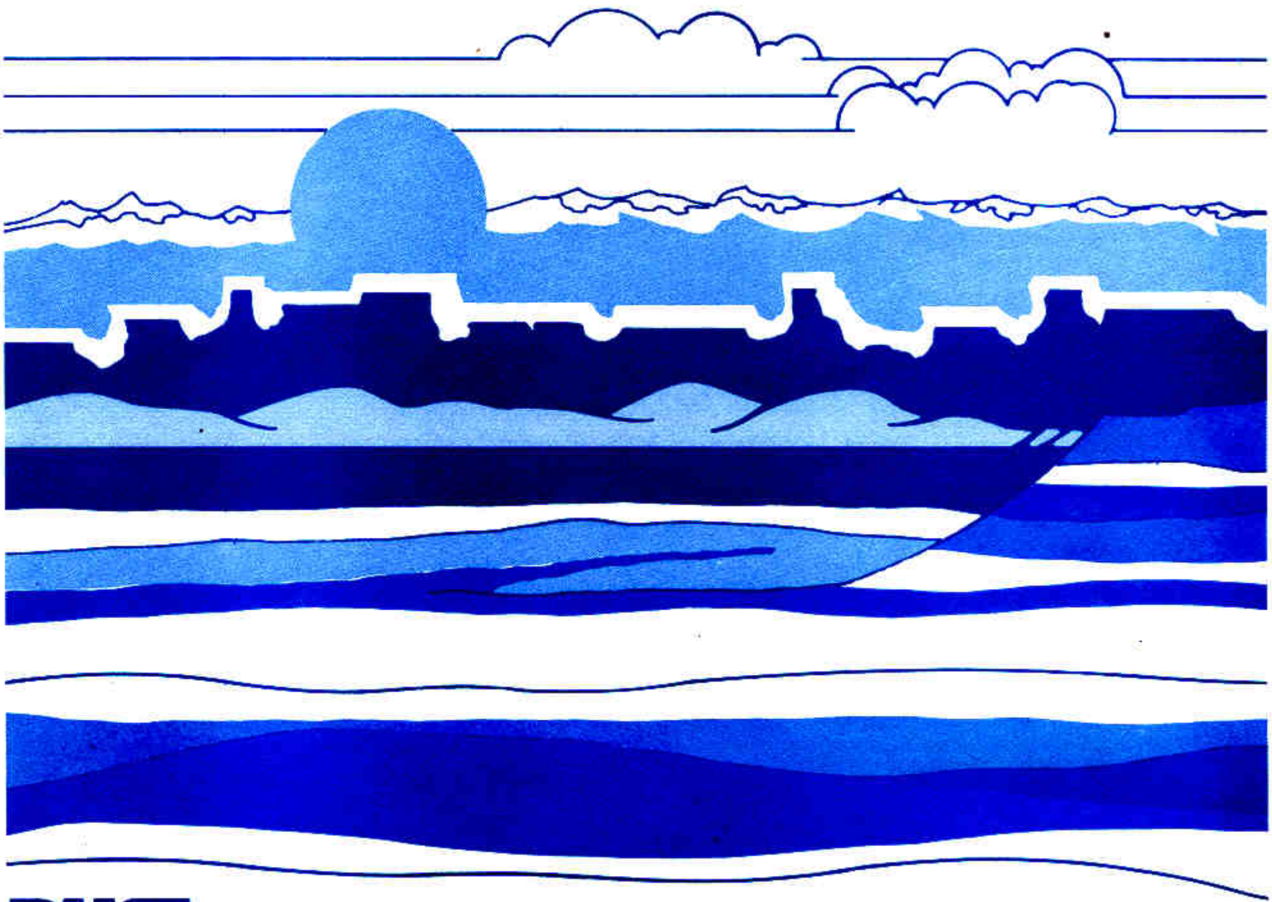
Field Calibration Facilities for Environmental Measurement of Radium, Thorium, and Potassium

Third Edition

R. Leino, D. C. George, B. N. Key, L. Knight, and W. D. Steele

Technical Measurements Center

Grand Junction Projects Office



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Errata Sheet

October 31, 2001

Field Calibration Facilities for Environmental Measurement of Radium, Thorium, and Potassium, DOE/ID/12584-179, Third Edition, U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado, June 1994.

The following models have been removed from the Grand Junction Office facility and disposed of:

H Pads
P Pads
E Pads
L Pads
C Model
PW Model
PD Model
R Model
Thin Dipping Bed Models
300-Foot-Deep Test Hole

Long-Term Surveillance and Maintenance Program
U.S. Department of Energy
Grand Junction, Colorado, Office
(970) 248-6000

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June 1994

Prepared by
RUST Geotech Inc.
P.O. Box 14000
Grand Junction, Colorado 81502

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U.S. Department of Energy
Grand Junction Projects Office

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*****Note*** Table of Contents is linked.**

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Preface

The first edition of this report, prepared by D. C. George and L. Knight and released in October 1982, presented physical-characteristic information for the various U.S. Department of Energy radiologic-instrument calibration facilities located throughout the United States. The primary and secondary calibration facilities are maintained by the Technical Measurements Center. The second edition, prepared by W. D. Steele and D. C. George and released in August 1986, was an effort to provide the most current information available regarding the calibration facilities. This third edition is necessary to keep current with changes to the facilities. Three secondary field calibration facilities were decommissioned and several models were added to or removed from the primary calibration facility. Every attempt has been made to ensure that the information presented is accurate.

Summary

This report describes calibration facilities located at Grand Junction, Colorado, and at three secondary sites. These facilities are available to contractors for the calibration of radiometric field instrumentation for in situ measurements of radium, thorium, and potassium.

The U.S. Department of Energy and its predecessor agencies constructed all of the calibration facilities described herein for use in annual uranium-reserve determinations. The use of these facilities for the calibration of radiometric field instruments used in remedial action is made possible by the commonality of the radiometric measurement technique for uranium and for radium. The use of these facilities standardizes remedial action measurements in a cost-effective manner.

1.0 Introduction and Discussion

The U.S. Department of Energy (DOE) Office of Environmental Management has responsibility for four major remedial action programs: the Grand Junction Remedial Action Program (GJRAP), authorized by congressional legislation,* the Uranium Mill Tailings Remedial Action Project (UMTRAP), also authorized by congressional legislation, the Formerly Utilized Sites Remedial Action Program (FUSRAP),† and the Surplus Facilities Management Program (SFMP).††

In support of these programs, the DOE Office of Environmental Management established the Technical Measurements Center (TMC) in 1982 at the DOE Grand Junction Projects Office in Grand Junction, Colorado. RUST Geotech Inc. is the current contractor responsible for operation of the TMC.

A key component of TMC support is the development, identification, standardization, and maintenance of calibration facilities for environmental radioelement measurements. The borehole facilities also can serve as standards to calibrate high-resolution passive gamma logging systems for analyses of cobalt-60, cesium-137, europium-152, europium-154, and other man-made nuclides (Koizumi et al. 1991; Brodeur et al. 1991; Koizumi et al. 1994). Logging systems calibrated for these anthropogenic gamma-ray emitters have been used to assess subsurface contaminants at the DOE Hanford nuclear weapons facility in Washington State.

Over the past 25 years, DOE and its predecessor agencies have been developing facilities for calibrating gamma-ray-measuring instruments used in uranium exploration. These facilities are also suitable for calibration of gamma-ray instruments used for remedial action measurements, specifically, in situ assays for natural radionuclides. The calibration facilities are available for use free of charge at four sites located throughout the United States (see Figure 1). The primary calibration facilities are located at Grand Junction, Colorado, and secondary facilities are located at each of three sites: Casper, Wyoming, Grants, New Mexico, and George West, Texas.

In addition, calibration pads are currently located at Niagara Falls, New York, and Middlesex, New Jersey (referred to herein as the PP and NP calibration pads). These pads (and the T pads currently located at Grand Junction, Colorado) may be moved as requirements change, and information as to their current location is available from the TMC.

To use any of the facilities described in this report, contact TMC personnel at

RUST Geotech Inc.
P.O. Box 14000
Grand Junction, CO 81502
(303) 248–6702
Fax (303) 248–6040

1.1 Description of the Calibration Facilities

The calibration facilities provide distributed sources of radium, thorium, and/or potassium. In general, they were constructed by enriching a concrete mix with uranium ore, monazite sand, and/or orthoclase sand. The facilities consist of pads and borehole models with the following characteristics:

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*Public Law 92–314, "Radiation Exposure Remedial Action," dated June 16, 1972. Also, "Amendments to Program Providing Remedial Action Regarding Uranium Mill Tailings," dated February 21, 1978.

U S Public Law, 1978. "Uranium Mill Tailings Radiation Control Act of 1978," Public Law 95–604, November 8, 1978.

†In 1974, the Atomic Energy Commission (AEC) initiated a survey program to identify all formerly utilized sites and determine their radiologic status. The survey program was continued by the Energy Research and Development Administration (ERDA) and the U S Department of Energy (DOE), successors to the AEC. In 1978, the Formerly Utilized Sites Remedial Action Program (FUSRAP) was established and a generic program plan was prepared by DOE. Legislative authority for 14 FUSRAP sites is implied in the Atomic Energy Act of 1954, as amended.

††The Atomic Energy Act of 1954, as amended, is the DOE's charter that gives it responsibility for the many Federal sites and facilities involved in various nuclear programs. In 1978, a program plan, the Surplus Facilities Management Program (SFMP), was established by DOE for those sites and facilities classified as surplus and owned by the Federal Government. Beginning in FY 1982, Congress directed that surplus facility projects be budgeted according to their primary use during operation, that is, energy-related or defense-related.

Figure 1. Locations of U.S. Department of Energy Calibration Facilities

- Cylinders approximately 4 feet in diameter by 2 feet high, referred to as "scintillometer pads," "spectrometer pads," or simply "pads."
- Large-area slabs, 30 feet by 40 feet and 1.5 feet thick, referred to as "Walker Field pads" because they are located at Walker Field Airport in Grand Junction, Colorado.
- Cylinders and other equivalent configurations approximately 4 feet in diameter and up to 30 feet deep containing boreholes along their axes, referred to as "borehole models" or simply "models."

This report presents descriptions of the facilities and the accompanying physical-characteristic information contained in Appendices A, B, and C. The values for radioelement concentrations within the models and pads use information from studies conducted by George, Heistand, and Krabacher (1983), Heistand and Novak (1984), and George, Novak, and Price (1985). Information concerning dimensional descriptions of the models and pads, as well as maps to all of the calibration sites, have been updated as required to reflect the latest available information. Concepts and details of calibration procedures for specific instruments are beyond the scope of this report; however, many of these procedures are presented in other TMC reports (Marutzky and others, 1984; George and Price, 1982).

1.2 Characterization of the Calibration Facilities

Over the years, several studies have been performed to characterize the models and pads referred to in this document. The information provided in this third edition regarding the calibration facilities is as current as possible. Every effort has been made to ensure that the data are consistent with DOE remedial action contractor procedures.

Concentrations were not assigned for the barren zones of the models in any of the recent studies. Consequently, barren-zone data have not been included in this report. Because some parameters for the Grand Junction A and D Models were not reassigned, the original assignments have been included here in an effort to present the most complete data set possible. Footnotes presented with each data set are intended to clarify the origin of the assigned parameters.

Tables 1, 2, and 3 are summary descriptions of pads and models at the calibration facilities. The entries in the column labeled "Intended Use" are not necessarily intended to be restrictions on the use of the calibration facility, because some models and pads are useful for several instrument types. The entries in the column labeled "Approximate Concentration" are meant only for order-of-magnitude comparisons. More precise values for the models and pads can be found in Appendices A, B, and C. The entries in the column labeled "Notes" suggest appropriate uses for the pads and models.

Discussions of calibration procedures for specific instrument types can be found in TMC reports by Marutzky and others (1984) and George and Price (1982). It is recommended that personnel involved in remedial action programs who intend to utilize the calibration facilities contact TMC personnel to discuss specific procedures not covered in these documents.

Several units of measure have been used over the years to represent radionuclide concentrations. The accepted units for remedial action programs are picocuries per gram. All concentrations stated herein are reported in picocuries per gram. Useful conversion factors are presented in Appendix D. In addition, Appendix D contains the constants used to derive these conversion factors. The derivation of the conversion factors is discussed in Appendix E.

Table 1. Summary of Surface Calibration Facilities for Radiometric Instruments

Intended Use	Pad Designation	Approximate Concentration[a] Potassium-40 (pCi/g)	Radium-226[b] (pCi/g)	Thorium-232[b] (pCi/g)	Location	Notes
Portable or Mobile Instrument Calibrations	W1	10	1	1	Grand Junction Airport	These large-area pads, 30 ft by 40 ft, are intended for calibration of spectral "surface-surveying" instruments.
	W2	50	2	1		
	W3	20	2	5		
	W4	20	10	1		
	W5	50	8	2		
Portable Spectrometer Calibrations	H1	10	1	1	GJPO[c]	These pads are intended for calibration of portable spectral instruments.
	H2	50	1	1		
	H3	10	160	1		
	H4	10	10	70		
	H5	50	100	20		
Portable Scintillometer and Spectrometer Calibrations	PK, XPK[d]	50	1	0	All Sites	These pads are intended for calibration of both scintillometers and spectral instruments.
	PL, XPL[d]	15	80	1		
	PH, XPH[d]	15	400	1		
	PT, XPT[d]	15	7	30		
	PB, XPB[d]	0	0	0		
	NPL, PPL	11	16	1	See Footnote e	
	NPH, PPH	50	11	1		
	TL1, TL2, TL3, TL4	2	1	10	GJPO[c]	
	TH1, TH3, TH3, TH4	5	1	40		
Portable Scintillometer Calibrations	E1, E2, E4, E5	10, 10, 10, 10	30, 80, 400, 900	1, 1, 1, 1	GJPO[c]	These pads are intended for calibration of portable total-count instruments.
	XE2[d], XE4[d]	10, 10	80, 400	1, 1	C, G, T[c]	
	L1, L2, L3		100, 200, 400		GJPO[c]	These pads were made from the same materials as models A1, A2, and A3. These pads have a 2-inch diameter vertical borehole through the center of the pad.

[a]Concentrations shown are rounded to order of magnitude for purposes of comparison. Consult data sheets in Appendices A, B, and C for concentrations to be used for calibration.
[b]Values tabulated are radiometric equivalent (e) concentrations; see Appendices D and E.
[c]GJPO—Grand Junction Projects Office; C, G, T—secondary sites as explained in footnote d.
[d]The X designates any of the three secondary sites. C = Casper, Wyoming; G = Grants, New Mexico; T = George West, Texas. For example CH is at Casper.
[e]At the time of publication, pad NPL was located at Niagara Falls, New York, and pad NPH was located at Middlesex, New Jersey.

Table 2. Summary of Subsurface Calibration Facilities for Radiometric Instruments

Intended Use	Pad Designation	Approximate Concentration[a]			Location	Notes
		Potassium-40 (pCi/g)	Radium-226[b] (pCi/g)	Thorium-232[b] (pCi/g)		
Spectral Logging System Calibrations	K	50	1	2	GJPO[c]	The K, U, and T models are used to determine stripping factors for spectral logging systems. The U, BU, and XBU models are useful for Ra calibrations for total-count systems. The KW model has five different borehole diameters; the enriched middle zone is a mixture of Ra–Th–K.
	U	10	160	6		
	T	10	10	500		
	KW	40	120	200		
	BK, XBK[d]	50	1	2	All Sites	
	BU, XBU[d]	10	200	8		
	BT, XBT[d]	10	10	600		
	BM, XBM[d]	40	130	500		
Total-Count Logging System Calibrations	N3, U1, U2, U3		700, 7000, 3000, 1500		GJPO[c]	The high concentrations of models in this group make them unsuitable for some logging systems. Lower "radium-only" concentrations can be found in other models. The WF model is useful for water, casing, and hole size corrections; the D model has a lower Ra concentration and is similar to the WF model.
	WF		800			
	XL, XH[d]		800, 6000		C, G, T[c]	
	BL, BH, XBL, XBH[d]		300, 3000		GJPO[c]	
Total-Count Logging Systems Measurements	N1		700		GJPO[c]	The high concentrations of these models make them unsuitable for some logging systems. These models are for experimental use.
	N2		1200			
	N4		700, 2600			
	N5		300, 600, 700, 2700, 4900			
Total-Count and Spectral Logging System Measurements of Thin Dipping Enriched Zones	TDB–1, TDB–2	17	700	1	GJPO[c]	These models are intended for the total-count and spectral measurements of thin dipping enriched zones.
Fission-Neutron Logging System Calibrations	A1, A2, A3, A4, A5, A6		90, 200, 500, 600, 200, 200		GJPO[c]	These models are intended for fission-neutron logging system calibrations. However, they are useful for gamma-ray system calibrations if they have not been recently used with a neutron source. The D model has seven different borehole diameters.
	D		200		GJPO[c]	
	BA, BB, XBA, XBB[d]		60, 800, 900		All Sites	

[a]Concentrations shown are rounded to order of magnitude for purposes of comparison. Consult data sheets in Appendices A, B, and C for concentrations to be used for calibration.
[b]Values tabulated are radiometric equivalent (e) concentrations, see Appendices D and E.
[c]GJPO—Grand Junction Projects Office; C, G, T—secondary sites as explained in footnote d.
[d]The X designates any of the three secondary sites. C = Casper, Wyoming; G = Grants, New Mexico; T = George West, Texas. For example CH is at Casper.

Table 3. Summary of Calibration Facilities for Nonradiometric Instruments

Intended Use	Pad Designation			Location	Notes
		Porosity (vol %)	**Dry Bulk Density (g/cm³)**		
Moisture/Porosity and Density	SW SS, SB	40 20, 5	1.6 2.2, 2.6	GJPO[a]	These models are intended for calibration of moisture/porosity and/or density measurement systems. Model SW is water and sand and also is suitable for tool background determination.
		Magnetic Susceptibility (μCGS)	**Dry Bulk Density (g/cm³)**		
Magnetic Susceptibility Calibration	Granite Block	385	2.63	GJPO[a]	This model is intended for calibration of magnetic susceptibility measurement systems.
		Depth (ft)			
Depth Odometer Verification	300-Foot Test Hole	80.9 180.5		GJPO[a]	This model is intended for verification of depth odometers using measurements of radium sources placed at various depths.

[a]GJPO—Grand Junction Projects Office

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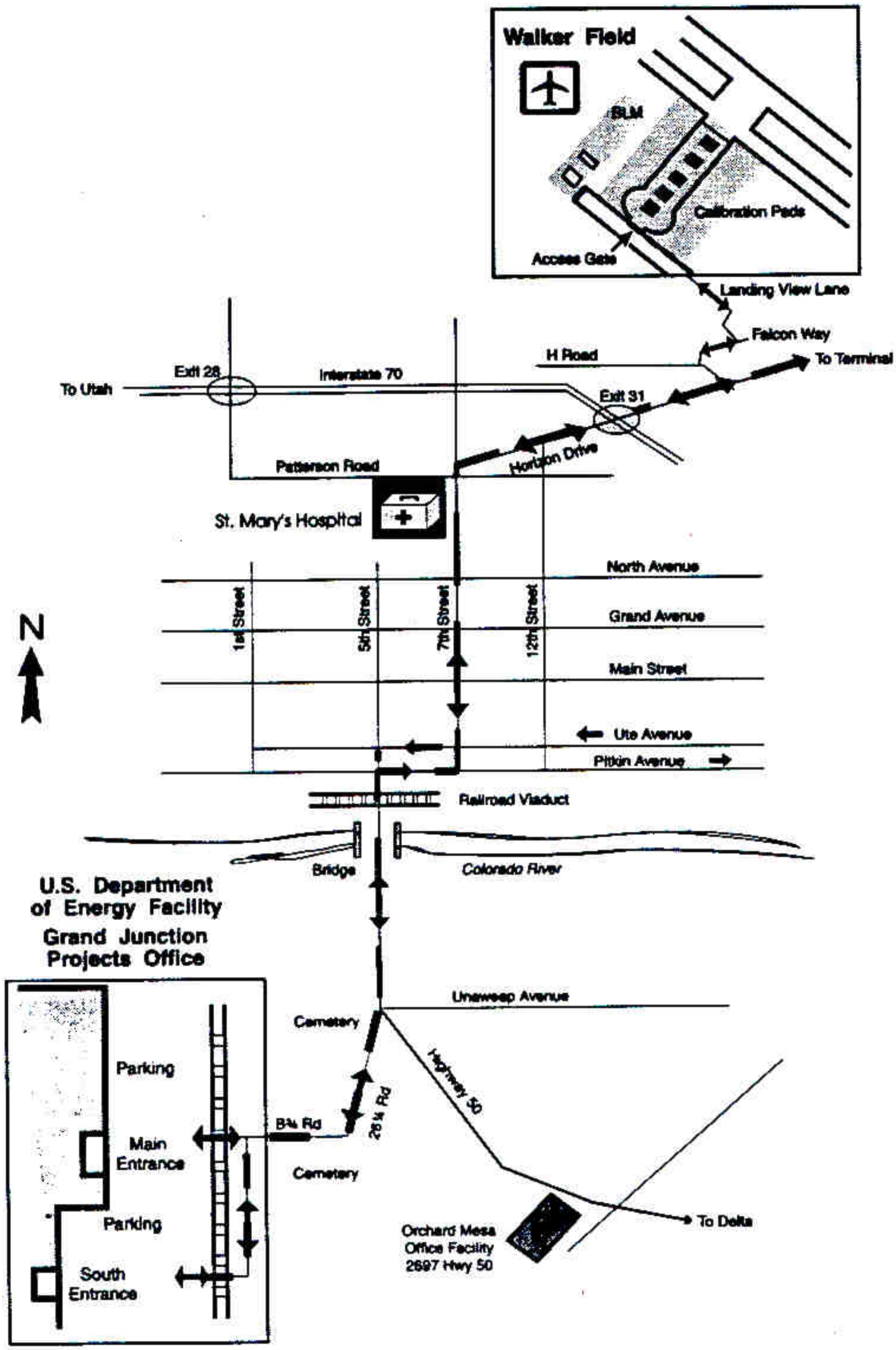
Appendix A
Primary Field Calibration Facilities

Primary Field Calibration Facilities

This appendix presents detailed information concerning location, layout, pad and model descriptions, and radioelement concentrations for the primary calibration facilities at Grand Junction, Colorado. These facilities are administered by the U.S. Department of Energy Grand Junction Projects Office and are maintained and operated by the Technical Measurements Center.

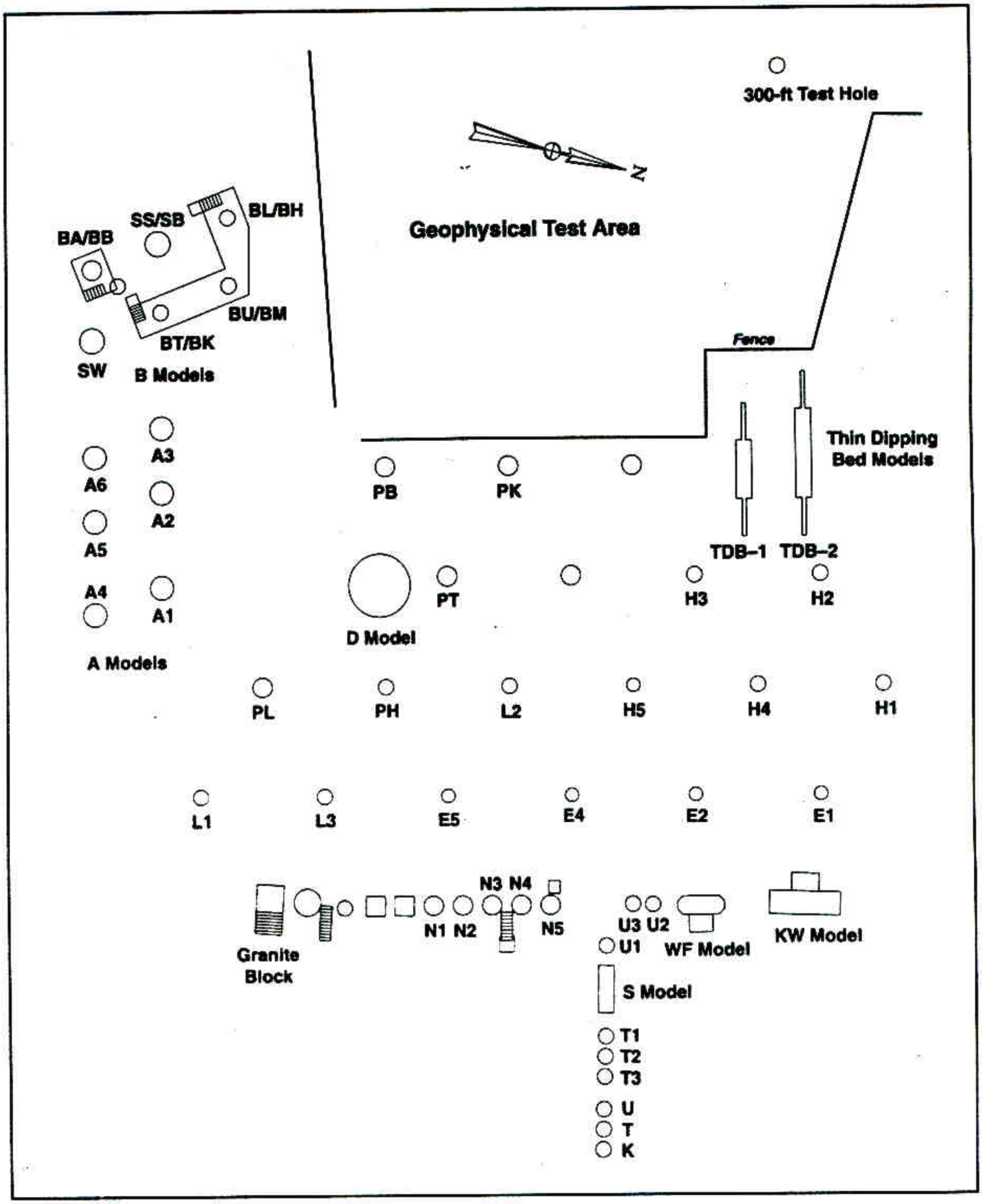
Questions concerning use of the facilities and/or calibration procedures should be addressed to the Technical Measurements Center.

Map to Grand Junction Calibration Site



Map not to scale.

Layout of Grand Junction Calibration and Test Site



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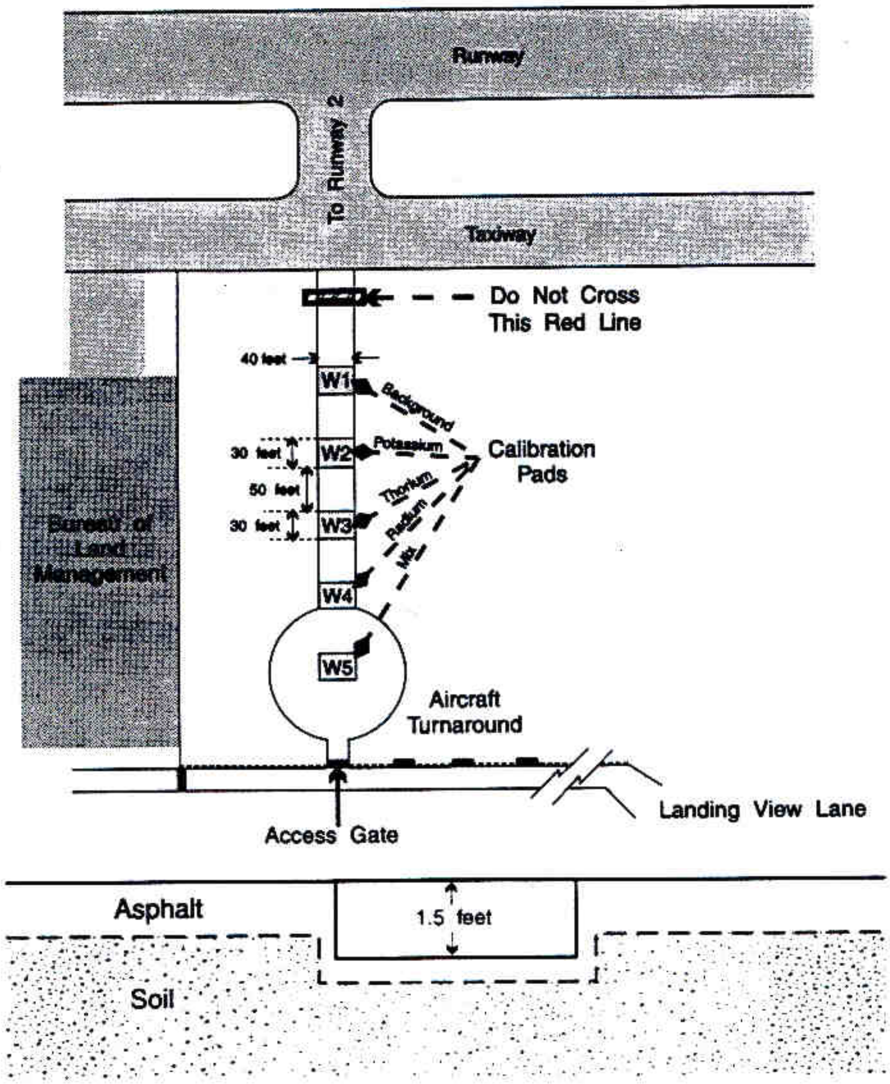
Walker Field Large-Area Calibration Pads: Grand Junction



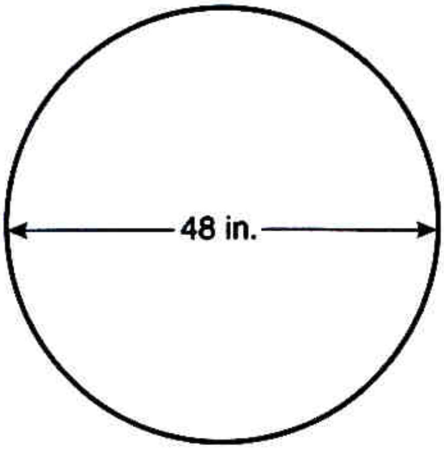
Section (typical)

Table A–1. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a] Ra–226	Th–232	K–40	Dry Bulk Density $(g/cm^3)^b$	Partial Density H_2O $(g/cm^3)^b$
W1	0.82 ± 1.02	0.67 ± 0.10	12.67 ± 0.72	1.91	0.256
W2	1.92 ± 1.54	0.87 ± 0.12	45.58 ± 1.82	1.99	0.260
W3	1.70 ± 1.38	4.92 ± 0.26	17.07 ± 0.82	1.92	0.208
W4	12.07 ± 5.64	1.04 ± 0.12	17.56 ± 0.98	1.91	0.247
W5	8.36 ± 3.52	1.91 ± 0.16	34.68 ± 1.46	1.97	0.244

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

Grand Junction H Pads



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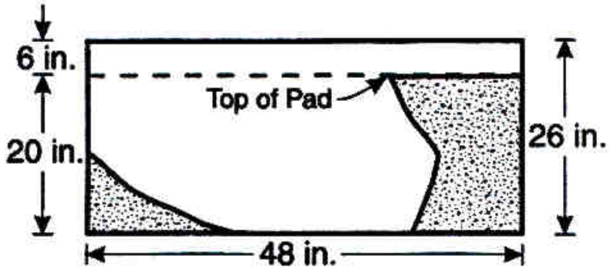


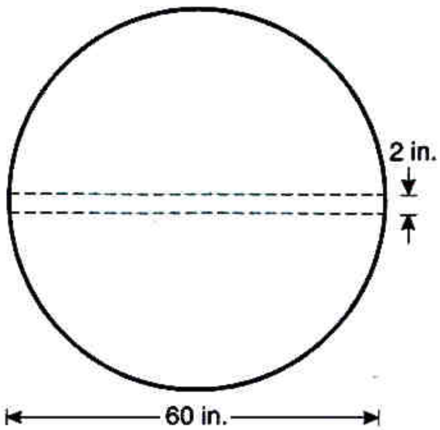
Section

Table A–2. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
	Ra–226	Th–232	K–40		
H1	0.84 ± 0.90	0.67 ± 0.10	10.95 ± 0.62	1.86	0.185
H2	0.67 ± 0.90	0.08 ± 0.06	54.00 ± 1.56	1.87	0.142
H3	161.83 ± 20.40	0.66 ± 0.08	11.31 ± 0.86	1.89	0.181
H4	11.03 ± 4.00	67.90 ± 1.24	10.76 ± 1.48	1.92	0.099
H5	102.59 ± 17.42	19.57 ± 0.54	37.75 ± 1.60	1.93	0.143

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

Grand Junction P Pads



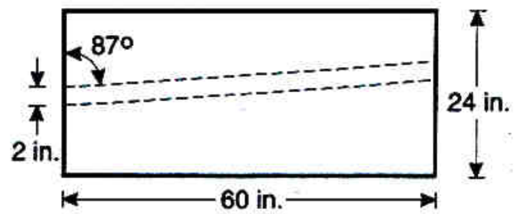


Table A–3. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
	Ra–226	Th–232	K–40		
PK	1.16 ± 0.78	0.04 ± 0.06	50.96 ± 1.50	1.94	0.145
PL	85.71 ± 14.16	0.64 ± 0.10	15.78 ± 1.02	1.90	0.180
PH	374.36 ± 47.06	0.60 ± 0.10	15.80 ± 1.58	1.92	0.180
PT	6.63 ± 3.06	31.28 ± 0.86	14.92 ± 1.08	1.90	0.162
PB[c]	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 0.1	d	d

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.
[c]Pad PB does not have a hole as shown above.
[d]Value not assigned.

Grand Junction E Pads

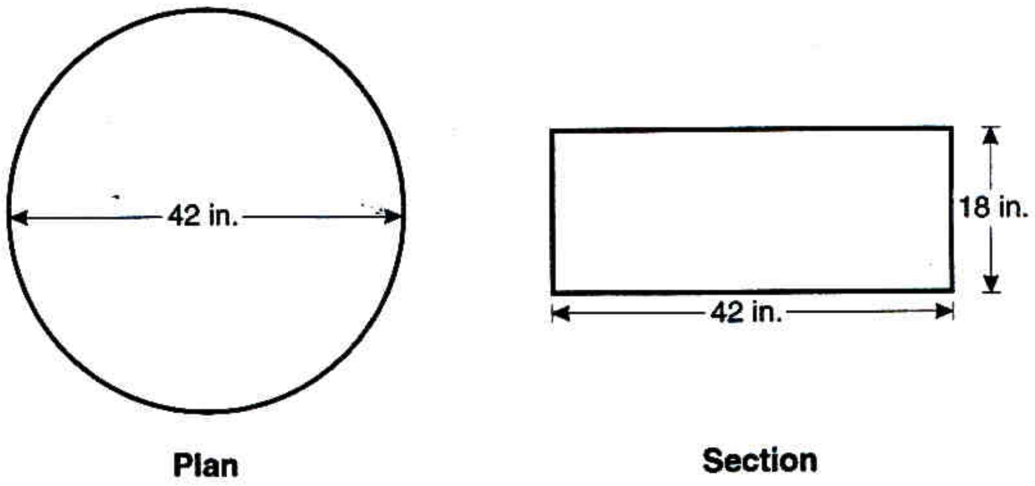
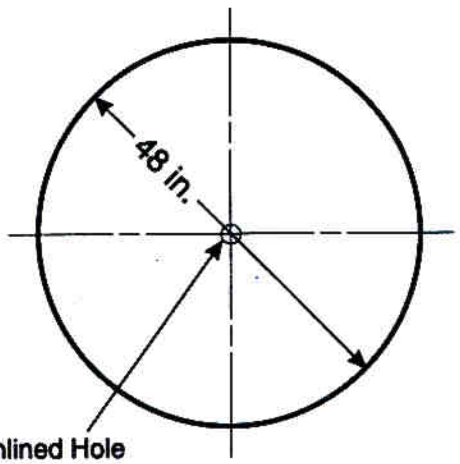


Table A–4. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
	Ra–226	Th–232	K–40		
E1	25.21 ± 6.68	0.67 ± 0.10	13.30 ± 0.72	1.89	0.116
E2	80.34 ± 14.12	0.79 ± 0.10	13.83 ± 0.98	1.84	0.123
E4	395.84 ± 46.92	0.66 ± 0.12	11.43 ± 1.48	1.84	0.143
E5	871.45 ± 97.72	0.75 ± 0.12	14.27 ± 2.18	1.94	0.114

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

Grand Junction L Pads



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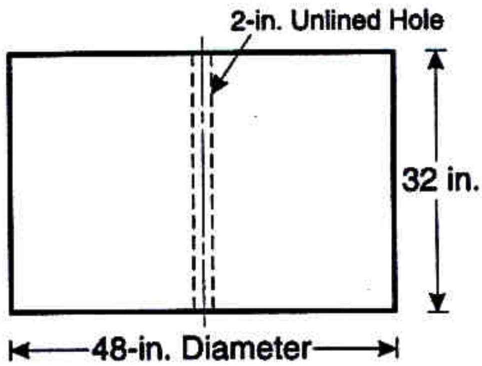


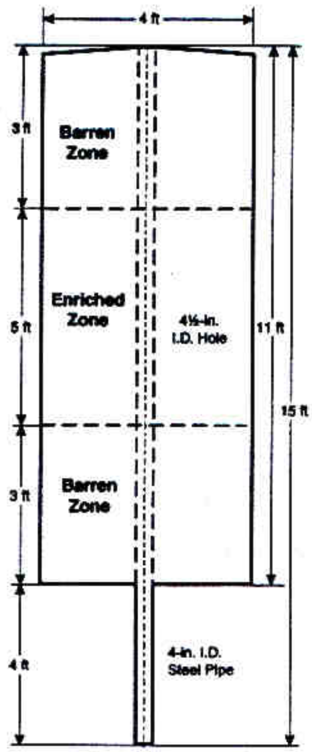
Section

Table A–5. Assigned Parameters

Model Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
	Ra–226	Th–232	K–40		
L1	86.3 ± 2.5[c]	0.73 ± 0.15	15.0 ± 3.0	2.22	0.184[c]
L2	224.7 ± 6.5[c]	1.04 ± 0.35	18.2 ± 4.2	2.17	0.200[c]
L3	455.8 ± 3.3[c]	0.73 ± 0.33	15.5 ± 2.2	2.18	0.195[c]

[a]These models were constructed from the same material as borehole models A1, A2, and A3 and are assumed to have the same parameters. Uncertainties are 95 percent confidence level. Assigned values taken from Koizumi (1979), except as noted.
[b]Uncertainties for these values have not been determined.
[c]Assigned values taken from George and others (1983).

Grand Junction K, U, and T Models



Typical Section

Table A–6.1. Assigned Parameters for Calibration of Spectral Gamma-Ray Logging Systems

Model Designation	Zone	Concentration (pCi/g)[a] Ra–226	Th–232	K–40	Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
K	Enriched	0.92 ± 0.09	0.28 ± 0.03	52.24 ± 1.67	1.86	0.269
U	Enriched	162.9 ± 5.34	0.73 ± 0.06	10.21 ± 0.84	1.89	0.274
T	Enriched	8.47 ± 0.47	53.03 ± 1.49	10.38 ± 1.17	1.88	0.275

[a]Uncertainties are 95 percent confidence level. Assigned values taken from Heistand and Novak (1984).
[b]Uncertainties for these values have not been determined.

Table A–6.2. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm³)[c]	Partial Density H_2O (g/cm³)[c]
U	Enriched	158 ± 6.0	4.98 ± 0.00	1.89	0.274

[a]Uncertainties are 95 percent confidence level. Assigned value taken from George and others (1983).
[b]Uncertainty reported as 0.00 is not zero, but is less than 0.01 ft.
[c]Uncertainties for these values have not been determined.

Grand Junction KW Model

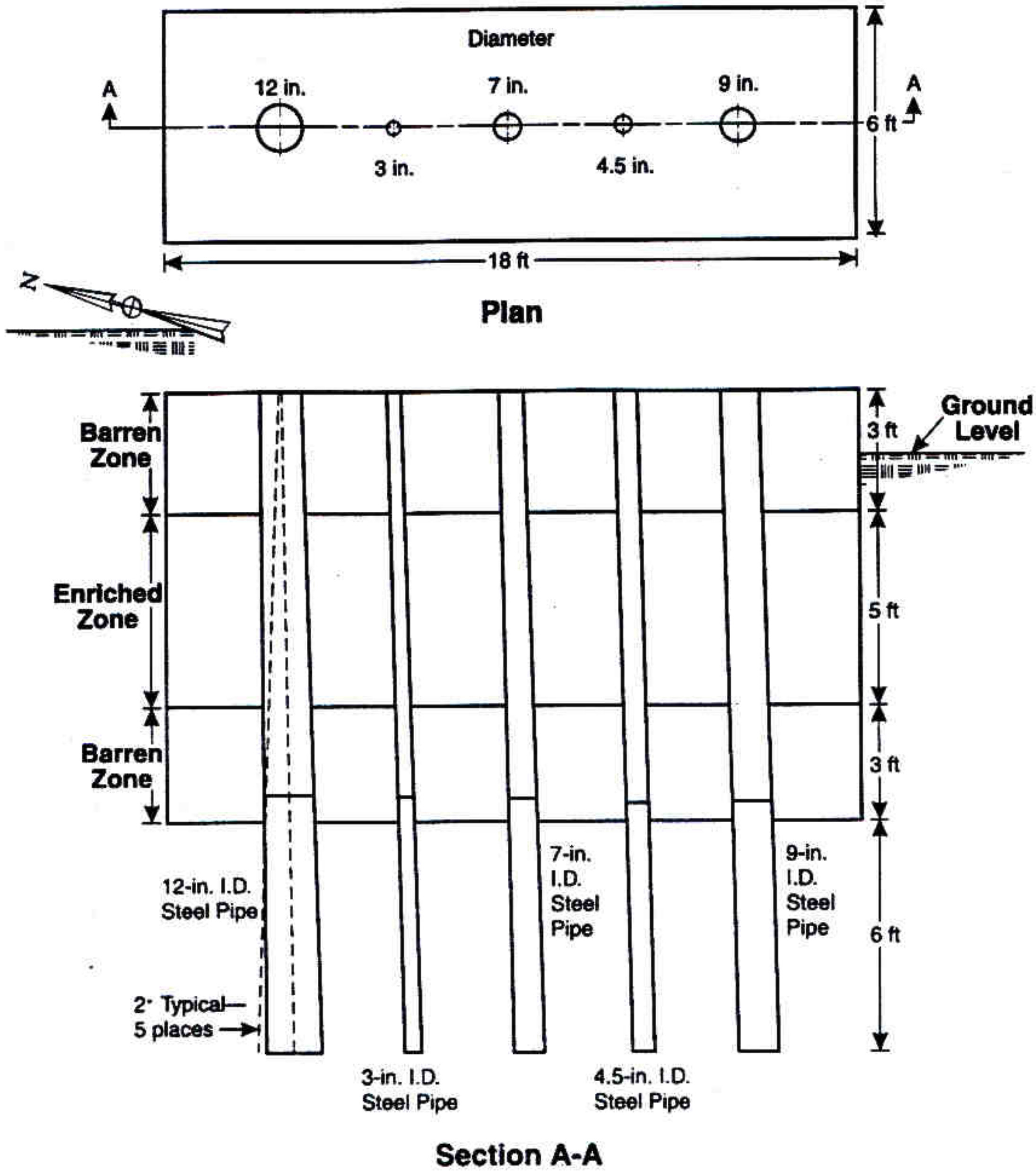
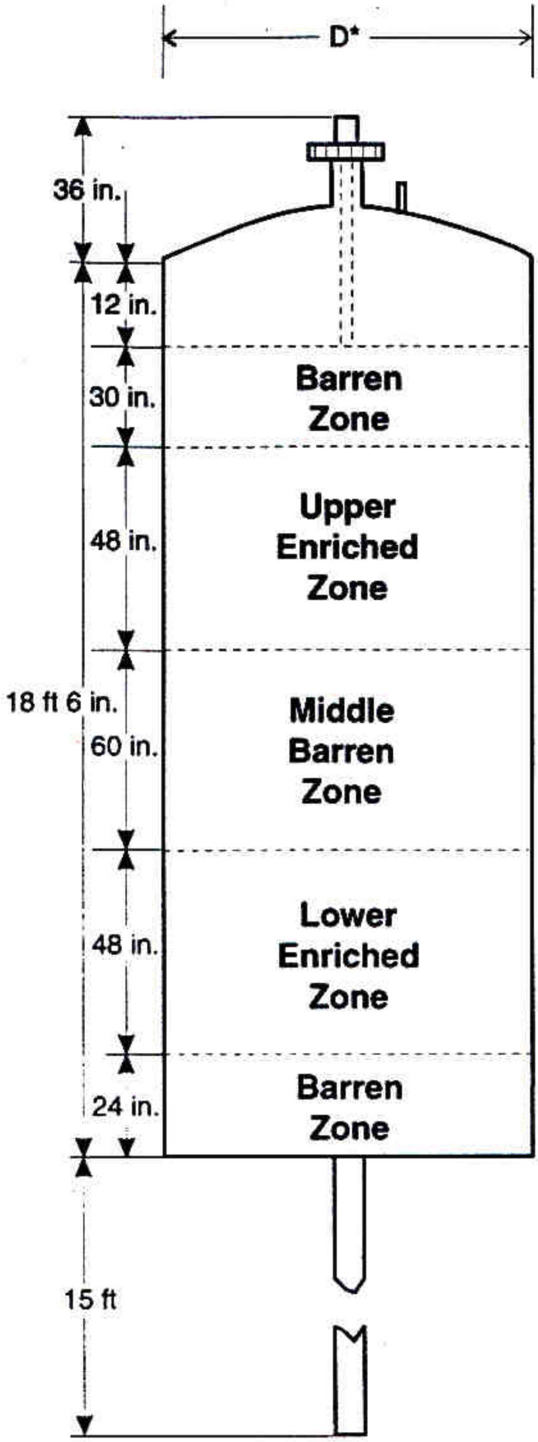


Table A–7. Assigned Parameters for Calibration of Spectral Gamma-Ray Logging Systems

Model Designation	Zone	Concentration (pCi/g)[a] Ra–226	Th–232	K–40	Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
KW	Enriched	120.55 ± 4.00	26.71 ± 0.79	38.43 ± 1.67	1.86	0.264

[a]Uncertainties are 95 percent confidence level. Assigned values taken from Heistand and Novak (1984).
[b]Uncertainties for these values have not been determined.

Grand Junction BL/BH, BT/BK, BU/BM, and BA/BB Models



*D

Model	Diameter (in.)
BL/BH	48
BT/BK	48
BU/BM	48
BA/BB	60

Table A–8.1. *Assigned Parameters for Calibration of Total-Count Gamma-Logging Systems*

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
BU	Upper	188 ± 6	4.01 ± 0.02	1.91	0.243
BL	Upper	334 ± 9	3.97 ± 0.00	2.23	0.188
BH	Lower	3136 ± 181	4.00 ± 0.02	2.22	0.196
BA	Upper	62.4 ± 1.8	3.99 ± 0.00	2.22	0.187
BB	Lower	913 ± 27	3.97 ± 0.00	2.21	0.188

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.01 ft.
[c]Uncertainties for these values have not been determined.

Table A–8.2. *Assigned Parameters for Calibration of Spectral Gamma-Ray Logging Systems*

Model Designation	Zone	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
		Ra–226	Th–232	K–40		
BT	Upper	10.46 ± 0.51	58.78 ± 1.53	10.13 ± 1.34	1.91	0.244
BK	Lower	1.03 ± 1.67	0.10 ± 0.02	54.00 ± 1.67	1.81	0.250
BU	Upper	194.59 ± 5.94	0.65 ± 0.06	10.63 ± 1.00	1.91	0.243
BM	Lower	131.16 ± 4.07	40.12 ± 1.09	42.86 ± 2.01	1.88	0.251

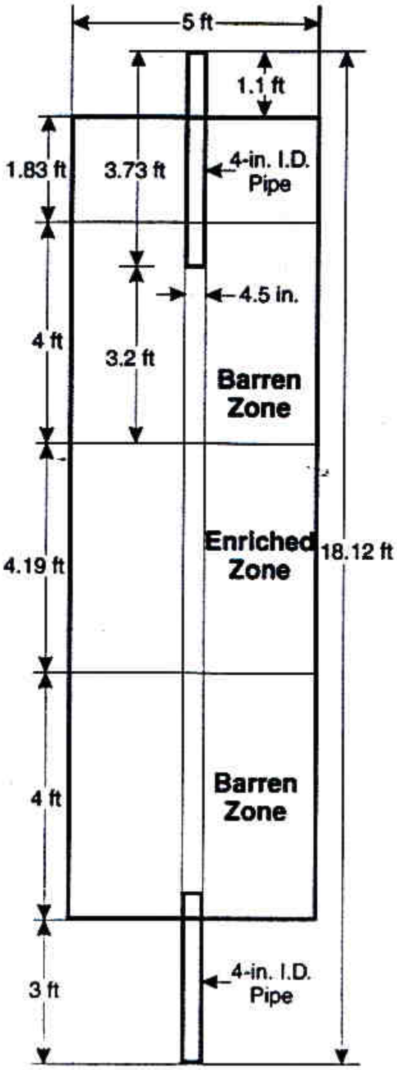
[a]Uncertainties are 95 percent confidence level. Assigned values taken from Heistand and Novak (1984).
[b]Uncertainties for these values have not been determined.

Table A–8.3. *Assigned Parameters for Calibration of Fission-Neutron Logging Systems*

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Partial Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
BA	Upper	62.4 ± 1.8	3.99 ± 0.00	2.22	0.187
BB	Lower	913 ± 27	3.97 ± 0.00	2.21	0.188

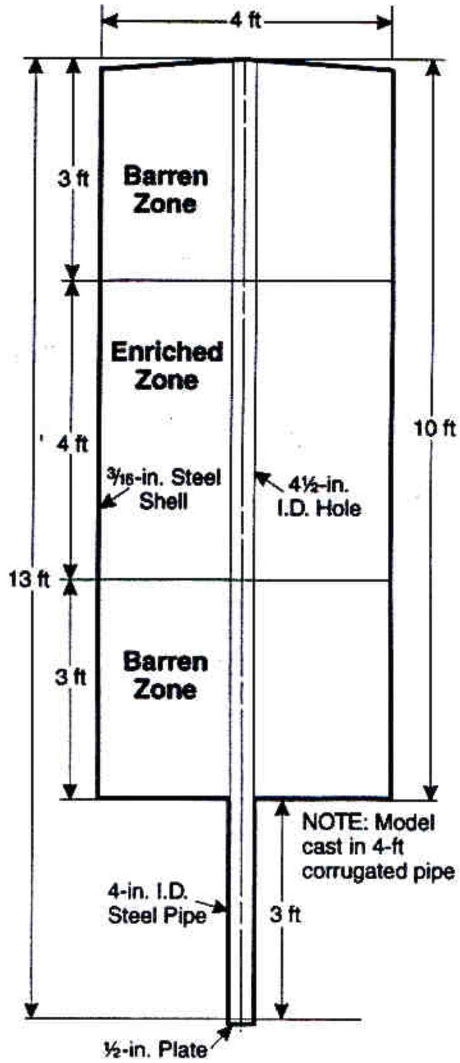
[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.01 ft.
[c]Uncertainties for these values have not been determined.

Grand Junction N3, U1, U2, and U3 Models



Section

N3 Model



Typical Section

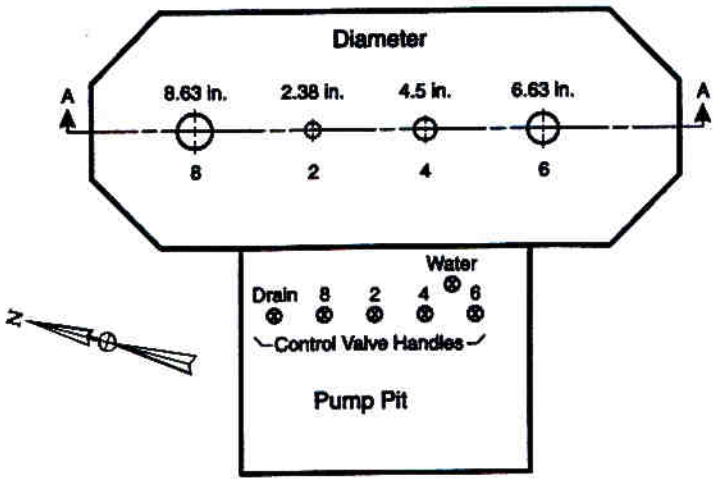
U1, U2, and U3 Models

Table A–9. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

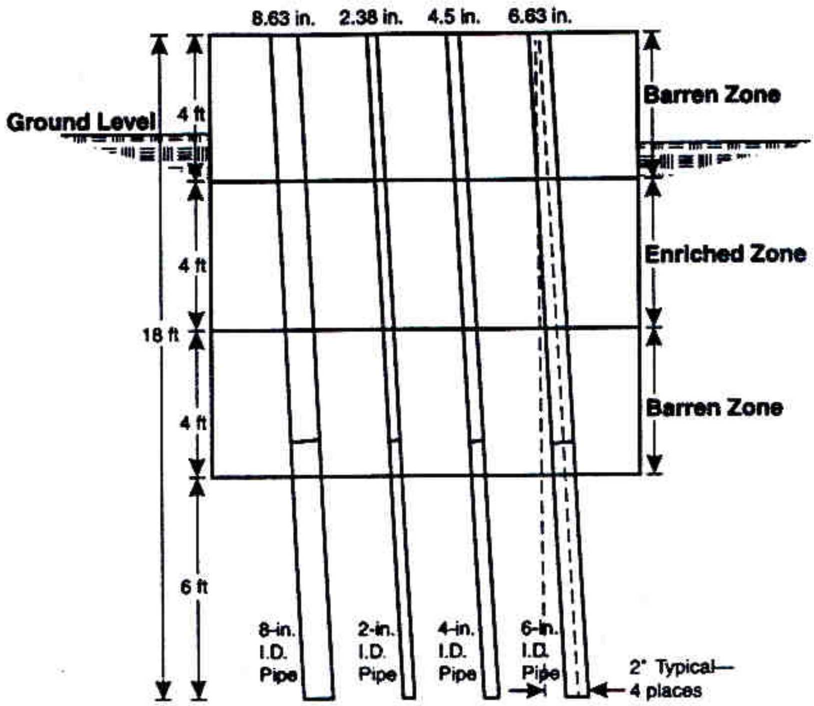
Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
N3	Enriched	654 ± 23	4.19 ± 0.00	1.83	0.281
U1	Enriched	7460 ± 465	4.06 ± 0.02	2.07	0.255
U2	Enriched	3478 ± 218	4.01 ± 0.00	1.70	0.295
U3	Enriched	1278 ± 51	4.01 ± 0.00	1.67	0.304

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Uncertainties for these values have not been determined.

Grand Junction WF Model



Plan



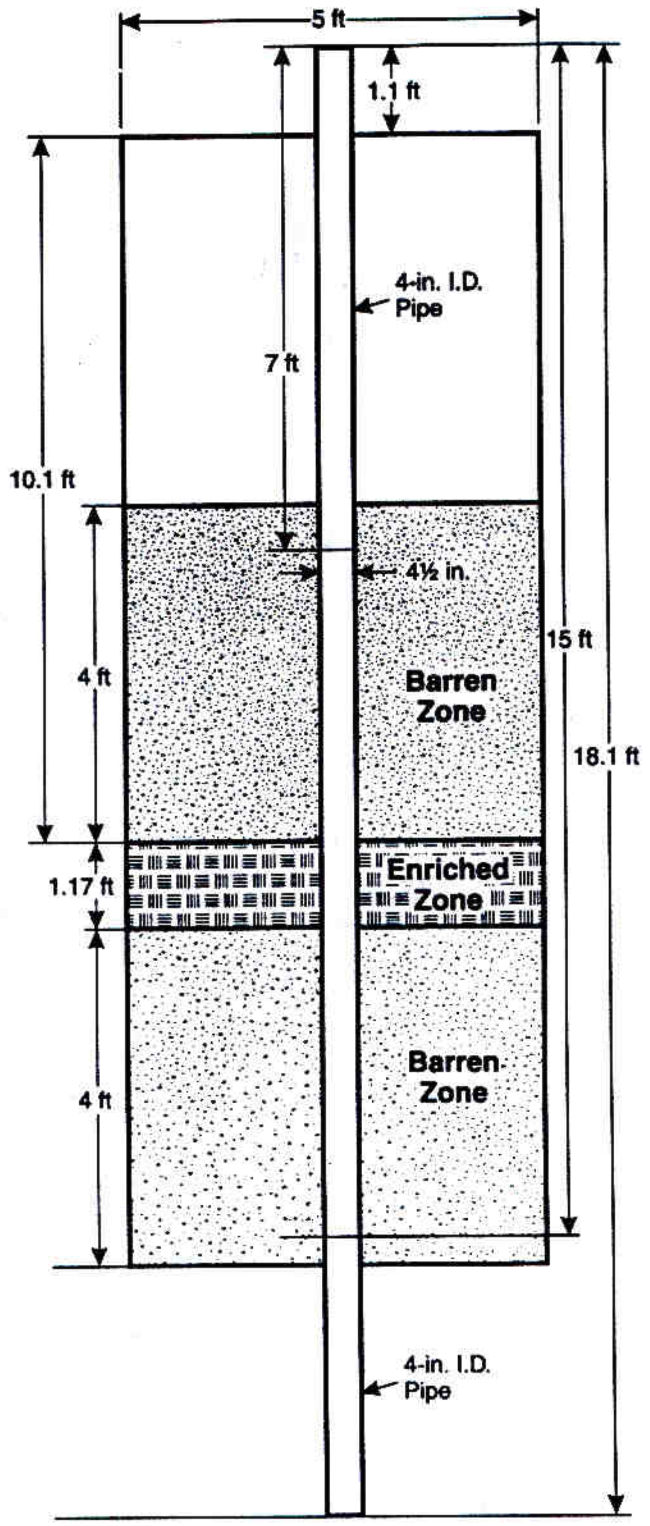
Section A-A

Table A–10. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
WF	Enriched	850 ± 30	4.02 ± 0.00	1.86	0.282

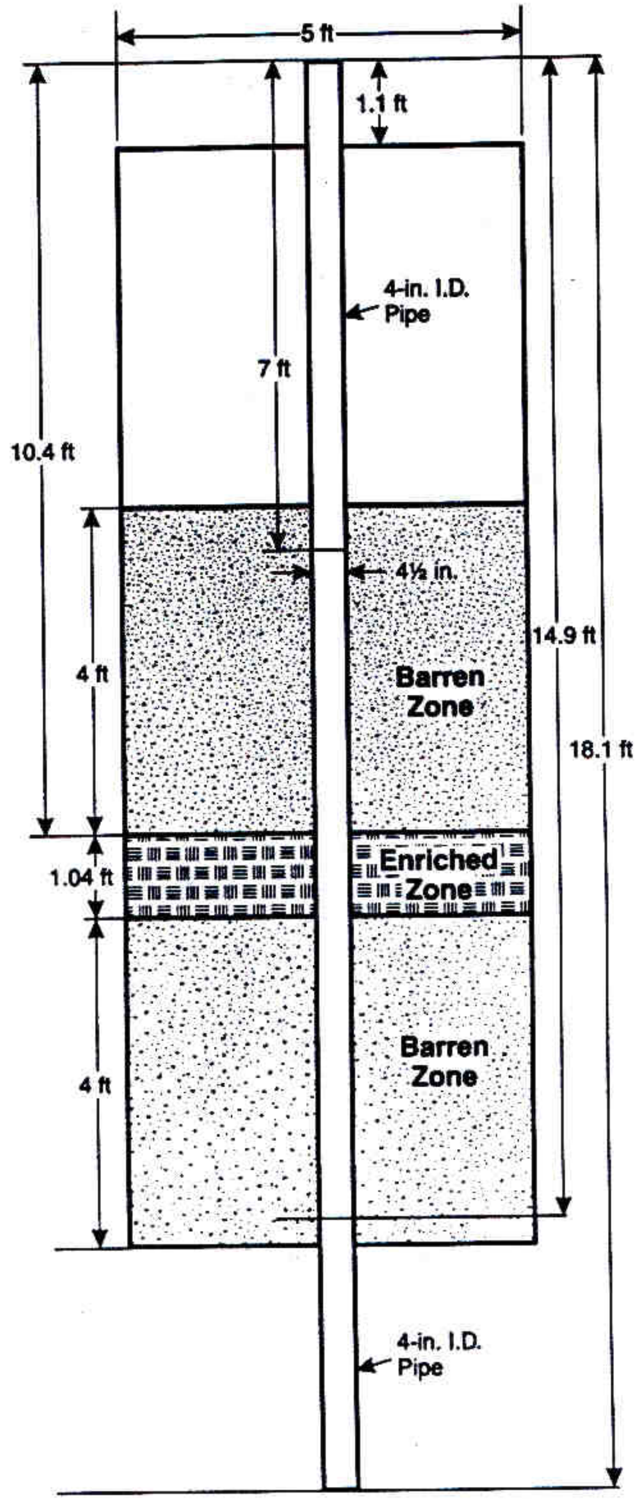
[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Uncertainties for these values have not been determined.

Grand Junction N1 Model



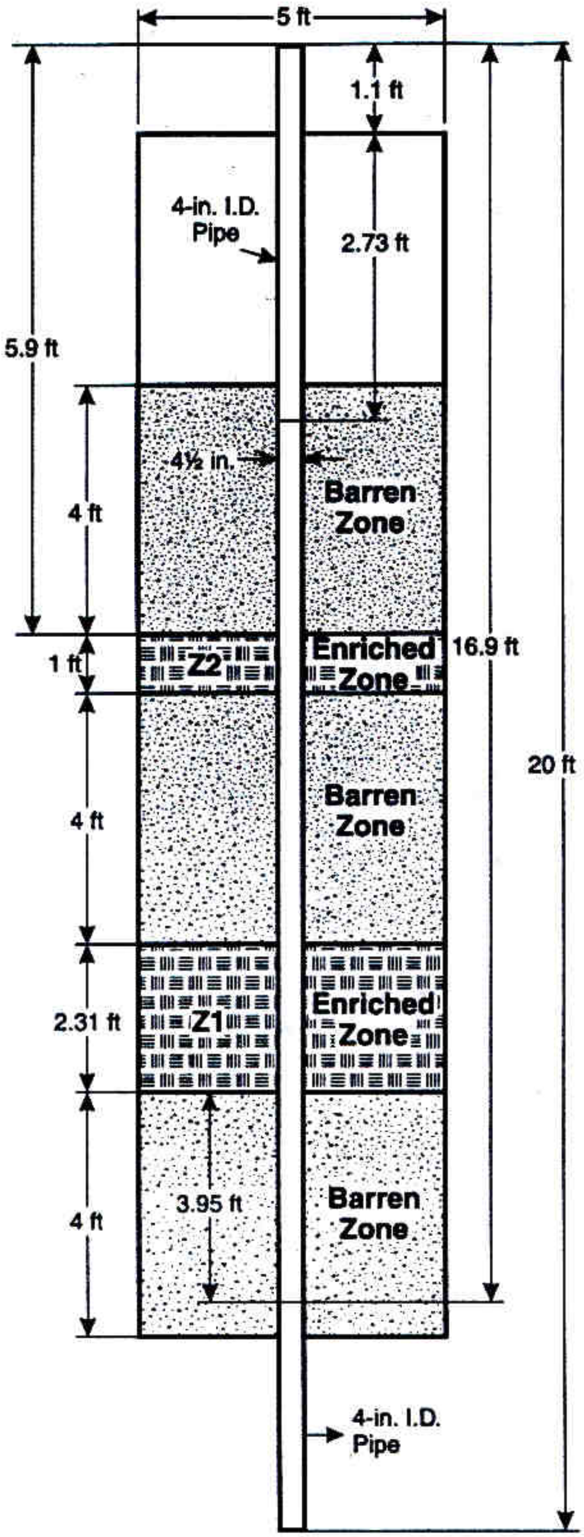
Dimensions shown are for reference only; complete as-built dimensions are not available.

Grand Junction N2 Model



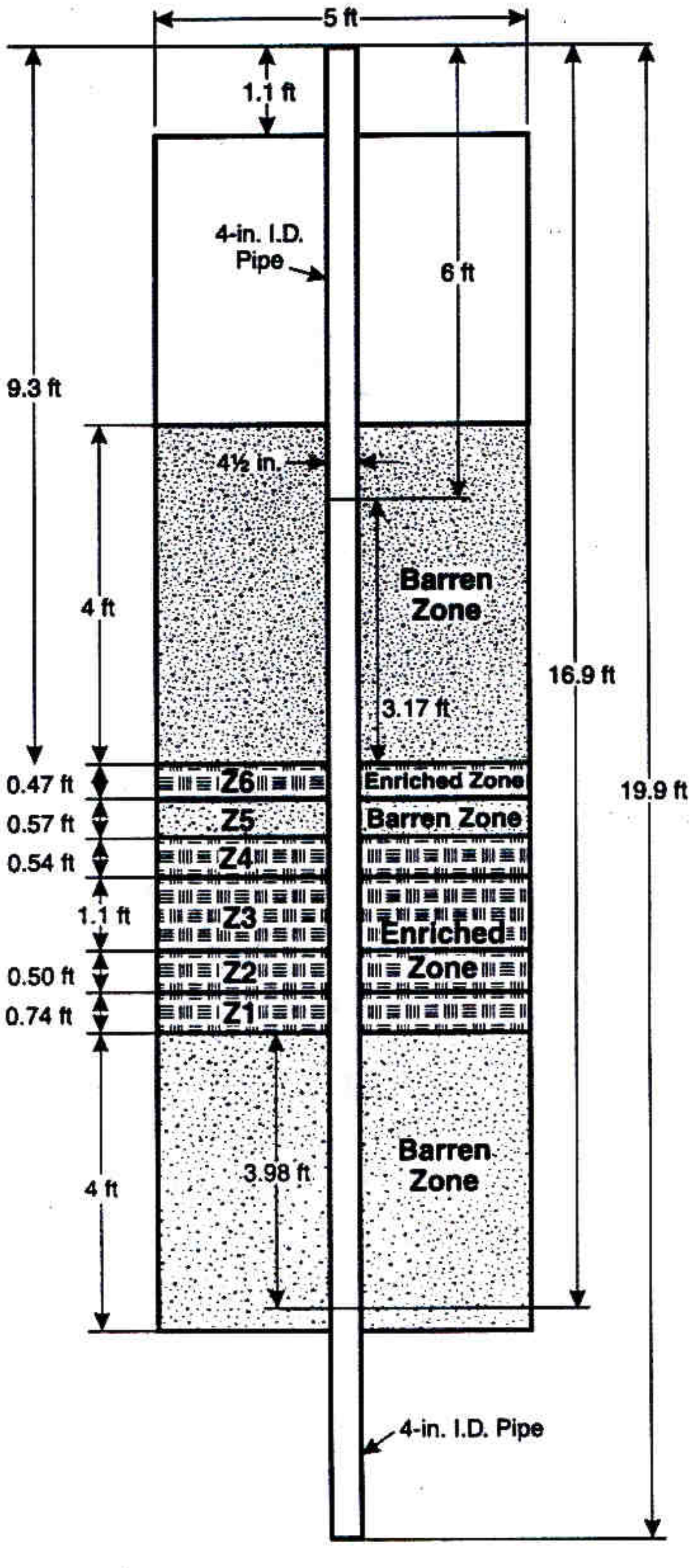
Dimensions shown are for reference only; complete as-built dimensions are not available.

Grand Junction N4 Model



Dimensions shown are for reference only; complete as-built dimensions are not available.

Grand Junction N5 Model



Dimensions shown are for reference only; complete as-built dimensions are not available.

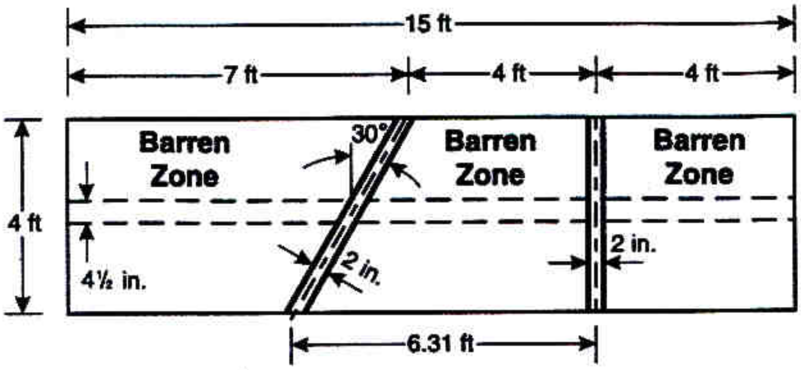
Table A–11. Assigned Parameters[a]

Model Designation	Zone	Ra–226 Concentration (pCi/g)[b,c]	Uranium Concentration (U ppm)[b,c]	Thickness (in.)[c]
N1	Enriched	702	1,642	14.0
N2	Enriched	1,216	3,218	12.5
N3	Enriched	654	1,573	50.3
N4	Z1 Enriched	696	1,628	27.8
N4	Z2 Enriched	2,599	7,527	12.0
N5	Z1 Enriched	708	1,662	8.9[d]
N5	Z2 Enriched	291	712	6.0[d]
N5	Z3 Enriched	2,678	7,714	13.2
N5	Z4 Enriched	620	1,454	6.5
N5	Z5 Barren[d]	—	—	6.8
N5	Z6 Enriched[d]	4,852	13,830	5.6

[a]Values for dry bulk density have not been determined.
[b]Assigned values, except for N3 Ra–226 concentration and thickness taken from George and others (1983), are calculated using conversion factors in Appendix D and values taken from an internal report Matthews (1975). The values reported were determined by "gamma-only" and chemical analyses on samples taken from the model during its construction.
[c]Uncertainties of the values have not been determined.
[d]Data for four zones in N5 are based on analysis of logging data published by Bristow and others (1984), data which was subsequently substantiated by researchers at the GJPO.

Grand Junction Thin Dipping Bed Models

Model TDB–1



Model TDB–2

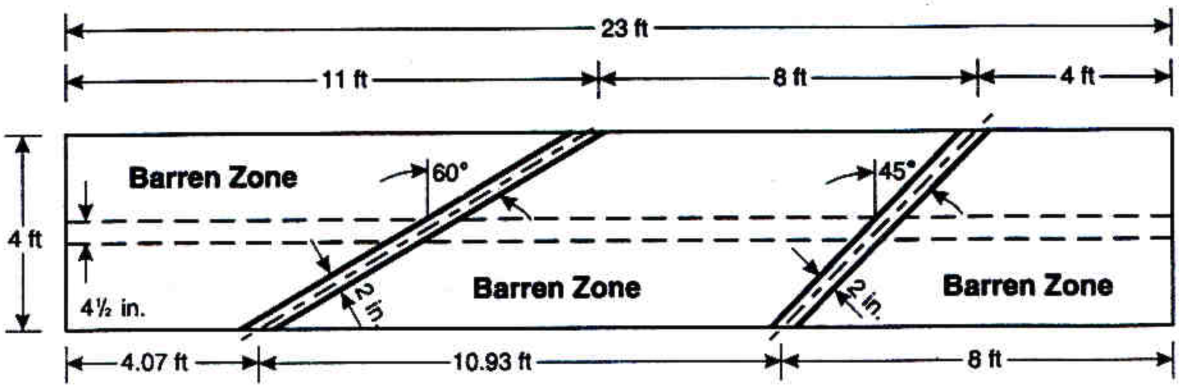


Table A–12.1. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (in.)[b]	Dry Bulk Density (g/cm^3)	Partial Density H_2O (g/cm^3)[c]
TDB	Enriched	710.6 ± 6.8	2.0	1.90 ± 0.05	—

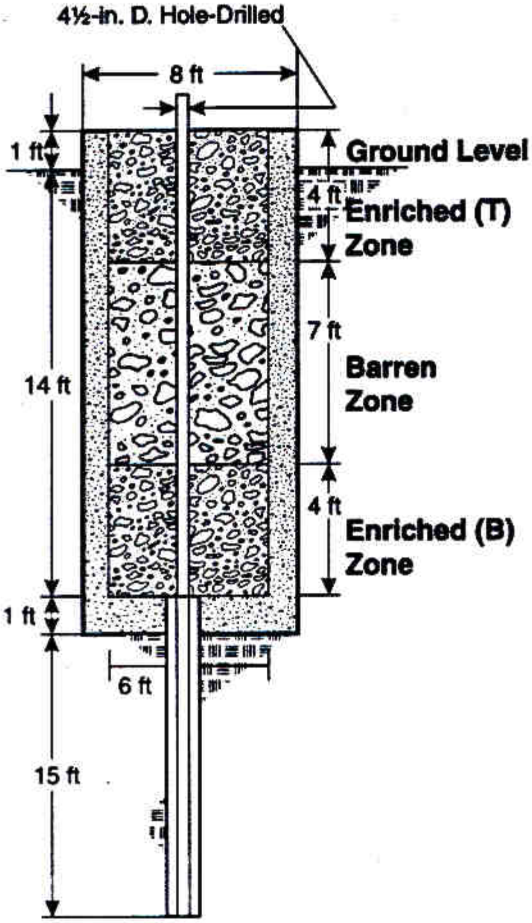
[a]Uncertainties are 95 percent confidence level. Assigned values taken from Koizumi (1980). Value determined by NaI(Tl) based total gamma-ray method.
[b]Uncertainties for these values have not been determined.
[c]Value has not been determined.

Table A–12.2. Assigned Parameters for Calibration of Spectral Gamma-Ray Logging Systems

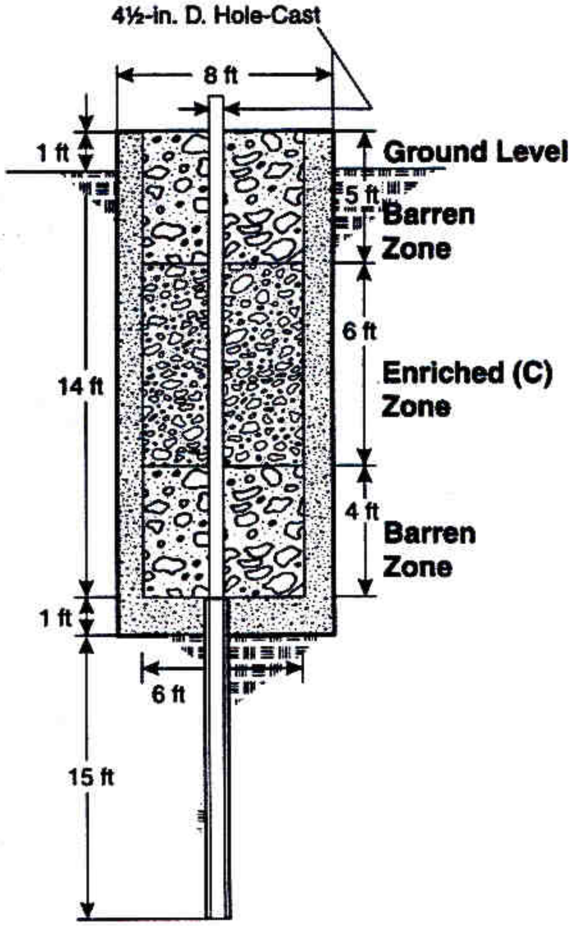
Model Designation	Zone	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)	Partial Density H_2O (g/cm^3)[b]
		Ra–226	Th–232	K–40		
TDB	Enriched	694.7 ± 6.8	0.94 ± 0.54	17.64 ± 8.7	1.90 ± 0.05	—

[a]Uncertainties are 95 percent confidence level. Assigned values taken from Koizumi (1980). Values determined by Ge(Li) based spectral gamma-ray method.
[b]Value has not been determined.

Grand Junction A Models



A5 and A6 Models



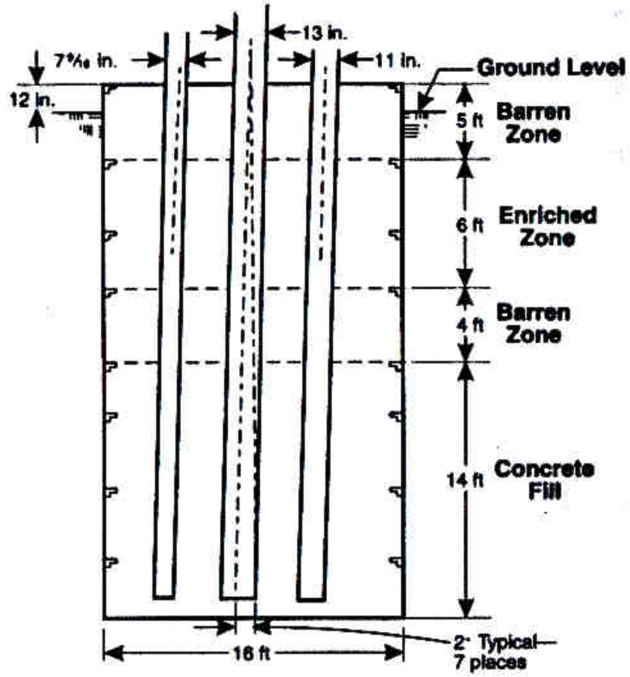
A1, A2, A3, and A4 Models

Table A-13. Assigned Parameters for Calibration of Fission-Neutron Logging Systems[a]

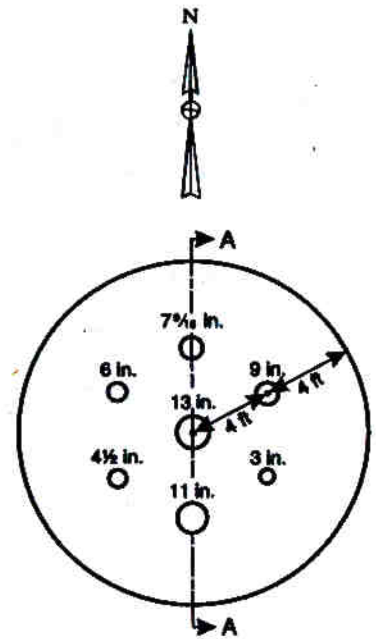
Model Designation	Zone	Zone Thickness (ft)[b]	Characteristic[c]	Concentration (pCi/g)			Dry Bulk Density (g/cm^3)[d]	Partial Density H_2O (g/cm^3)[d]	Grain Density (g/cm^3)[d]	Porosity (%)[d]	Magnetic Susceptibility (10^{-6} cgs)[d]
				Ra-226	Th-232	K-40					
A1	C	6.01 ± 0.00[e]	–	86.3 ± 2.5[e]	0.73 ± 0.15	15.0 ± 3.0	2.22	0.184[e]	–	18[f]	841
A2	C	5.94 ± 0.00[e]	–	224.7 ± 6.5[e]	1.04 ± 0.35	18.2 ± 4.2	2.17	0.200[e]	–	18[f]	804
A3	C	5.95 ± 0.00[e]	–	455.8 ± 13.3[e]	0.73 ± 0.33	15.5 ± 2.2	2.18	0.195[e]	–	18[f]	822
A4	C	6	–	600.5 ± 270.1	0.92 ± 0.37	17.8 ± 8.4	2.22	–	–	18[f]	844
A5	T	4	High Σ	204.6 ± 20.8	1.16 ± 0.31	20.1 ± 8.4	2.17	–	2.64	17.8	741
A5	B	4	High ρ	208.6 ± 6.5	0.86 ± 0.22	19.6 ± 4.2	2.40	–	2.92	17.8	596
A6	T	4	High ø	206.6 ± 7.5	0.78 ± 0.13	13.9 ± 3.5	1.85	–	2.60	28.8	348
A6	C	4	Low ø	201.8 ± 60.0	0.98 ± 0.15	18.8 ± 3.7	2.21	–	2.64	16.3	1055

[a]Uncertainties are 95 percent confidence level. Assigned values taken from Koizumi (1979), except as noted.
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Σ = macroscopic neutron cross section; ρ = density; ø = porosity.
[d]Uncertainties for these values have not been determined.
[e]Assigned values taken from George and others (1983).
[f]Estimated.

Grand Junction D Model



Section A-A



Plan

Table A–14. Assigned Parameters for Calibration of Fission-Neutron Logging Systems[a]

Model Designation	Zone	Zone Thickness (ft)[b]	Concentration (pCi/g)			Dry Bulk Density (g/cm^3)	Partial Density H_2O (g/cm^3)[b]	Grain Density (g/cm^3)	Porosity (%)	Magnetic Susceptibility (10^{-6} cgs)
			Ra–226[b]	Th–232	K–40					
D	Enriched	5.80 ± 0.00[c]	218 ± 7	0.84 ± 0.37	14.9 ± 4.4	2.12 ± 0.06	0.216	2.72 ± 0.14	22.1 ± 0.2	826 ± 94

[a]Uncertainties are 95 percent confidence level. Assigned values taken from Koizumi (1979), except as noted.
[b]Assigned value taken from George and others (1983).
[c]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.

Grand Junction SW Model

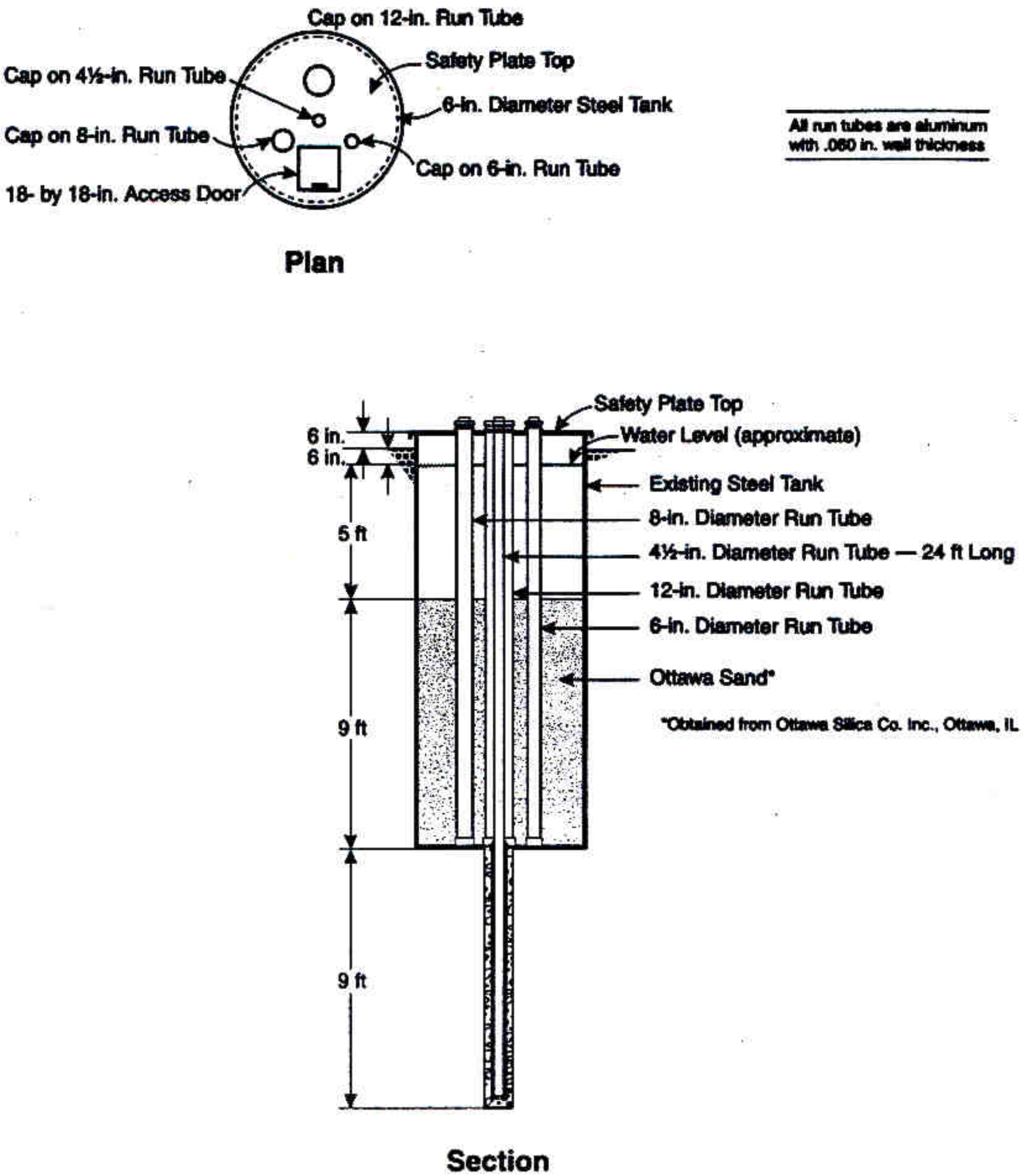
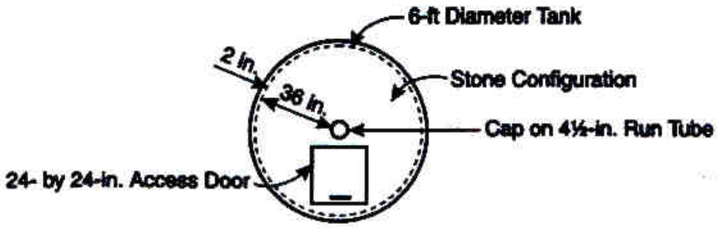


Table A–15. Assigned Parameters[a]

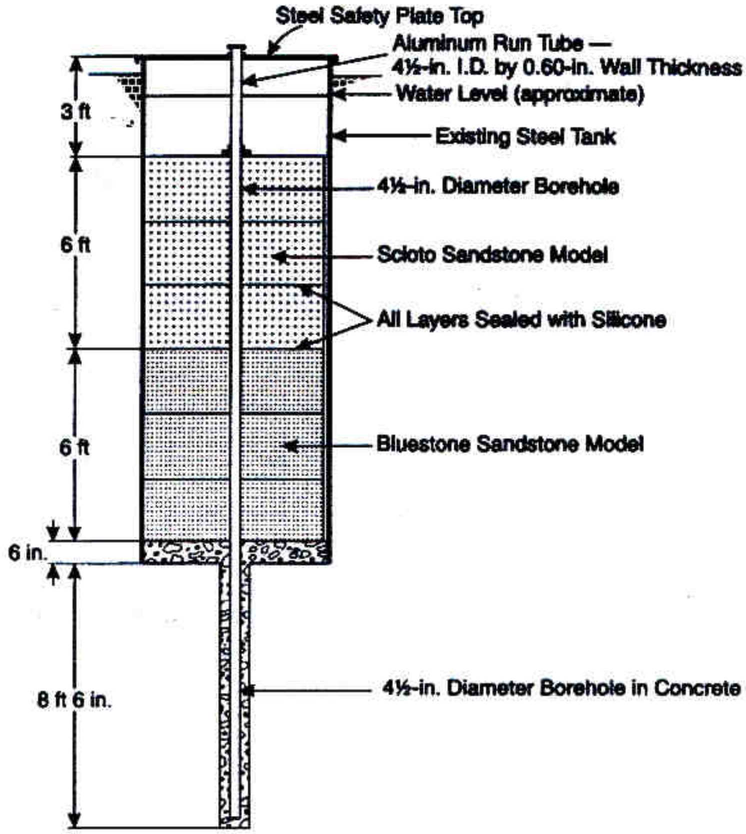
Zone Designation	Zone Description	Porosity (vol %)[b]	Dry Bulk Density (g/cm^3)[b]	Wet Bulk Density (g/cm^3)[b]	Grain Density (g/cm^3)[b]	Moisture Fraction (wt %)[b]
W	Water	0	–	1.0	–	100
WS	Ottawa Sand	36.0	1.60	1.96	2.50	18.4

[a]Assigned values taken from George (1986) and George (in preparation).
[b]Uncertainties for these values have not been determined.

Grand Junction SS/SB Model



Plan



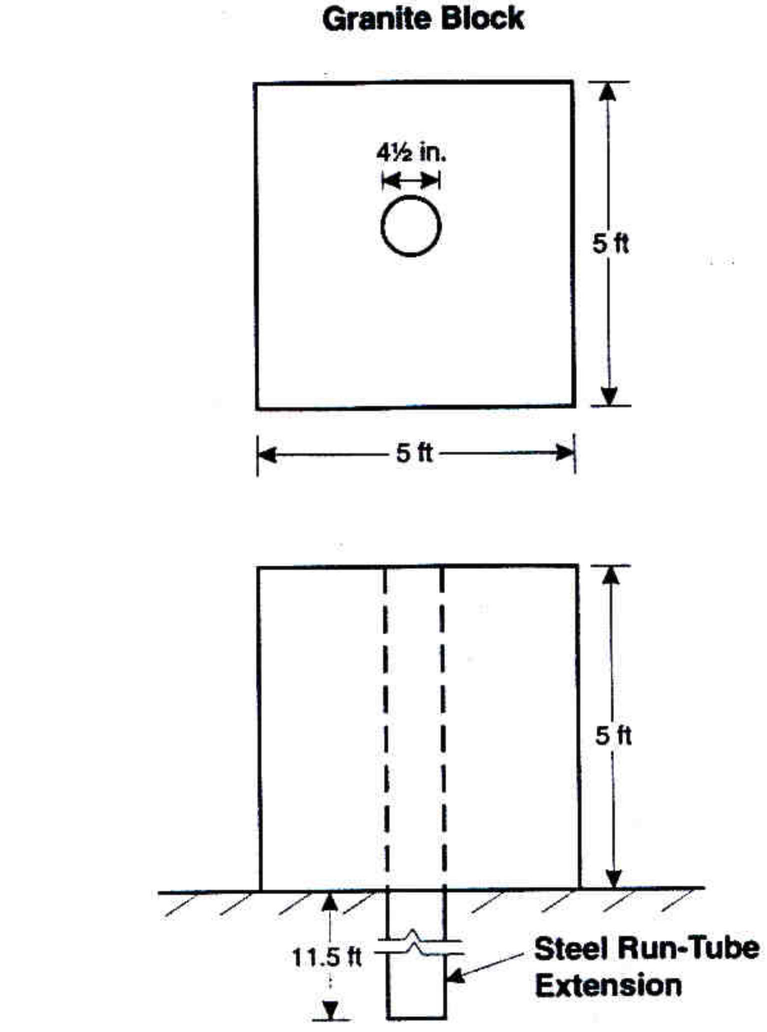
Section

Table A–16. Assigned Parameters[a]

Zone Designation	Zone Description	Porosity (vol %)[b]	Dry Bulk Density (g/cm^3)[b]	Wet Bulk Density (g/cm^3)[b]	Grain Density (g/cm^3)[b]	Moisture Fraction (wt %)[b, c]
SS	Scioto Sandstone	18.3	2.20	2.38	2.69	7.7
SB	Bluestone Sandstone	5.1	2.60	2.65	2.74	1.9

[a]Assigned values taken from George (1986) and George (in preparation).
[b]Uncertainties for these values have not been determined.
[c]100 percent saturation is assumed.

Grand Junction Granite Block Model



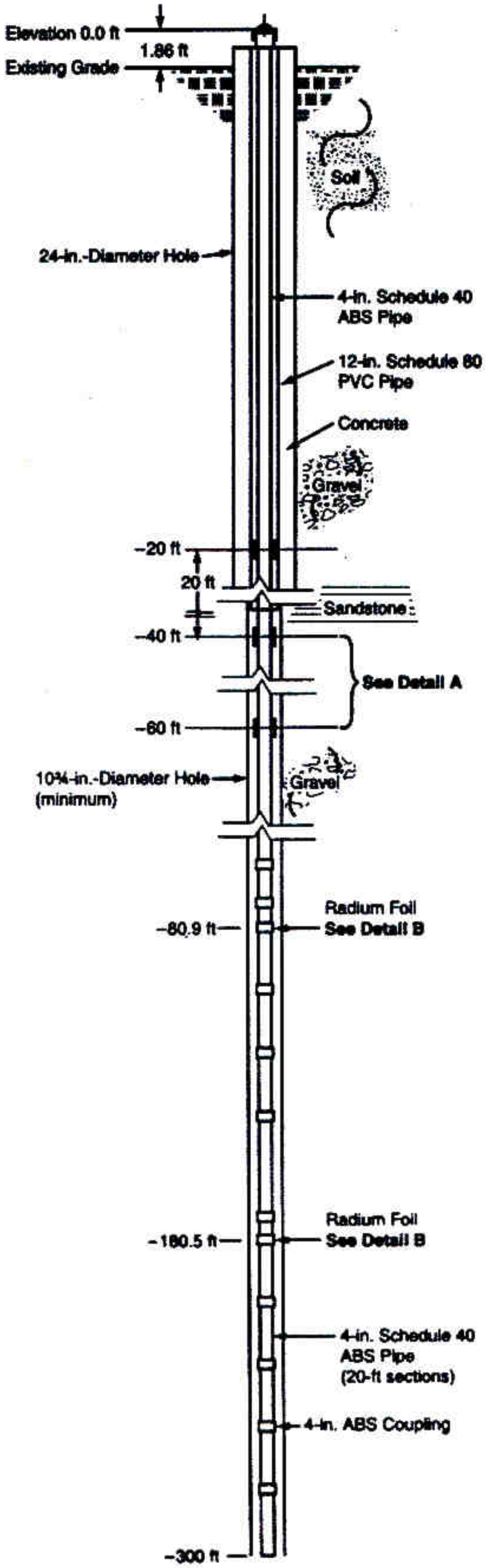
Borehole in the granite block is uncased.

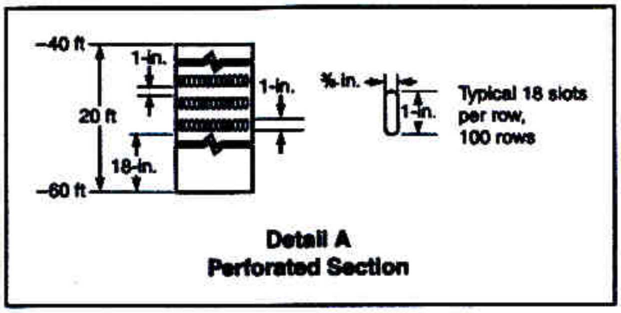
Table A–17. Assigned Parameters

Model Designation	Magnetic Susceptibility (μCGS)[a]	Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[c]
Granite Block	385 ± 30	2.63	—

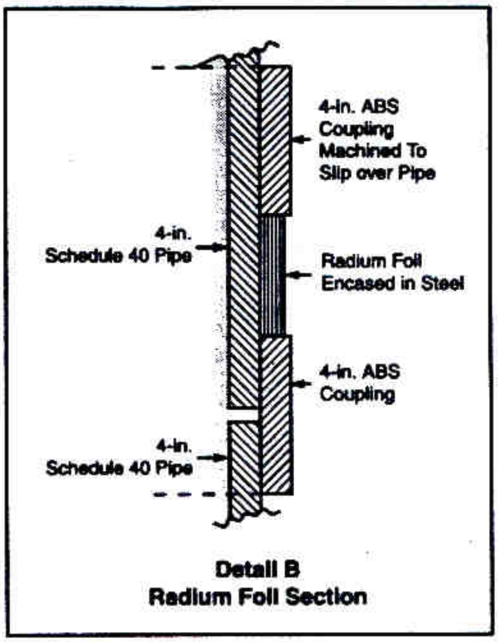
[a]Uncertainties are 95 pecent confidence level. Assigned values taken from Emilia and others (1981).
[b]Uncertainties for these values have not been determined.
[c]Value has not been determined.

Grand Junction 300-Foot Test Hole





Detail A
Perforated Section



Detail B
Radium Foil Section

Drawing not to scale.

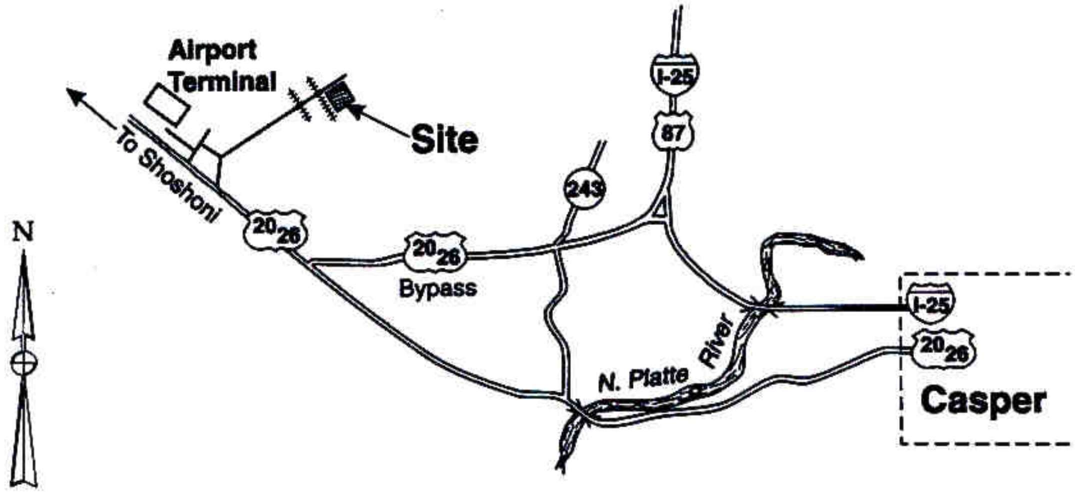
Appendix B
Secondary Field Calibration Facilities

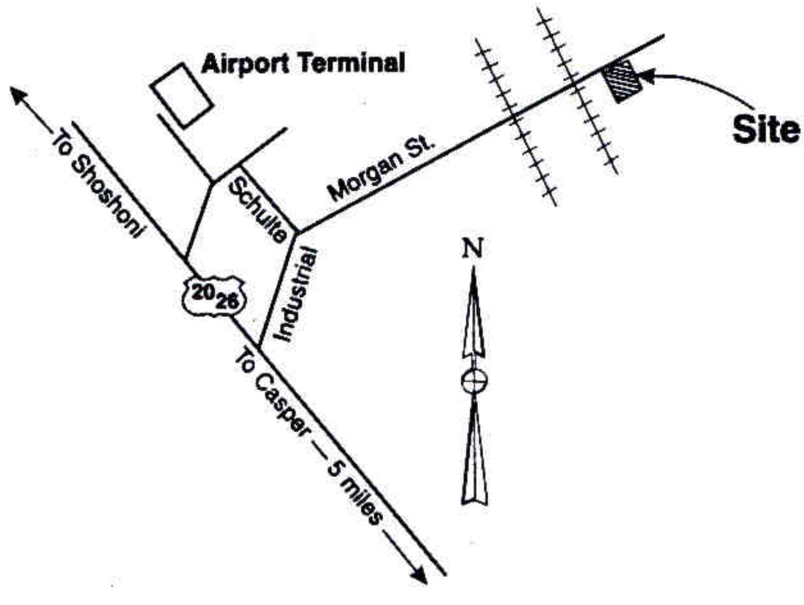
Secondary Field Calibration Facilities

This appendix presents detailed information concerning location, layout, pad and model descriptions, and radioelement concentrations for the secondary field calibration facilities. These facilities are administered by the U.S. Department of Energy Grand Junction Projects Office.

Questions concerning the use of the facilities should be addressed to the Technical Measurements Center.

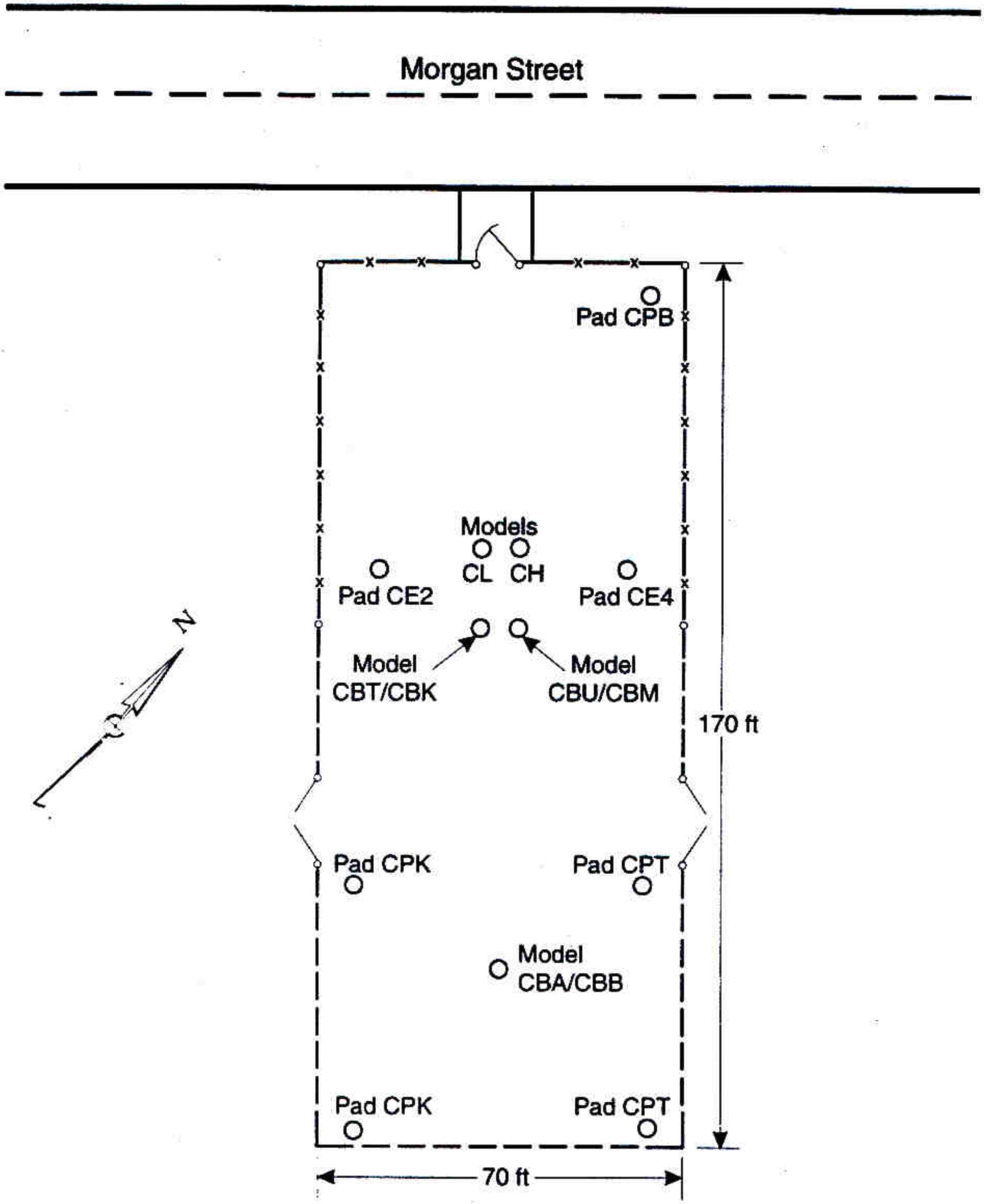
Map to Casper Calibration Site





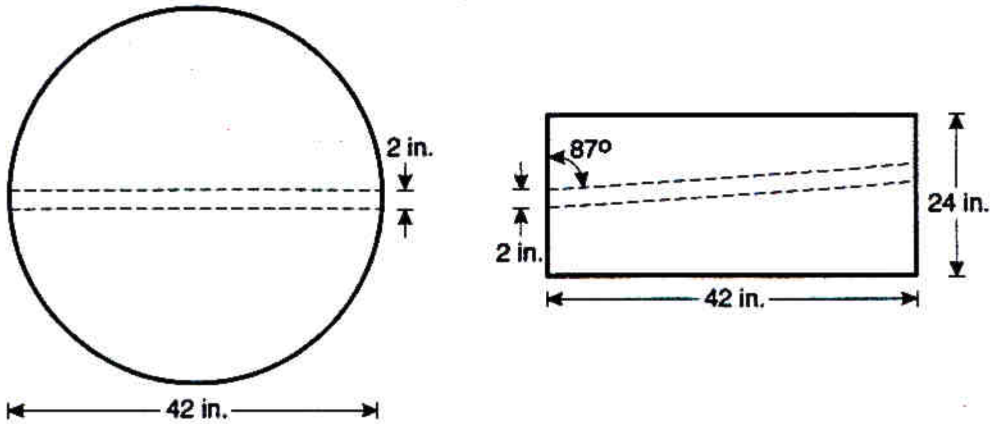
Map not to scale.

Layout of Casper Calibration Site



Map not to scale.

Casper P Pads



Plan

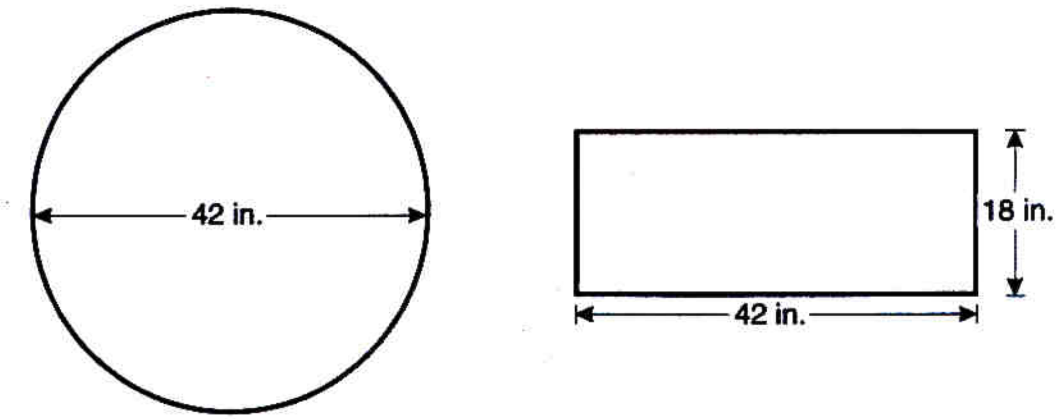
Section

Table B–1. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a] Ra–226	Th–232	K–40	Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
CPK	0.76 ± 0.90	0.04 ± 0.06	51.36 ± 1.46	1.94	0.130
CPL	91.77 ± 15.20	0.54 ± 0.10	15.44 ± 1.02	1.89	0.148
CPH	360.65 ± 43.82	0.55 ± 0.10	14.99 ± 1.58	1.91	0.153
CPT	6.07 ± 2.92	30.18 ± 0.78	14.13 ± 1.02	1.89	0.157
CPB[c]	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 0.1	d	d

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.
[c]Pad does not have a hole as shown above.
[d]Value not assigned.

Casper E Pads



Plan

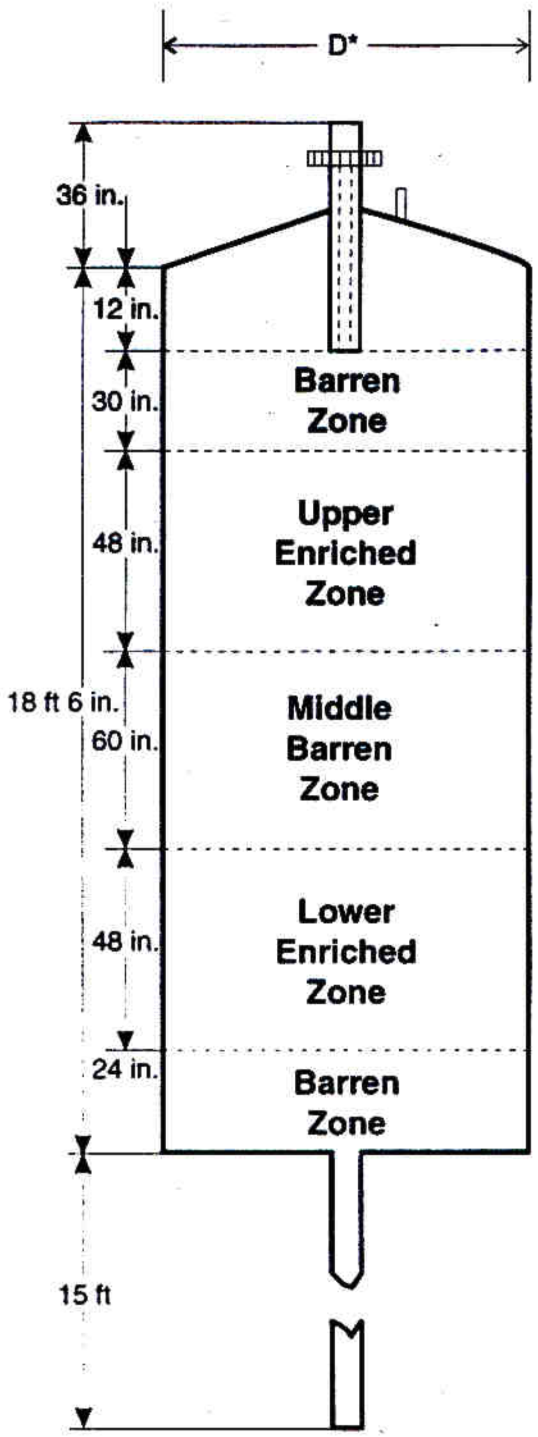
Section

Table B–2. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a] Ra–226	Th–232	K–40	Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
CE2	81.45 ± 14.42	0.79 ± 0.12	13.63 ± 0.98	1.85	0.135
CE4	409.93 ± 50.90	0.66 ± 0.10	12.29 ± 1.58	1.84	0.162

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

Casper CBT/CBK, CBU/CBM, and CBA/CBB Models



*D

Model	Diameter (in.)
CBT/CBK	48
CBU/CBM	48
CBA/CBB	60

Table B–3.1. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
CBU	Upper	169 ± 6	3.99 ± 0.02	1.91	0.244
CBA	Upper	64.8 ± 1.9	4.00 ± 0.00	2.23	0.189
CBB	Lower	862 ± 26	4.02 ± 0.02	2.21	0.201

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Uncertainties for these values have not been determined.

Table B–3.2. Assigned Parameters for Calibration of Spectral Gamma-Ray Logging Systems

Model Designation	Zone	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
		Ra–226	Th–232	K–40		
CBT	Upper	11.43 ± 0.56	68.46 ± 1.81	10.55 ± 2.01	1.91	0.238
CBK	Lower	1.16 ± 0.10	0.11 ± 0.02	51.21 ± 1.67	1.81	0.255
CBU	Upper	175.94 ± 5.61	0.69 ± 0.06	11.55 ± 0.84	1.91	0.239
CBM	Lower	128.13 ± 4.07	47.73 ± 1.29	41.27 ± 1.84	1.88	0.252

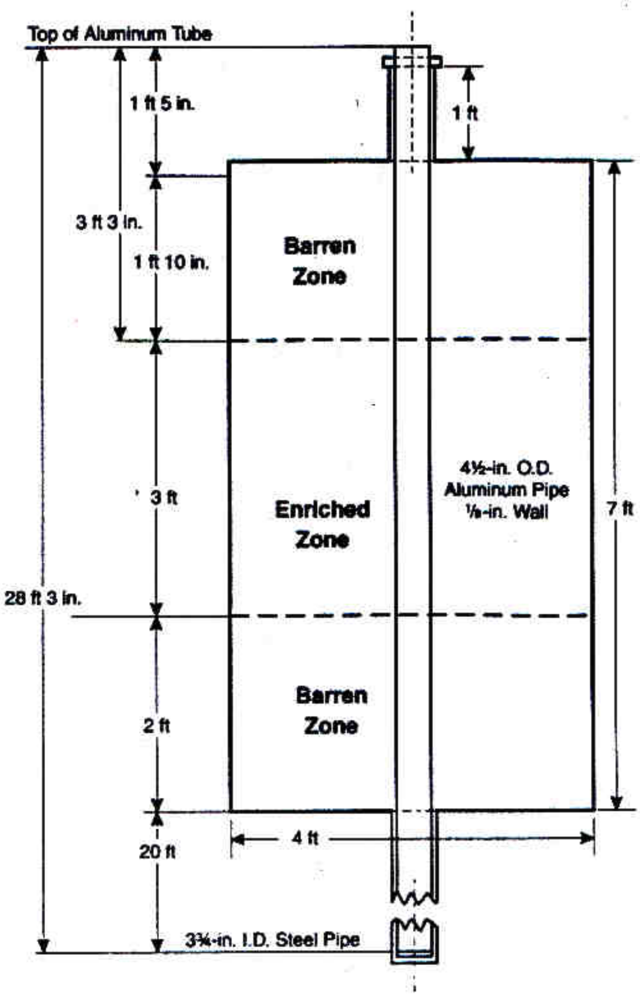
[a]Uncertainties are 95 percent confidence level. Assigned values taken from Heistand and Novak (1984).
[b]Uncertainties for these values have not been determined.

Table B–3.3. Assigned Parameters for Calibration of Fission-Neutron Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
CBA	Upper	64.8 ± 1.9	4.00 ± 0.00	2.23	0.189
CBB	Lower	862 ± 26	4.02 ± 0.02	2.21	0.201

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Uncertainties for these values have not been determined.

Casper CH and CL Models



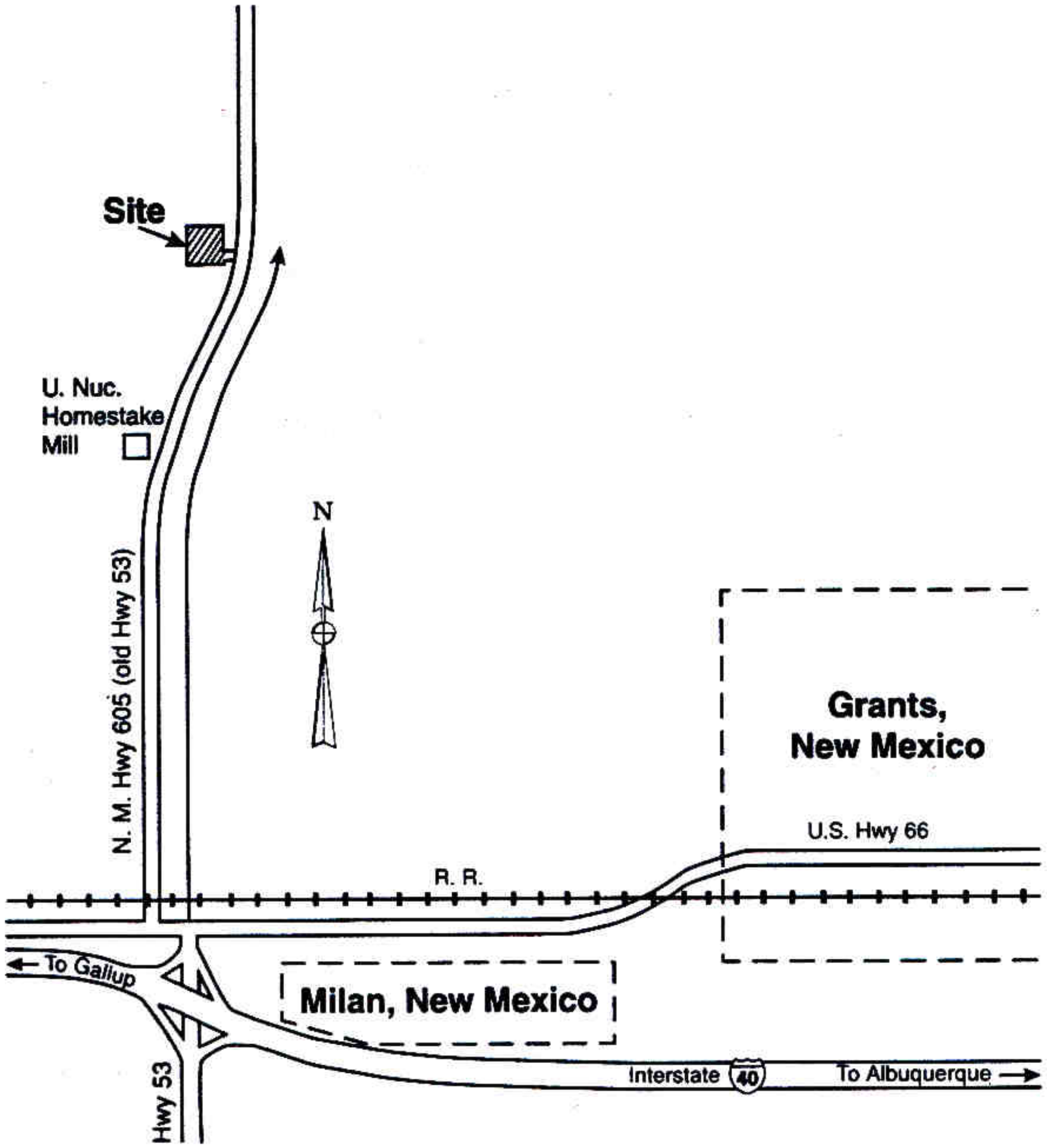
Typical Section
Each Model

Table B–4. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

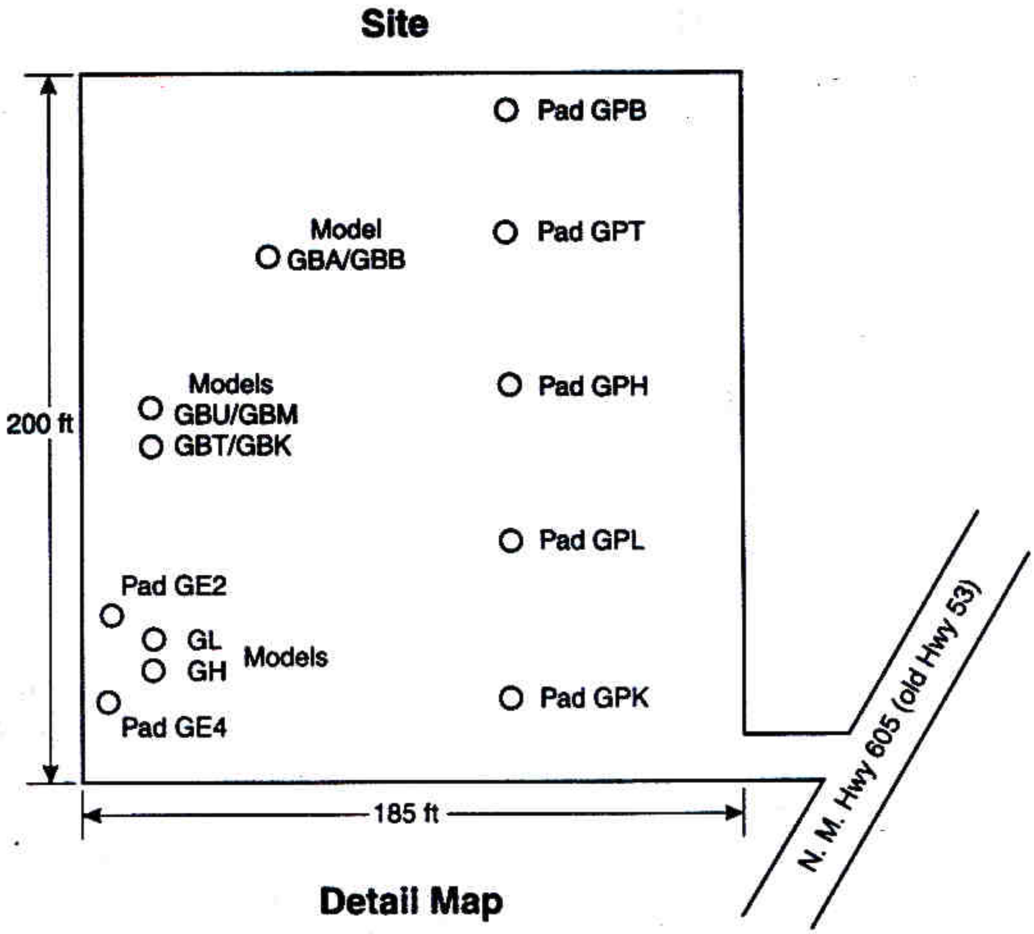
Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
CH	Enriched	6635 ± 388	2.89 ± 0.00	2.21	0.235
CL	Enriched	852 ± 26	2.97 ± 0.00	2.27	0.217

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Uncertainties for these values have not been determined.

Map to Grants Calibration Site



Layout of Grants Calibration Site



Detail Map

Grants P Pads

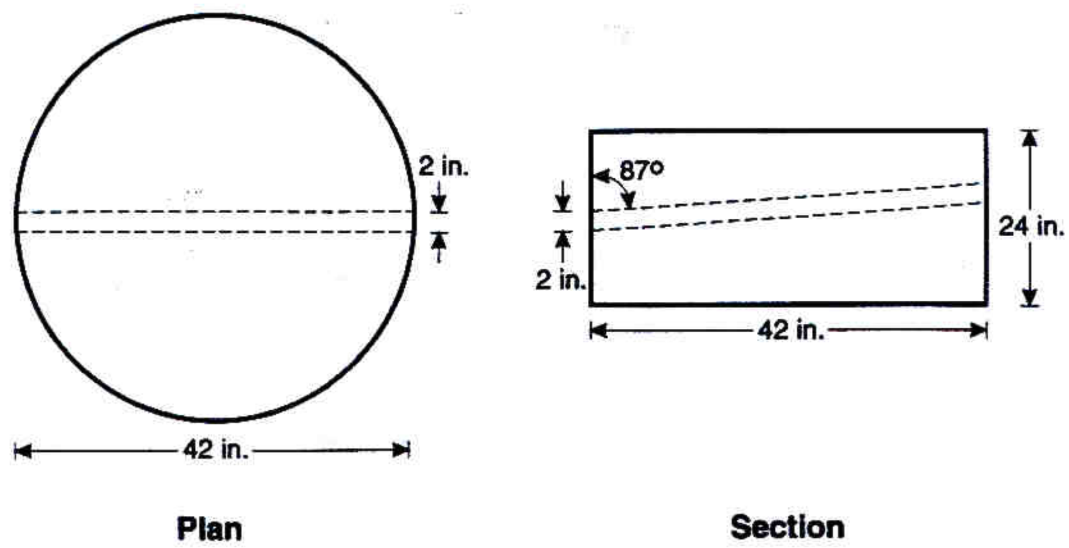


Table B–5. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
	Ra–226	Th–232	K–40		
GPK	0.58 ± 0.82	0.01 ± 0.06	51.53 ± 1.46	1.96	0.127
GPL	87.78 ± 14.32	0.50 ± 0.10	15.58 ± 1.02	1.90	0.165
GPH	375.74 ± 45.14	0.61 ± 0.10	15.93 ± 1.62	1.91	0.142
GPT	6.57 ± 3.14	30.23 ± 0.80	14.94 ± 1.02	1.89	0.146
GPB[c]	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 0.1	d	d

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.
[c]Pad does not have a hole as shown above.
[d]Value not assigned.

Grants E Pads

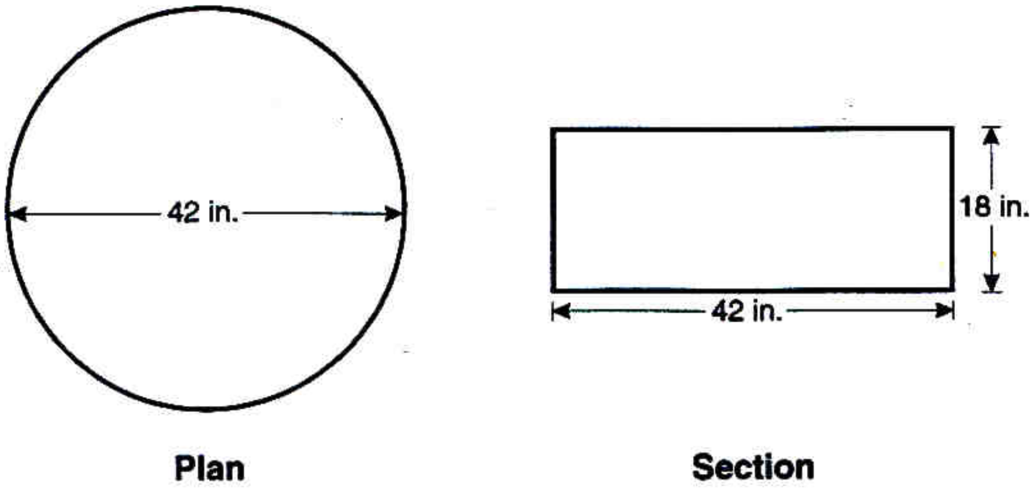
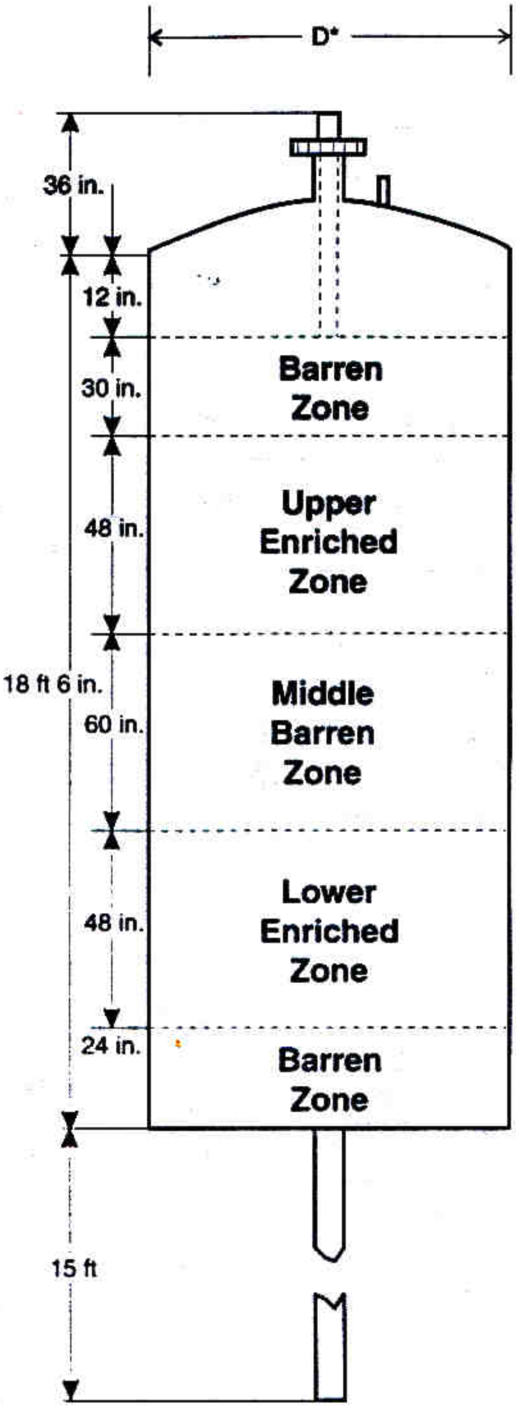


Table B–6. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
	Ra–226	Th–232	K–40		
GE2	83.13 ± 15.42	0.70 ± 0.10	12.93 ± 1.02	1.85	0.237
GE4	396.66 ± 49.70	0.80 ± 0.12	12.20 ± 1.48	1.84	0.148

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

Grants GBT/GBK, GBU/GBM, and GBA/GBB Models



*D

Model	Diameter (in.)
GBT/GBK	48
GBU/GBM	48
GBA/GBB	60

Table B–7.1. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
GBU	Upper	167 ± 5	3.98 ± 0.00	1.88	0.247
GBA	Upper	64.8 ± 1.9	3.97 ± 0.02	2.21	0.189
GBB	Lower	881 ± 27	3.99 ± 0.00	2.22	0.199

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.01 ft.
[c]Uncertainties for these values have not been determined.

Table B–7.2. Assigned Parameters for Calibration of Spectral Gamma-Ray Logging Systems

Model Designation	Zone	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
		Ra–226	Th–232	K–40		
GBT	Upper	11.34 ± 0.58	68.06 ± 1.83	9.71 ± 1.51	1.93	0.248
GBK	Lower	1.08 ± 0.10	0.10 ± 0.02	52.16 ± 1.84	1.81	0.263
GBU	Upper	178.18 ± 5.47	0.71 ± 0.06	11.80 ± 0.84	1.88	0.244
GBM	Lower	129.09 ± 4.14	48.22 ± 1.35	41.84 ± 2.01	1.87	0.257

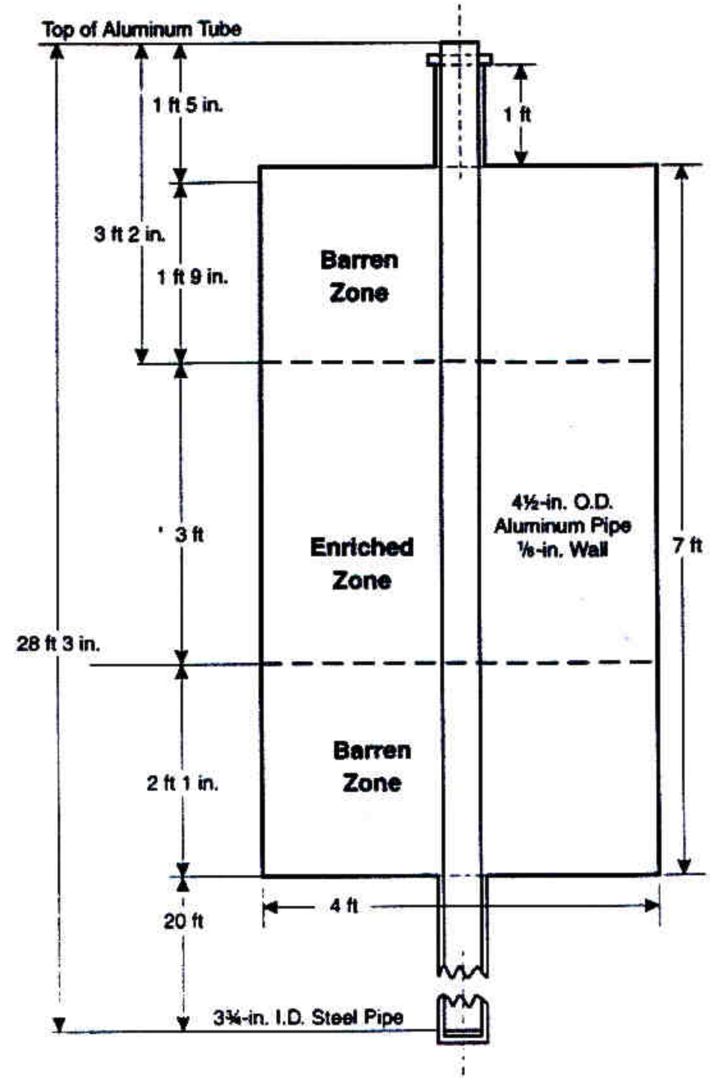
[a]Uncertainties are 95 percent confidence level. Assigned values taken from Heistand and Novak (1984).
[b]Uncertainties for these values have not been determined.

Table B–7.3. Assigned Parameters for Calibration of Fission-Neutron Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
GBA	Upper	64.8 ± 1.9	3.97 ± 0.02	2.21	0.189
GBB	Lower	881 ± 27	3.99 ± 0.00	2.22	0.199

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.01 ft.
[c]Uncertainties for these values have not been determined.

Grants GH and GL Models



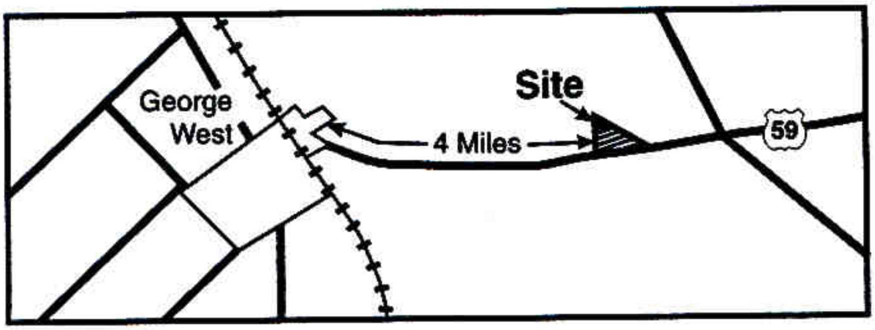
Typical Section
Each Model

Table B–8. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
GH	Enriched	5645 ± 344	2.89 ± 0.02	2.22	0.247
GL	Enriched	777 ± 24	2.99 ± 0.00	2.22	0.236

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Uncertainties for these values have not been determined.

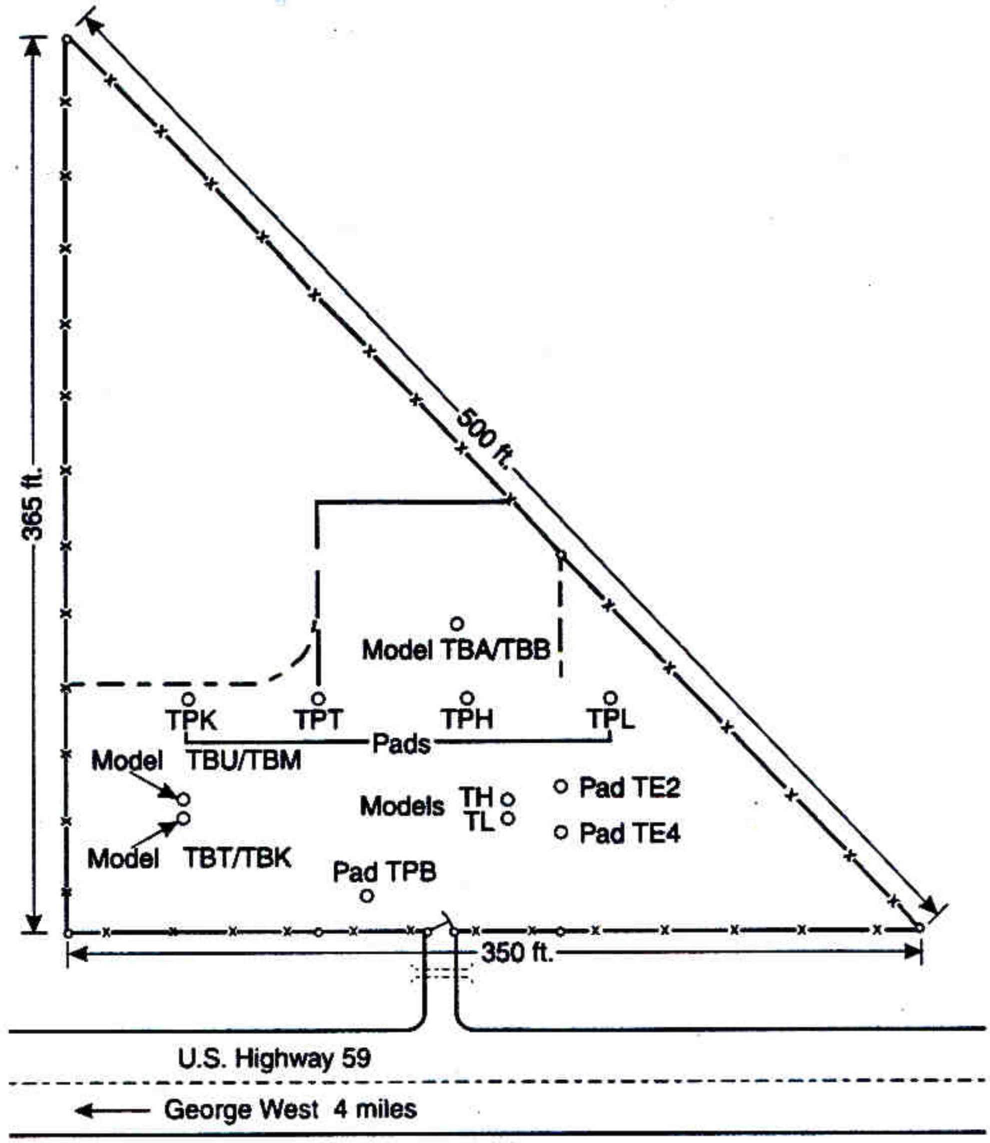
Map to George West Calibration Site



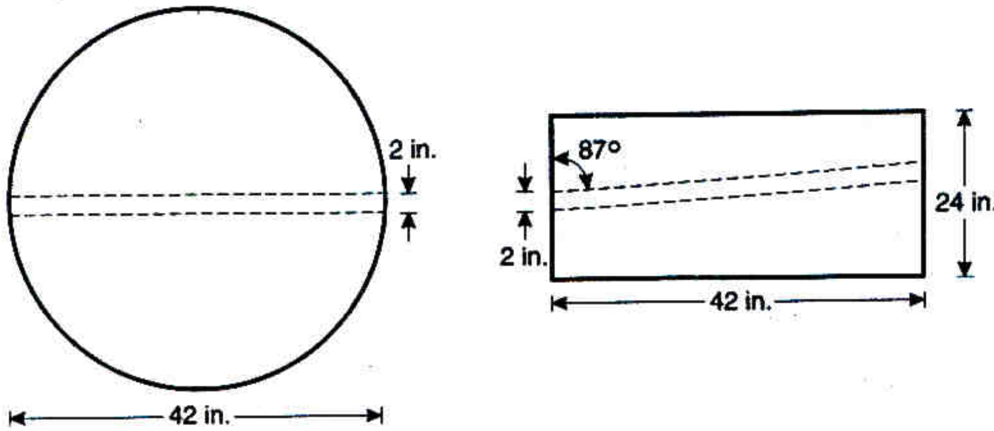
Vicinity Map

No Scale

Layout of George West Calibration Site



George West P Pads



Plan **Section**

Table B-9. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a] Ra-226	Th-232	K-40	Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
TPK	0.69 ± 0.86	0.00 ± 0.06	52.81 ± 1.46	1.95	0.131
TPL	87.02 ± 14.68	0.57 ± 0.10	15.49 ± 1.02	1.88	0.157
TPH	385.36 ± 47.52	0.45 ± 0.10	14.85 ± 1.42	1.90	0.158
TPT	5.96 ± 2.96	31.21 ± 0.82	15.03 ± 1.08	1.90	0.155
TPB[c]	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 0.1	d	d

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.
[c]Pad does not have a hole as shown above.
[d]Value not assigned.

George West E Pads

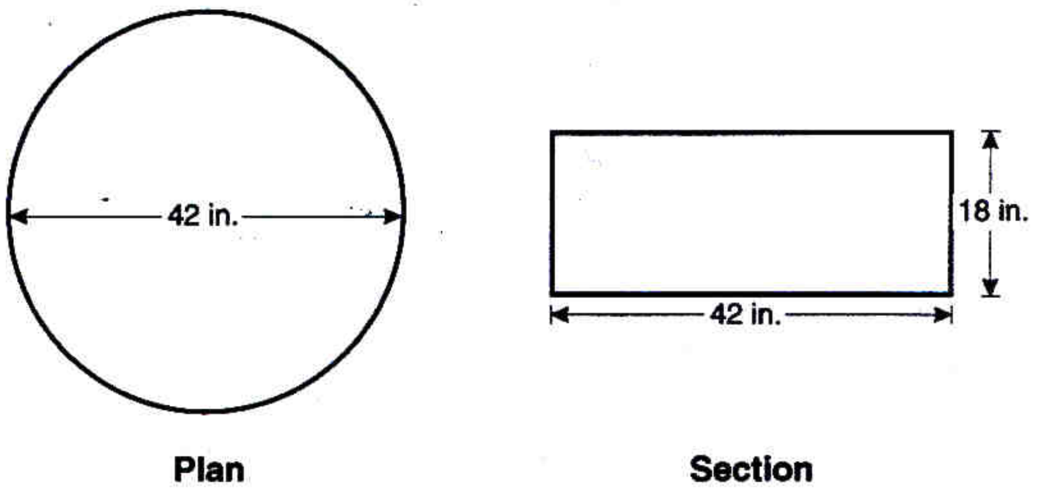
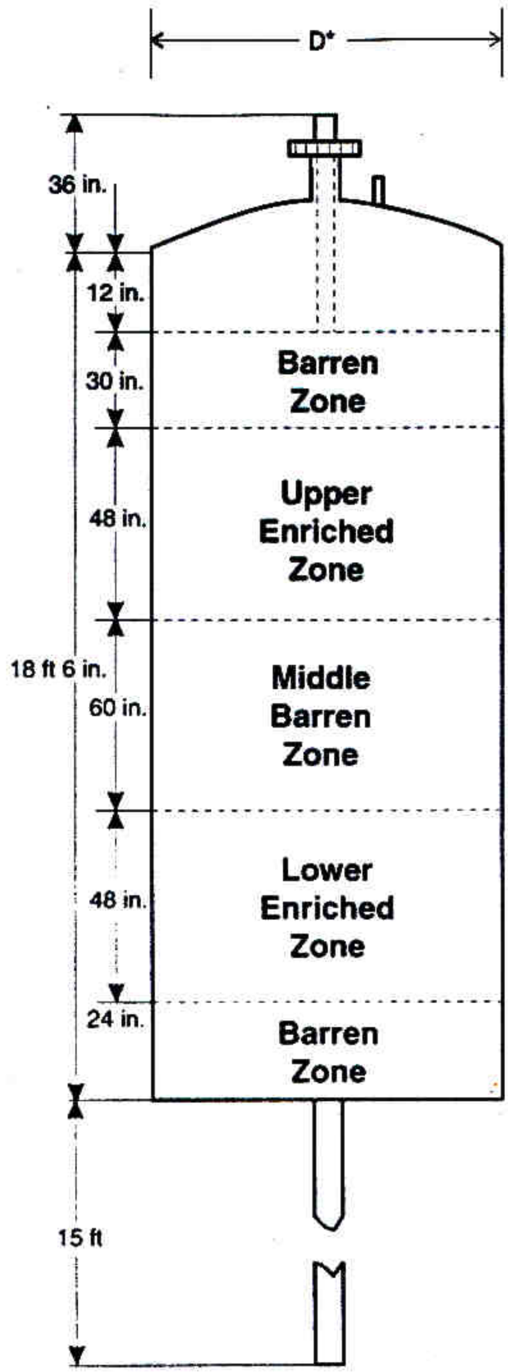


Table B–10. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
	Ra–226	Th–232	K–40		
TE2	83.53 ± 15.10	0.66 ± 0.10	13.17 ± 0.98	1.83	0.177
TE4	398.74 ± 50.36	0.51 ± 0.10	11.44 ± 1.58	1.86	0.223

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

George West TBT/TBK, TBU/TBM, and TBA/TBB Models



*D

Model	Diameter (in.)
TBT/TBK	48
TBU/TBM	48
TBA/TBB	60

Table B–11.1. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm³)[c]	Partial Density H_2O (g/cm³)[c]
TBU	Upper	168 ± 6	3.98 ± 0.00	1.87	0.247
TBA	Upper	61.8 ± 1.7	3.95 ± 0.02	2.20	0.184
TBB	Lower	840 ± 25	3.96 ± 0.00	2.21	0.187

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.01 ft.
[c]Uncertainties for these values have not been determined.

Table B–11.2. Assigned Parameters for Calibration of Spectral Gamma-Ray Logging Systems

Model Designation	Zone	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
		Ra–226	Th–232	K–40		
TBT	Upper	11.30 ± 0.55	67.66 ± 1.88	9.71 ± 1.67	1.94	0.243
TBK	Lower	1.13 ± 0.10	0.09 ± 0.02	53.58 ± 1.84	1.81	0.264
TBU	Upper	177.01 ± 5.54	0.69 ± 0.06	11.39 ± 1.00	1.87	0.247
TBM	Lower	128.63 ± 4.14	48.62 ± 1.40	42.03 ± 2.01	1.85	0.257

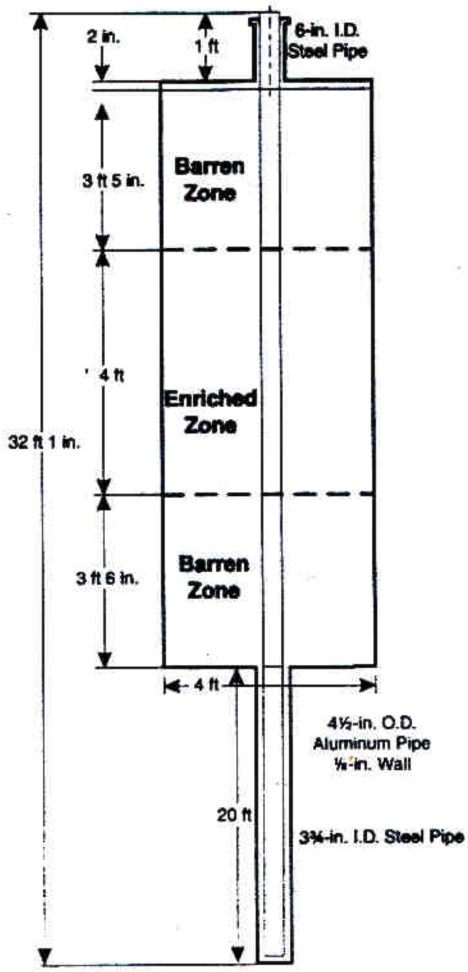
[a]Uncertainties are 95 percent confidence level. Assigned values taken from Heistand and Novak (1984).
[b]Uncertainties for these values have not been determined.

Table B–11.3. Assigned Parameters for Calibration of Fission-Neutron Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm³)[c]	Partial Density H_2O (g/cm³)[c]
TBA	Upper	61.8 ± 1.7	3.95 ± 0.02	2.20	0.184
TBB	Lower	840 ± 25	3.96 ± 0.00	2.21	0.187

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.01 ft.
[c]Uncertainties for these values have not been determined.

George West TH and TL Models



Typical Section

Table B–12. Assigned Parameters for Calibration of Total-Count Gamma-Ray Logging Systems

Model Designation	Zone	Ra–226 Concentration (pCi/g)[a]	Thickness (ft)[b]	Dry Bulk Density (g/cm^3)[c]	Partial Density H_2O (g/cm^3)[c]
TH	Enriched	5770 ± 368	3.94 ± 0.00	1.86	0.302
TL	Enriched	680 ± 23	3.99 ± 0.00	2.07	0.272

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George and others (1983).
[b]Uncertainties reported as 0.00 are not zero, but are less than 0.005 ft.
[c]Uncertainties for these values have not been determined.

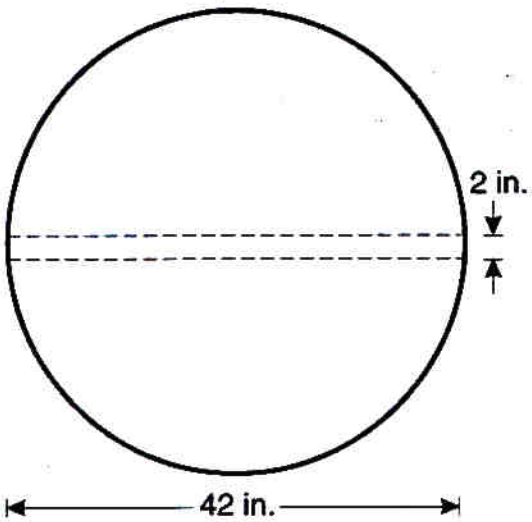
Appendix C
Relocatable Field Calibration Pads

Relocatable Field Calibration Pads

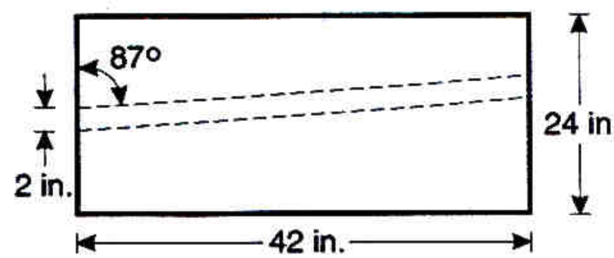
This appendix presents detailed information concerning pad descriptions and radioelement concentrations for the relocatable field calibration pads. These pads are administered by the U.S. Department of Energy Grand Junction Projects Office.

Questions concerning present location, use, and/or calibration should be addressed to the Technical Measurements Center.

NP Pads



Plan



Section

Table C–1. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)[b]	Partial Density H_2O (g/cm^3)[b]
	Ra–226	Th–232	K–40		
NPL	15.83 ± 5.32	0.64 ± 0.10	10.92 ± 0.72	1.94	0.176
NPH	44.20 ± 9.72	0.73 ± 0.10	11.13 ± 0.82	1.95	0.191

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

NOTE: Contact the Technical Measurements Center for the present location of these pads.

PP Pads

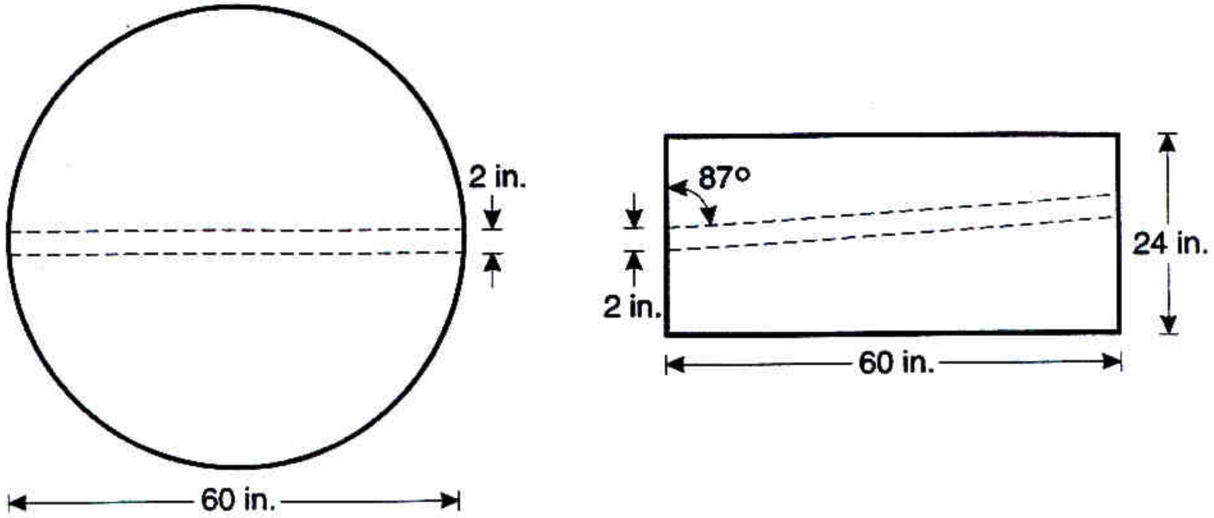


Table C–2. Assigned Parameters

Pad Designation	Concentration (pCi/g)[a]			Dry Bulk Density (g/cm³)[b]	Partial Density H_2O (g/cm³)[b]
	Ra–226	Th–232	K–40		
PPL	15.08 ± 5.54	0.62 ± 0.10	10.84 ± 0.66	1.95	0.176
PPH	49.34 ± 10.78	0.63 ± 0.10	10.97 ± 0.86	1.95	0.199

[a]Uncertainties are 95 percent confidence level. Assigned values taken from George, Novak, and Price (1985).
[b]Uncertainties for these values have not been determined.

NOTE: Contact the Technical Measurements Center for the present location of these pads.

T Pads

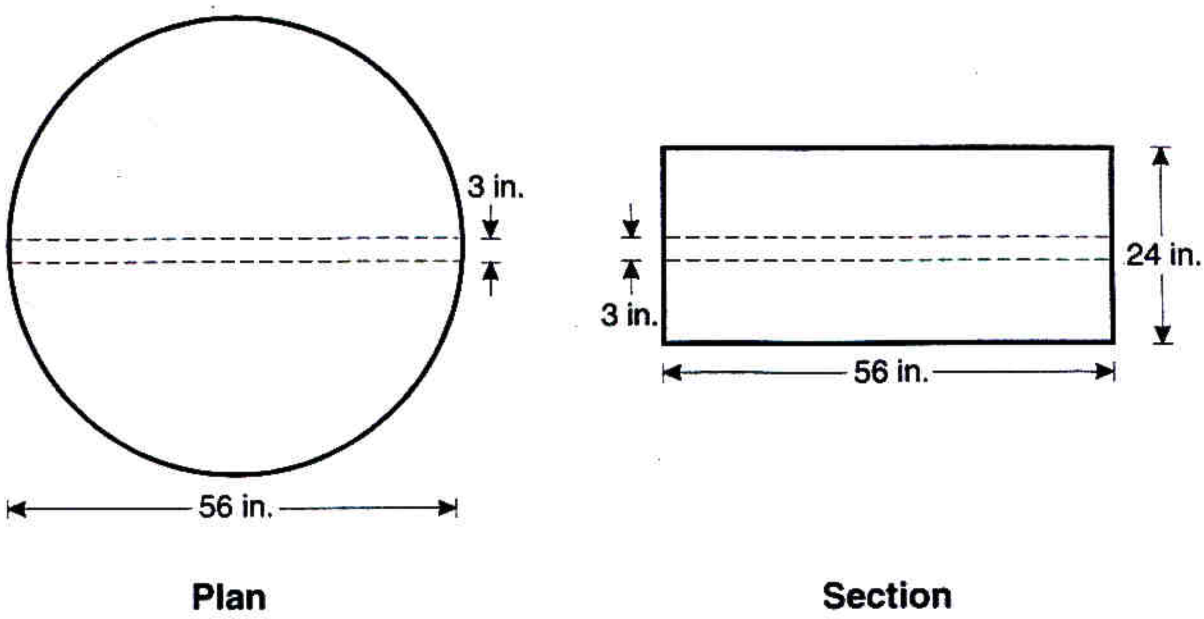


Table C–3. Assigned Parameters

Pad	Diameter (in.)	Assigned Concentration (pCi/g)[a]			Dry Bulk Density (g/cm^3)	Partial Density H_2O (g/cm^3)
		Ra–226	Th–232	K–40		
TL1	56	<1	10.18 ± 0.43	2.07 ± 0.16	1.89	0.209
TL2	56	<1	10.56 ± 0.45	2.80 ± 0.16	1.92	0.225
TL3	57	<1	10.28 ± 0.43	2.28 ± 0.16	1.84	0.206
TL4	60	<1	11.36 ± 0.45	2.18 ± 0.16	1.85	0.191
TH1	56	<1	41.48 ± 1.30	<3	1.89	0.206
TH2	56	<1	42.00 ± 1.27	<3	1.94	0.192
TH3	60	<1	42.48 ± 1.33	<3	1.88	0.200
TH4	60	<1	45.31 ± 1.27	<3	1.90	0.168

[a]Uncertainties are two sigma (95 percent confidence interval).

Appendix D
Conversion Factors

Conversion Factors

This appendix presents conversion factors used to determine radioelement concentrations for the calibration facilities. An example of conversion-factor derivation is presented in Appendix E. The nuclear data referenced in this appendix are taken from the *Table of Isotopes* (Lederer and Shirley, 1978). Half-life (T), isotopic-abundance (P), and gram atomic weight (A) data agree (within quoted significant figures) with those listed in the *Chart of the Nuclides* (Walker and others, 1977).

Conversion factors for a sample containing uranium in secular equilibrium with its daughters are

$$1 \text{ g (eU–238)} = 3.400 \times 10^{-7} \text{ g (Ra–226)}$$

$$1 \text{ g (eU)} = 3.376 \times 10^{-7} \text{ g (Ra–226)}$$

$$1 \text{ wt-ppm (eU)} = 0.3337 \text{ pCi (Ra–226)/g}$$

$$1 \text{ pCi (Ra–226)/g} = 3.534 \times 10^{-4} \text{ wt-\%}(eU_3O_8)$$

$$1 \text{ pCi (Ra–226)/g} = 2.997 \text{ wt-ppm (eU)}$$

$$1 \text{ wt-\% } (eU_3O_8) = 2830 \text{ pCi (Ra–226)/g}$$

The conversion factor for radium is

$$\begin{aligned} n_{Ra-226} &= \text{specific activity of Ra–226} \\ &= N_o \lambda_{Ra-226}/A_{Ra-226} \\ &= 0.9885 \text{ Ci/g} \end{aligned}$$

Conversion factors computed for a sample containing thorium are

$$1 \text{ pCi (Th–232)/g} = 9.159 \text{ wt-ppm (eTh)}$$

$$1 \text{ wt-ppm (eTh)} = 0.1092 \text{ pCi (Th–232)/g}$$

Conversion factors computed for a sample containing naturally occurring potassium are

$$0.0117 \text{ atom-\% (K–40)} = 0.01196 \text{ wt-\% (K–40)}$$

$$1 \text{ pCi (K–40)/g} = 0.1195 \text{ wt-\% (K)}$$

$$1 \text{ wt-\% (K)} = 8.372 \text{ pCi (K–40)/g}$$

$$1 \text{ pCi (K–40)/g} = 1.428 \times 10^{-5} \text{ wt-\% (K–40)}$$

Numerical values used for computing the conversion factors are

$$A_{U-238} = 238.9597 \text{ g/mole}$$

$$A_{U-235} = 235.0439 \text{ g/mole}$$

$$A_{U-234} = 234.0409 \text{ g/mole}$$

$$A_{Ra-226} = 226.0254 \text{ g/mole}$$

$$A_{Th-232} = 232.0380 \text{ g/mole}$$

$$A_{K-41} = 40.9618 \text{ g/mole}$$

$$A_{K-40} = 39.9640 \text{ g/mole}$$

$$A_{K-39} = 38.9637 \text{ g/mole}$$

$$P_{U-238} = 99.275\%$$

$$P_{U-235} = 0.720\%$$

$$P_{U-234} = 0.0054\%$$

$$P_{Th-232} = 100\%$$

$$P_{K-41} = 6.73\%$$

$$P_{K-40} = 0.0117\%$$

$$P_{K-39} = 93.26\%$$

$$T_{U-238} = 4.468 \times 10^{9} \text{ years} = 1.410 \times 10^{17} \text{ sec}$$

$$T_{Ra-226} = 1600 \text{ years} = 5.049 \times 10^{10} \text{ sec}$$

$$T_{Th-232} = 1.411 \times 10^{10} \text{ years} = 4.453 \times 10^{17} \text{ sec}$$

$$T_{K-40} = 1.278 \times 10^{9} \text{ years} = 4.033 \times 10^{16} \text{ sec}$$

$$N_o = 6.022045 \times 10^{23} \text{ atoms/mole}$$

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ disintegrations/sec}$$

Appendix E
Example Conversion Factor Derivation

Example Conversion Factor Derivation

The calibration of gamma-ray counting instruments at Grand Junction has been traditionally performed using equivalent uranium (eU) as the reporting unit for spectral instruments and equivalent uranium oxide (eU_3O_8) as the reporting unit for gross-count or total-count instruments. The word equivalent (e) has been traditionally taken to mean radiometric equivalent or gamma-ray equivalent, because concentrations assigned to the calibration models are based on gamma-ray measurements. The purpose of this derivation is to establish the factors needed to convert from currently assigned uranium concentrations in parts per million on a weight basis for eU [wt-ppm(eU)] and in weight-percentage for eU_3O_8 [wt-% (eU_3O_8)] to radium concentrations [pCi (Ra–226)/g].

For the conversion derived, it is necessary to assume secular equilibrium between uranium and radium-226 in the uranium decay series. This assumption has always been made in the past when assigning equivalent-uranium concentrations to the models and pads. Because previous assignments are based on gamma-ray counting measurements, and because those measurements are responsive primarily to radium-226 daughters, the assumption is appropriate here.

For a given sample of mass M, containing uranium and its daughters in secular equilibrium, the decay rates of U–238 and Ra–226 are equal by definition. That is,

$$\text{Decay rate } (-dN/dt) = N_{Ra-226}\lambda_{Ra-226} = N_{U-238}\lambda_{U-238} \qquad (1)$$

where N = number of atoms of the isotope indicated by the subscript,

λ = decay constant of the isotope indicated by the subscript,

= $\ln(2)/T$,

T = half-life of the isotope indicated by the subscript.

If both sides of Equation (1) are divided by the mass of the sample, M, and if mass-normalized decay rate is r,

$$r_{Ra-226} = r_{U-238} = \frac{N_{Ra-226}\lambda_{Ra-226}}{M} = \frac{N_{U-238}\lambda_{U-238}}{M} \qquad (2)$$

Computing the number of atoms of U–238 from the mass of U–238 in the sample, M_{U-238},

$$r_{Ra-226} = N_{U-238}\lambda_{U-238}/M = (M_{U-238}/M)(N_o/A_{U-238})\lambda_{U-238} \qquad (3)$$

where N_o = Avogadro's number, and

A = gram atomic weight of the isotope indicated by the subscript.

Noting that M_{U-238}/M is the weight fraction of U–238 in the sample,

$$c_{U-238} = M_{U-238}/M \qquad (4)$$

Equation (3) produces the result

$$r_{Ra-226} = c_{U-238}(N_o\lambda_{U-238}/A_{U-238}) \qquad (5)$$

The desired units are picocuries of Ra–226 per gram of sample [pCi(Ra–226)/g], and parts per million on a weight basis for U–238 (wt-ppm). Performing the computation indicated in Equation (5) and converting units produces

$$r_{Ra-226} = c_{U-238}/2.975 \qquad (6)$$

where r_{Ra-226} is the mass-normalized decay rate of Ra–226 in picocuries per gram and c_{U-238} is the weight concentration of U–238 in parts per million.

Numerical values and conversion factors used for the computations are presented in Appendix B.

The result in Equation (6) must be adjusted to account for the isotopic abundance of U–238 within naturally occurring uranium (U). The isotopic abundance of U–238 must first be computed on a weight basis because the isotopic abundance values in the *Table of Isotopes* (Lederer and Shirley, 1978) are given on an atom-percent basis.

$$P'_{U-238} = \frac{P_{U-238}A_{U-238}}{P_{U-238}A_{U-238} + P_{U-235}A_{U-235} + P_{U-234}A_{U-234}} \quad (7)$$

$$= 0.9928 \; \frac{g\,(U\text{–}238)}{g\,(U)}$$

where P′ is the isotopic abundance on a weight basis for the isotope indicated by the subscript, and P is the isotopic abundance on an atom-percent basis for the isotope indicated by the subscript.

From this result, $c_{U-238} = 0.9928c_U$, which is then substituted into Equation (6) to produce the final and desired result

$$r_{Ra-226} = c_U/2.997 \quad (8)$$

where c_U is the weight concentration of naturally occurring uranium in parts per million (ppm) and r_{Ra-226} is the mass-normalized decay rate of Ra–226 in picocuries per gram.

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