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A RADIOLOGICAL ENVIRONMENTAL ASSESSMENT FOR THE FMPC SOIL REMOVAL ACTION AROUND MANHOLE 180

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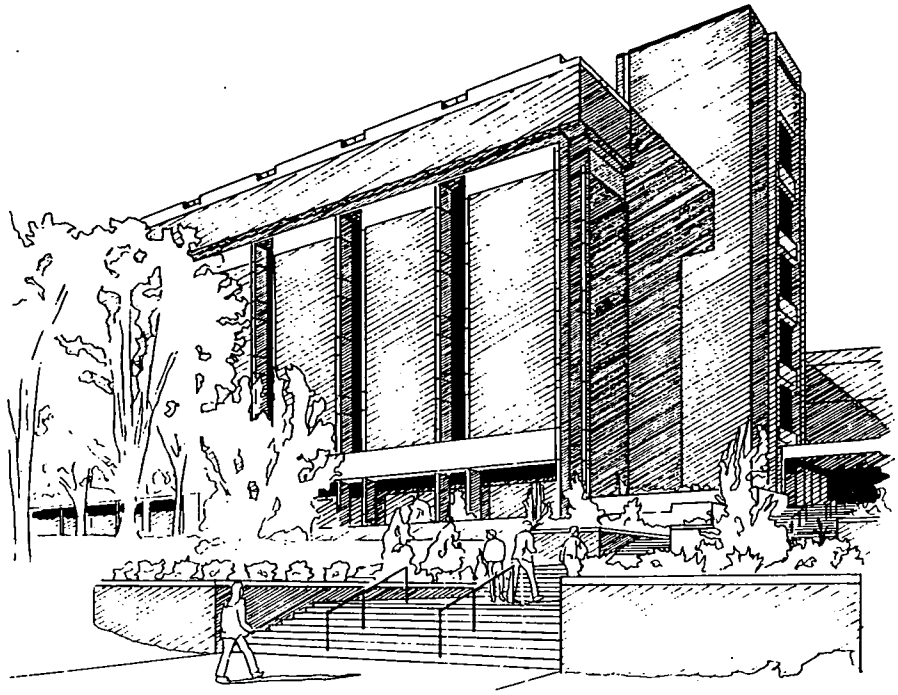

UNIVERSITY OF CINCINNATI
COLLEGE OF ENGINEERING

A Radiological Environmental Assessment For The FMPC Soil Removal Action Around Manhole 180

An ALARA Application

November 3, 1989

The University of Cincinnati
Department of
Mechanical, Industrial, and Nuclear Engineering

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Executive Summary

1.0 Objectives and Project Methodology

The objective of this work was to prepare an independent ALARA (As Low As Reasonably Achievable) assessment of the soil removal action in the vicinity of manhole 180. In order to complete this ALARA cost-benefit analysis a radiological environmental assessment was performed by the University of Cincinnati. The analysis methods, techniques, and procedures were all based on industry accepted procedures adopted from the Department of Energy, Nuclear Regulatory Commission, Environmental Protection Agency, and the International Commission on Radiological Protection.

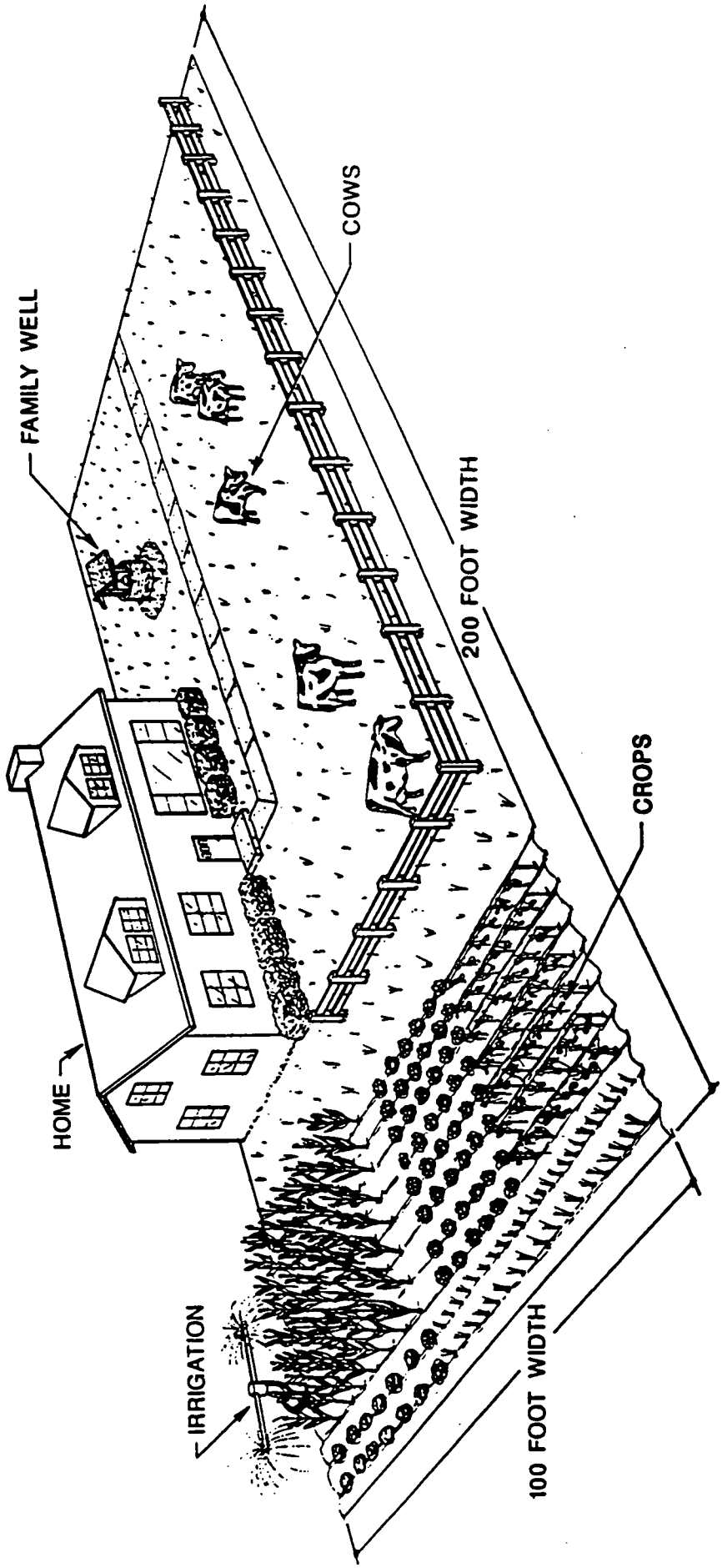
ALARA is a radiation protection philosophy. It is a philosophy that requires radiation exposure to be kept as low as possible. The ALARA assessment, therefore, requires that those people who may be exposed be identified and the dose to these identified people must be calculated.

The maximally exposed individuals would be a resident farm family that, sometime in the future, establishes a small farm family located on the assessment area, adjacent to manhole 180. Figure 1.1 illustrates the family farm concept. This "resident farm family" scenario defines the human activities that lead to exposure, inhalation, or ingestion of residual radioactive material in the soil. Experience has shown that this scenario leads to the most conservative results and requires that a detailed radiological assessment be performed.

The resident farmer scenario assumes that a family would consume produce grown on the farm and water from a well located on the farm. The well would also supply irrigation water for the food crops and animal fodder. Because of the small size of the assessment area, 1860 square meters, only a small fraction of the meat and milk for the family would be obtained from the family farm. In order to calculate the dose to humans from this scenario, a detailed radiological environmental pathway analysis was performed.

The pathway analysis was performed using site-specific information, obtained from the Feed Materials Production Center Annual Environmental Monitoring Report (FMPC, 1987), U.S. Geological Survey maps and results (USGS, 1988), and the Hydrogeological Study of the FMPC Discharge to the Great Miami River, Final Report (IT, 1988). These sources were used to construct two models for the evaluation of the transport of uranium and thorium and other selected radionuclides, which may have been present in the effluent discharge, from the surface soil to the groundwater. Using this information, the dose to the resident farmer was calculated for the near term use of the assessment area and also for the long term use of the assessment area.

FIGURE 1.1: PICTORIAL REPRESENTATION OF THE FARM SCENARIO APPLIED TO THE SOIL REMOVAL ACTION NEAR MANHOLE 180



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1.0 Objectives and Project Methodology (continued)

For the near term use of the area, the residual radioactive material primarily resides at the top of the surface soil. As time progresses, however, the radioactive material begins to migrate downward toward the aquifer. Topographical and hydrogeological models were constructed to determine these migration times. The radiological environmental pathways are constructed to assess the dose to humans for both the near term use of the site and for selected time intervals up to a thousand years.

2.0 Development of the ALARA Concept and Risk-Benefit Analysis

Radiation standards are based on the premise that there is no threshold for radiation induced risks to health or genetic defects. The risk model that is used to predict health effects is a linear, no-threshold model. According to this linear hypothesis, some small degree of risk is associated with any radiation exposure, regardless of how low the exposure. Based on this model, the philosophy evolved such that any unnecessary exposure to ionizing radiation should be avoided and the dose to individuals should be kept "As Low As Reasonably Achievable," or ALARA. Thus, ALARA is a radiation protection philosophy. It is basically a philosophy that requires radiation exposure be kept as low as possible to both nuclear industry workers and members of the general population.

One of the fundamental objectives of an ALARA program is to achieve a balance between detriment (adverse health effect) and benefit. As usual, practice requires a trade off of benefit against detriment and risk. The ALARA philosophy is strongly motivated to reduce personnel and environmental radiation exposures to the lowest possible levels consistant with cost and operating requirements. Figure 2.1 illustrates the ALARA concept. ALARA or reduction of dose is applied in the region from an applicable standard down to a dose level determined by prudent judgement, or a risk-benefit analysis.

Exposure to radiation is equated with risk, and risk with detriment. Any dose reduction would therefore be considered beneficial. In this analysis, dose reduction is considered the principle benefit. Thus, the benefit will be measured in terms of the person-rem avoided as a result of the soil removal operation.

It is now widely acknowledged that the "risk" from low level exposure to ionizing radiation is the risk of a fatal cancer. Thus, the current discussion focuses on the risk coefficient associated with the induction of a fatal cancer. Most scientists (BEIR III, ICRP, and NCRP) now use a risk coefficient of 2×10^{-4} per rem of exposure. This means that if 10,000 people were exposed to 1 rem of radiation, there is a probability that 2 fatal cancers would be induced. Since the national cancer rate is about 21%, a cohort of 10,000 people will have 2100 "natural" cancer deaths.

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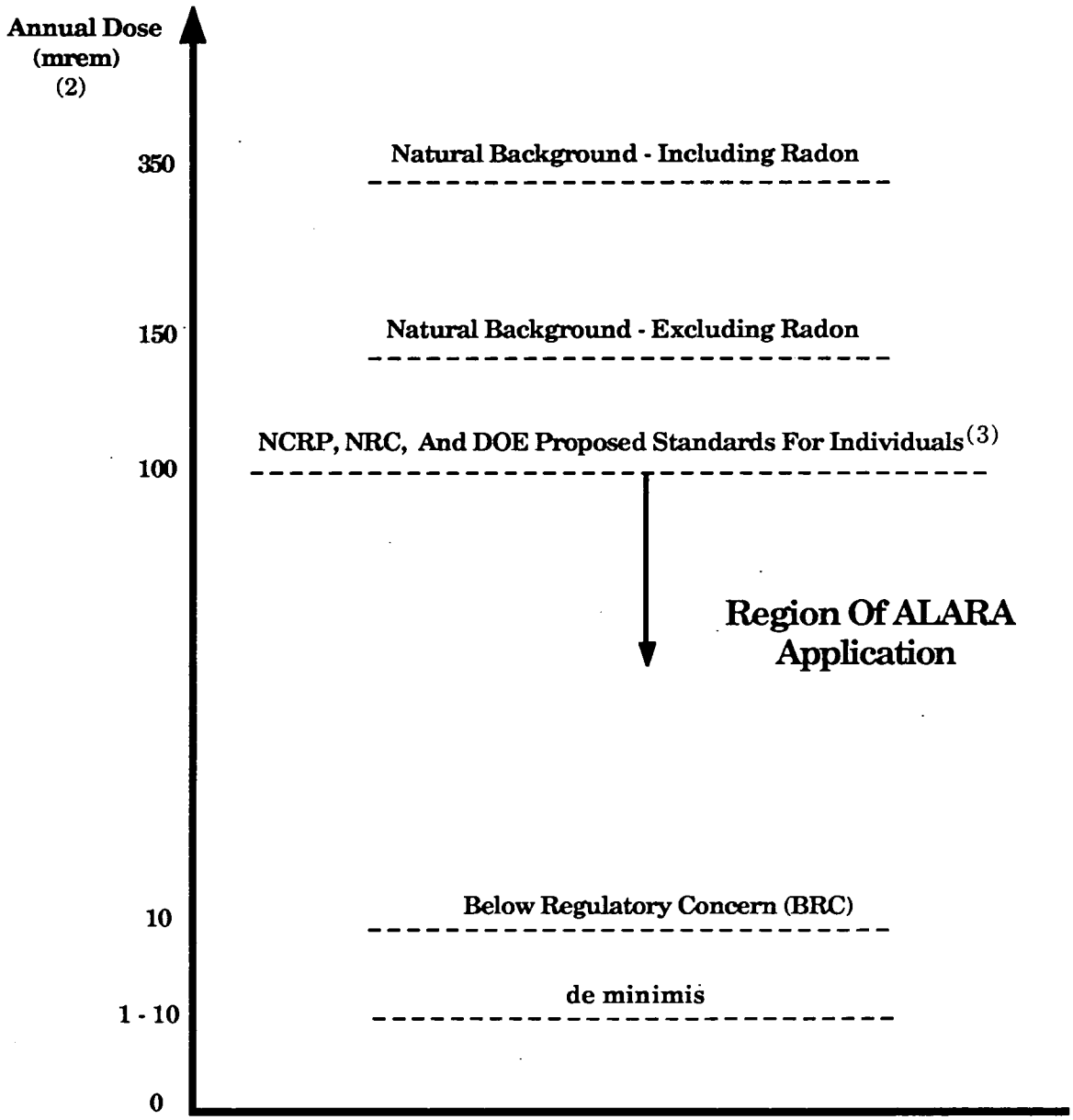
Figure 2.1: The Region For ALARA Application (1)



(1) Ordinate Scale Is Not To Scale.

(2) Effective Dose Equivalent.

(3) General Population, Not Radiation Workers.

3.0 Environmental Radiation Standards for the Public

The regulatory framework for limiting normal exposures of the general public can be divided into two basic categories:

(1) Radiation protection standards that generally apply to most sources.

(2) Environmental radiation standards that apply to specific practices or sources.

The radiation protection standards in (1) above are intended to provide a limit based on stochastic risk. This is the statistically based risk of fatal cancer from radiation exposure. The environmental radiation standards, (2) above, are based on regulatory judgement of the best available technology to limit radioactive effluents or cleanup of residual radioactivity in the soil. In both categories, (1) and (2), ALARA practices must still be applied. It is worth noting that the environmental radiation standards already incorporate some ALARA consideration.

This report includes a complete review of all existing environmental standards for specific practices. The conclusion is reached that none of the existing standards are directly applicable to the manhole 180 soil removal action. The NCRP report 91 guidance appears to be the criteria that should be applied in lieu of a standard. The NCRP recommendation is 100 mrem per year for chronic exposure to members of the general public. The NRC is proposing a similar standard for a revision to 10 CFR Part 20. It is also recommended that ALARA be applied to reduce the dose to 25 mrem per year, consistant with other standards for specific practices (40 CFR Part 190, 40 CFR Part 192, and 10 CFR Part 91).

4.0 Analysis Methodology

The purpose of this analysis was to evaluate the soil removal action conducted at manhole 180. The assessment consists of determining the health effects from the observed above background concentrations of uranium and thorium in the soil around manhole 180 and also determining a cost-benefit analysis of the soil removed.

4.1 Environmental Pathways

A radiological environmental pathway analysis was performed to determine the dose to the resident farm family from radioactivity in the soil. The report describes this analysis in great detail. Ten pathways were analyzed:

- **Direct Radiation from Contaminated Soil**
- **Inhalation of Resuspended Dust**
- **Food Ingestion - Crops and Plants (3 Subpathways)**
- **Food Ingestion - Meat and Milk (4 Subpathways)**
- **Drinking Water**

4.2 Hydrogeological Models

Actual boring log data were used to establish the soil composition for the hydrogeological models. The hydrogeological model determines the rate at which the radioactive material migrates from the surface to the aquifer region. This is very important to the drinking water and irrigation water obtained from the family well. Figure 4.2.1 shows a typical hydrogeological model used in the analysis.

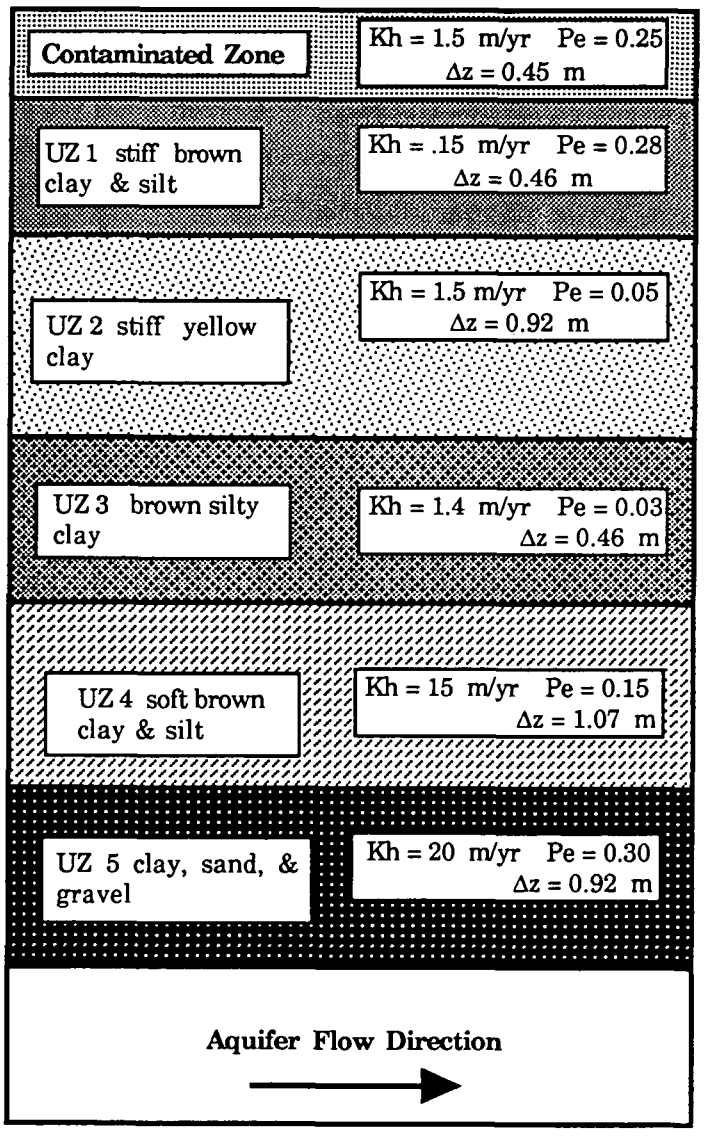
4.3 Assessment Area

The area around manhole 180 that was evaluated in this analysis is called the assessment region. The assessment region and the excavated area is shown in Figure 4.3.1.

4.4 Time Points Used to Calculated Dose-To-Source Ratios

The transport of radioactive material in the environment is a continuous process that begins as soon as material is released to the environment and is essentially an ongoing process. The evaluation of the environmental transport factors (ETF) and the resulting dose-to-source ratios (DSR) are evaluated at particular times based on the nature of the transport processes and any applicable standards relating to the exposure from radioactive material in the environment. The time frames for which environmental transport and dose-to-source ratios were calculated are: 1, 70, 200, 500, and 1,000 years.

Figure 4.2.1: Model 2 Silt and Clay Cross Section of Vadose Region with Typical Hydraulic Properties



Legend

Kh = Vertical Hydraulic Conductivity (m/yr)

Pe = Effective Porosity

ρ = Soil Density (average = 1.8 g/cc)

Δz = Depth of Layer (m)

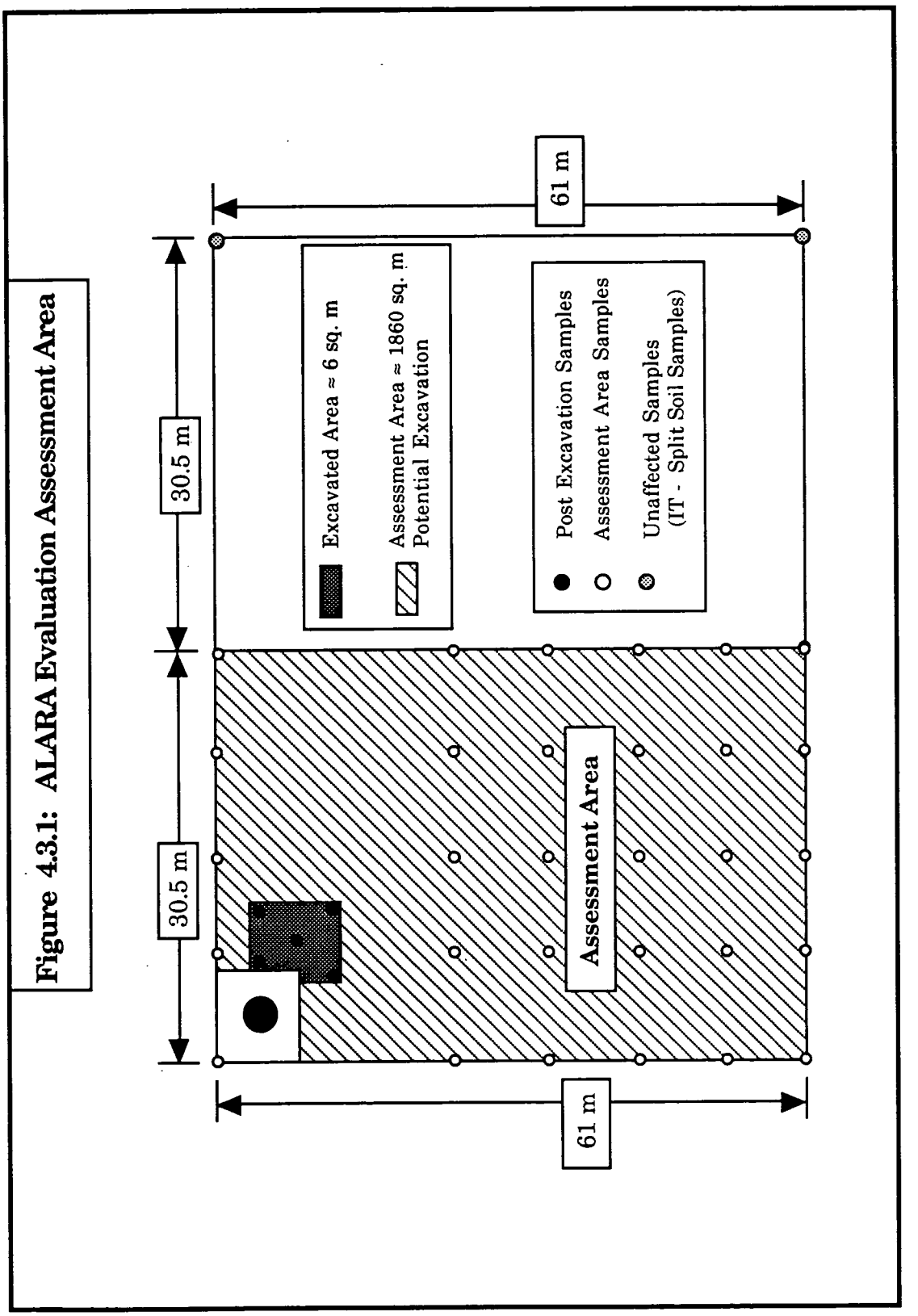


Figure 4.3.1: ALARA Evaluation Assessment Area
30.5 m
30.5 m
61 m
61 m
Assessment Area
Excavated Area ≈ 6 sq. m
Assessment Area ≈ 1860 sq. m
Potential Excavation
Post Excavation Samples
Assessment Area Samples
Unaffected Samples
(IT - Split Soil Samples)

4.5 Procedures Employed in the Pathway Analysis

The pathway analysis methods, techniques, and procedures used in this study are based on currently accepted procedures either in the U.S. Department of Energy (U.S. DOE), the U.S. Nuclear Regulatory Commission (U.S. NRC), the U.S. Geological Survey (USGS), the International Commission on Radiological Protection (ICRP), or the U.S. Environmental Protection Agency (U.S. EPA). The intent was to stay within currently accepted guidelines for the methods and analytical techniques.

The inhalation rate and drinking water intake factors were taken from EPA sources, (EPA, 1986). Food intake parameters were taken from the EPA or ICRP publications and the highest, or most conservative, value was used whenever possible. Distribution coefficients relating the ratio of dissolved concentration to adsorbed concentration for particular radionuclides in specific media, such as clay, silt, and sand were taken from NRC or USGS sources. The lower limits for specific parameters were used in order to yield conservative results for both concentration of the radioactive material in the water and the time frame for the transport process to occur.

4.6 Dose-To-Source Ratios

The pathway analysis results are given in a dose-to-source ratio (DSR). The DSR is in units of mrem/year per picocurie of a specific radionuclide in a gram of soil. The total dose from each pathway for each radionuclide is found by multiplying the actual concentration of the radionuclide in the soil times the DSR.

5.0 Results of the ALARA Analysis

5.1 Total Dose-To-Source Ratios

Table 5.1.1 lists the total dose-to-source ratio (DSR) results for uranium and thorium for model I. The DSRs shown here are the maximum values which occur at the time indicated. Thus, the maximum DSR for uranium isotopes occur about 200 years from now. The maximum values of the DSR would result in a maximum dose to an individual. The dose would be obtained by multiplying the DSR by the actual content of the radionuclide in the soil.

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Table 5.1.1: Total Dose-To-Source Ratios for Uranium and Thorium-Model I

Radionuclide	Time Frame† of Analysis (years)	Total DSR (mrem/yr per pCi/g)
Uranium-238	200	0.73
Uranium-235	200	0.90
Uranium-234	200	0.78
Thorium-228	70	4.85
Thorium-230	70	0.42
Thorium-232	70	2.12

†Time frame refers to the time at which the DSR was calculated. The time which results in the maximum dose-to-source ratio is listed.

5.2 Plan for the ALARA Calculation

An ALARA calculation begins when a standard is satisfied or reached (see Figure 2.1). Standards must be met at any cost. ALARA is the application of the philosophy that all exposures to humans should be kept as low as reasonably achievable. Figure 5.2.1 details the plan for the ALARA calculation.

In order to perform the ALARA cost-benefit analysis it is necessary to identify the level, which consists of either a dose level or a concentration level of radioactivity in the soil, from which the ALARA application is initiated. Also, it necessary to determine the level to which the ALARA application will be practiced. These ALARA results, which are in terms of person rem saved, consist of applying ALARA from a guideline to either the post excavation activity levels or to the sample measurements from an unaffected area (an area outside the assessment region).

Samples were taken by the FMPC within the assessment area in order to characterize the extent of above background levels of uranium and thorium in the soil. Check samples were sent to International Technologies Incorporated (IT) to measure the radioactivity. These results were reported in terms of total uranium and total thorium, parts per million (ppm). These results indicated that uranium-238 had a maximum value of approximately 30 picocuries per gram of soil (this sample existed in the excavated region prior to excavation). While, thorium-228 had a maximum value of approximately 4 picocuries per gram of soil prior to excavation activities.

These measurements indicated that uranium and thorium existed at levels below the NRC Branch Technical Position Guideline prior to the start of any excavation activities. Furthermore, these measurements indicated that the dose from the above background levels, prior to any removal action, would never be as high as the DOE Standard of 100 mrem per year. Therefore, it was conservatively assumed that the starting point of the ALARA calculations would be the NRC guideline. Figure 5.2.1 illustrates this starting point for the ALARA application. Table 5.2.1 shows these NRC guidelines for depleted uranium and natural thorium with units of picocuries per gram of soil. These NRC guidelines were multiplied by the total dose-to-source ratios of Table 5.1.1 to give doses. These dose results are presented in Table 5.2.1 as well.

The ending point of the ALARA assessment was considered for two points: 1) post excavation soil sample radioactivity measurements and 2) radioactivity measurements from an area that is outside the manhole 180 assessment region. The application of the ALARA cost-benefit analysis from the NRC Guideline to the post excavation soil samples details the

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Figure 5.2.1: ALARA Application To Current Situation

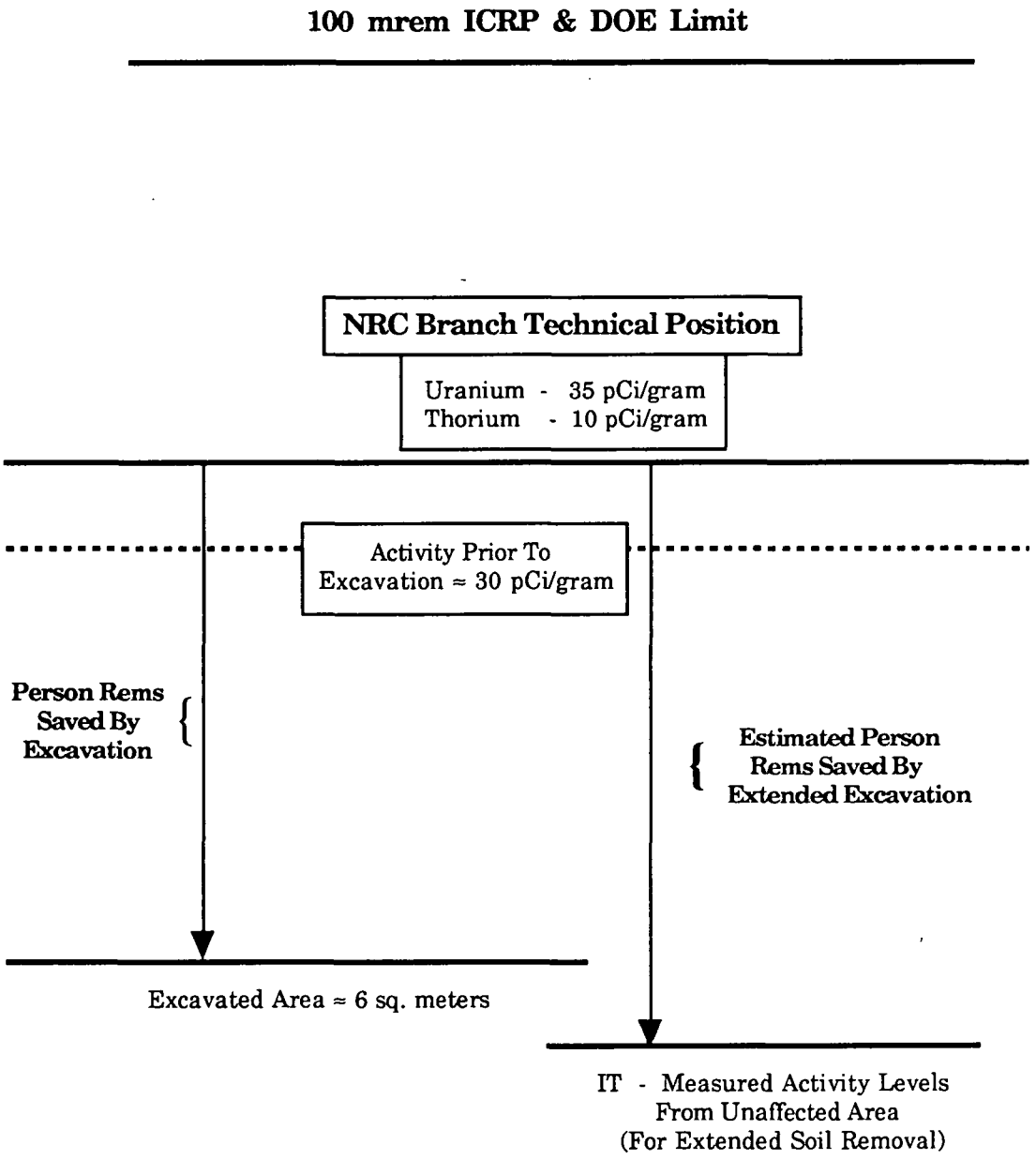

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Table 5.2.1: Doses Based on the NRC Branch Technical Position Guideline

Radionuclide	NRC† (pCi/g)	Dose-NRC†† (mrem/yr)
Uranium-238	17.5	12.77
Uranium-235	0.8	0.72
Uranium-234	17.5	13.73
Thorium-228	5	24.30
Thorium-230	17.5	7.41
Thorium-232	5	10.60

†These values, in units of pCi/g, are from the NRC Branch Technical Position Paper-35 pCi/g depleted uranium and natural thorium (NRC, Federal Register 1981).

††These doses are based on the NRC Guidelines for depleted uranium and natural thorium and represents the dose the resident farmer would receive with this level of residual radioactivity in the soil. All ten pathways and subpathways are included for each radionuclide in this calculation.

number of person rem saved for the excavation activity. While considering the ALARA analysis from the NRC Guideline to samples taken from an area which is unaffected, outside the manhole 180 region, provides an estimate of person rems which would be saved if the entire assessment region was excavated.

The University of Cincinnati measured the radioactivity in the post-excavation soil samples (see Figure 4.3.1 for the sample location). These are soil samples which have been taken from the excavated area following the cleanup activities. Column 2 of Table 5.2.2 shows the radionuclide content of these samples. Based on this actual radionuclide content, the dose was calculated for the resident farmer. Column 3 shows this dose.

Table 5.2.3 shows the results of the IT split soil samples. Again, these samples represent an area outside the assessment region. Column 2 illustrates the activity level of each radionuclide, while column 3 shows the dose (mrem per year) that the resident farmer would receive based on this concentration of radionuclide in the soil.

5.3 Person Rem Saved for the Two Endpoints

Table 5.3.1 shows the ALARA results for the current soil removal action. These results were calculated first by substracting the mrem per year of the post excavation soil samples (Table 5.2.2) from the mrem per year of the NRC Guideline (Table 5.2.1) to give mrem avoided. The mrem avoided were converted to rem avoided (dividing by 1000) and then multiplied by a 70 year lifetime (EPA, 1986) to give person rem saved. The third column of Table 5.2.1 gives the person rem saved for a resident farm family of 5 with each member of the family having a 70 year lifetime (found by multiplying column 2 by 5).

Table 5.3.2 predicts ALARA results based on an excavation of the remaining 1854 square meters of the assessment area down to a level of that measured outside the assessment area, determined by the IT split sample measurements. These person rem saved, column 2, are estimated based on the radionuclides of uranium and thorium being reduced in concentration to a value which is typical of the surrounding farm land. Column 3 estimates the person rem saved for a resident farm family of 5.

Table 5.2.2: Doses Based on Current Soil Removal Action

Radionuclide	Post Excavation† Samples (pCi/g)	Dose-Post Excavation†† Samples (mrem/yr)
Uranium-238	5.30	3.87
Uranium-235	0.24	0.22
Uranium-234	5.30	4.16
Thorium-228	0.55	2.69
Thorium-230	2.10	0.89
Thorium-232	0.51	1.09

† Post Excavation Soil Samples were collected by the FMPC and measured for radioactivity at the University of Cincinnati (pCi/g).

††These doses are calculated for the post excavation soil samples with units of mrem/yr. They represent the committed effective dose equivalent that the resident farmer receives from the excavated region based on the total of the ten pathways and subpathways.

Table 5.2.3: Doses Based on the IT Split Soil Samples-Representing Soil Measurements Outside Assessment Area

Radionuclide	IT Samples† (pCi/g)	Dose-IT†† (mrem/yr)
Uranium-238	2.1	1.53
Uranium-235	0.6	0.54
Uranium-234	1.7	1.33
Thorium-228	1.5	7.29
Thorium-230	2.75	1.16
Thorium-232	0.9	1.91

*These measurements represent the average of two IT Split Soil Samples located outside the assessment region (See Figure), units are pCi/g. The samples are: #7 and #47.

**These doses represent what the resident farmer receives from considering each radionuclide over the ten pathways and subpathways analyzed, units are mrem/yr committed effective dose equivalent.

Table 5.3.1: ALARA Results for the Current Soil Removal Action

Radionuclide	Rem Saved† Excavated Region (70 year)	Rem Saved†† Excavated Region (5-Family-70 year)
Uranium-238	0.62	3.12
Uranium-235	0.035	0.18
Uranium-234	0.67	3.35
Total rem saved for Uranium:	**1.33**	**6.65**
Thorium-228	1.51	7.56
Thorium-230	0.46	2.28
Thorium-232	0.67	3.33
Total rem saved for Thorium:	**2.64**	**13.17**

†Rem saved for the excavated region represent the reduction in dose from the NRC guideline to the level of the post excavation soil sample values determined from radioactivity measurements performed at the University of Cincinnati. These person rem saved include the contribution from all ten pathways and subpathways and is considered for a 70 year lifetime.

††This column is the same as the first column except the person rem saved have been multiplied by 5 to compensate for a family of five.

Table 5.3.2: ALARA Results Based on a Soil Removal Action of the Remaining Portion of the Assessment Area

Radionuclide	Rem Saved† 1854 meter^2 (70 year)	Rem Saved†† 1854 meter^2 (5-Family-70 year)
Uranium-238	0.79	3.93
Uranium-235	0.013	0.063
Uranium-234	0.87	4.34
Total rem saved for Uranium:	**1.67**	**8.33**
Thorium-228	1.19	5.95
Thorium-230	0.44	2.19
Thorium-232	0.61	3.04
Total rem saved for Thorium:	**2.24**	**11.18**

†Rem saved for the 1854 square meters represent the reduction in dose from the NRC guideline to the level of the IT Split Soil Sample values (Sample Nos. 7 and 47). These person rem saved includes the contribution from all ten pathways and subpathways and is considered for a 70 year lifetime. The 1854 square meters represent the unexcavated portion of the assessment area.

††This column is the same as the first column except the person rem saved have been multiplied by 5 to compensate for a family of five.

5.4 ALARA Cost-Benefit Analysis

The ALARA cost-benefit analysis consists of calculating the cost per person rem avoided for both the current soil removal action and the extended soil removal action. The extended soil removal action represents the soil removal of the remaining portion of the assessment area to the above background level of the IT split soil samples taken outside the assessment area. The cost per person rem avoided is for both the individual and the resident farm family, which consists of five individuals. The cost of the current soil removal action was supplied by the FMPC and is equal to 153,970 dollars. The cost estimate to perform the soil removal action for the remaining portion of the assessment area was provided by the FMPC as well and is equal to 176,000 dollars, excluding any soil disposal costs.

Table 5.4.1 describes the ALARA cost-benefit analysis for the current soil removal action. Column 2 indicates the total person rem saved and the cost per person rem avoided for uranium and thorium together. Column 3 gives the total person rem saved and the cost per person rem avoided for the resident farm family.

Table 5.4.2 describes the ALARA cost-benefit analysis estimate for the soil removal action of the remaining portion of the assessment area. Included in Table 5.4.2 are the total person rem saved and the cost per person rem avoided for uranium and thorium together over this area. Results are also provided in Table 5.4.2 for the resident farm family.

6.0 Conclusions

Based on the previous technical discussions, the recommendation of the University of Cincinnati is that an additional cleanup action can not be justified for the remaining portion of the assessment area located adjacent to manhole 180. This conclusion was arrived at through several considerations. These considerations are: 1) the low levels of uranium and thorium prior to any excavation activities (see Figure 5.2.1), 2) the highly conservative nature of the assessment, and 3) the cost per person rem spent for the completed soil removal action and the projected cost per person rem estimated for the extended soil removal action is considerably higher than the 2000 dollars per person rem recommended by the NRC.

As shown in Figure 5.2.1 the levels of uranium and thorium in the soil prior to any excavation activities correspond to a dose which is well below the Department of Energy's dose limit of 100 mrem per year. Also, the NRC guidance levels cited for uranium and thorium (35 pCi/g for depleted uranium and 10 pCi/g for natural thorium) are above the levels which were actually measured prior to any excavation activities.

6.0 Conclusions (continued)

The person rem saved for the current cleanup action and also the estimation of person rem saved for the remaining portion of the assessment area were calculated very conservatively. These person rem saved are calculated from the doses that the resident farmer and farm family would receive based on the conservative scenario illustrated in Figure 1.1. Also, the person rem avoided represent a cumulative dose over a 70 year lifetime for the resident farmer and each member of the farm family. In reality the person rem saved for these cleanup actions are much lower which means the cost per person rem avoided is much higher.

Tables 5.4.1 and 5.4.2 show the costs for the current soil removal action and also estimate the cost for the extended soil removal action. Notice that for the current cleanup action the cost per person rem avoided for the resident farmer was calculated to be $ 38,783 and the cost per person rem avoided for the farm family was found to be $ 7,768. The estimated cost per person rem for the remaining portion of the assessment region are even higher than these current costs per person rem avoided. Both of these cost figures, either for the current cleanup action or the extended cleanup action, greatly exceed the two-thousand dollars per person rem avoided recommended by the NRC Branch Technical Position Paper (NRC, 1981).

Therefore, the conclusion of the University of Cincinnati is that no further action is warranted with respect to the current condition of the surface soil near manhole 180.

Table 5.4.1: ALARA Cost-Benefit Results for the Current Soil Removal Action

Radionuclide	Rem Saved And Cost Analysis Excavated Region (70 year)	Rem Saved And Cost Analysis Excavated Region (5-Family-70 year)
Uranium-238	0.62	3.12
Uranium-235	0.035	0.18
Uranium-234	0.67	3.35
Total rem saved for Uranium:	**1.33**	**6.65**
Thorium-228	1.51	7.56
Thorium-230	0.46	2.28
Thorium-232	0.67	3.33
Total rem saved for Thorium:	**2.64**	**13.17**
Total Person Rem Saved for Uranium & Thorium:	**3.97**	**19.82**
Cost of Current Cleanup:	**$ 153,970**	**$ 153,970**
Cost per Person Rem Saved: for the Current Cleanup of Uranium and Thorium	**$ 38,783**	**$ 7,768**

Table 5.4.2: ALARA Cost-Benefit Results Based on a Soil Removal Action of the Remaining Portion of the Assessment Area

Radionuclide	Rem Saved And Cost Analysis 1854 meter^2 (70 year)	Rem Saved And Cost Analysis 1854 meter^2 (5-Family-70 year)
Uranium-238	0.79	3.93
Uranium-235	0.013	0.063
Uranium-234	0.87	4.34
Total rem saved for Uranium:	**1.67**	**8.33**
Thorium-228	1.19	5.95
Thorium-230	0.44	2.19
Thorium-232	0.61	3.04
Total rem saved for Thorium:	**2.24**	**11.18**
Total Person Rem Saved for Uranium & Thorium:	**3.91**	**19.51**
Estimated Cost:	**$ 176,000**	**$ 176,000**
Cost per Person Rem Saved: for the Extended Cleanup of Uranium and Thorium	**$ 45,013**	**$ 9,021**

These costs exclude disposal costs associated with the soil removal.

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1.0 Introduction

On April 4, 1989 the FMPC was informed of a problem concerning water overflowing from manhole 180 located on a property adjacent to the outfall line which leads to the Great Miami River. The area was investigated and soil samples were taken to characterize the extent of above background concentrations of uranium and thorium in the soil. The samples were analyzed for total uranium and total thorium content. Some of the samples were found to have higher concentrations than background.

The FMPC initiated an immediate removal action plan. This plan included 1) repair of the effluent line, 2) removal of soil containing elevated levels of uranium and thorium, and 3) storage of the excavated soil on site. To facilitate this removal action the FMPC employed a residual radioactivity soil guideline adopted from the 1981 NRC Branch Technical Position (NRC, 1981). This ALARA assessment was performed to evaluate the soil cleanup action.

This report presents a brief description of the methodology and approach in Section 1.1 along with pertinent background details. Section 2 describes ALARA and its history in the Nuclear Industry along with the approach for implementing an environmental ALARA assessment for the soil removal action. Section 3 details the standards and regulations that were reviewed for the analysis. Section 4 describes the methodology of the study, including the pathway analysis. Section 5 describes the results of the pathway analysis and also the cost-benefit analysis of the ALARA application. Finally, Section 6 discusses these results.

1.1 Study Objectives and Approach

The objective of the study was to prepare an independent ALARA assessment of the soil removal action completed at manhole 180 employing industry accepted pathway analysis techniques. Manhole 180 is located approximately 460 meters east of the FMPC site boundary on an adjacent property. The manhole is located at the beginning edge of a flood plain that extends east towards the Great Miami River. The study area is characterized by a small sloping region which then levels off. This small sloping region drops in elevation by about 1.5 meters over a horizontal stretch of approximately 31 meters.

The area excavated was approximately 6 square meters to a depth of approximately 0.6 meters. The area excavated resulted in about 3.6 cubic meters of soil removed. An equivalent amount of soil, supplied by a local soil and gravel contractor, was used as backfill for the excavated region.

1.1 Study Objectives and Approach (continued)

The pathway analysis was performed for an area of approximately 30.5 meters by 61 meters near manhole 180. Site-specific information describing the location and topographical environment around manhole 180 was used to determine these 1858 square meters of assessment. This region was then assumed to have a uniform concentration of the analyzed radionuclides per gram of soil. Boring logs for two areas in the vicinity of the manhole 180 were used to establish analytical models for the pathway analysis. The first boring log is for the region Northeast of manhole 180 at an elevation of 165 meters above mean sea level and the second is from a location south of the manhole at an elevation of 163 meters. These boring logs are included in Appendix A of this report. The boring logs provided excellent data for the analysis.

The human activity scenario chosen for the pathway analysis is the resident farmer. This scenario is used to estimate the maximum credible dose to an individual as a result of establishing a family farm on the study area. Since the total area affected is approximately 1860 square meters, the family farm scenario is considered realistic and the most conservative.

The pathway analysis was performed using site-specific information, supplied by the Feed Materials Production Center Annual Environmental Monitoring Report (FMPC, 87), U.S. Geological Survey maps and results (USGS, 1988) , and the Hydrogeological Study of FMPC Discharge to the Great Miami River, Final Report (IT, 1988). These sources were used to construct two models for the evaluation of the transport of uranium and thorium and other selected radionuclides, which may have been present in the effluent discharge, from the surface soil to the groundwater.

The analysis methods, techniques, and procedures used in this analysis are based on industry accepted procedures adopted from applicable U. S. Department of Energy (U.S. DOE), U. S. Nuclear Regulatory Commission (U.S. NRC), U.S. Geological Survey (USGS), International Commission on Radiological Protection (ICRP), or U.S. Environmental Protection Agency (U.S. EPA) sources and guidance. Specific references are cited throughout this report.

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2.0 The Application of ALARA

2.1 Development of the ALARA Concept and Risk-Benefit Analysis

The radiation standards discussed in Section 3 are based on the premise that there is no threshold for radiation induced risks to health or genetic defects. The risk model that is used to predict health effects is a linear, no-threshold model. According to this linear hypothesis, some small degree of risk is associated with any radiation exposure, regardless of how low the exposure. Based on this cautious model, the philosophy evolved that any unnecessary exposure to ionizing radiation should be avoided and the dose to individuals should be kept "As Low As Reasonably Achievable," or ALARA. Thus, ALARA is a radiation protection philosophy. It is basically a philosophy that requires radiation exposure be kept as low as possible to both nuclear industry workers and members of the general population.

As early as 1954, the National Committee on Radiation Protection (NCRP) stated that, "...radiation exposure should be kept as low as practicable." This terminology, as low as practicable, persisted for many years in the publications of the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP). The word "practicable" was changed to "practical" in 1958 and 1959 by the NCRP and the ICRP, respectively. In 1960, the U.S. Federal Radiation Council (FRC) added to the "low as practical" terminology the basic concept of a risk-benefit balance (FRC, 1960).

In 1965, the ICRP also called for risk-benefit considerations in applying the as low as readily achievable concept (ICRP, 1966). Economic considerations were to be applied such that incremental health detriments should not exceed incremental costs to reduce or avoid these detriments. Although not precisely defined, this appears to be the introduction of the optimization principle in the risk-benefit analysis. The benefit was understood to be the reduction in exposure (rem) to individuals.

In early 1970, the Atomic Energy Commission (AEC) proposed design criteria for limits on effluents from Nuclear Power Plants that included a recommendation that doses be kept, "as low as practicable (AEC, 1970)." In the final released version of 10 CFR Part 50, the Nuclear Regulatory Commission (NRC) recommended the 1000 dollars per person rem avoided as a value to be used in deciding what is "practicable."

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2.1 Development of the ALARA Concept and Risk-Benefit Analysis (continued)

In 1973, the ICRP had changed the term "readily" achievable to "reasonably" achievable. In 1982, the ICRP published a document entitled, "Cost - Benefit Analysis in the Optimization of Radiation Protection (ICRP, 1982)." Cost-benefit methods are described in detail in this publication. In 1985, the NRC proposed changes to 10 CFR Parts 19, 20, 30, 31, 32, 34, 40, 50, 61, and 70 that would require an ALARA application rather than simply recommend an ALARA program. These revisions did not require a detailed cost-benefit calculation because it was recognized as difficult in many situations. In many practical situations, the ALARA process was to continue until there were few additional benefits achieved. That is, there would be a point where the reduction in person-rem did not warrant further action. Instead, the NRC stated that "judgmental decisions" could be used instead of detailed calculations for the cost-benefit analysis.

Finally, it is worth pointing out some of the precedents that have been established in the risk-benefits concept. In the area of cost and health detriments the current NRC guidance appears to be 2000 dollars per person rem avoided (Peterson, 1987). The linear, no-threshold model has a risk coefficient of 2×10^{-4} (risk of fatal cancer incidences per rem). This is the risk coefficient recommended by the ICRP. The concept of risk is discussed in Section 2.4.2 in this report

In summary, research at the University of Cincinnati has led to the conclusion that radiation standards must be met regardless of cost, then considerations of cost and technology must be used to determine a lower limit of exposure. We believe this principle of ALARA application is shown clearly in Figure 2.1.1.

2.2 Objectives of an ALARA Program

One of the fundamental objectives of an ALARA program is to achieve a balance between detriment (adverse health effect) and benefit. As usual, practice requires a trade off of benefit against detriment and risk. The ALARA philosophy is strongly motivated to reduce personnel and environmental radiation exposures to the lowest possible levels consistent with cost and operating requirements. This philosophy maintains that no radiation exposure should be allowed without some benefit. Implicit in this conservative approach is the previously stated concept, that any radiation exposure, no matter how low, implies some detriment or risk.

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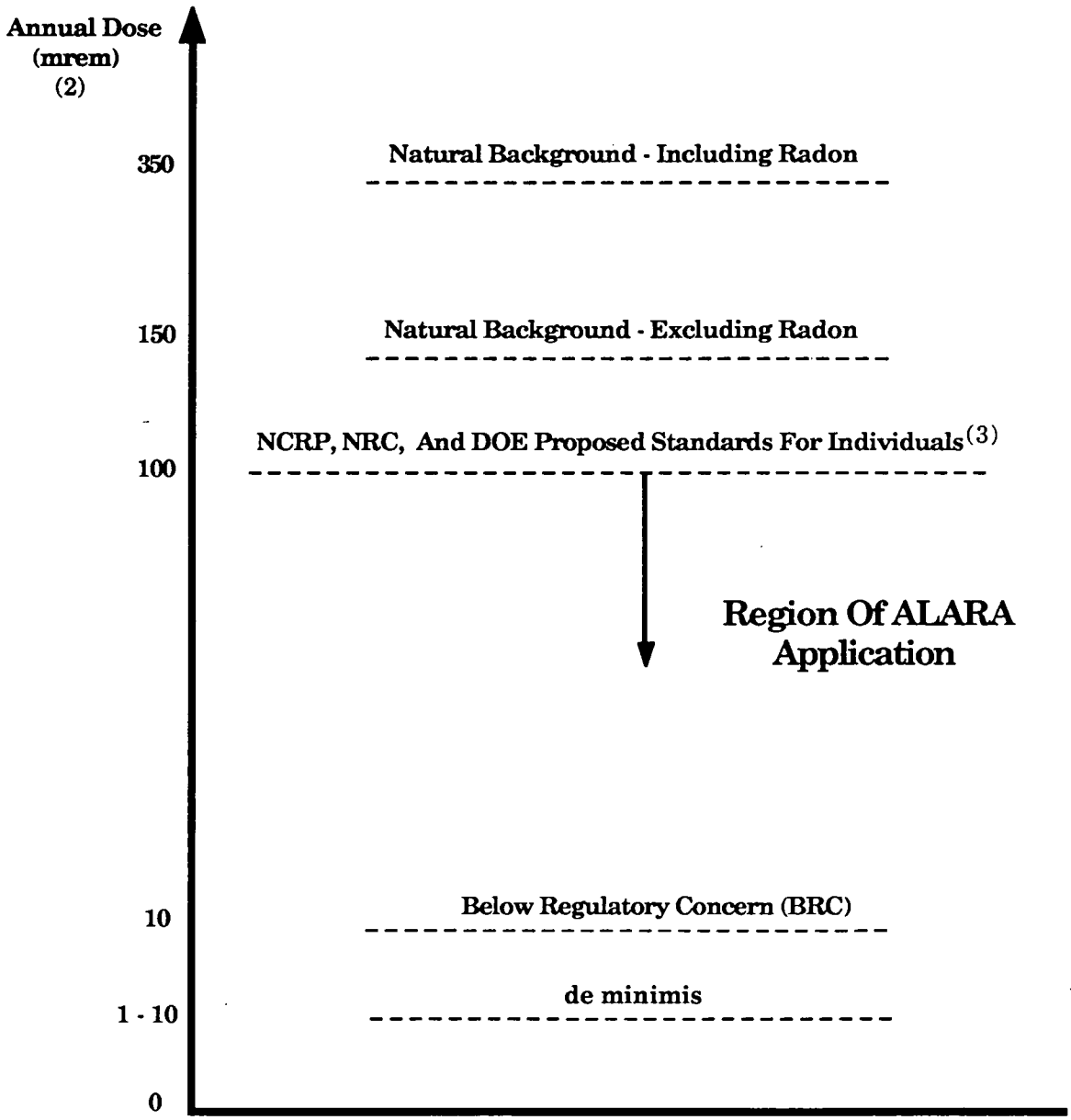
Figure 2.1.1: The Region For ALARA Application(1)



(1) Ordinate Scale Is Not To Scale.

(2) Effective Dose Equivalent.

(3) General Population, Not Radiation Workers.

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2.2 Objectives of an ALARA Program (continued)

For many applications of the ALARA concept, and in order to reduce subjective decisions, the point at which the ALARA program is terminated is determined by the dollars spent to save (or avoid) a person-rem of dose. Originally, the collective dose equivalent of one person-rem was assigned a value of one-thousand dollars (10 CFR Part 50, Appendix I). On this basis, if the cost to achieve a dose reduction of one person-rem exceeds one-thousand dollars, then the ALARA requirements are considered satisfied. Recent work utilizes a value of two-thousand per person-rem avoided (Peterson, 1987).

2.3 Extension of the ALARA Concept to Environmental Protection

The ALARA concept was originally devised for industry workers who are monitored for radiation exposure in a controlled access work situation. The ALARA concept has been expanded to include all radiation workers, non-radiation workers, members of the general public and the environment. Thus, exposures to individuals and the environment must now be considered. This application or extension of the ALARA concept must also be evaluated through the use of a risk/benefit analysis.

The exposure to individuals must be evaluated in an ALARA program. In this report, the exposure to individuals is determined by the radiological environmental assessment. A pathway analysis methodology is utilized to perform this risk assessment. The dose to individuals is calculated for a family farm on the small contaminated area. Section 4.1 of this report describes the activity scenario for the family farm that leads to the dose calculation.

The environmental ALARA concept is measured in terms of a collective dose commitment to present and future populations. Even though an exposure can be shown to have minimal effect today, it may not satisfy the ALARA philosophy if it imposes a high future burden on the population. In order to meet this environmental ALARA objective, this analysis included migration of the contamination from the surface soil through the vadose zone to the aquifer. Also, the collective dose was considered at the present time and at 70 years.

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2.4 Risk, Cost, and Benefit

2.4.1 Benefit

Exposure to radiation is equated with risk, and risk with detriment. Any dose reduction would therefore be considered beneficial. In this analysis, dose reduction is considered the principle benefit. Thus, the benefit will be measured in terms of the person-rem avoided as a result of the decontamination operation.

2.4.2 Risk

Risk is synonymous with a hazard or peril and appears as a loss or injury. Risk analysis addresses the probability related to this loss or injury. This view of risk, although simplified, provides a measure of the hazard. In everyday life risk is often expressed as a probability. This probability is often stated in very general terms. For example, the risk of being killed in a car accident is 1 in 4000. The EPA recently issued warnings regarding radon gas in the home. The EPA established an action level at 4 pCi/liter of air. This was based on the risk to individuals breathing this air. The risk to individuals from radon gas (its daughter products) is lung cancer incidence. The EPA radon data, shown in Figure 2.4.2.1, indicates that radon gas at a level of 4 picocuries per liter would result in 13-50 lung cancer deaths per 1000 people exposed over their lifetime. This would be considered a lifetime risk of 50/1000 or 5×10^{-2}.

Evaluating the risk from chronic low level exposure to ionizing radiation has been the subject of countless research papers and prestigious scientific committee evaluations. Excellent discussions of the effect of low level ionizing radiation on humans can be found in the United Nations Scientific Committee on the Effects of Atomic Radiation (UN, 1977) and National Academy of Sciences / National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (known as BEIR III)(NAS, 1972). Both reports contain risk estimates for exposure to chronic low level ionizing radiation. These risk estimates vary and are the subject of much scientific discussion.

It is now widely acknowledged that the "risk" from low level exposure to ionizing radiation is the risk of a fatal cancer. Thus, the current discussion focuses on the risk coefficient associated with the induction of a fatal cancer. Most scientists (BEIR III, ICRP, and NCRP) now use a risk coefficient of 2×10^{-4} per rem of exposure. This means that if 10,000 people were exposed to 1 rem of radiation, there is a probability that 2 fatal cancers would be induced. Since the national cancer rate is about 21%, a cohort of 10,000 people will have 2100 "natural" cancer deaths.

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Figure 2.4.2.1: U.S. EPA Data On Radon Risk

Radon Risk Evaluation Chart

† Picocuries/Liter	†† Lung Cancer Deaths	Comparable Exposure Levels	Comparable Risk
200	440-770	1,000 times average outdoor level	More than 60 times non-smoker
100	270-630	100 times average indoor level	20,000 chest X-rays/yr.
40	120-380		
20	60-210	100 times average outdoor level	2 pack/day smoker
10	30-120	10 times average indoor level	1 pack/day smoker
4	13-50		5 times non-smoker risk
2	7-30	10 times average outdoor level	200 chest x-ray per year
1	3-13	Average indoor level	Non-smoker risk of dying from cancer
0.2	1-3	Average outdoor level	20 chest x-rays per year

† Radiation in the air is measured in picocuries per liter.

†† Estimated number of deaths due to radon exposure (out of 1,000).

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2.4.2 Risk (continued)

The National Council on Radiation Protection (NCRP) reports that the average annual rate for accidental deaths in all of U.S. industry was 1.1 per 10,000 workers, a risk of 1.1×10^{-4} (NCRP, 1987). The "safe" industries report a risk of 1.0×10^{-4}. Safe industries are service, government, trade, etc. The more dangerous industries are construction, agriculture, and mining. These industries report fatalities at a rate as high as 6.0 per 10,000 workers or 6×10^{-4}. Risk coefficients are used to establish the standards for radiation protection discussed in Section 3.0 of this report.

Standards are established to insure the risk to radiation workers is no greater than the risk in a "safe" industry. This would mean that the allowable dose to a worker should be such that the risk of a fatal cancer incidence would be no greater than 1 in 10,000 or 1×10^{-4}. The standards for the general public are established at levels that reduce this risk by a factor of 10 to 0.1 in 10,000 or 1×10^{-5} (NCRP, 1987). These are annual risks. The lifetime risk is found by multiplying the annual risk by 50 years or 70 years. The lifetime risk to an individual in the general population who was exposed to 100 mrem per year is shown in Equation 2.4.2.1:

$$\textbf{Life-Time Risk: } 1 \times 10^{-5} \text{ risk/year} \times 70 \text{ years} = 7.0 \times 10^{-4} \qquad (2.4.2.1)$$

Compare this with the risk from indoor radon, 5×10^{-2} or 500×10^{-4}, or 70 times higher risk.

3.0 Environmental Radiation Standards for the Public

3.1 Introduction

The regulatory framework for limiting normal exposures of the general public can be divided into two basic categories:

(1) Radiation protection standards that generally apply to most sources.

(2) Environmental radiation standards that apply to specific practices or sources.

The radiation protection standards in (1) above are intended to provide a limit based on stochastic risk. This would be the statistically based risk of fatal cancers or genetic effects from radiation exposure. These radiation protection standards usually follow the recommendations of the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP). The NCRP makes the recommendations for the United States.

The standards based on the recommendation of the NCRP are regarded as necessary for the protection of public health and must be met regardless of cost. On the other hand, the environmental radiation standards, (2) above, where available are based on regulatory judgement of the best available technology to limit radioactive effluents or cleanup the residual radioactivity in the soil. In both categories, (1) and (2), ALARA (As Low As Reasonably Achievable) practices must still be applied.

It is also worth noting that the environmental radiation standards already incorporate some ALARA considerations. For example, many of the environmental standards or standards that apply to specific practices have a dose limit of 25 mrem per year. Since a comparable risk based standard would be 100 mrem, some regulatory judgement and/or analysis has applied ALARA to reduce the risk based dose to 25 mrem.

3.2 Radiation Protection Standards

Radiation protection standards in the United States for limiting exposures of the public from all sources have been established by the Nuclear Regulatory Commission (NRC). Current standards, as specified in 10 CFR Parts 0-199, limit the dose to an individual in the general public to 500 mrem per year (annual dose equivalent, a whole body type of limit). In addition, limits are placed on the maximum concentration of radionuclides in air or water (MPC values) in order to limit the internal dose to the whole body or organs. These standards are based on ICRP Publications 1 and 2 as amended in Publications 6 and 9. Proposed revisions to these standards are currently being reviewed by the NRC. It is expected that such revisions will follow the recommendations of the NCRP. (See discussion that follows)

The ICRP revised its standards recommendations in Publication 26 (1977). The 500 mrem annual limit was retained but with the recommendation that the limit should be calculated by the weighted sum of dose equivalents to a number of important organs, and then this value should not exceed 500 mrem. This limit was given the name, "Effective Dose Equivalent." The organ weighting factor represents the portion of the stochastic risk from the irradiation of a particular organ to the comparable whole body uniform irradiation risk (risk still implying the risk of a fatal cancer).

The ICRP also observed in Publication 26, that chronic or continuous exposure of individuals in the public to 500 mrem per year would result in a higher lifetime risk than could be justified. For long term, continuous exposures, the ICRP recommended that it would be best to limit the chronic exposure dose to 100 mrem per year, annual effective dose equivalent.

The NCRP has recently adopted similar standards. NCRP Report 91 (June, 1987) includes similar limits for the standards of the general public: 500 mrem per year for occasional exposure and 100 mrem per year for chronic exposure. In addition, this is interpreted as 100 mrem per year from <u>all technically produced sources</u> (which excludes background and medical exposures). In case an individual receives exposure from a number of different sources, ICRP 91 suggests that an individual may encounter a maximum of 4 technically enhanced sources on a chronic (yearly) basis. Thus, the limit based on NCRP 91 would be 25 mrem annual effective dose equivalent. Newly proposed NRC standards (1986) in 10 CFR Part 20 also incorporate the 500 mrem/100 mrem concept.

3.3 Environmental Radiation Standards

Environmental radiation standards are written for specific practices or sources. These standards are primarily the responsibility of the EPA, but DOE orders and NRC regulations can also be cited. These standards usually specify a limit on dose. The dose limit is not based on stochastic limits of risk, but on the technology available to achieve this dose limit. It appears to be an ALARA application (see discussion at end of Section 3.1). These standards are based on doses that are regarded as reasonably achievable using the best available control technologies, not a detailed cost-benefit analysis.

Another important fact to keep in mind as these standards are reviewed is that the limits apply not only to a specific practice, but the limits are primarily intended to "control" effluent release and hence dose to the public. The limits are generally not intended to set standards for residual radioactivity in the soil. However, in two cases, the quantity of radium-226 or thorium-232 in the soil is specifically addressed.

Standards have been established for operations of commercial fuel cycle facilities, radioactivity in public drinking water systems, uranium and thorium mill tailings, radioactive waste disposal, and airborne radioactivity. Table 3.3.1 summarizes the current EPA, DOE, and NRC environmental radiation standards. This report will review standards for only the specific practices that are relevant to this situation.

3.4 Standards for Normal Operations of the Uranium Fuel Cycle

In 40 CFR Part 190, the EPA has established standards for normal operation of the uranium fuel cycle. The parts of the uranium fuel cycle included are: milling of ore, chemical conversion, fuel fabrication, electrical power generation in a nuclear power plant, and if ever applicable, fuel reprocessing. These standards limit the annual dose equivalent from all radionuclides to 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ. These standards are intended to control effluent releases from operating facilities and do not provide standards for residual radioactivity in the soil.

Table 3.3.1: Environmental Standards Summary

DOE Standards	Effective Dose Equivalent
ALARA required for all practices.	
DOE Order 5400.xx for DOE Operations	
Annual Effective Dose Equivalent	100 mrem
Drinking Water (Public Water Systems)	4 mrem
DOE Order 5820.2 Low Level Waste	
Whole Body	25 mrem
EPA Standards	
40 CFR 190 Uranium Fuel Cycle (Uranium Limits)	
Whole Body	25 mrem
Thyroid	75 mrem
Other Organs	25 mrem
40 CFR 192 Uranium Mill Tailings (Thorium Limits)	
Whole Body	25 mrem
Thyroid	75 mrem
Other Organs	25 mrem
40 CFR 141 Drinking Water (Public Water Systems)	
Whole Body (beta/gamma)	4 mrem
Critical Organ	4 mrem
40 CFR 61 Airborne Emissions	
Whole Body	25 mrem
Any Organ	75 mrem
NRC Standards	
10 CFR 61 Low Level Waste Disposal	
Whole Body	25 mrem
Thyroid	75 mrem
Other Organ	25 mrem
Draft EPA Standards	
40 CFR 193 Standards for Low Level Waste Management	
Annual Effective Dose Equivalent	25 mrem
Drinking Water	4 mrem
40 CFR 194 Standards for Residual Radioactivity	
No information as yet.	

3.5 Radioactivity in Drinking Water

The public water systems are protected by EPA standards contained in 40 CFR Part 141 for radioactivity in public drinking water systems. In summary, these standards are:

- A limit of 4 mrem annual dose equivalent to whole body or any organ from beta/gamma radiation.
- A concentration limit of 5 pCi/L for radium-226 and radium-228 (combined).
- A concentration limit of 15 pCi/L for gross alpha activity, excluding uranium and radon but including radium-226.

Revisions to 40 CFR Part 141 are being considered, but we do not have current information on these revisions.

3.6 Standards for Mill Tailings

Mill tailings are the residual rock and sand from the chemical milling operation that separates the uranium from the host rock. The EPA standard 40 CFR Part 192 applies to this operation. The standards are for control of the effluent streams from the operation and cleanup of residual uranium and thorium by-product materials. Briefly, the standards include:

- Limits on radium-226 concentration in soil to above background concentrations of 5 pCi/g averaged over the first 15 cm thick layers of soil and to 15 pCi/g for 15 cm thick layers of soil below 15 cm.
- Limits on annual dose equivalent from thorium processing operations of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ.
- Limits on the release rate of radon-222 of 20 pCi/m^2/s averaged over a year.
- Limit on photon radiation level at 20 μR per hour above background in an occupied building.
- Limits on groundwater concentration of 5 pCi/L for radium-226 and radium-228 combined and 15 pCi/L for gross alpha particle activity excluding radon and uranium.

The above limits for radon-222 and radium-226 also apply to thorium, radon-220, and radium-228.

3.7 Nuclear Regulatory Commission - Branch Technical Position

The Federal Register on October 23, 1981, page 52061-52063 presented for comment a proposed regulation entitled, "Disposal or on site storage of thorium or uranium wastes from past operations." This proposed regulation never appeared as a standard, but has been used in the past as a guide for limits on residual radioactive material in the soil. A number of options are cited in the paper. Table 3.7.1, below, summarizes the concentration limits. This NRC proposed regulation was never enacted into a standard.

Table 3.7.1: NRC Branch Technical Position (NRC, 1981)

Kind of Material	Concentration (pCi/g)
Natural Thorium (Th-232 plus Th-228) if all daughters are in equilibrium	10
Depleted Uranium	35
Enriched Uranium	30
Natural Uranium Ores (U-238 plus U-234) if all daughters are present and in equilibrium	10

3.8 University of Cincinnati Recommendation

We recommend that the cleanup criteria be established at 100 mrem annual effective dose equivalent, consistant with NCRP 91 and the proposed revisions to 10 CFR Part 20. We also recommend that ALARA practices be applied to reduce the dose to 25 mrem to the maximally exposed individual, consistant with the ALARA applications for other "specific practices" (40 CFR Part 190, 40 CFR Part 192, and 10 CFR Part 61). Since these latter ALARA applications have been acceptable to both the EPA and NRC, we believe they should provide excellent guidance in this case also.

3.9 Summary

It is our opinion that there is no standard that directly applies to the soil cleanup near manhole-180. We believe that ICRP 91provides the best available guidance for the dose to individuals in the general population. We also believe that the ALARA considerations implicit in 40 CFR Part 190, 40 CFR Part 192, and 10 CFR Part 61 provide a rationale for an ALARA program that reduces the dose to individuals to a maximum of 25 mrem. On this basis, our recommendation is a dose limit of 25 mrem, annual effective dose equivalent. The best method of insuring that this limit is not exceeded is by a detailed radiological environmental pathway analysis.

On the basis of stochastic risk, using the BEIR IV risk coefficient of 2×10^{-4} risk per rem, the 25 mrem dose corresponds to an annual risk of 5×10^{-6} and a lifetime risk of 3.5×10^{-4}. It may also be noted, that NCRP Report 94 cites an average natural background radiation dose to an individual in the general population at 350 mrem per year when radon is included. Thus the 25 mrem limit is less than 7% of background.

4.0 Methodology

The purpose of this analysis was to evaluate the soil removal action conducted at manhole 180 by the FMPC. Specifically, the assessment consists of determining the health effects from the observed above background concentrations of uranium and thorium in the soil around manhole 180 and also determining a cost-benefit analysis of the soil removed. The soil removal action was initiated by the FMPC as a result of an effluent release occurring on April 4, 1989. An effluent discharge line at the site backed up and overflowed as a result of heavy rains. The overflow occurred at manhole 180 and resulted in the subsequent release of water containing radioactive materials to an adjacent property.

The cleanup of the site consisted of excavating a quantity of surface soil containing elevated levels of uranium and thorium. This separate analysis is made to evaluate the residual material remaining in the soil and the long term dose effects from human exposure through all credible pathways.

The pathway analysis methodology describes the methods, procedures, and data used in the evaluation of the dose resulting from exposure to soil containing quantities of various radionuclides. Each part of Section 3 will discuss a pertinent feature of the analysis. The analysis is separated into three basic components: 1) establishing the exposure scenario, 2) evaluating the environmental transport (ETF), and 3) applying the corresponding dose conversion factors (DCF). The resulting dose from each pathway is evaluated by multiplying the environmental transport factor (ETF) and the dose conversion factor (DCF) to calculate the dose-to-source ratio (DSR) for each radionuclide considered. The general equation representing each pathway is given by:

$$ETF_{ip} * DCF_{ip} = DSR_{ip} \qquad (1)$$

The subscript i refers to the ith radionuclide and the subscript p refers to the pathway. The dose-to-source ratio is the dose an individual would receive each year (in mrem) for each picocurie of a particular radionuclide in the soil. The DSR is calculated for each pathway and the total DSR from all pathways is found by summing over the number of pathways considered.

4.1 Exposure Scenario

To adequately evaluate the near term and long term consequences from above background levels of radioactive material in the surface soil near manhole 180 an exposure scenario must be developed. The exposure scenario considered for this assessment was taken to be that associated with a resident family farm. This exposure scenario is considered to be the most conservative based on the number of exposure pathways evaluated.

4.1 Exposure Scenario (continued)

The resident farm scenario is based on a family of five assuming residence on the 30.5 meter by 61 meter area. This resident farm family would be self-sufficient, thus having the capability of producing general vegetable and grain products along with milk, meat, and water. The methodology utilized in developing the resident family farm scenario was taken from Gilbert 1988, "A Manual for Implementing Residual Radioactive Material Guidelines." This family farm scenario is depicted in Figure 4.1.1. The total quantity of any or all of these products is based on the total area available for farming. The amount of food produced and consumed will be addressed as part of each pathway later in this section.

4.2 Evaluation of Assessment Area

The total area used in this study was determined to be approximately 1860 square meters. The size of the area was evaluated based on topographical and hydrogeological considerations. The slope of the ground and the composition of the subsurface material were considered in the determination of the size of the area.

The Great Miami River is located less than a kilometer from the manhole 180 area. Manhole 180 resides at the beginning edge of a large flood plain. The average slope of the flood plain is approximately three-quarters of a meter per kilometer, while the slope in the immediate vicinity of the manhole is approximately one and one-half meters per 31 meters. The general topographical features of the region are shown in Figure 4.2.1. This information was used to evaluate the amount of runoff and the extent of erosion. Utilizing this information concerning the erosion and runoff characteristics of the region the assessment area used in this analysis was determined to be 1858 square meters. The assessment area is depicted in Figure 4.2.2, with the outside dimensions and the average slope identified.

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FIGURE 4.1.1: PICTORIAL REPRESENTATION OF THE FARM SCENARIO APPLIED TO THE SOIL REMOVAL ACTION NEAR MANHOLE 180

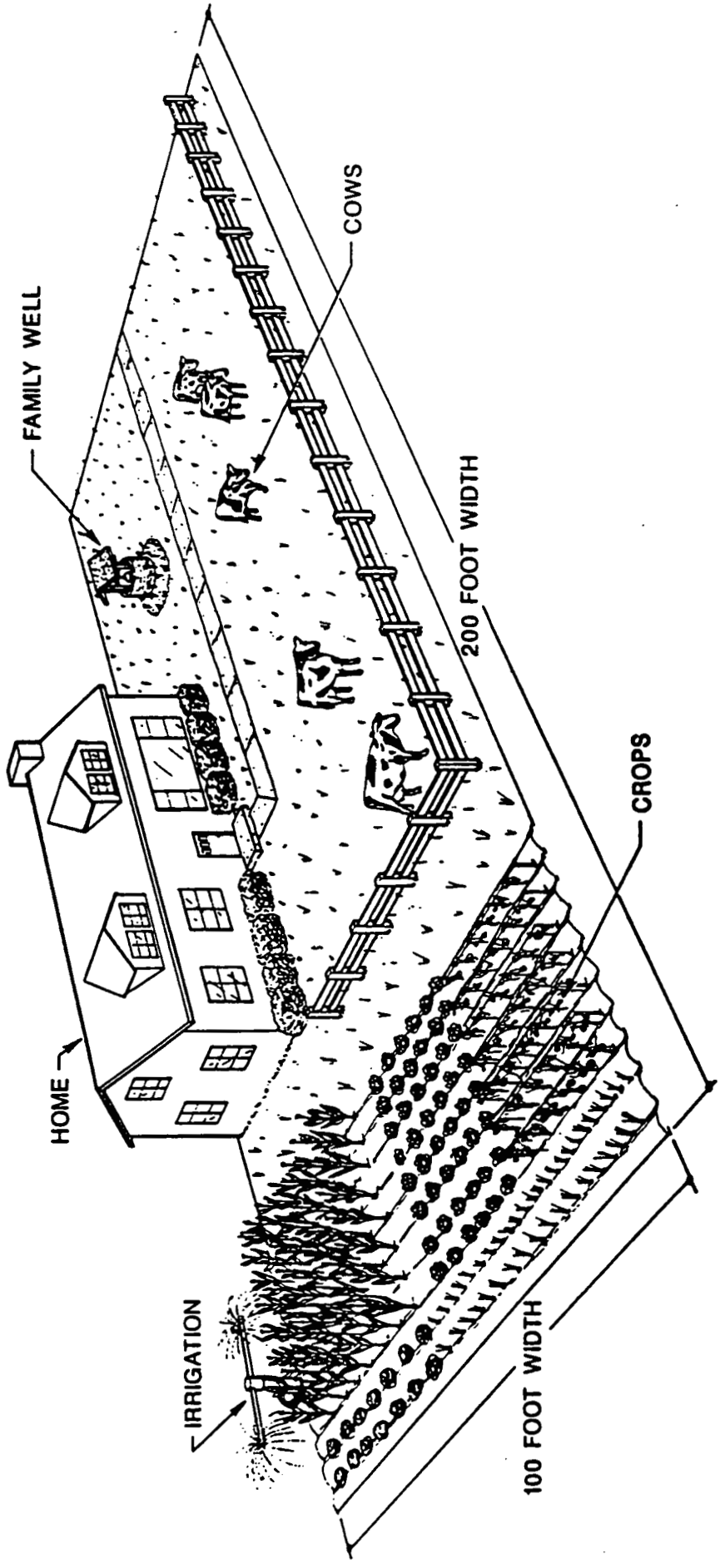

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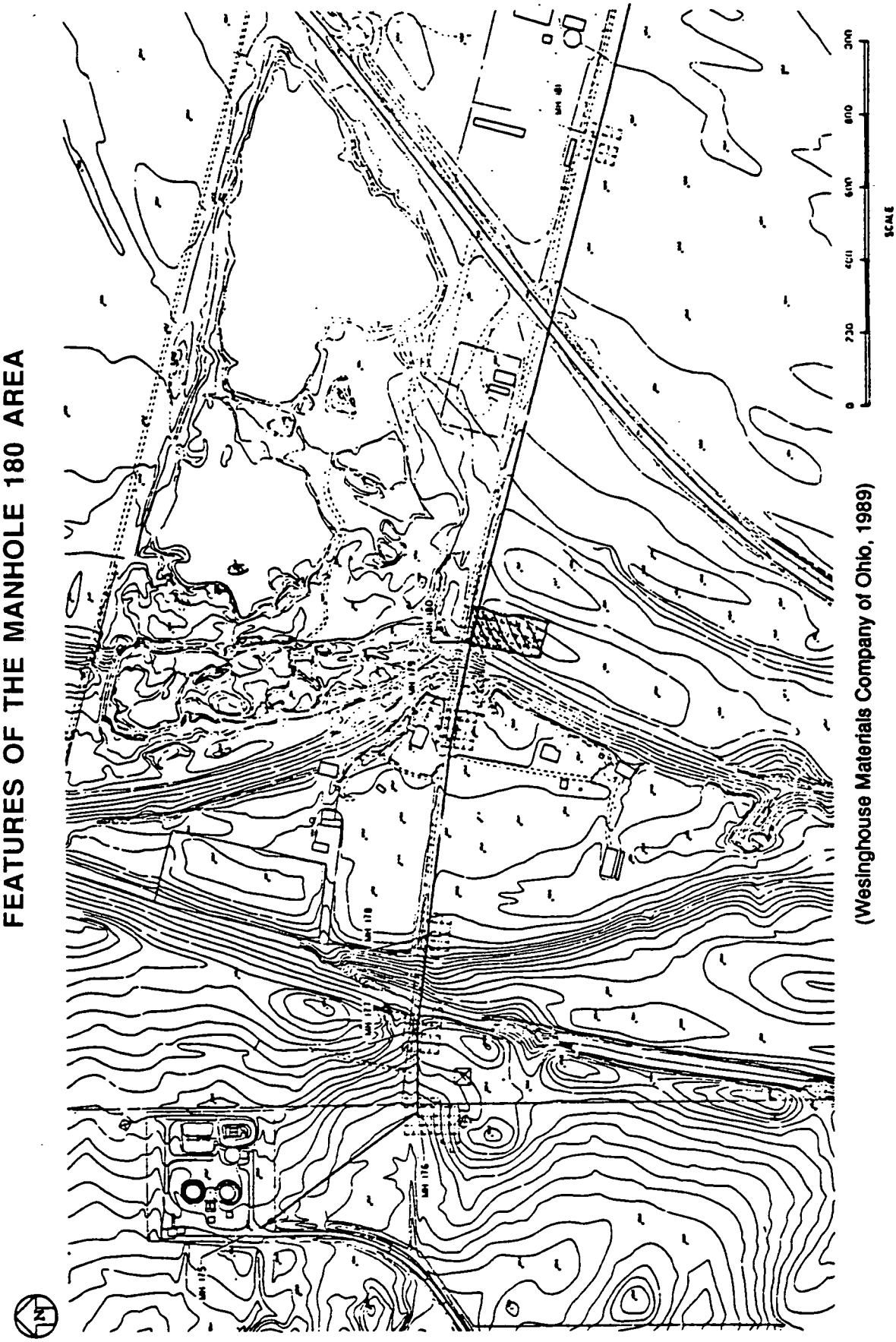
FIGURE 4.2.1: GENERAL TOPOGRAPHICAL AND REGIONAL FEATURES OF THE MANHOLE 180 AREA



(Wesinghouse Materials Company of Ohio, 1989)

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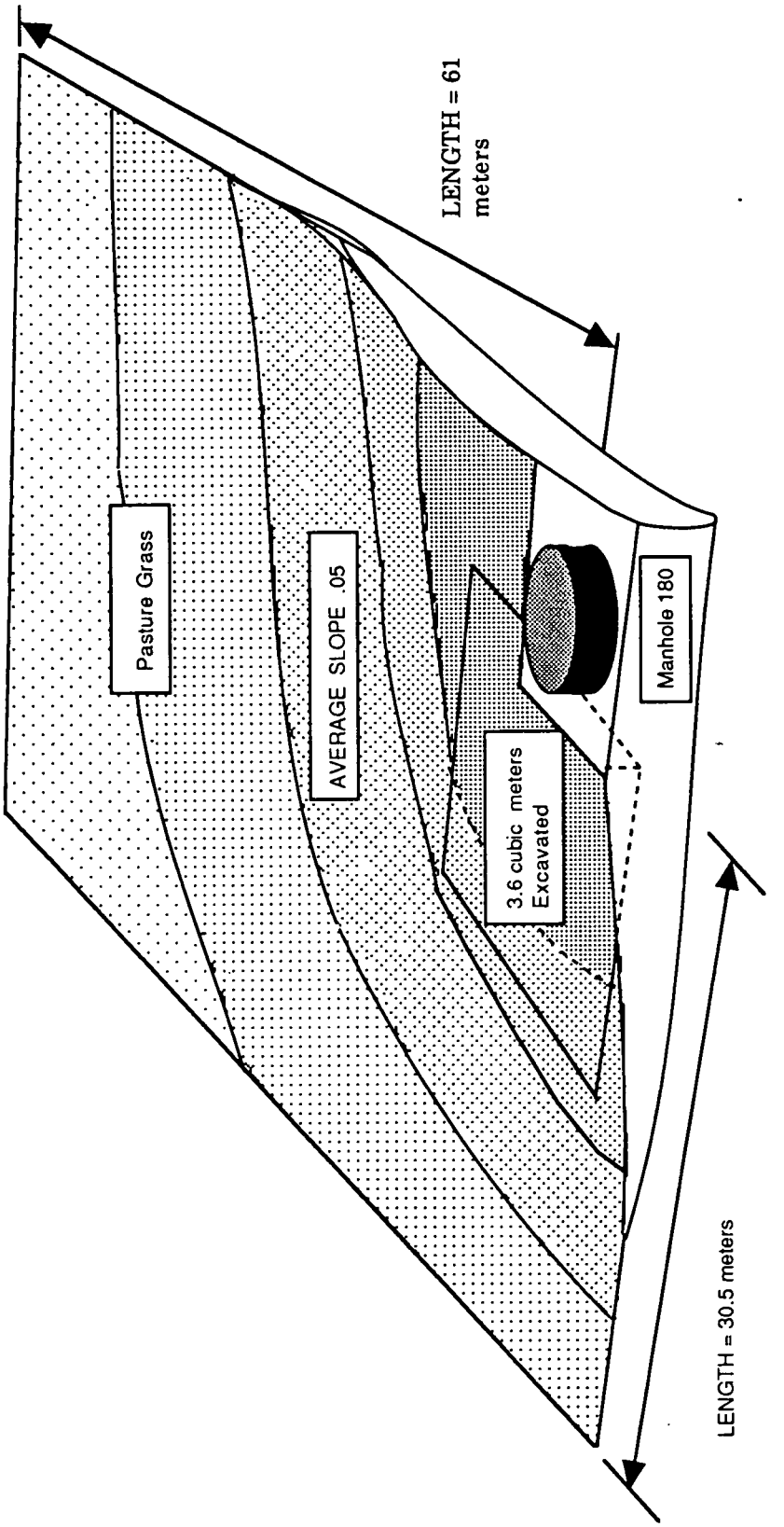

Figure 4.2.2: Schematic Diagram of the Assessment Region Around Manhole 180

4.3 Development of Hydrogeological Models

The topography of the region was briefly presented in the previous section. In this section the hydrogeological characteristics of the assessment region are used to construct two models for determining the transport of radioactive material in the vadose region (region of ground between the surface and the top of the water table).

The hydrogeological information available shows that there is considerable variations in soil composition from one region to another. For this reason two models were constructed to cover the range of possibilities of radioactive material transport in the ground. The stratification of the vadose zone was determined using boring logs (attached in the Appendix). Figures 4.3.1 and 4.3.2 illustrate the two models used and the typical hydraulic conductivity values used (Freeze and Cherry, 1979). These models formed the basis of the environmental transport for this analysis. The quantity of radioactive material available for any one pathway is determined by evaluating the leaching, migration, and overall loss of the radionuclide in the vadose zone.

Figure 4.3.1: Model 1 Silt and Sand Cross Section of Vadose Region with Typical Hydraulic Properties

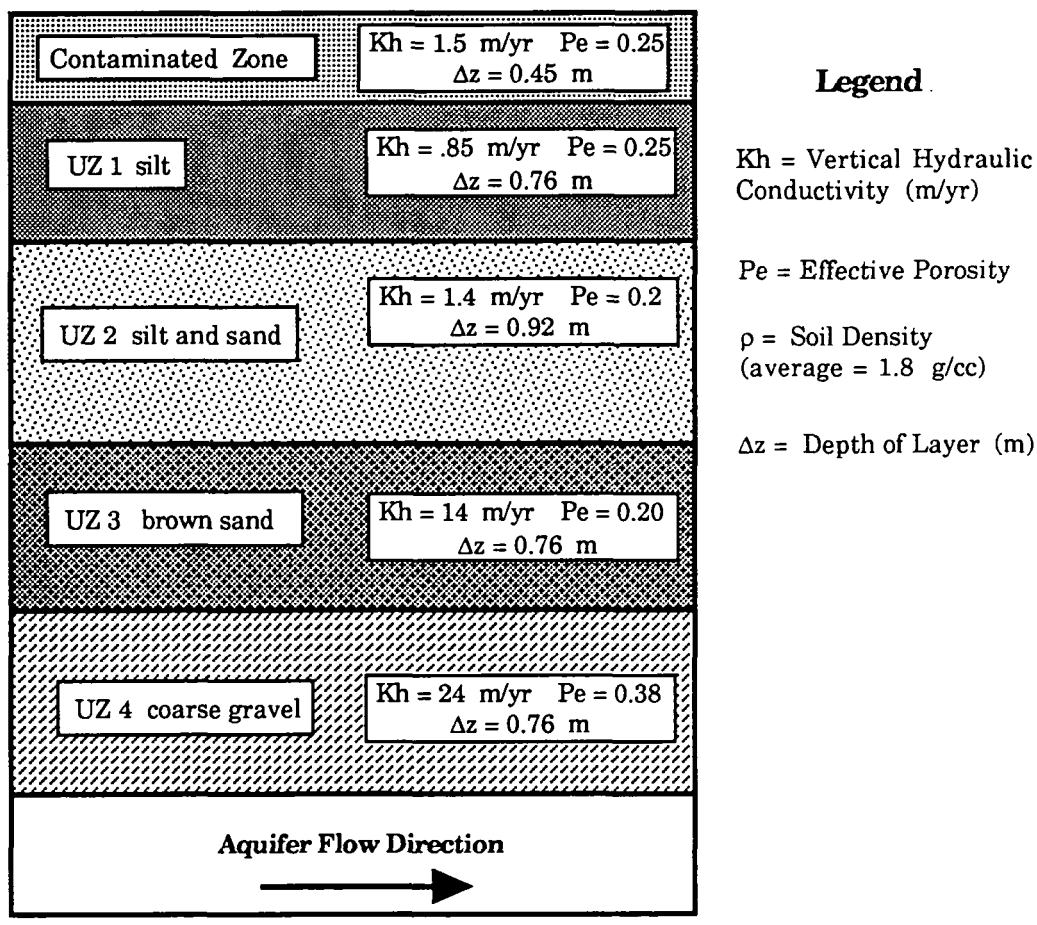

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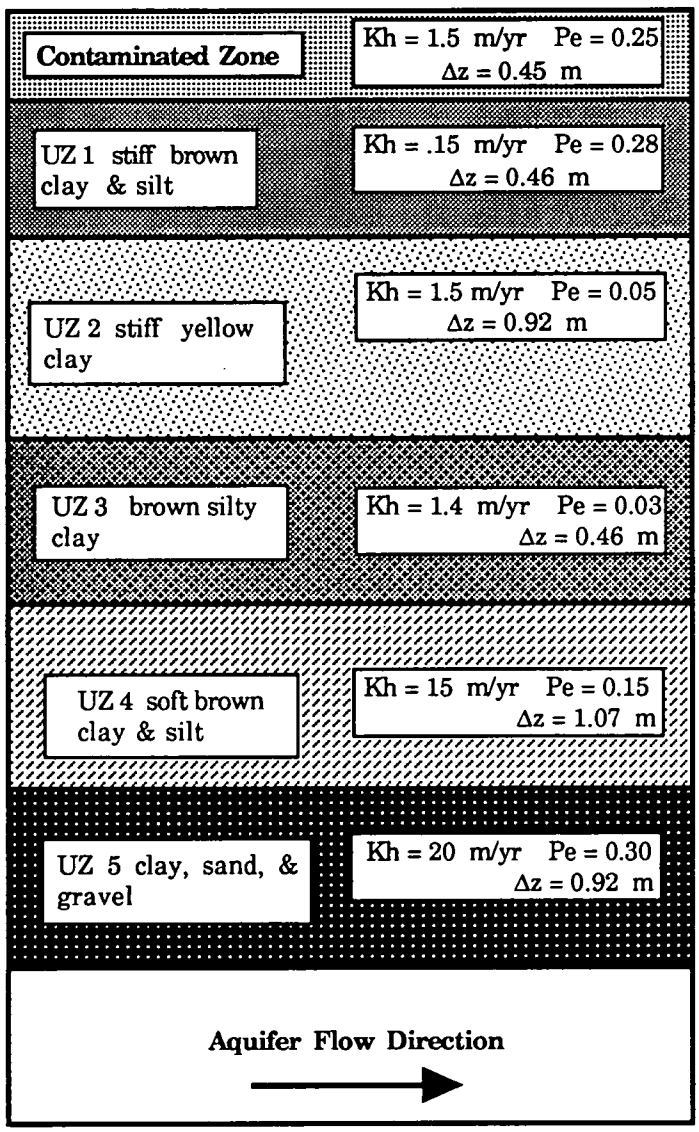
Figure 4.3.2: Model 2 Silt and Clay Cross Section of Vadose Region with Typical Hydraulic Properties



Legend

Kh = Vertical Hydraulic Conductivity (m/yr)

Pe = Effective Porosity

ρ = Soil Density (average = 1.8 g/cc)

Δz = Depth of Layer (m)

4.4 Time Frame For The Analysis

The transport of radioactive material in the environment is a continuous process that begins as soon as material is released to the environment and is essentially an ongoing process. Numerical expressions are used to estimate the concentration at a particular location and at a particular time.

The evaluation of the environmental transport factors (ETF) and the resulting dose-to-source ratios (DSR) are evaluated at particular times based on the nature of the transport processes. Typically the time frames for long term exposure considerations are based on: 1) the expected life span of an individual in the general public, 2) an effective working life time for an individual employed in the industry, and 3) time required for institutional or other type of control measures.

These considerations do not have direct applicability to the exposure scenario considered here; however, the time frames selected cover a sufficiently wide range that the environmental transport is adequate for establishing the short and long term effects from radioactive material in the environment. The time frames for which environmental transport and dose-to-source ratios were calculated are 1, 70, 200, 500, and 1000 years.

4.5 Exposure Pathways Analyzed

The resident farm scenario, as discussed earlier, encompasses a wide variety of exposure routes, such as the ingestion of crops, meat, and milk and also drinking water from an on site well. In order to evaluate the most significant pathways pertinent to this small region of analysis an initial assessment of all pathways to man from either gaseous or liquid radioactive releases was determined. Figures 4.5.1 and 4.5.2 illustrate the liquid and gaseous pathways to man. The next step was to analyze these general pathways for application to the assessment of the soil removal actions. A screening analysis indicated that there were ten routes of radionuclide transport which were the most significant. These ten routes of radionuclide transport to man include six different pathways: 1) direct radiation exposure from the soil, 2) inhalation of resuspended dust, 3) ingestion of crops and plants, 4) ingestion of meat, 5) ingestion of milk, and 6) ingestion drinking water from an on site well. The ten pathways and subpathways are shown in Table 4.5.1.

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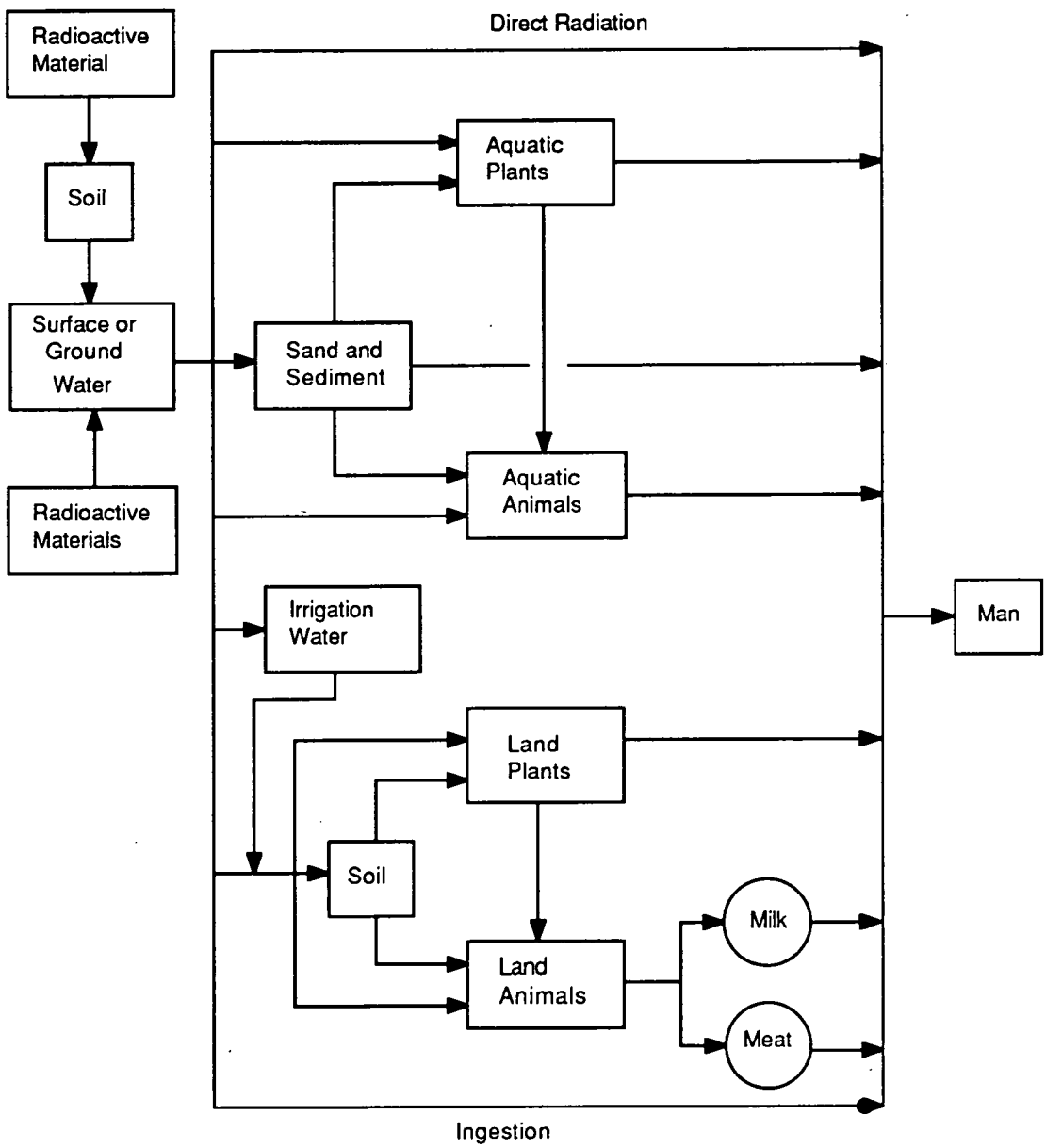
Figure 4.5.1 : Generalized Liquid Pathways to Man



This figure was adapted from U.S. EPA, 1972.

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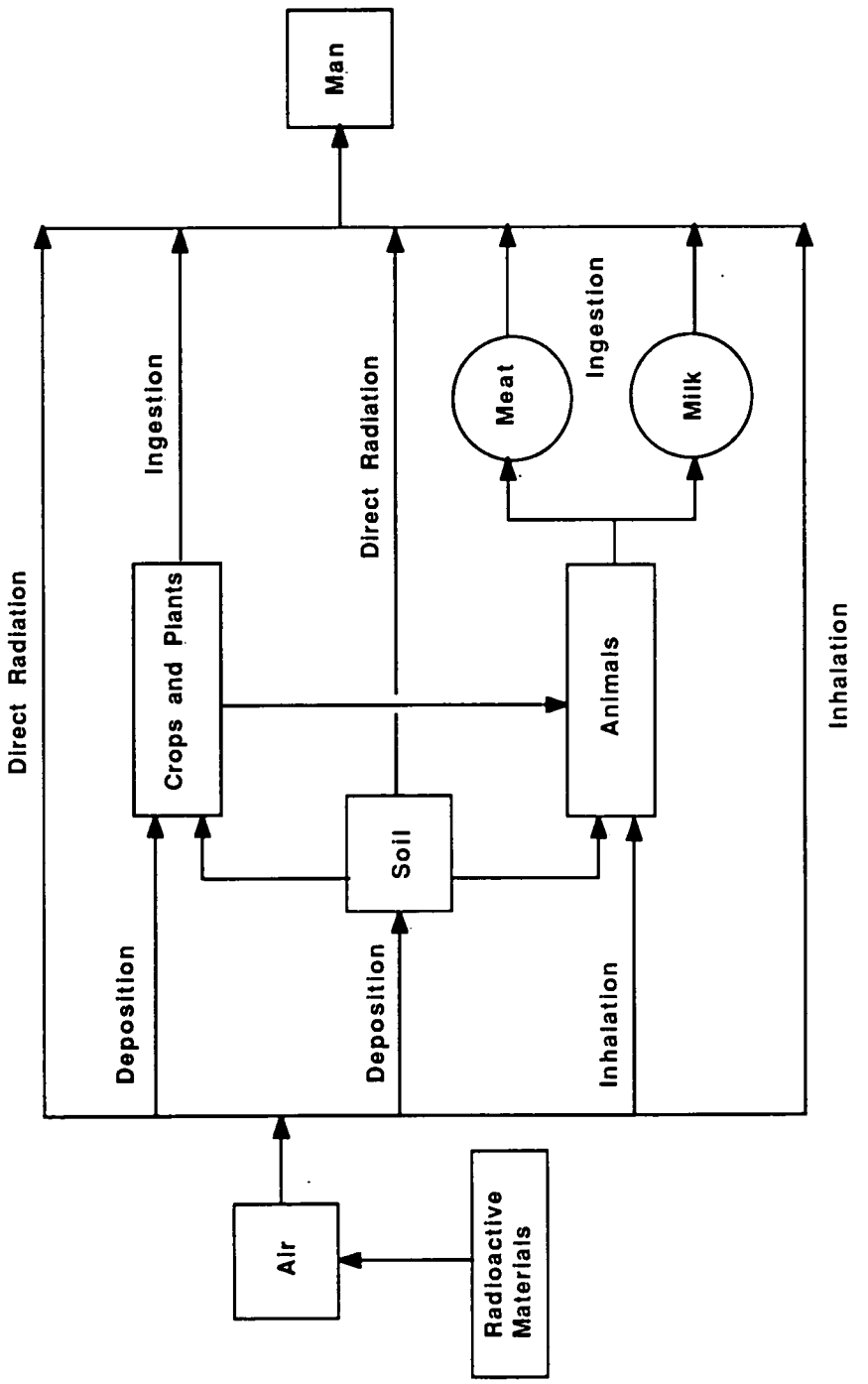

Figure 4.5.2: Generalized Gaseous Pathways to Man (U.S. EPA, 1972)

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Table 4.5.1: Pathways Analyzed For The Soil Removal Assessment Around Manhole 180

Section 4.7.1: Direct Radiation Pathway - External Ground

Section 4.7.2: Inhalation of Resuspended Dust

Section 4.7.3: Ingestion of Crops & Plants - Foliar Deposition Subpathway

Section 4.7.4: Ingestion of Crops & Plants - Root Uptake Subpathway

Section 4.7.5: Ingestion of Crops & Plants - Overhead Irrigation Subpathway

Section 4.7.6: Ingestion of Meat & Milk - Foliar Deposition Subpathway

Section 4.7.7: Ingestion of Meat & Milk - Root Uptake Subpathway

Section 4.7.8: Ingestion of Meat & Milk - Overhead Irrigation Subpathway

Section 4.7.9: Ingestion of Meat & Milk - Livestock Watering Subpathway

Section 4 .7.10: Ingestion of Drinking Water - Groundwater Route

4.6 Analysis Methods And Procedures Used In The Pathway Analysis

The pathway analysis methods, techniques, and procedures used in this analysis are based on currently accepted procedures either in the U. S. Department of Energy (U.S. DOE), the U. S. Nuclear Regulatory Commission (U.S. NRC), the U.S. Geological Survey (USGS), the International Commission on Radiological Protection (ICRP), or the U.S. Environmental Protection Agency (U.S. EPA). Specific references are sited when applied throughout this report. The intent was to stay within currently accepted guidelines for calculational methods and analytical techniques. In this facet the analysis can be presented without increasing uncertainties from untried and untested calculational procedures.

The inhalation rate and drinking water intake factors were taken from EPA sources, (EPA, 1986). Food intake parameters were taken from the EPA or ICRP publications and the highest or most conservative value was used whenever possible. Distribution coefficients relating the ratio of dissolved concentration to adsorbed concentration for particular radionuclides in specific media, such as clay, silt and sand, were taken from NRC or USGS sources. The lower limits for the specific parameters were used in order to yield conservative results for both concentration of the radioactive material in the water and the time frame for the transport process to occur.

4.7 Pathway Models

This section describes each pathway considered and their results. The results for each pathway are in terms of dose-to-source ratios. These dose-to-source ratios are calculated for 1 picocurie of radioactivity in the surface soil. There is a total of six pathways considered with one being an external exposure route and the remaining being internal exposure routes. The internal exposure routes are further separated into inhalation and ingestion pathways. The inhalation route is the result of breathing air containing contaminated dust. The ingestion pathways are the result of consuming vegetables, meat, milk, and water contaminated as a result of the transport of the radionuclides in the surface soil.

4.7.1 Direct Radiation Pathway

The direct radiation pathway from soil to man is illustrated in Figure 4.7.1.1. This pathway considers the soil as a volume source. The dose-to-source ratio, DSR_{i1}, is described by Equation 4.7.1.1 (Gilbert, 88). Equation 4.7.1.2 was used to evaluate the environmental transport factor, ETF_{i1}, for this pathway.

The dose to man from the direct radiation pathway is due to the external gamma and beta radiation emitted by a volume source within the contaminated zone. This absorbed dose to man is calculated for a height of one meter.

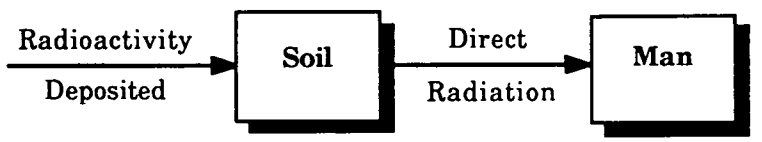

Figure 4.7.1.1: Direct Radiation from Volume Source Pathway

Equations:

$$DSR_{i1} = DCF_{i1} \times ETF_{i1} \qquad (4.7.1.1)$$

DSR_{i1} = Dose-to-source ratio for radionuclide, i, pathway 1, in units of mrem/yr per pCi/g.

DCF_{i1} = Dose conversion factor for radionuclide, i, pathway 1, in units of mrem/yr per pCi/cm^3 (Kocher, 1985).

ETF_{i1} = Environmental transport factor for radionuclide, i, pathway 1, in units of g/cm^3.

$$ETF_{i1} = \rho_b \times FS \times FO \times FA_1 \times FD_{i1} \qquad (4.7.1.2)$$

Where the terms FS, FA, FD_{i1}, and FO are defined, (Gilbert, 1988), as:

FS = Shape factor.

FO = Occupancy and shielding factor.

FA_1 = Area factor, subscript 1 refers to the direct radiation pathway.

ρ_b = Bulk soil density.

FD_{i1} = Depth factor, unitless. The time dependence for this pathway is expressed in the depth factor. Subscript i refers to the radionuclide and subscript 1 refers to the direct radiation pathway.

The environmental transport factor calculation is shown in Equation 4.7.1.2, using the appropriate parameters from Table 4.7.1.1:

$$ETF_{i1} = 1.8\ g/cm^3 \times 1.0 \times 0.6 \times 1.0 \times FD_{i1}$$

$$ETF_{i1} = 1.08\ g/cm^3 \times FD_{i1} \qquad \textbf{(4.7.1.2)}$$

The dose-to-source ratio, DSR_{i1}, is defined by Equation 4.7.1.3:

$$DSR_{i1} = 1.08\ g/cm^3 \times FD_{i1} \times DCF_{i1} \qquad \textbf{(4.7.1.3)}$$

The isotopes of uranium and thorium were analyzed as well as the other radionuclides of consideration. The other radionuclides which were considered are listed in Table 4.7.1.2. The dose-to-source ratios have been calculated for these other radionuclides for information only, radioactivity measurements have not indicated their presence. These additional radionuclides were determined from the 1987 Annual Environmental Monitoring Report for the Feed Materials Production Center.

The results for this pathway are defined in terms of dose-to-source ratios. These results are listed in Table 4.7.1.2. The dose-to-source ratios, DSRs, are calculated on a unit basis, 1 picocurie of the radionuclide per gram of soil.

The direct radiation pathway is the only external pathway taken into account to calculate the dose-to-source ratios for the ALARA Assessment. Analysis shows that surface source pathway and the immersion pathway are considerably less significant than the volume source pathway (Gilbert,1988).

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Table 4.7.1.1: Parameters Utilized In The Direct Radiation Pathway

FS(1) = 1.0 (Gilbert, 1988)

FO(1) = 1.0 (Gilbert, 1988)

FA(1) = 1.0 (Gilbert, 1988)

FD(i1) = Values Range Between 0.028 To 0.55 For Uranium And Thorium (Gilbert, 1988)

Bulk Density, ρ (b), = 1.8 g/cm(3) (Weston, 1987)

Table 4.7.1.2: Results of the Direct Radiation Pathway

Radionuclide	DSR (mrem/yr per pCi/g)*
Uranium-238	4.17×10^{-2}
Uranium-235	2.93×10^{-1}
Uranium-234	4.17×10^{-4}
Thorium-232	3.62×10^{-4}
Thorium-230	6.18×10^{-4}
Thorium-228	4.41
Technetium-99	5.57×10^{-7}
Neptunium-237	5.32×10^{-1}
Strontium-90	0
Radium-226	5.12
Radium-228	2.70
Cesium-137	1.66
Plutonium-238	3.98×10^{-4}
Plutonium-239	2.25×10^{-4}

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

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4.7.2 Inhalation of Contaminated Dust Pathway

This pathway consists of the inhalation of radionuclide contaminated dust in the air and is described schematically by Figure 4.7.2.1. As described by Gilbert, the inhalation pathway is composed of two segments: 1) an airborne exposure segment linking the contaminated zone with the airborne radionuclides at an exposure location and 2) an inhalation segment linking the airborne radionuclides with an exposed individual. The airborne exposure segment is represented by the air-to-soil concentration ratio, defined in Equation 4.7.2.2 as ASR_2.

Equation 4.7.2.2 describes the environmental transport factor, ETF_{i2}, for this pathway. The dose conversion factor for the inhalation pathway, DCF_{i2}, is described by Equation 4.7.2.1. The dose conversion factor represents the inhalation segment which links the airborne radionuclides with the exposed individual.

The ICRP model (ICRP 1978) of the respiratory tract was utilized in the development of the inhalation dose conversion factors. The ICRP model divides the respiratory tract into three compartments: 1) nasopharyngeal, 2) tracheobronchial, and 3) pulmonary. Furthermore, body fluids and the gastrointestinal tract are interconnected with these three compartments. The percent deposition of the contaminant laden dust in each of these regions is a function of the size of the airborne particles. A smaller dust particle size results in greater deposition in the pulmonary (lung) region and therefore a higher lung dose. The rate of contaminant removal from these compartments is characterized by the chemical form of the particles. Chemical compounds are assigned to one of three classes to characterize their removal rate from the lung. These lung classes are denoted by the letters **D**, **W**, and **Y**, which correspond to clearance or removal times from the pulmonary region of the lung on the order of days, weeks, and years, respectively. These dose conversion factors are based on the 1 AMAD (activity median aerodynamic diameter) particle size.

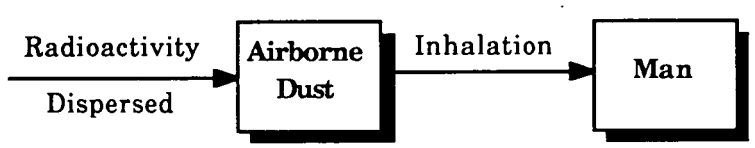

Figure 4.7.2.1: Inhalation of Resuspended Dust Pathway

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Equations:

$DSR_{i2}(t) = ETF_{i2}(t) \times DCF_{i2}$ **(4.7.2.1)**

Where:

$DSR_{i2}(t)$ = Dose-to-source ratio for radionuclide, i, pathway 2, in units of mrem/yr per pCi/g.

DCF_{i2} = Dose conversion factor for radionuclide, i, pathway 2, in units of mrem/pCi (ICRP, 1975).

$ETF_{i2}(t)$ = Environmental transport factor for radionuclide, i, pathway 2, in units of g/yr.

$ETF_{i2}(t) = FA_{i2} \times FD_{i2}(t) \times FO_2 \times FI_2 \times ASR_2$ (g/yr) **(4.7.2.2)**

FA_2 = Area factor, evaluated by Equation 4.7.2.3 (Gilbert, 88):

$FA_2 = (\text{Area of Cont. } (m^2))^{1/2} / [(\text{Area of Cont. } (m^2))^{1/2} + 3\text{ m}]$ **(4.7.2.3)**

FO_2 = Occupancy factor.

$FD_{i2}(t)$ = Depth factor, dimensionless. The depth factor represents the time dependence of this pathway (Gilbert, 88).

FI_2 = Annual intake of air, (EPA, 1986).

ASR_2 = Air-to-soil concentration ratio, which is the average mass loading of airborne contaminated soil particles (Gilbert, 1988)

The dose-to-source ratio for this pathway can be summarized by Equation 4.7.2.4:

$DSR_{i2}(t) = FA_{i2} \times FD_{i2}(t) \times FO_2 \times FI_2 \times ASR_2 \times DCF_{i2}$ **(4.7.2.4)**

The parameters used in Equation 4.7.2.4 are shown in Table 4.7.2.1. As with the direct radiation pathway, isotopes of uranium and thorium were analyzed as well as the other radionuclides. These additional radionuclides were calculated for information only. The results of this pathway are defined in terms of dose-to-source ratios. These dose-to-source ratios for are displayed in Table 4.7.2.2. The inhalation of resuspended dust is a principal contributor to the dose the resident farmer receives in the near term assessment, 1 - 10 years, of the manhole 180 region.

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Table 4.7.2.1: Parameters Used In The Inhalation of Resuspended Dust Pathway

FA(2) = 0.935 (Gilbert, 1988)

FO(2) = 0.5 (Gilbert, 1988)

FD(i2)t = Values For Uranium And Thorium Range Between 0 And 1. (Gilbert, 1988)

FI(2) = 7,300 m(3)/yr (EPA, 1986)

ASR(2) = 1 x 10(-4) g/m(3) (Gilbert, 1988)

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Table 4.7.2.2: Results of the Inhalation of Resuspended Dust Pathway

Radionuclide	DSR (mrem/yr per pCi/g)*
Uranium-238	1.63×10^{-3}
Uranium-235	1.69×10^{-3}
Uranium-234	1.82×10^{-3}
Thorium-232	1.12
Thorium-230	2.22×10^{-1}
Thorium-228	1.73×10^{-1}
Technetium-99	6.80×10^{-7}
Neptunium-237	3.50×10^{-1}
Strontium-90	1.48×10^{-4}
Radium-226	5.74×10^{-3}
Radium-228	3.25×10^{-3}
Cesium-137	2.14×10^{-5}
Plutonium-238	3.11×10^{-1}
Plutonium-239	3.48×10^{-1}

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

4.7.3 Ingestion of Crops and Plants - Foliar Deposition Subpathway

The foliar deposition subpathway for the ingestion of crops and plants is described in Figure 4.7.3.1. The ingestion pathway for plants and crops is analyzed over two food classes, designated by subscript k. The two food classes for crops and plants are: 1) fruit, nonleafy vegetables, and grain and 2) leafy vegetables.

The dose-to-source ratio for the foliar deposition subpathway of crops and plants is described by Equation 4.7.3.1. Equation 4.7.3.2 describes the environmental transport factor, ETF_{i32}, for this subpathway of foliar deposition. The dose conversion factor for ingestion is represented by the term DCF_{i3}, which refers to i^{th} principal radionuclide for ingestion.The dose conversion factor for ingestion is the dose-to-exposure ratio of the committed effective dose equivalent incurred by an individual from the ingestion intake of a unit quantity of the ith radionuclide. Dose conversion factors for ingestion frequently depend on the chemical form of the radionuclide. The chemical form determines the fraction of a radionuclide entering the gastrointestinal (GI) tract that reaches the body fluids.

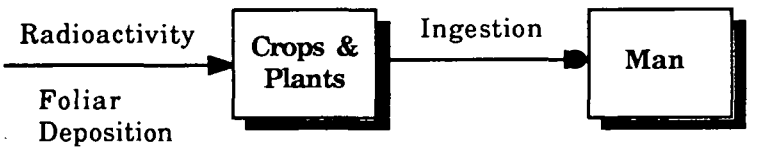

Figure 4.7.3.1 Ingestion of Crops and Plants - Foliar Deposition Subpathway

Equations:

$$DSR_{ipq}(t) = ETF_{ipq}(t) \times DCF_{ip} \qquad \textbf{(4.7.3.1)}$$

The subscripts p and q are defined for the plant pathway, p = 3, and for the foliar dust deposition subpathway, q = 2, Equation 4.7.3.1 becomes:

$$DSR_{i32}(t) = ETF_{i32}(t) \times DCF_{i3} \qquad \textbf{(4.7.3.1)}$$

$$ETF_{i32}(t) = FA_3 \times FD_{i32}(t) \times \sum_{k}^{2} DF_{3k} \times FSR_{i32k} \qquad \textbf{(4.7.3.2)}$$

The various components of the $ETF_{i32}(t)$ are described as follows:

FA_3 = Area factor. The area factor, FA_3, is evaluated at 0.5 in Gilbert because it is assumed that not all of the food consumed is grown on site. The formula used by Gilbert to describe the area factor for pathway 3 is illustrated in Equation 4.7.3.3. The 2000 square meters in the denominator specifies the minimum area needed to grow the crops and plants.

$$FA_3 = A/2000 \text{ for } 0 \leq A \leq 1000 \text{ m}^2; FA_3 = 0.5 \text{ for } A > 1000 \text{ m}^2 \qquad \textbf{(4.7.3.3)}$$

$FD_{i32}(t)$ = Depth factor, evaluated utilizing the same equations as the dust inhalation pathway. No units.

DF_{3k} = Dietary factor, p for plants and k for type of plants, (g/yr).

FSR_{i32k} = The food-to-soil concentration ratio for this pathway can be found from Equation 4.7.3.4 below:

$$FSR_{i32k} = FA_2 \times FAR_{i32k} \times ASR_3 \qquad \textbf{(4.7.3.4)}$$

where:

FA_2 = Area factor for pathway 2, dust inhalation, see Equation 4.7.2.3.

FAR_{i32k} = The plant food-to-air concentration ratio by airborne foliar deposition, m^3/g.

ASR_3 = The air-to-soil concentration ratio.

The plant food-to-air concentration ratio is computed using Equation 4.7.3.5 (Gilbert, 88):

$$FAR_{i32k} = 3.16 \times 10^4 \frac{[V_{di} \times f_r \times T_{ivk}][1-e^{(-\lambda_w t_{ek})}]}{Y_{vk} \times \lambda_w} \qquad \textbf{(4.7.3.5)}$$

with V_{di}, f_r, T_{ivk}, λ_w, t_{ek}, t_{ek}, and Y_{vk} being defined as:

V_{di} = Deposition velocity of contaminated dust.

f_r = Fraction of deposited radionuclide retained on the vegetation.

T_{ivk} = Foliage-to-food radionuclide transfer coefficient for the ith principle radionuclide and k^{th} plant food class.

λ_w = Weathering constant.

t_{ek} = Time of exposure of the kth plant food class to contamination during the growing season.

Y_{vk} = Wet-weight crop yield for the kth plant food class.

The 3.16×10^4 is a conversion factor with units of (kg/g)(s/yr) to convert the FAR_{i32k} to units of m^3/g.

Therefore, FAR_{i321} and FAR_{i322} are the values for the plant food-to-air concentration ratio for radionuclide transfer by airborne foliar deposition for the kth food classes, 1 and 2. These are illustrated in Equations 4.7.3.5 and 4.7.3.6:

$$FAR_{i321} = 5.45 \times 10^{-2}\ m^3/g \qquad \textbf{(4.7.3.5)}$$

$$FAR_{i322} = 2.62 \times 10^{-1}\ m^3/g \qquad \textbf{(4.7.3.6)}$$

Knowing the FAR terms one can calculate the FSR terms for k = 1 and k = 2 food classes. These are illustrated in Equations 4.7.3.7 and 4.7.3.8:

$$FSR_{k=1} = 2.72 \times 10^{-6} \qquad \textbf{(4.7.3.7)}$$

$$FSR_{k=2} = 1.31 \times 10^{-5} \qquad \textbf{(4.7.3.8)}$$

The environmental transport factor is summarized in Equation 4.7.3.9:

$$ETF_{i32}(t) = FA_3 \times FD_{i32}(t) \times (FSR_{k=1} \times DF_{31} + FSR_{k=2} \times DF_{32}) \qquad \textbf{(4.7.3.9)}$$

The dose-to-source ratio for this subpathway is then defined by Equation 4.7.3.10:

$$DSR_{i32}(t) = FA_3 \times FD_{i32}(t) \times (FSR_{k=1} \times DF_{31} + FSR_{k=2} \times DF_{32}) \{ \times DCF_{i3} \} \qquad \textbf{(4.7.3.10)}$$

Equation 4.7.3.10 can be evaluated by using the parameters listed in Table 4.7.3.1. This equation is used to calculate the dose-to-source ratio on a picocurie basis for each radionuclide. Table 4.7.3.2 lists the DSRs for each of the radionuclides of uranium and thorium and also the additional radionuclides. Recall the calculations for these additional radionuclides have been included for information only.

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Table 4.7.3.1: Parameters Used In The Ingestion Of Crops & Plants Pathway - Foliar Deposition Subpathway

FA(3) = 0.5 (Gilbert, 1988)

FD(i32)t = Values Range Between 0 and 1.0 (Gilbert, 1988)

DF(3,k=1) = 160,000 g/yr (ICRP, 1977)
DF(3,k=2) = 14,000 g/yr (ICRP, 1977)

FA(2) = 0.935 (Gilbert, 1988)

ASR(3) = 1 x 10(-4) g/m3 (Gilbert, 1988)

The Following Terms Are For The Plant Food-To-Air Concentration Factor (Gilbert, 1988)

V(di) = 1 x 10(-3) m/s

f(r) = 0.25

T(iv,k=1) = 0.1

T(iv,k=2) = 1.0

λ (w) = 20/yr

t(e,k=1) = 0.17 yr

t(e,k=2) = 0.25

Y(v,k=1) = 0.7 kg/m(2)

Y(v,k=2) = 1.5 kg/m(2)

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Table 4.7.3.2: Results of the Foliar Deposition Subpathway of Plants and Crop Ingestion

Radionuclide	DSR (mrem/yr per pCi/g)*
Uranium-238	2.89×10^{-4}
Uranium-235	3.01×10^{-4}
Uranium-234	3.20×10^{-4}
Thorium-232	3.16×10^{-3}
Thorium-230	6.35×10^{-4}
Thorium-228	8.82×10^{-4}
Technetium-99	1.65×10^{-6}
Neptunium-237	4.50×10^{-2}
Strontium-90	1.49×10^{-4}
Radium-226	1.50×10^{-3}
Radium-228	1.63×10^{-3}
Cesium-137	5.68×10^{-5}
Plutonium-238	4.52×10^{-4}
Plutonium-239	5.02×10^{-4}

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

4.7.4 Ingestion of Crops and Plants - Root Uptake Subpathway

The ingestion of crops and plants through the root uptake subpathway is described schematically in Figure 4.7.4.1. The ingestion pathway model was described previously in the introduction to the ingestion pathways. The general form of the dose-to-source ratio, DSR_{ipq}, is described by Equation 4.7.4.1. The dose-to-source ratio specifically for this subpathway is shown by Equation 4.7.4.2 The environmental transport factor, ETF_{i31}, is determined by Equation 4.7.4.3.

Figure 4.7.4.1: Ingestion of Crops and Plants - Root Uptake Subpathway

Equations:

$$DSR_{ipq}(t) = ETF_{ipq}(t) \times DCF_{ip} \qquad (4.7.4.1)$$

$$DSR_{i31}(t) = ETF_{i31}(t) \times DCF_{i3} \qquad (4.7.4.2)$$

$$ETF_{i31}(t) = FA_3 \times FD_{i31}(t) \times \sum_{k}^{2} DF_{3k} \times FSR_{i31k} \qquad (4.7.4.3)$$

Recall that the subscript p refers to primary pathway and is equal to 3 for plants. Also, the secondary pathway is designated by the subscript q, which in this case is 1 for root uptake.

The formula describing the area factor for pathway 3 is illustrated in Equation 4.7.4.4. This equation gives Gilbert's approach and assumes that not all of the crops and plants consumed are grown on site.

$$FA_3 = A/2000 \text{ for } 0 \le A \le 1000 \text{ m}^2;\ FA_3 = 0.5 \text{ for } A > 1000 \text{ m}^2 \qquad (4.7.4.4)$$

The values for Dietary Factors, DF_{3k}, will not change since the pathway is still for plants.

The depth factors characterize the time dependence of this pathway.

The food-to-soil concentration ratios, FSR_{i31k}, for plant foods in terms of root uptake is given by Equation 4.7.4.5 (NRC, 77):

$$FSR_{i31k} = B_{iv} \qquad \textbf{(4.7.4.5)}$$

The B_{iv} term indicates the vegetable/soil transfer factors. As noted by Gilbert, the same root uptake transfer factors can be used for nonleafy vegetables (k = 1) and leafy vegetables (k = 2). A higher value of B_{iv} indicates a larger fraction of the radionuclide is transferred from the soil to the edible portion of the plant.

The dose-to-source ratio for this subpathway of root uptake is defined by Equation 4.7.4.6:

$$DSR_{i31}(t) = FA_3 \times FD_{i31}(t) \times \sum_{k}^{2} (DF_{3k} \times FSR_{i31k}) \times DCF_{i3} \qquad \textbf{(4.7.4.6)}$$

Equation 4.7.4.6 is evaluated by using the parameters listed in Table 4.7.4.1. The dose-to-source ratios have been calculated for the isotopes of uranium and thorium and the additional radionuclides identified in the previous two sections. These dose-to-source ratios are listed in Table 4.7.4.2. The root uptake subpathway of plants and crops ingestion is the principal subpathway contributing to the dose of the resident farmer.

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Table 4.7.4.1: Parameters Used In The Ingestion Of Crops & Pathway - Root Uptake Subpathway

FA(3) = 0.5 (Gilbert, 1988)

FD(i31)t = Values Range Between 0 And 0.95 For Uranium And Thorium (Gilbert, 1988)

DF(3,k=1) = 160 kg/yr (ICRP, 1977)

DF(3,k=2) = 14 kg/yr (ICRP, 1977)

B(iv) = Food-To-Soil Transfer Factors (NRC, 1977)

Table 4.7.4.2: Results of the Root Uptake Subpathway of Plants and Crop Ingestion

Radionuclide	DSR (mrem/yr per pCi/g)*
Uranium-238	1.88×10^{-2}
Uranium-235	2.0×10^{-2}
Uranium-234	2.08×10^{-2}
Thorium-232	3.38×10^{-1}
Thorium-230	6.79×10^{-2}
Thorium-228	9.44×10^{-2}
Technetium-99	1.08×10^{-2}
Neptunium-237	2.92
Strontium-90	8.32×10^{-1}
Radium-226	5.44×10^{-2}
Radium-228	5.94×10^{-2}
Cesium-137	2.95×10^{-3}
Plutonium-238	2.92×10^{-3}
Plutonium-239	3.24×10^{-3}

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

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4.7.5 Ingestion of Crops and Plants - Overhead Irrigation Subpathway

The ingestion of crops and plants by man through the overhead irrigation subpathway is depicted in Figure 4.7.5.1. This subpathway results from the transfer of radionuclides from overhead irrigation water to the edible portions of the plants and crops. Equation 4.7.5.1 defines the general dose-to-source equation for this subpathway. Equation 4.7.5.2 defines the environmental transport factor of Equation 4.7.5.1.

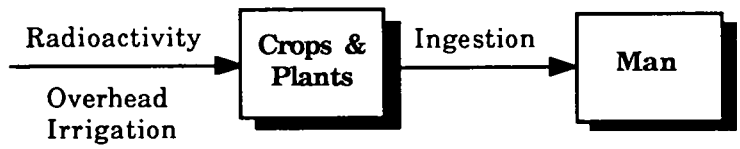

Figure 4.7.5.1: Schematic Diagram representing the Ingestion of Crops and Plants by Man for the Overhead Irrigation Subpathway

Equations:

$$DSR_{i34}(t) = ETF_{i34}(t) \times DCF_{i3} \qquad \textbf{(4.7.5.1)}$$

$$ETF_{i34}(t) = FA_3 \times FD_{i34}(t) \times \Sigma_k (DF_{3k} \times FSR_{i34k}(t)) \qquad \textbf{(4.7.5.2)}$$

The area factor, FA_3, was previously defined in Section 4.7.3 (**0.5**). The subpathways of overhead irrigation are independent of the depth of the contaminated zone in the models used because the infiltrating water will carry the contamination to the aquifer and contaminate the water regardless of the depth, and the subsequent contamination mechanisms do not depend on depth (Gilbert, 88). Therefore, the depth factors are unity. The dietary terms have also been previously defined, see Section 4.7.3. The food-to-soil concentration term, FSR_{i34k}, is defined by Equation 4.7.5.3 below:

$$FSR_{i34k}(t) = FWR_{i34k} \times WSR_{i1}(t) \qquad \textbf{(4.7.5.3)}$$

The FWR_{i34k}, plant food-to-water concentration ratio for overhead irrigation with units of L/g, is defined by Equation 4.7.5.4 (Gilbert, 88):

$$FWR_{i34k} = \frac{[I_{rr} \times f_r \times T_{ivk}]\,[1 - Exp(-\lambda_w t_{ek})]}{Y_{vk} \times \lambda_w} \qquad \textbf{(4.7.5.4)}$$

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The terms of Equation 4.7.5.4 are defined as follows:

I_{rr} = Irrigation Rate.

f_r = Fraction of deposited radionuclides retained on the vegetation.

T_{ivk} = Foliage-to-food radionuclide transfer coefficient for the ith principal radionuclide and the kth plant food class.

Y_{vk} = Wet-weight crop yield for the kth plant food class.

λ_w = Weathering removal constant for vegetation.

t_{ek} = Time of exposure of the kth plant food class to contamination during the growing season.

The water-to-soil ratio, WSR_{i1}, represents the contribution from the groundwater pathway route. The WSRs were evaluated at 1, 70, 200, 500, and 1000 years and along with the depth factors they represent the time dependence of this subpathway.

The dose-to-source ratio for this subpathway can then be defined as in Equation 4.7.5.5:

$$DSR_{i34}(t) = \{FA_3 \times FD_{i34}(t) \times \Sigma_k (DF_{3k} \times FSR_{i34k}(t))\} \times DCF_{i3} \quad \textbf{(4.7.5.5)}$$

The dose-to-source ratio, shown in Equation 4.7.5.5, is calculated by using the parameters shown in Table 4.7.5.1. These parameters detail the calculation of the environmental transport factor. The results for this subpathway are in the form of dose-to-source ratios for each radionuclide. Since this subpathway is intimately dependent upon the transport of the radionuclides to the aquifer, the dose-to-source ratios are illustrated for the two hydrogeological models evaluated.

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Table 4.7.5.1: Parameters Utilized In The Overhead Irrigation Subpathway Of Plants And Crops Ingestion

FA(3) = 0.5 (Gilbert, 1988)

The Following Terms Of The Plant Food-To-Water Concentration Ratio For The Overhead Irrigation Subpathway Are Defined As Follows (Gilbert, 1988):

Irrigation Rate, Irr = 1 m/yr

f(r) = 0.25

T(iv,k=1) = 0.1

T(iv,k=2) = 1.0

Y(v,k=1) = 0.7 kg/m(2)

Y(v,k=2) = 1.5 kg/m(2)

λ (w) = 20/yr

t(e,k=1) = 0.17 yr

t(e,k=2) = 0.25 yr

WSR(i1)t = Water-To-Soil Ratio (Gilbert, 1988)

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Table 4.7.5.2: Results of the Overhead Irrigation Subpathway of Plants and Crop Ingestion

Radionuclide	DSR Model I (mrem/yr per pCi/g)*	DSR Model II (mrem/yr per pCi/g)*
Uranium-238	1.18×10^{-1}	7.65×10^{-2}
Uranium-235	1.23×10^{-1}	7.98×10^{-2}
Uranium-234	1.31×10^{-1}	8.94×10^{-2}
Thorium-232	0	0
Thorium-230	0	0
Thorium-228	0	0
Technetium-99	8.64×10^{-4}	0
Neptunium-237	15.83	4.00
Strontium-90	5.29×10^{-2}	3.19×10^{-2}
Radium-226	0.57	0.40
Radium-228	0.62	0.43
Cesium-137	2.00×10^{-2}	0
Plutonium-238	1.22×10^{-1}	0
Plutonium-239	1.35×10^{-1}	0

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

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4.7.6 Ingestion of Contaminated Meat and Milk - Foliar Deposition Subpathway

This subpathway of meat and milk ingestion is represented by the schematic diagram of Figure 4.7.6.1. This section and the next two sections represent two subpathways of meat and milk ingestion which are composed of plants and crops being grown and used as fodder, feed, for livestock. These subpathways are identical to the subpathways of foliar deposition, root uptake, and overhead irrigation discussed previously for crops and plants, except an additional step has been added to account for the transfer of the radionuclide from the fodder to the meat and milk. As one would expect, the dose-to-source ratios for these subpathways of meat and milk will be lower than those for the corresponding subpathways of crops and plants since the extra step represents a dilution of the ingested radionuclide.

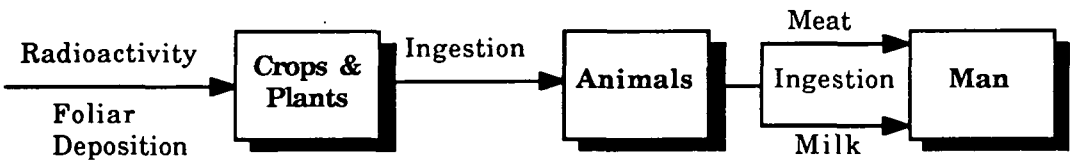

Figure 4.7.6.1: Ingestion of Meat and Milk - Foliar Deposition Subpathway

Fodder intake rates were obtained from Baes, 1984. Standard man intake rates for the ingestion of meat and milk were obtained from ICRP, 1978. The dose-to-source ratios for this section can be found by Equation 4.7.6.1. The environmental transport factor, $ETF_{i(4,5)2}$, for the foliar deposition subpathway of meat and milk ingestion is described by Equation 4.7.6.2.

Equations:

$$DSR_{i(4,5)2}(t) = ETF_{i(4,5)2}(t) \times DCF_{i3} \qquad \textbf{(4.7.6.1)}$$

$$ETF_{i(4,5)2}(t) = FA_{4,5} \times FD_{i(4,5)2}(t) \times DF_{4,5} \times FSR_{i(4,5)2} \qquad \textbf{(4.7.6.2)}$$

$FA_{(4,5)}$ = Area factor, evaluated by Equation 4.7.6.3. The 20,000 square meters in the denominator specifies the minimum area needed to raise the meat and milk animals, as opposed to 2,000 m^2 for crops and plants.

$$\text{Contamination Area } (m^2)/20{,}000 \qquad \textbf{(3.7.6.3)}$$

$FD_{i(4,5)2}(t)$ = Depth factors are the same as for Section 4.7.3.

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$DF_{4,5}$ = Dietary factor for ingestion of meat and milk:

The environmental transport factor for meat and milk ingestion by the foliar deposition subpathway is analogous to the environmental transport factor for the ingestion of crops and plants by the foliar deposition subpathway. The difference is manifested in the food-to-soil concentration ratio, $FSR_{i(4,5)2}$. The food-to-soil concentration ratio is described by Equation 4.7.6.4:

$$FSR_{ipq} = FQR_{ip} \times FI_{pq} \times QSR_{ipq} \qquad \textbf{(4.7.6.4)}$$

The terms of Equation 4.7.6.4 are described below:

FQR_{ip} = Radionuclide transfer factor for meat, p = 4, or milk, p = 5, is the ratio of the concentration of the ith principal radionuclide in meat or milk in pCi/kg to the rate of intake in fodder or water by livestock of the ith principal radionuclide in pCi/d, hence units for the transfer factor are days/kilogram (Baes,1984)

FI_{p2} = Daily intake of contaminated fodder, by q = 2. It is defined as the ratio of intake of a radionuclide in pCi/d to the concentration of the same radionuclide in fodder in pCi/kg, hence the units are kg/days (Baes, 1984)

QSR_{ipq} = Fodder/soil concentration ratio for meat (p = 4) or milk (p = 5) for the ith principal radionuclide and q^{th} pathway. No units. The fodder-to-soil concentration ratio is described by Equation 4.7.6.5:

$$QSR_{i42} = QSR_{i52} = FA_2 \times FAR_{i323} \times ASR_3 \qquad \textbf{(4.7.6.5)}$$

ASR_3 = Air-to-soil concentration ratio for undiluted contaminated dust. Previously presented in Equation 4.7.2.2.

FAR_{i323} = Plant-food/air concentration ratio defined by Equation 4.7.3.5. This has been evaluated for k = 3 for fodder and is illustrated below (see Table 4.7.6.1 for the parameters used).

$$FAR_{i323} = 2.8 \times 10^{-1}\ m^3/g$$

Therefore, the fodder-to-soil concentration ratio for meat and milk over the foliar dust deposition subpathway can now be evaluated from Equation 4.7.6.5:

$QSR_{i42} = QSR_{i52} = 0.93\ (FA_2) \times 2.8 \times 10^{-1}\ m^3/g \times 1 \times 10^{-4}\ g/m^3$

$= 1.4 \times 10^{-5}$

Using Equation 4.7.6.4, the FSR_{ipq} term can be determined. These values are illustrated in Equations 4.7.6.6 and 4.7.6.7 below.

$FSR_{i42} = FQR_{i4} \times 68\ kg/d \times 1.4 \times 10^{-5} = 9.5 \times 10^{-4}\ kg/d(FQR_{i4})$ **(4.7.6.6)**

$FSR_{i52} = FQR_{i5} \times 55\ kg/d \times 1.4 \times 10^{-5} = 7.7 \times 10^{-4}\ kg/d(FQR_{i5})$ **(4.7.6.7)**

The environmental transport factors for meat and milk ingestion by the foliar deposition subpathway can be stated by Equations 4.7.6.8 and 4.7.6.9:

$ETF_{i42}(t) = FA_4 \times FD_{i42}(t) \times DF_4 \times 9.5 \times 10^{-4}\ kg/d(FQR_{i4})$ **(4.7.6.8)**

$ETF_{i52}(t) = FA_5 \times FD_{i52}(t) \times DF_5 \times 7.7 \times 10^{-4}\ kg/d(FQR_{i5})$ **(4.7.6.9)**

The dose-to-source ratios for this meat and milk subpathway are defined by Equations 4.7.6.10 and 4.7.6.11.

$DSR_{i42}(t) = FA_4 \times FD_{i42}(t) \times DF_4 \times 9.5 \times 10^{-4}\ kg/d(FQR_{i4}) \times DCF_{i3}$ **(4.7.6.10)**

$DSR_{i52}(t) = FA_5 \times FD_{i52}(t) \times DF_5 \times 7.7 \times 10^{-4}\ kg/d(FQR_{i5}) \times DCF_{i3}$ **(4.7.6.11)**

To obtain the total dose for each radionuclide in this subpathway one must add the dose-to-source contributions from both meat and milk.

The Equations of 4.7.6.10 and 4.7.6.11, shown above, can be evaluated by using the parameters listed in Table 4.7.6.1. These parameters are identical to those identified in Section 4.7.3, except that additional parameters to evaluate the transfer of the radionuclides from the fodder to the meat and milk have been added. The dose-to-source ratios are listed for the various radionuclides in Table 4.7.6.1. This subpathway represents the smallest contribution to the dose of the resident farmer.

Table 4.7.6.1: Parameters Utilized In The Ingestion Of Meat And Milk Pathway - Subpathway Of Foliar Deposition

FA(4,5) = 0.093 (Gilbert, 1988)

FD(i4,5,2t) = Values For Uranium And Thorium Range Between 0 and 1.0 (Gilbert, 1988)

DF(4) = 63 kg/yr (ICRP, 1977)
DF(5) = 92 L/yr (ICRP, 1977)

FI(4) = 68 kg/d (Baes, 1984)
FI(5) = 55 kg/d (Baes, 1984)

FA(2) = 0.935 (Gilbert, 1988)

ASR(3) = 1 x 10(-4) g/m(3) (Gilbert, 1988)

The Following Terms of The Plant Food-To-Air Concentration Ratio Are Defined As Follows (Gilbert, 1988):

V(di) = 1 x 10(-3) m/s

f(r) = 0.25

T(iv,k=3) = 1.0

λ (w) = 20/yr

t(e,k=3) = 0.08 yr

Y(v,k=3) = 1.1 kg/m(2)

FQR(i4,5) = Radionuclide Transfer Factors For Meat And Milk (Baes, 1984)

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Table 4.7.6.2: Results of the Foliar Deposition Subpathway of Meat and Milk Ingestion

Radionuclide	DSR (mrem/yr per pCi/g)*
Uranium-238	3.03×10^{-5}
Uranium-235	3.16×10^{-5}
Uranium-234	3.37×10^{-5}
Thorium-232	2.91×10^{-4}
Thorium-230	5.85×10^{-4}
Thorium-228	8.13×10^{-4}
Technetium-99	4.61×10^{-7}
Neptunium-237	4.15×10^{-2}
Strontium-90	5.70×10^{-6}
Radium-226	3.41×10^{-5}
Radium-228	3.72×10^{-5}
Cesium-137	3.76×10^{-5}
Plutonium-238	4.16×10^{-4}
Plutonium-239	4.63×10^{-4}

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

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4.7.7 Ingestion of Meat and Milk - Root Uptake Subpathway

The ingestion of contaminated meat and milk by man through the root uptake subpathway is illustrated by the schematic diagram of Figure 4.7.7.1. This subpathway is identical to the root uptake subpathway for ingestion of crops and plants, except an additional step has been added to account for the dilution of the radionuclide and subsequent absorbed dose resulting from the transfer of the radionuclide from fodder to meat and milk.

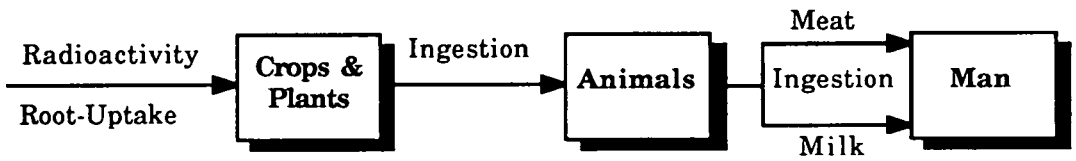

Figure 4.7.7.1: Ingestion of Contaminated Meat and Milk by Man via Root Uptake Subpathway

The dose-to-source ratios for this subpathway can be calculated from Equation 4.7.7.1. Equation 4.7.7.2 describes the environmental transport factor, $ETF_{i(4,5)1}$, for the root uptake subpathway of meat and milk ingestion. The food-to-soil concentration ratios for this root uptake subpathway are given by Equation 4.7.7.4.

Equations:

$$DSR_{i(4,5)1}(t) = ETF_{i(4,5)1}(t) \times DCF_{i3} \qquad \textbf{(4.7.7.1)}$$

$$ETF_{i(4,5)1}(t) = FA_{(4,5)} \times FD_{i(4,5)1}(t) \times DF_{(4,5)1} \times FSR_{i(4,5)1} \qquad \textbf{(4.7.7.2)}$$

The terms of Equation 4.7.7.2 are defined as follows:

$FA_{(4,5)}$ = Area factor, area of contamination that is utilized for growing the crops and plants, defined by Equation 4.7.7.3 below:

$$\text{Area of Contamination} / 20{,}000 \qquad \textbf{(4.7.7.3)}$$

$FD_{i(4,5)1}(t)$ = Depth factor for i^{th} radionuclide, ingestion pathway of meat and milk, and for root uptake subpathway. Previously defined for Section 4.7.4.

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DF_4 = Dietary factor.

DF_5 = Dietary factor for milk intake.

$$FSR_{i(4,5)1} = FQR_{i(4,5)} \times FI_{(4,5)1} \times QSR_{i(4,5)1} \quad \textbf{(4.7.7.4)}$$

$FSR_{i(4,5)1}$ = food-to-soil concentration ratio for meat and milk.

$FQR_{i(4,5)}$ = Radionuclide transfer factor for meat and milk (Baes, 1984).

$FI_{(4,5)1}$ = Daily intake of contaminated fodder, by q = 1. Recall the fodder intake rates from the previous subpathway:

$QSR_{i(4,5)1}$ = Fodder-to-soil concentration ratio for meat, p = 4, or milk, p = 5, for the ith principal radionuclide and q^{th} subpathway, No units. For root uptake, QSR, is equal to the vegetable to soil transfer factor, B_{iv}. The QSR values are described by Equation 4.7.7.5:

$$QSR_{i41} = QSR_{i51} = B_{iv} \quad \textbf{(4.7.7.5)}$$

The FSR terms for the meat and milk root uptake subpathway can be calculated in a manner analogous to the previous section. These FSR values are described by Equations 4.7.7.6 and 4.7.7.7:

$$FSR_{i41} = 68 \text{ kg/d} \times FQR_{i4} \times B_{iv} \quad \textbf{(4.7.7.6)}$$

$$FSR_{i51} = 55 \text{ kg/d} \times FQR_{i5} \times B_{iv} \quad \textbf{(4.7.7.7)}$$

The expressions for the ETF_{i41} and ETF_{i51} can be simplified to Equations 4.7.7.8 and 4.7.7.9:

$$ETF_{i41}(t) = FA_4 \times FD_{i41}(t) \times DF_4 \times FI_4 \times FQR_{i4} \times B_{iv} \quad \textbf{(4.7.7.8)}$$

$$ETF_{i51}(t) = FA_5 \times FD_{i51}(t) \times DF_5 \times FI_5 \times FQR_{i5} \times B_{iv} \quad \textbf{(4.7.7.9)}$$

The corresponding dose-to-source ratios for meat and milk ingestion through this subpathway are defined by Equations 4.7.7.10 and 4.7.7.11:

$$DSR_{i41}(t) = FA_4 \times FD_{i41}(t) \times DF_4 \times FI_4 \times FQR_{i4} \times B_{iv} \times DCF_{i3} \qquad \textbf{(4.7.7.10)}$$

$$DSR_{i51}(t) = FA_5 \times FD_{i51}(t) \times DF_5 \times FI_5 \times FQR_{i5} \times B_{iv} \times DCF_{i3} \qquad \textbf{(4.7.7.11)}$$

The Equations illustrated above are used to evaluate the dose-to-source ratios. The parameters used to calculate the environmental transport factors are listed in Table 4.7.7.1. The dose-to-source ratios for the various radionuclides are listed in Table 4.7.7.2. The radionuclides other than uranium and thorium are illustrated for information only, since measurements have not indicated their presence in the assessment region.

Table 4.7.7.1: Parameters Utilized In Root Uptake Subpathway Of Meat And Milk Ingestion

FA(4,5) = 0.093 (Gilbert, 1988)

FD(i,4,51)t = Values Range For Thorium And Uranium Between 0 To 0.95 (Gilbert, 1988)

DF(4) = 63 kg/yr (ICRP, 1977)

DF(5) = 92 L/yr (ICRP, 1977)

FI(4) = 68 kg/d (Baes, 1984)

FI(5) = 55 kg/d (Baes, 1984)

FQR(i4,5) = Radionuclide Transfer Factors (Baes, 1984)

B(iv) = Food-To-Soil Transfer Factors (NRC, 1977)

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Table 4.7.7.2: Results of the Root Uptake Subpathway of Meat and Milk Ingestion

Radionuclide	DSR (mrem/yr per pCi/g)*
Uranium-238	4.90×10^{-4}
Uranium-235	5.11×10^{-4}
Uranium-234	5.44×10^{-4}
Thorium-232	7.74×10^{-3}
Thorium-230	1.55×10^{-3}
Thorium-228	2.16×10^{-3}
Technetium-99	7.46×10^{-4}
Neptunium-237	6.67×10^{-2}
Strontium-90	7.89×10^{-3}
Radium-226	3.08×10^{-4}
Radium-228	3.36×10^{-4}
Cesium-137	4.84×10^{-4}
Plutonium-238	6.67×10^{-5}
Plutonium-239	7.41×10^{-5}

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

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4.7.8 Ingestion of Meat and Milk - Overhead Irrigation Subpathway

The ingestion of contaminated meat and milk by man with the radionuclides introduced to the livestock fodder by overhead irrigation is depicted in Figure 4.7.8.1. This subpathway is similar to the subpathway of Section 4.7.5, except that now transfer factors must be added to predict the fraction of the radionuclides which enter the meat and milk. The general dose-to-source ratio is defined by Equation 4.7.8.1. The environmental transport factor is defined by Equation 4.7.8.2. Notice that the depth factor is neglected since, as in Section 4.7.5, this subpathway is independent of the depth of the contaminated zone.

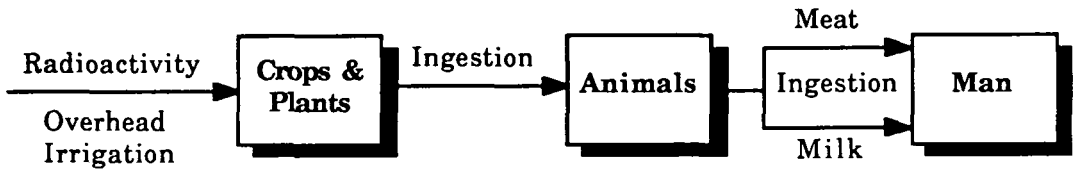

Figure 4.7.8.1: Schematic Diagram Representing the Ingestion of Meat and Milk by Man for the Overhead Irrigation Subpathway

Equations:

$$DSR_{i4,54}(t) = ETF_{i4,54}(t) \times DCF_{i3} \qquad (4.7.8.1)$$

$$ETF_{i4,54}(t) = FA_{4,5} \times \Sigma_k (DF_{3k} \times FSR_{i4,54k}(t)) \qquad (4.7.8.2)$$

The area factor, $FA_{4,5}$, is as previously defined in Sections 4.7.6 and 4.7.7, **0.093**. The food-to-soil concentration ratio, $FSR_{i4,54k}(t)$, is defined by Equation 4.7.8.3:

$$FSR_{i4,54k}(t) = FI_{4,5} \times FQR_{i4,5} \times QSR_{i4,54}(t) \qquad (4.7.8.3)$$

The fodder intake factors, FI, and the meat and milk transfer factors, FQR, have been previously defined, Sections 4.7.6 and 4.7.7. The $QSR_{i4,54}(t)$ is defined by Equation 4.7.8.4 and represents the transport of the contaminated water to the plants and crops which will then be utilized as fodder. Note that the subscript k of the FSR term is for k equal to three, the fodder food class.

$$QSR_{i4,54}(t) = FWR_{i343} \times WSR_{i1}(t) \qquad (4.7.8.4)$$

The environmental transport factor for this subpathway can then be summarized by Equation 4.7.8.5:

$$ETF_{i4,54}(t) = FA_{4,5} \times FWR_{i343} \times WSR_{i1}(t) \times (FI_4 \times FQR_4 \times DF_4 + FI_5 \times FQR_5 \times DF_5) \quad \textbf{(4.7.8.5)}$$

The dose-to-source ratio for this subpathway is shown in Equation 4.7.8.6:

$$DSR_{i4,54}(t) = FA_{4,5} \times FWR_{i343} \times WSR_{i1}(t) \times (FI_4 \times FQR_4 \times DF_4 + FI_5 \times FQR_5 \times DF_5) \times DCF_{i3} \quad \textbf{(4.7.8.6)}$$

Equation 4.7.8.6 illustrates the dose-to-source ratio for the ingestion of meat and milk through the overhead irrigation subpathway. The terms of this equation, detailing the environmental transport factor, are listed in Table 4.7.8.1. The dose-to-source ratios for this subpathway are listed in Table 4.7.8.2. Note that these DSRs are listed for both hydrogeological models, since the environmental transport factor is characterized by the water-to-soil ratio which in turn differs for each model. These DSRs have been calculated for the radionuclides of uranium and thorium along with the additional radionuclides.

Table 4.7.8.1: Parameters Utilized In The Overhead Irrigation Subpathway Of Meat And Milk Ingestion

FA(4,5) = 0.093 (Gilbert, 1988)

FD(i4,5,2t) = Values For Uranium And Thorium Range Between 0 and 1.0 (Gilbert, 1988)

DF(4) = 63 kg/yr (ICRP, 1977)
DF(5) = 92 L/yr (ICRP, 1977)

FI(4) = 68 kg/d (Baes, 1984)
FI(5) = 55 kg/d (Baes, 1984)

FA(2) = 0.935 (Gilbert, 1988)

ASR(3) = 1 x 10(-4) g/m(3) (Gilbert, 1988)

The Following Terms of The Plant Food-To-Air Concentration Ratio Are Defined As Follows (Gilbert, 1988):

V(di) = 1 x 10(-3) m/s

f(r) = 0.25

T(iv,k=3) = 1.0

λ (w) = 20/yr

t(e,k=3) = 0.08 yr

Y(v,k=3) = 1.1 kg/m(2)

FQR(i4,5) = Radionuclide Transfer Factors For Meat And Milk (Baes, 1984)

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Table 4.7.8.2: Results of the Overhead Irrigation Subpathway of Meat and Milk Ingestion

Radionuclide	DSR Model I (mrem/yr per pCi/g)*	DSR Model II (mrem/yr per pCi/g)*
Uranium-238	1.61×10^{-2}	1.05×10^{-2}
Uranium-235	1.68×10^{-2}	1.10×10^{-2}
Uranium-234	1.79×10^{-2}	1.17×10^{-2}
Thorium-232	0	0
Thorium-230	0	0
Thorium-228	0	0
Technetium-99	3.15×10^{-4}	0
Neptunium-237	1.90	0.48
Strontium-90	2.63×10^{-3}	1.59×10^{-3}
Radium-226	1.68×10^{-2}	1.18×10^{-2}
Radium-228	1.83×10^{-2}	1.28×10^{-2}
Cesium-137	1.73×10^{-2}	0
Plutonium-238	1.46×10^{-2}	0
Plutonium-239	1.63×10^{-2}	0

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

4.7.9 Ingestion of Meat and Milk - Livestock Watering Subpathway

This subpathway of meat and milk ingestion represents the route through which man is exposed to radiation when livestock are ingesting water from a contaminated well source. Figure 4.7.9.1 describes this subpathway of meat and milk ingestion by man. The dose-to-source ratio for this subpathway is defined by Equation 4.7.9.1 (Gilbert, 88). The environmental transport factor is defined by Equation 4.7.9.2 (Gilbert, 88). The quantity of radionuclides which enter the aquifer from the surface soil is characterized by the water-to-soil ratio, WSR_{i1}, included in Equation 4.7.9.3 (Gilbert, 88). The water-to-soil ratio determines the time dependence of this subpathway.

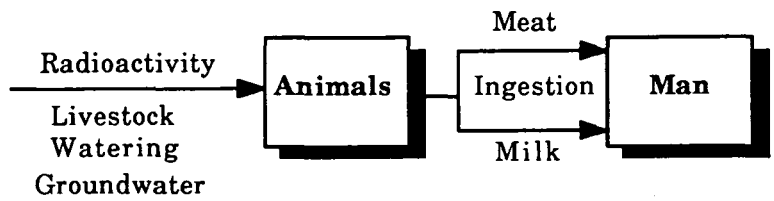

Figure 4.7.9.1: Schematic Diagram of Meat and Milk Ingestion by Man through the Subpathway of Livestock Watering

Equations:

$$DSR_{i4,55}(t) = ETF_{i4,55}(t) \times DCF_{i3} \qquad \textbf{(4.7.9.1)}$$

$$ETF_{i4,55}(t) = FA_{4,5} \times DF_{4,5} \times FSR_{i4,55}(t) \qquad \textbf{(4.7.9.2)}$$

The food-to-soil concentration ratio is further define by Equation 4.7.9.3.

$$FSR_{i4,55}(t) = FQR_{i4,5} \times FI_{4,55} \times WSR_{i1}(t) \qquad \textbf{(4.7.9.3)}$$

The units of Equation 4.7.9.3 are grams per liter since the FQR and FI terms have inverse units. The units of Equation 4.7.9.2 are grams per year, since the dietary factor has units of kilograms per year and it's multiplied by the FSR term of grams per liter. One liter equals approximately one kilogram.

The final dose-to-source ratio can be expressed as shown in Equation 4.7.9.4:

$$DSR_{i4,55}(t) = FA_{4,5} \times DF_{4,5} \times FQR_{i4,5} \times FI_{4,55} \times WSR_{i1}(t) \qquad \textbf{(4.7.9.4)}$$

The dose-to-source ratio for this subpathway, shown in Equation 4.7.9.4, is evaluated by using the parameters listed in Table 4.7.9.4. These parameters detail the calculation of the environmental transport factor. The dose-to-source ratios for the radionuclides of uranium and thorium and the additional radionuclides are listed in Table 4.7.9.2. The additional radionuclides have been evaluated on a picocurie basis to illustrate their contribution to the dose of the resident farmer should they be present in the soil of the assessment region. It is important to note, however, that soil radioactivity measurements have not indicated the presence of any of these additional radionuclides.

Table 4.7.9.1: Parameters Used In The Livestock Watering Subpathway Of Meat And Milk Ingestion

FA(4,5) = 0.093 (Gilbert, 1988)

DF(4) = 63 kg/yr (ICRP, 1977)

DF(5) = 92 L/yr (ICRP, 1977)

FI(4) = 50 L/d (Baes, 1984)

FI(5) = 160 L/d (Baes, 1984)

FQR(i4,5) = Radionuclide Transfer Factors (Baes, 1984)

WSR(i1)t = Water-To-Soil Ratio (Gilbert, 1988)

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Table 4.7.9.2: Results of the Livestock Watering Subpathway of Meat and Milk Ingestion

Radionuclide	DSR Model I (mrem/yr per pCi/g)*	DSR Model II (mrem/yr per pCi/g)*
Uranium-238	1.78×10^{-3}	1.16×10^{-3}
Uranium-235	1.86×10^{-3}	1.21×10^{-3}
Uranium-234	1.97×10^{-3}	1.29×10^{-3}
Thorium-232	0	0
Thorium-230	0	0
Thorium-228	0	0
Technetium-99	3.48×10^{-5}	0
Neptunium-237	0.21	5.29×10^{-2}
Strontium-90	2.90×10^{-4}	1.75×10^{-4}
Radium-226	1.85×10^{-3}	1.30×10^{-3}
Radium-228	2.02×10^{-3}	1.42×10^{-3}
Cesium-137	1.90×10^{-3}	0
Plutonium-238	1.61×10^{-3}	0
Plutonium-239	1.79×10^{-3}	0

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

4.7.10 Ingestion of Drinking Water by a Groundwater Pathway

The pathway for the ingestion of groundwater by drinking is described by Figure 4.7.10.1. The dose-to-source ratio for this pathway is defined by Equation 4.7.10.1. The environmental transport factor is defined by Equation 4.7.10.2. The environmental transport factor for the ingestion of groundwater is composed of two components: the dietary factor for water intake by man and the water-to-soil concentration ratio. This pathway, as with the previous nine sections, was evaluated for two different types of vadose zone models in the area near the soil removal action.

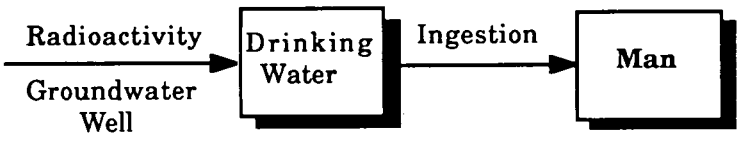


Figure 4.7.10.1: Ingestion of Drinking Water from a Groundwater Well

Equations:

$$DSR_{i7}(t) = DCF_{i3} \times ETF_{i7}(t) \qquad \textbf{(4.7.10.1)}$$

$$ETF_{i7}(t) = DF_7 \times WSR_{i1}(t) \qquad \textbf{(4.7.10.2)}$$

Where ETF_{i7} is the environmental transport factor for the drinking water pathway, with units of (g/yr) (Gilbert, 88).

DF_7 = Dietary intake of drinking water, **730 L/yr.** (EPA, 1986).

$WSR_{i1}(t)$ = Water-to-soil concentration ratios for well water, (g/L).

The time dependent dose-to-source ratio for this pathway is then illustrated in Equation 4.7.10.3:

$$DSR_{i7}(t) = DCF_{i3} \times DF_7 \times WSR_{i1}(t) \qquad \textbf{(4.7.10.3)}$$

Table 4.7.10.2: Results of the Drinking Water Pathway

Radionuclide	DSR Model I (mrem/yr per pCi/g)*	DSR Model II (mrem/yr per pCi/g)*
Uranium-238	0.57	0.37
Uranium-235	0.60	0.39
Uranium-234	1.97×10^{-3}	0.41
Thorium-232	0	0
Thorium-230	0	0
Thorium-228	0	0
Technetium-99	4.20×10^{-3}	0
Neptunium-237	76.0	19.4
Strontium-90	2.57×10^{-1}	0.16
Radium-226	2.75	1.93
Radium-228	3.00	2.10
Cesium-137	9.72×10^{-2}	0
Plutonium-238	5.92×10^{-1}	0
Plutonium-239	6.58×10^{-1}	0

*Note: Dose-to-source ratio is the committed effective dose equivalent based on a unit concentration of the radionuclide at 1 pCi/g of soil.

5.0 Results Of The ALARA Cost-Benefit Analysis

5.1 Total Dose-To-Source Ratios

The total dose-to-source ratios (DSR) for each radionuclide are found by summing the DSRs from each pathway and subpathway. Table 5.1.1 lists the total dose-to-source ratio results for uranium and thorium for model I. The DSRs shown here are the maximum values which occur at the time indicated. Thus, the maximum DSR for uranium isotopes occur about 200 years from now. The maximum values of the DSR would result in a maximum dose to an individual. The dose would be obtained by multiplying the DSR by the actual content of the radionuclide in the soil.

An ALARA calculation begins when a standard is satisfied or reached (see Figure 2.1.1). Standards must be met at all costs. ALARA is the application of the philosophy that all exposures to humans should be kept as low as reasonably achievable. The application of ALARA to the manhole 180 soil removal action is shown in Figure 5.1.1.

In order to perform the ALARA cost-benefit analysis it is necessary to identify the level, which consists of either a dose level or a concentration level of radioactivity in the soil, from which the ALARA application is initiated. Also, it necessary to determine the level to which the ALARA application will be practiced. These ALARA results, which are in terms of person rem saved, consist of applying ALARA from a guideline to either the post excavation activity levels or to the sample measurements from an unaffected area (an area outside the assessment region). Figure 5.1.2 provides a schematic diagram of the assessment region. Specifically, Figure 5.1.2 defines: 1) post excavation samples, 2) assessment area and samples, 3) unaffected samples (IT split soil samples), and 4) excavated area.

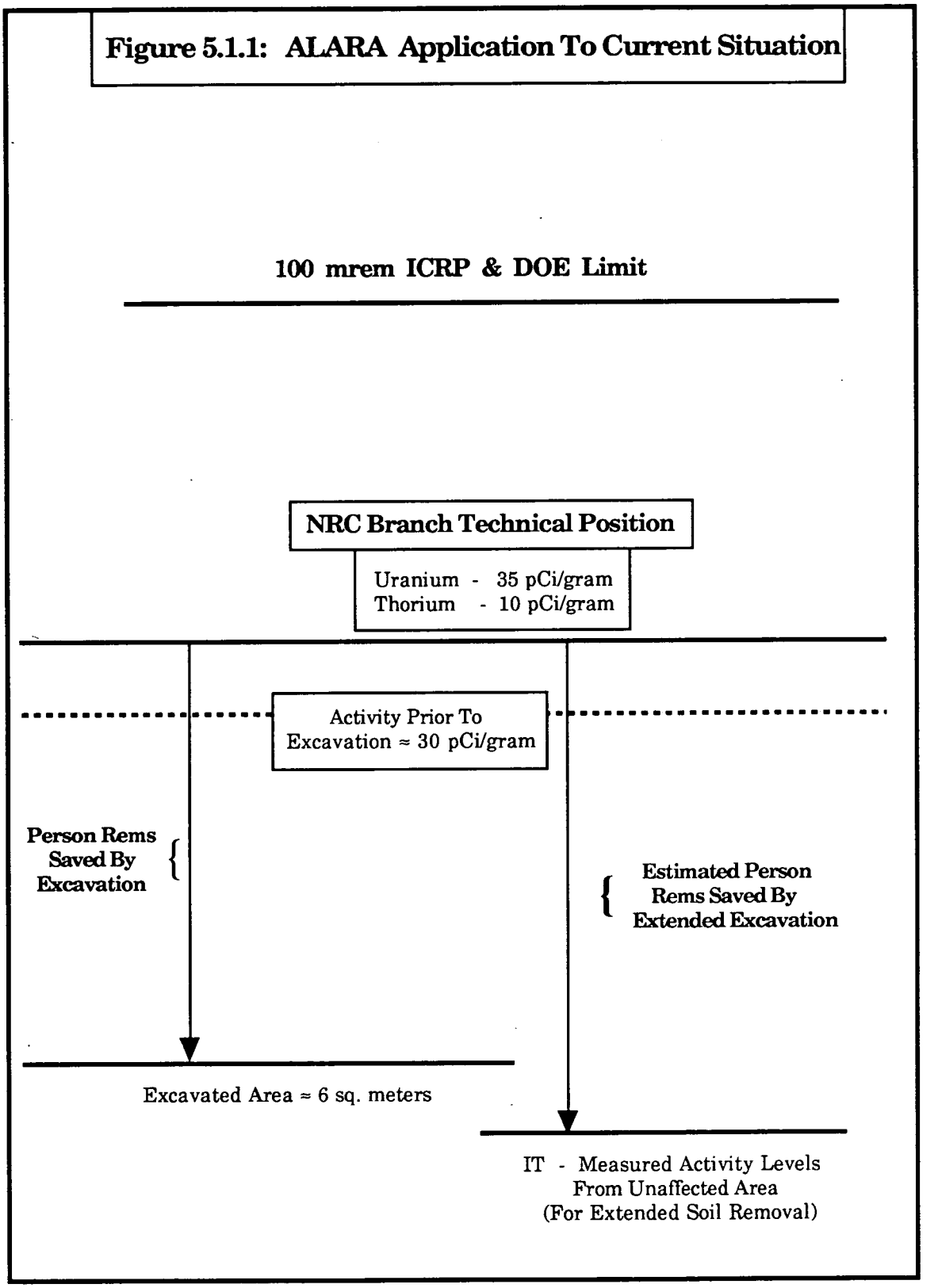
Samples were taken by the FMPC within the assessment area in order to characterize the extent of above background levels of uranium and thorium in the soil. Check samples were sent to International Technologies Incorporated (IT) to measure the radioactivity. These results were reported in terms of total uranium and total thorium, parts per million (ppm). These results indicated that uranium-238 had a maximum value of approximately 30 picocuries per gram of soil (this sample existed in the excavated region prior to excavation). While, thorium-228 had a maximum value of approximately 4 picocuries per gram of soil prior to excavation activities.

Table 5.1.1: Total Dose-to-Source Ratios for Uranium and Thorium-Model I

Radionuclide	Time Frame† of Analysis (years)	Total DSR (mrem/yr per pCi/g)
Uranium-238	200	0.73
Uranium-235	200	0.90
Uranium-234	200	0.78
Thorium-228	70	4.85
Thorium-230	70	0.42
Thorium-232	70	2.12

†Time frame refers to the time at which the DSR was calculated. The time which results in the maximum dose-to-source ratio is listed.

Figure 5.1.1: ALARA Application To Current Situation



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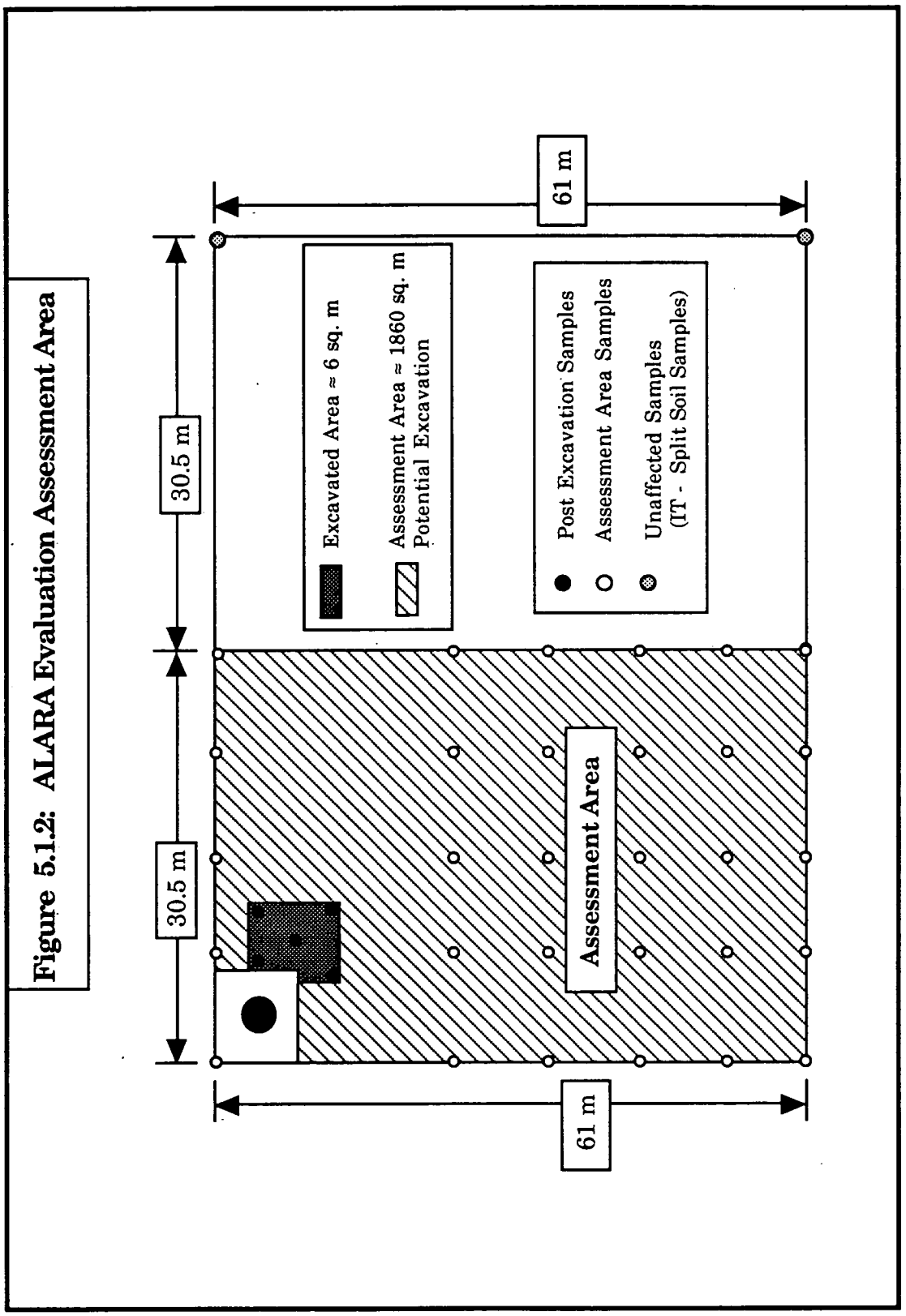

Figure 5.1.2: ALARA Evaluation Assessment Area

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These measurements indicated that uranium and thorium existed at levels below the NRC Branch Technical Position Guideline (NRC, 1981) prior to the start of any excavation activities. Furthermore, these measurements indicated that the dose from the above background levels, prior to any removal action, would never be as high as the DOE Standard of 100 mrem per year. Therefore, it was conservatively assumed that the starting point of the ALARA calculations would be the NRC guideline. Figure 5.1.1 illustrates this starting point for the ALARA application. Table 5.1.2 shows the NRC guidelines for depleted uranium and natural thorium with units of picocuries per gram of soil. These NRC guidelines were multiplied by the total dose-to-source ratios of Table 5.1.1 to give doses. These dose results are presented in Table 5.1.2 as well.

Table 5.1.2: Doses Based on the NRC Branch Technical Position Guideline

Radionuclide	NRC† (pCi/g)	Dose-NRC†† (mrem/yr)
Uranium-238	17.5	12.77
Uranium-235	0.8	0.72
Uranium-234	17.5	13.73
Thorium-228	5	24.30
Thorium-230	17.5	7.41
Thorium-232	5	10.60

†These values, in units of pCi/g, are from the NRC Branch Technical Position Paper-35 pCi/g depleted uranium and natural thorium (NRC, Federal Register 1981).

††These doses are based on the NRC Guidelines for depleted uranium and natural thorium and represents the dose the resident farmer would receive with this level of residual radioactivity in the soil. All ten pathways and subpathways are included for each radionuclide in this calculation.

The ending point of the ALARA assessment was considered for two points: 1) post excavation soil sample radioactivity measurements and 2) radioactivity measurements from an area that is outside the manhole 180 assessment region (see Figure 5.1.2). The application of the ALARA cost-benefit analysis from the NRC Guideline to the post excavation soil samples details the number of person rem saved for the excavation activity. While considering the ALARA analysis from the NRC Guideline to samples taken from an area which is unaffected, outside the manhole 180 region, provides an estimate of person rems which would be saved if the entire assessment region was excavated.

The University of Cincinnati measured the radioactivity in the post-excavation soil samples (see Figure 5.1.2 for the sample location). These are soil samples which had been taken from the excavated area following the cleanup activities. Column 2 of Table 5.1.3 shows the radionuclide content of these samples. Based on this actual radionuclide content, the dose was calculated for the resident farmer. Column 3 shows this dose.

Table 5.1.3: Doses Based on Current Soil Removal Action

Radionuclide	Post Excavation† Samples (pCi/g)	Dose-Post Excavation†† Samples (mrem/yr)
Uranium-238	5.30	3.87
Uranium-235	0.24	0.22
Uranium-234	5.30	4.16
Thorium-228	0.55	2.69
Thorium-230	2.10	0.89
Thorium-232	0.51	1.09

† Post Excavation Soil Samples were collected by the FMPC and measured for radioactivity at the University of Cincinnati (pCi/g).

††These doses are calculated for the post excavation soil samples with units of mrem/yr. They represent the committed effective dose equivalent that the resident farmer receives from the excavated region based on the total of the ten pathways and subpathways.

Table 5.1.4 shows the results of the IT split soil samples. Again, these samples represent an area outside the assessment region. Column 2 illustrates the activity level of each radionuclide, while column 3 shows the dose (mrem per year) that the resident farmer would receive based on this concentration of radionuclide in the soil.

Table 5.1.4: Doses Based on the IT Split Soil Samples-Representing Soil Measurements Outside Assessment Area

Radionuclide	IT Samples† (pCi/g)	Dose-IT†† (mrem/yr)
Uranium-238	2.1	1.53
Uranium-235	0.6	0.54
Uranium-234	1.7	1.33
Thorium-228	1.5	7.29
Thorium-230	2.75	1.16
Thorium-232	0.9	1.91

*These measurements represent the average of two IT Split Soil Samples located outside the assessment region (See Figure), units are pCi/g. The samples are: #7 and #47.

**These doses represent what the resident farmer receives from considering each radionuclide over the ten pathways and subpathways analyzed, units are mrem/yr committed effective dose equivalent.

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5.2 Person Rem Saved for the Two Endpoints

Table 5.2.1 shows the ALARA results for the current soil removal action. These results were calculated first by substracting the mrem per year of the post excavation soil samples (Table 5.1.3) from the mrem per year of the NRC Guideline (Table 5.1.2) to give mrem avoided. The mrem avoided were converted to rem avoided (dividing by 1000) and then multiplied by a 70 year lifetime (EPA, 1986) to give person rem saved. The third column of Table 5.2.1 gives the person rem saved for a resident farm family of 5 individuals with each member of the family having a 70 year lifetime (found by multiplying column 2 by 5).

Table 5.2.1: ALARA Results for the Current Soil Removal Action

Radionuclide	Rem Saved† Excavated Region (70 year)	Rem Saved†† Excavated Region (5-Family-70 year)
Uranium-238	0.62	3.12
Uranium-235	0.035	0.18
Uranium-234	0.67	3.35
Total rem saved for Uranium:	**1.33**	**6.65**
Thorium-228	1.51	7.56
Thorium-230	0.46	2.28
Thorium-232	0.67	3.33
Total rem saved for Thorium:	**2.64**	**13.17**

†Rem saved for the excavated region represent the reduction in dose from the NRC guideline to the level of the post excavation soil sample values determined from radioactivity measurements performed at the University of Cincinnati. These person rem saved include the contribution from all ten pathways and subpathways and is considered for a 70 year lifetime.

††This column is the same as the first column except the person rem saved have been multiplied by 5 to compensate for a family of five.

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Table 5.2.2 predicts ALARA results based on an excavation of the remaining 1854 square meters of the assessment area down to a level of that measured outside the assessment area, determined by the IT split sample measurements. These person rem saved, column 2, are estimated based on the radionuclides of uranium and thorium being reduced in concentration to a value which is typical of the surrounding farm land. Column 3 estimates the person rem saved for a resident farm family consisting of 5 individuals.

Table 5.2.2: ALARA Results Based on a Soil Removal Action of the Remaining Portion of the Assessment Area

Radionuclide	Rem Saved† 1854 meter^2 (70 year)	Rem Saved†† 1854 meter^2 (5-Family-70 year)
Uranium-238	0.79	3.93
Uranium-235	0.013	0.063
Uranium-234	0.87	4.34
Total rem saved for Uranium:	**1.67**	**8.33**
Thorium-228	1.19	5.95
Thorium-230	0.44	2.19
Thorium-232	0.61	3.04
Total rem saved for Thorium:	**2.24**	**11.18**

†Rem saved for the 1854 square meters represent the reduction in dose from the NRC guideline to the level of the IT Split Soil Sample values (Sample Nos. 7 and 47). These person rem saved includes the contribution from all ten pathways and subpathways and is considered for a 70 year lifetime. The 1854 square meters represent the unexcavated portion of the assessment area.

††This column is the same as the first column except the person rem saved have been multiplied by 5 to compensate for a family of five.

5.3 ALARA Cost-Benefit Analysis

The ALARA cost-benefit analysis consists of calculating the cost per person rem avoided for both the current soil removal action and the extended soil removal action. The extended soil removal action represents the soil removal of the remaining portion of the assessment area to the level of the IT split soil samples. The cost per person rem avoided is for both the individual and the resident farm family, which consists of five individuals. The cost of the current soil removal action was supplied by the FMPC and is equal to 153,970 dollars. The cost estimate to perform the soil removal action for the remaining portion of the assessment area was provided by the FMPC as well and is equal to 176,000 dollars, excluding any soil disposal costs.

Table 5.3.1 describes the ALARA cost-benefit analysis for the current soil removal action. Column 2 indicates the total person rem saved and the cost per person rem avoided for uranium and thorium together. Column 3 gives the total person rem saved and the cost per person rem avoided for the resident farm family.

Table 5.3.2 describes the ALARA cost-benefit analysis estimate for the soil removal action of the remaining portion of the assessment area. Included in Table 5.3.2 are the total person rem saved and the cost per person rem avoided for uranium and thorium together over this area. Results are also provided in Table 5.3.2 for the resident farm family.

6.0 Conclusions

Based on the previous technical discussions, the recommendation of the University of Cincinnati is that an additional cleanup action can not be justified for the remaining portion of the assessment area located adjacent to manhole 180. This conclusion was arrived at through several considerations. These considerations are: 1) the low levels of uranium and thorium prior to any excavation activities (see Figure 5.1.1), 2) the highly conservative nature of the assessment, and 3) the cost per person rem spent for the completed soil removal action and the projected cost per person rem estimated for the extended soil removal action is considerably higher than the 2000 dollars per person rem recommended by the NRC.

As shown in Figure 5.1.1 the levels of uranium and thorium in the soil prior to any excavation activities correspond to a dose which is well below the Department of Energy's dose limit of 100 mrem per year. Also, the NRC guidance levels cited for uranium and thorium (35 pCi/g for depleted uranium and 10 pCi/g for natural thorium) are above the levels which were actually measured prior to any excavation activities.

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6.0 Conclusions (continued)

The person rem saved for the current cleanup action and also the estimation of person rem saved for the remaining portion of the assessment area were calculated very conservatively. These person rem saved are calculated from the doses that the resident farmer and farm family would receive based on the conservative scenario illustrated in Figure 4.1.1. Also, the person rem avoided represent a cumulative dose over a 70 year lifetime for the resident farmer and each member of the farm family. In reality the person rem saved for these cleanup actions are much lower which means the cost per person rem avoided is much higher.

Tables 5.4.1 and 5.4.2 show the costs for the current soil removal action and also estimate the cost for the extended soil removal action. Notice that for the current cleanup action the cost per person rem avoided for the resident farmer was calculated to be $ 38,783 and the cost per person rem avoided for the farm family was found to be $ 7,768. The estimated cost per person rem for the remaining portion of the assessment region are even higher than these current costs per person rem avoided. Both of these cost figures, either for the current cleanup action or the extended cleanup action, greatly exceed the two-thousand dollars per person rem avoided recommended by the NRC Branch Technical Position Paper (NRC, 1981).

Therefore, the conclusion of the University of Cincinnati is that no further action is warranted with respect to the current condition of the surface soil near manhole 180.

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Table 5.3.1: ALARA Cost-Benefit Results for the Current Soil Removal Action

Radionuclide	Rem Saved And Cost Analysis Excavated Region (70 year)	Rem Saved And Cost Analysis Excavated Region (5-Family-70 year)
Uranium-238	0.62	3.12
Uranium-235	0.035	0.18
Uranium-234	0.67	3.35
Total rem saved for Uranium:	**1.33**	**6.65**
Thorium-228	1.51	7.56
Thorium-230	0.46	2.28
Thorium-232	0.67	3.33
Total rem saved for Thorium:	**2.64**	**13.17**
Total Person Rem Saved for Uranium & Thorium:	**3.97**	**19.82**
Cost of Current Cleanup:	**$ 153,970**	**$ 153,970**
Cost per Person Rem Saved: for the Current Cleanup of Uranium and Thorium	**$ 38,783**	**$ 7,768**

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Table 5.3.2: ALARA Cost-Benefit Results Based on a Soil Removal Action of the Remaining Portion of the Assessment Area

Radionuclide	Rem Saved And Cost Analysis 1854 meter^2 (70 year)	Rem Saved And Cost Analysis 1854 meter^2 (5-Family-70 year)
Uranium-238	0.79	3.93
Uranium-235	0.013	0.063
Uranium-234	0.87	4.34
Total rem saved for Uranium:	**1.67**	**8.33**
Thorium-228	1.19	5.95
Thorium-230	0.44	2.19
Thorium-232	0.61	3.04
Total rem saved for Thorium:	**2.24**	**11.18**
Total Person Rem Saved for Uranium & Thorium:	**3.91**	**19.51**
Estimated Cost:	**$ 176,000**	**$ 176,000**
Cost per Person Rem Saved: for the Extended Cleanup of Uranium and Thorium	**$ 45,013**	**$ 9,021**

These costs exclude any soil disposal costs.

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7.0 References

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7.0 References

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7.0 References

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APPENDIX A

BORING LOGS

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DI 2/5/89

1st Review	TSF	9/7/88
2nd Review		
Hard Copy Verification		

FERNALD RI/FS

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 6007 03 02	PROJECT NAME: FMPC RI/FS		
BORING NUMBER: B497	COORDINATES:		DATE: 07 25 88
ELEVATION: 540 Ft.	GWL: Depth	Date/Time	DATE STARTED: 07 25 88
ENGINEER/GEOLOGIST: Schwartz	Depth	Date/Time	DATE COMPLETED: 08 03 88
DRILLING METHODS: Cable tool			PAGE 1 OF 10

DEPTH (ft)	SAMPLE TYPE & NO	BLOWS ON SAMPLER PER 6 in	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
1	072588 1100 10053	5 6 7	6	stiff brown (10YR 3/2) topsoil clayie silt, dry	ml	1.5	HNu = 0 ppm γβ = 20 cpm α = NA
2	072588 1105 10054	10 13 16	6	stiff brown (10YR 3/2) clayie silt	ml	1.5	HNu = 0 ppm γβ = 20 cpm
3	072588 1110 10055	9 11 13	3	very stiff yellow brown (10YR 4/3) silty clay to clayie silt, dry	ml	2.5	HNu = 0 ppm γβ = 20 cpm
5 6	072588 1118 10056	11 8 10	15	very stiff yellow brown (10YR 4/3) clayie silt, dry	ml	2.5	HNu = 0 ppm γβ = 20 cpm
7	072588 1124 10057	7 9 12	15	stiff dark grey brown (10YR 4/2) silty clay, dry	cl	1.5	HNu = 0 ppm γβ = 20 cpm
8 9	072588 1130 10058	7 10 10	12	soft dark grey brown (10YR 4/2) silty clay, moist	cl	<1	HNu = 0 ppm γβ = 20 cpm
10	072588 1140 10059	6 6 7	12	soft dark grey brown (10YR 4/2) silty clay, some sand lenses	cl	<1	HNu = 0 ppm γβ = 20 cpm
11 12	072588 1150 10060	12 7 20	15	soft dark grey brown silty clay	cl	<1	HNu = 0 ppm γβ = 20 cpm
				soft dark brown clayie sand (10YR 4/3), moist	SC	<1	
				grey brown sand some clay, gravel, moist	SC	NA	
13							
14							

NOTES:

Drilling Contr. : Penn Drill
Driller : Harry Dykes Jr
Helper : Tim Harris
Rig : Speed star

Water used : 700 gallons

- Color follow Munsell color chart
- Blows on split spoon follow ASTM standard

Background :
HNu = 0 ppm
γβ = 20 cpm
α = No instrument

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FERNALD RI/FS

DH 2589

	Initial	Date
1st Key In		
2nd Key In		9/12
Hard Copy Verification		

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 1002 03 02	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: B497 4097	COORDINATES:	DATE: 07 25 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED: 07 25 88
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable tool		PAGE 2 OF 10

DEPTH (Ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
16	072588 1600 100061	28 50 60	12	very dense sandy gravel, brown (10 YR 5/3) moist	gw	NA	HNu = 0 ppm γB = 20 cpm
17							
18							
19							
20	072688 0800 100062	23 26 30	12	very dense brown sandy gravel, (10 YR 5/3), moist	gw	NA	HNu = 0 ppm γB = 40-60 cpm
21							
22	100063	27 27 31	12	very dense brown (10 YR 5/3) sandy gravel, moist	gw	NA	HNu = 0 ppm γB = 40-60 cpm
23				very dense brown (10 YR 5/3) sandy gravel, wet	gw	NA	HNu = 0 ppm γB = 40-60 cpm
24			12				
25	072688 0915 100064	87 90	12	very dense brown (10 YR 5/3) sandy gravel, wet	gw	NA	HNu = 0 ppm γB = 40-60 cpm
26							
27							
28							
29							

Composite sample

NOTES:

Background:
HNu = 0 ppm
γB = 20-60 cpm (BG)
α = No instrument

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FERNALD RI/FS

DH 2/5/89

	Initial	Date
1st Key In	TSF	9/9/88
2nd Key In	[illegible]	9/12
Hard Copy Verification		

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602 03 02	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: B497 4097	COORDINATES:	DATE: 07 26 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED:
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable tool		PAGE 3 OF 13

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER 6 (in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
31	072688 1105 10065	26 39 53	6	very dense brown (10YR 5/3) sandy gravel, wet	gw	NA	HNu = 0 ppm γβ = 100-120 cpm (BG)
32							
33							
34							
35	072688 1150 10066	32 36 43	12	very dense brown (10YR 5/3) to yellow brown (10YR 5/4) sandy gravel, wet	gw	NA	HNu = 0 ppm γβ = 100-120 cpm (BG)
36							
37							
38							
39							
40	072688 1400 10067	10 11 9	6	med. dense gravelly sand grey brown (10YR 4/2), wet	SW	NA	HNu = 0 ppm γβ = 60-80 cpm (BG)
41							
42							
43							
44							

NOTES:

Background:
α = no instrument
HNu = 0 ppm
γβ = 100-120 cpm

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402-11-86

FERNALD RI/FS

BA 2/5/89

	Initial	Date
1st Key In	TSH	9/9/88
2nd Key In	[illegible]	[illegible]
Hard Copy Verification		

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 662 03 02	PROJECT NAME: FMPC / RI-FS	
BORING NUMBER: B497 4097	COORDINATES:	DATE: 07 27 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED: 07 25 88
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable tool		PAGE 4 OF 10

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
46	072688 1500 10068	15 18 24	12	dense grey brown (10YR 4/2) sand, ~~some~~ gravel, wet	SP	NA	HNu = 0ppm γB = BG
47							
48							
49							
50	072688 1540 10069	5 6 7	3	med dense grey brown (10YR 4/2) sand, wet	SP	NA	HNu = 0ppm γB = BG
51							
52							
53							
54							
55	072788 0830 10245	15 18 23	12	med dense grey brown (10YR 4/2) sand, tr. gravel, wet	SP	NA	HNu = 0ppm γB = 20-40 cpm (BG)
56							
57							
58							
59							

NOTES:

Background:
PID = no instrument
HNu = 0 ppm
γB = (BG)

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402-11-86

FERNALD RI/FS

BH 2/5/89

	Initial	Date
1st Key In	MB	2/13/89
2nd Key In	[illegible]	9/13
Hard Copy Verification		

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602 C3 02	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: B497	COORDINATES:	DATE: 07 27 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED:
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable tool		PAGE 5 OF 10

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER 6 (in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
61	072788 0910 10246	18 13 11	12	med dense grey brown (10YR 4/2) sand, wet	SP	NA	HNu = 0ppm γB = 20-40cpm (BG)
62							
63							
64							
65							
66	072788 1100 10247	30 65 50	10	very dense grey brown (10YR 4/2) sand, some gravel, tr. clay, wet	SW	NA	HNu = 0ppm γB = 60-80cpm (BG) last blow count is for 2 in
67							
68							
69							
70	072788 1150 10248	5 4 3	12	loose dark grey brown (2.5Y 4/2) sand, some gravel, wet	SW	NA	HNu = 0 ppm γB = 40 cpm (BG)
71							
72							
73							
74							

NOTES:

Background:
HNu = 0ppm
γB = (BG) = no instrument

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402-11-86

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FERNALD RI/FS

DH 2/5/89

	Initial	Date
1st Key In	MB	9/12/88
2nd Key In	[illegible]	9/13
Hard Copy		

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602 03 02	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 8497 4097	COORDINATES:	DATE: 07 27 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED: 07 25 88
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable tool		PAGE 10 OF 17

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
76	072788 1405 10249	38 36 50	12	very dense dark grey (5Y 4/1) sand, some gravel, wet	SW	NA	HNu = 0 γβ = 40-60 (BG)
77							
78							
79							
80							
81	072788 1500 10250	5 6 6	9	loose dark grey (5Y 4/1) sand, some gravel, wet	SW	NA	HNu = 0 γβ = 40-60 cpm (BG)
82							
83							
84							
85							
86	072788 0730 10251	18 29 34	12 29	very dense dark grey (5Y 4/1) sand, some gravel, wet	SW	NA	HNu = 0 ppm γβ = 20-40 cpm (BG)
87							
88							
89							

NOTES:

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	Initial	Date
1st Key In		
2nd Key In		9/13
Hard Copy Verification		

2/5/89

FERNALD RI/FS

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 6002 03 02	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: B497 4097	COORDINATES:	DATE: 07 28 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED:
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable tool		PAGE 7 OF 10

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER 6 (in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
91	072888 0820 10252	7 6 7	9	loose dark grey (5Y 4/1) sand, some gravel, wet	SW	NA	HNu = 0ppm γB = 20-40cpm (BG)
92							
93							
94							
95	072888 0950 10253	22 45 56	6	very dense dark grey (5Y 4/1) sand, some gravel, wet	SW	NA	HNu = 0ppm γB = 20-40cpm (BG)
96							
97							appeared to hit clay at 97 ft first cuttings were varved with trace to some silt.
98							
99							
100	072888 1150 10254	16 16 21		dense blue gray clay very plastic	CH-CL	1.5-2.5	HNu = 0ppm γB = (BG)
101							
102							extremely clean clay becoming more plastic toward bottom of unit
103							
104							

NOTES

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	Initials	Date
1st Key In		
2nd Key In		9/13
Hard Copy Verification		

DA 2/5/89

FERNALD RI/FS

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 6072 03 02	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: B497 4097	COORDINATES:	DATE: 08 02 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED:
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable tool		PAGE 8 OF 10

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER 1 (in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
106	080288 1005 10255	7 12 16	18	clean blue gray clay, highly plastic	ch	<1	HNu = 0 ppm γB = 40-60 cpm (BG)
107							apparent end of clay
108							
109							
110	080288 1045 10256	7 8 9	3	med. dense gray sandy gravel, wet	gp	NA	HNu = 0 ppm γB = 40-60 (BG)
111							
112							
113							
114							
115	080288 1325 10257	100 110 —	12	very dense grey (10YR 5/1) sandy med. to coarse gravel, wet	gw	NA	HNu = 0 ppm γB = 60-100 cpm (BG)
116							
117							
118							
119							

NOTES:

water level measured @ 0800 = 23.5 ft

Background:
HNu = 0 ppm
γB = (BG)
α = no instrument

120

402-11-86

FERNALD RI/FS

DJ 2/5/89

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	Initial	Date
1st Key In		
2nd Key In		
Hard Copy Verification		

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602 03 02	PROJECT NAME: FMPC RI/FS		
BORING NUMBER: ~~8497~~ 4097	COORDINATES:	DATE: 08 02 88	
ELEVATION:	GWL: Depth Date/Time	DATE STARTED:	
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED:	
DRILLING METHODS: Cable tool		PAGE 9 OF 10	

DEPTH (Ft.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in.)	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
121	080288 1430 10258	12 12 10	6	med. dense grey brown fine to med. sand, wet ~~2.5Y~~ (2.5Y 5/0)	SP	NA	HNu = 0 ppm γB = 60-100 cpm (BG) 2 trips for sample
122							
123							
124							
125	080288 1530 10259	7 7 9	18	med dense to loose olive brown med sand, tr gravel, wet ~~(2.5Y 4/4)~~ (2.5Y 4/4)	SP	NA	HNu = 0 ppm γB = 60-100 cpm (BG)
126							
127							
128							
129							
130	080288 1630 10260	24 29 52	12	dense brown (10YR 5/3) med sand, tr. gravel, wet	SP	NA	HNu = 0 ppm γB = 60-100 cpm (BG)
131							
132							
133							
134							

NOTES:

BACKGROUND: 121
HNu = 0 ppm
γB = 60-100 cpm (BG)
α = no instrument

FERNALD RI/FS

	Initial	Date
1st Key In		
2nd Key In		
Hard Copy Verification		

DH 2/5/89

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 1002 03 02	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: B497E 4001	COORDINATES:	DATE: 08 03 88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED:
ENGINEER/GEOLOGIST: Schwartz	Depth Date/Time	DATE COMPLETED: 080388
DRILLING METHODS: Cable tool		PAGE 10 OF 10

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in)	RECOVERY (in)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
136	080388 0820 10261	30 50 60	15	dense gray brown (2.5Y 5/2) sand, tr. gravel, wet	SW	NA	HNu = 0ppm γB = 20-40 cpm (BG)
137							
138							
139							
140	080388 0930 10262	5 7 9	12	loose to med dense yellow brown (10YR 5/6) med. to coarse sand, tr. gravel, wet	SW	NA	HNu = 0ppm γB = 40-60 cpm (BG)
141							
142							
143							
144							
145	080388 1130 10263	35 150 —	6	sandy coarse gravel fragments of limestone	GW	NA	HNu = 0ppm γB = 40-60 cpm (BG)
146							
147							
148							
149	080388 1430 10264	60	2	shale bedrock end of boring			

NOTES:

Background:
HNu = 0ppm
γB = (BG)
α = no instrument

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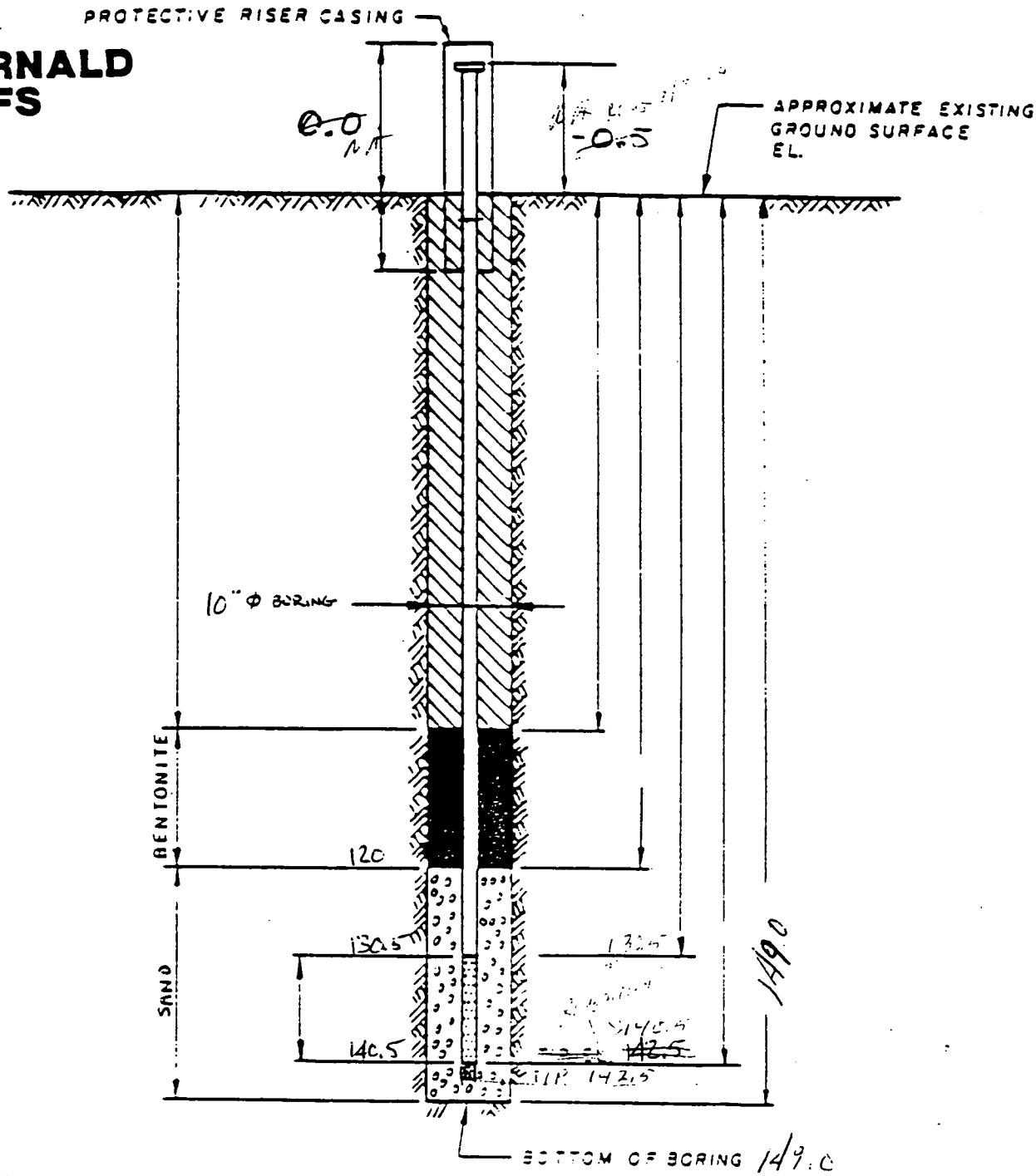
M. Schwartz 15
2/5/89 08 06 88

FERNALD RI/FS



DRAWING NUMBER	
CHECKED BY	APPROVED BY
DRAWN BY	

NOTES:

1. RISER PIPE IS 4 IN 10 SCHEDULE PIPE, THREADED, FLUSH-JOINTED.
2. SCREEN IS 4 IN 10 SS PIPE CONTINUOUS SLOT SCREEN (0.010 IN SLOT SIZE).
3. LOWER END OF SCREEN IS CAPPED.
4. ELEVATION OF WATER LEVEL
5. WATER LEVEL READING ON

INSTALLATION DETAILS
MONITORING WELL ~~417~~ 4097

PREPARED FOR

123

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	Initial	Date
1st Key In	[illegible]	11/3/89
2nd Key In		
Hard Copy Verification		

DH 2/5/89

FERNALD RI/FS

PIEZOMETER INSTALLATION SHEET

PROJECT NAME FMPC RI/FS FIELD ENG./GEO. Schwartz DATE 08/06/88
PROJECT NO. 602 03 02 CHECKED BY R Gebhart DATE 2/7/89
BORING NO. 497 4097 [illegible]
PIEZOMETER NO. 497 4097 [illegible] DATE OF INSTALLATION 8/6/88

BOREHOLE DRILLING

DRILLING METHOD cable tool	TYPE OF BIT flat head hammer
DRILLING FLUID (S) USED: water	CASING SIZE (S) USED:
FLUID 0 FROM 149 TO	SIZE 10" FROM 0 TO 149
FLUID FROM TO	SIZE FROM TO

PIEZOMETER DESCRIPTION

TYPE [illegible]	RISER PIPE MATERIAL stainless 314
DIAMETER OF PERFORATED SECTION 4"	RISER PIPE DIAMETERS:
PERFORATION TYPE:	O.D. [illegible] I.D. 10" [illegible]
SLOTS ☐ HOLES ☐ SCREEN ☒	LENGTH OF PIPE SECTIONS 10 ft
AVERAGE SIZE OF PERFORATIONS .010	JOINING METHOD thread & couple
TOTAL PERFORATED AREA 10 ft	

PROTECTION SYSTEM

RISER PROTECTIVE PIPE LENGTH [illegible]	OTHER PROTECTION [illegible]
PROTECTIVE PIPE O.D.	

ITEM	DISTANCE ABOVE/BELOW GROUND SURFACE (ft)		ELEVATION ( )	
TOP OF RISER PIPE	-0.5 N/A [illegible]			
GROUND SURFACE	0.0			
BOTTOM OF PROTECTIVE PIPE	N/A [illegible]			
BOREHOLE FILL MATERIALS:				
GROUT/SLURRY upper	-2	-9		
GROUT/SLURRY lower	TOP -15	BOTTOM -120	TOP	BOTTOM
BENTONITE	TOP -9	BOTTOM -15	TOP	BOTTOM
SAND	TOP —	BOTTOM —	TOP	BOTTOM
GRAVEL	TOP -120	BOTTOM -149	TOP	BOTTOM
PERFORATED SECTION	TOP -130.5	BOTTOM -140.5	TOP	BOTTOM
PIEZOMETER TIP	-142.5			
BOTTOM OF BOREHOLE	-149.0			
GWL AFTER INSTALLATION				

WAS THE PIEZOMETER FLUSHED AFTER INSTALLATION? YES ☐ NO ☒
WAS A SENSITIVITY TEST PERFORMED ON THE PIEZOMETER? YES ☐ NO ☒

REMARKS

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QC
Dat
2/5/89

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FERNALD RI/FS

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS		
BORING NUMBER: 491	COORDINATES: N477443.69 E1384451.36		DATE: 5/7/88
ELEVATION: 533.4 FT.	GWL: Depth	Date/Time	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: Goldberg/Sullivan	Depth	Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool			PAGE 1 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in.)	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
1	5/7 10000 1530	4 6 6	18	med. stiff, dark yellowish brown silt (10YR 4/4), trace sand, dry.	ml	<1	HNU=0 ppm γB=90 cpm α=0 cpm
2 3	5/7 10001 1535	2 3	12	med. stiff, dark yellowish brown (10YR 4/4) silt, trace sand, dry.	ml	<1	HNU=0 ppm γB=80 cpm α=0 cpm
4	5/7 10002 1540	3 4 5	18	med. stiff, dark yellowish brown (10YR 4/4) silt, trace sand, dry. 4.5	ml	<1	HNU=0 ppm γB=80 cpm α=0 cpm 2 inch lens of fine sand (10YR 4/4).
5 6	5/7 10003 1545	4 4 4	18	med. stiff, yellow brown (10YR 5/4) silty sand, moist.	sm	NA	HNU=0 ppm γB=80 cpm α=0 cpm
7	5/7 10004 1550	4 6 7	18	med. stiff, yellowish brown silty sand (10YR 5/4), moist. 7.0		<1	HNU=0 ppm γB=80 cpm α=0 cpm
8 9 10				med. stiff, yellowish brown sand (10YR 5/4), moist. 10.0	sw		
11 12 13 14	5/8 10005 1000	31 23 27	18	very dense, yellowish brown (10YR 5/4) very coarse gravel, dry.	gw	NA	HNU=0 ppm γB=60 cpm α=0 cpm Rock fragments from cobbles.

NOTES: Drilling Contractor: Pennsylvania Drilling
Driller: Joe Barile
Helpers: Pete Martin

- Colors follow Munsell color charts.
- Blows on split spoon follow ASTM standards.

Total Water Used for Drilling: 400 gallons

125

QC
DA
7/5/89

	Initial	Date
	DAK	7/14/89
Data Entry		
Hard Copy Verification		

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FERNALD RI/FS

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 4B1	COORDINATES: N 477973.69 E 1794457.52	DATE: 5/8/88
ELEVATION: 533.4 FT	GWL: Depth Date/Time	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 2 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in.)	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
16	5/8 10006 1440	4 26 30	14	very dense, yellow-brown (10YR 5/4) coarse gravel, some pebbles, broken cobbles, trace sand, wet.	gw	NA	HNU = 0ppm γB = 60cpm α = 0cpm
17							Large cobbles jammed the hammer in the casing.
18							
19				19.0			
20	5/8 10007 1525	12 15 18	8	dense, brown (10YR 4/2) fine gravel, some sand, trace silt, trace pebbles, wet.	gp	NA	HNU = 0ppm γB = 30cpm α = 0cpm
21							
22							
23							
24							
25	5/8 10008 1650	15 25 35	10	very dense, orange-brown (7.5YR 5/8) med. to coarse gravel, some coarse sand, trace pebbles, wet. (Sample appears very oxidized and "rusty" looking).	gp	NA	HNU = 6ppm abv. bkg. γB = 60cpm α = 0cpm
26							
27							HNU is functioning properly - "oxidized" sample causing readings on 11.7 probe(?) No VOA jars available to put sample in.
28							
29				29.0			

NOTES:

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402-11-86

FERNALD RI/FS

QC DH 2/5/89

	Initial	Date
	PAC	7/14/89

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 491	COORDINATES: N 477[illegible] E 6[illegible]	DATE: 5/9/88
ELEVATION: 533.4 ft	GWL: Depth 17.1 Date/Time 5/9/88 - 0720	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 3 OF 10

DEPTH (ft.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER 6 in.	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
31	5/9 10009 1005	13 33 30	14	Very dense, brown (10YR 4/3) fine gravel and coarse sand, some pebbles, some med. sand, trace silt, wet.	gm	NA	HNU=0 ppm γB=60cpm α=0cpm
32							Tried to drill out below casing but borehole caved, drove 10 ft. casing to 40 ft.
33							
34							
35	5/9 10010 1115	13 24 25	14	dense, brown (10YR 4/3) fine gravel and coarse sand, some med. sand, trace pebbles, trace silt, wet.	gm	NA	HNU=0 ppm γB<40 cpm α=0 cpm
36							
37							
38							
39							
40	5/9 10011 1150	5 7 13	11	med. dense, brown (10YR 4/3) fine gravel and med. to coarse sand, trace silt, wet.	gm	NA	HNU=0 ppm γB=50cpm α=0cpm
41							
42							
43							
44							

NOTES:

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FERNALD RI/FS

DA 2/5/89

155

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 491	COORDINATES: N 477243.67 E 1262457.22	DATE: 5/9/88
ELEVATION: 533.4 FT	GWL: Depth Date/Time	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 4 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in.)	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
46	5/9 1001B 1345	25 30 50	16	very dense, brown (10YR 4/2) med. sand and fine gravel, trace pebbles and silt, wet.	gm	NA	HNU = 0ppm; γB = 60cpm; α = 0cpm
47							
48							
49							
50	5/9 1001B 1425	9 12 20	9	dense, brown (10YR 4/2) med. to coarse sand and fine gravel, trace pebbles and silt, wet.	gm	NA	HNU = (11.7 probe) 1 ppm; γB = 60cpm; α = 0cpm; above background, after sample was put in jar 2-3ppm above background from headspace. (0ppm 10.2 probe).
51							
52							
53							
54							
55	5/9 1001A 1525	13 20 33	12	very dense, brown-gray (10YR 3/1) coarse sand and fine gravel, trace pebbles, trace silt, wet.	gm	NA	HNU = (11.7 probe) 1ppm; γB = 60cpm; α = 0cpm; above background, after sample was put in jar 2ppm above background from head space. (0ppm 10.2 probe).
56							
57							
58							
59							

NOTES.

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402-11-86

FERNALD RI/FS

DLH 2/5/89

	Initial	Date
1st Key In	DLH	2/5/89
2nd Key In	[illegible]	2/9/89
Final Review		
Verification		

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 491	COORDINATES:	DATE: 5/9/88
ELEVATION: 533.4 FT	GWL: Depth 19.4 Date/Time 5/10/88-0715	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 5 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in.)	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
61	5/9 100:15 1625	8 10 15	5	med. dense, brown-gray (10YR 4/1) fine gravel and coarse sand, trace fine sand and silt, wet. (1 in. wood fragments in sample).	gm	NA	HNU = (11.7 probe) 1 ppm, HB = 60 cpm above background, α = NA
62							(10.2 probe) 0 ppm.
63							
64				64.0			
65	5/10 100:6 0745	23 35 40	14	very dense, brown-gray (10YR 3/2) gravelly sand, med. to coarse sand, fine gravel, trace pebbles, wet.	SW	NA	HNU = 0 ppm (11.7), 0 ppm (10.2) HB = 80 cpm α = NA
66							
67							
68							
69				69.0			
70	5/10 100:7 0860	6 10 11	13	med. dense, brown-gray (10YR 3/2) fine gravel and med. to coarse sand, trace fine sand and silt, wet.	gm	NA	HNU = 0 ppm (11.7), 0 ppm (10.2) HB = 40 cpm α = NA
71							
72							
73							
74				74.0			

NOTES:

Large wood fragment from 60-61.5 ft. placed in VOA vial, headspace readings: 5 ppm (11.7), 0 ppm (10.2). HNU readings on 11.7 probe may be due to decaying organic material (?).

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FERNALD RI/FS

2/5/89

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: Fmpc RI/FS	
BORING NUMBER: 49	COORDINATES:	DATE: 5/10/88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 6 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in.)	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
76	S/10 10015 0940	13 23 40	18	very dense, gray-brown (10YR 4/1) med. sand, trace silt and fine sand, trace fine gravel, wet.	Sm	NA	HNU = 1 ppm (11.7), 0 ppm (10.2). γB = 60 cpm α = NA
77							Headspace after sample was put in jar: 2 ppm (11.7) 0 ppm (10.2).
78							
79				79.0			
80	S/10 10019 1010	4 19 29	13	dense, gray-brown (10YR 3/2) sandy gravel, fine to med. gravel, med. to coarse sand, wet. 81.5	GP	NA	HNU = 4 ppm (11.7), 0 ppm (10.2). γB = 60 cpm α = NA
81							
82				gray-brown (10YR 3/2) very fine sand, some silt, wet.	Sm		Headspace after sample was put in jar: 5 ppm (11.7) 0 ppm (10.2)
83				83.0			
84							
85	S/10 10020 1150	22 37 38	13	very dense, gray-brown (10YR 3/2) sand, gravel, med. to coarse sand, fine gravel, trace silt, wet.	GP	NA	HNU = 4 ppm (11.7), 0 ppm (10.2) γB = 42 cpm α = NA
86							
87							
88							
89				89.0			

NOTES:

(HNU readings noted are concentrations above background levels).

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402-11-86

FERNALD RI/FS

Dft 2/5/89

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI FS	
BORING NUMBER: 491	COORDINATES:	DATE: 5/10/88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 7 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER 6 in.	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
91	5/10 10021 1340	7 10 11	5	med. dense, brown-gray (10YR 4/1) fine gravel and coarse sand, some large gravel, trace fine sand and silt, wet.	gm	NA	HNU = 0 ppm (10.2) γB = 80 cpm α = NA
92							
93							
94							
95	5/10 10022 1505	19 50/5"	11	very dense, brown-gray (10YR 4/1) fine to coarse gravel and coarse sand, trace fine sand and silt, trace pebbles, wet.	gm	NA	HNU = 0 ppm (10.2) γB = 60 cpm α = NA
96							
97							
98							
99							
100	5/10 10023 1620	65/5"	4	brown-gray (10YR 4/1) fine to coarse gravel and med. to coarse sand, some silt, some pebbles and broken cobble fragments, wet.	gm	NA	HNU = 0 ppm (10.2) γB = 60 cpm α = NA
101							
102							Cobble broken in split spoon mouth caused high blow count. Can not use blow counts for density.
103							
104							

NOTES:

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402-11-86

FERNALD RI/FS

DM 2/5/89

	Initial	Date
1st Review	JPC	7/28/89
2nd Review		12/19/89
Hard Copy Verification		

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 47 4511	COORDINATES:	DATE: 5/11/88
ELEVATION: 533.4 FT	GWL: Depth 20.0 Date/Time 5/11/88 0725	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 8 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 IN.)	RECOVERY (IN.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
106	5/11 10024 0955	80/5"	2	brown-gray (10YR 4/1) fine gravel and coarse sand, trace silt, wet. 107.0	gm	NA	HNU=0ppm (10.2) γB=40 cpm α=NA
107							Broken cobble caught in spoon mouth caused high blow count - can not use blow counts for density.
108							
109							
110	5/11 10025 0940	6 12 18	10	med. dense, brown (10YR 3/3) fine to med. sand, uniform grain size, wet.	SW	NA	HNU=0 ppm (10.2) γB=60 α=NA
111							
112							
113				113.0			
114							
115	5/11 10026 1105	10 14 20	15	dense, gray-brown (10YR 3/2) very fine sand, some silt, uniform grain size, wet.	SM	NA	HNU=0 ppm (10.2) γB=80 α=NA
116							
117							
118							
119							

NOTES:

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FERNALD RI/FS

DM 2/5/89

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VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 491	COORDINATES:	DATE: 5/11/88
ELEVATION:	GWL: Depth Date/Time	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 9 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 in.)	RECOVERY (in.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
121	5/11 10027 1140	7 13 16	9	med. dense, gray-brown (10YR 4/1) very fine to fine sand, some silt,	Sm	NA	HNU=0 ppm (10.2) γB=80cpm α=NA
122							
123				123.0			
124							
125	5/11 10028 1335	22 45 42	11	very dense, gray-brown (10YR 4/1) med. to coarse sand, some fine gravel, trace silt, wet.	SP	NA	HNU=0 ppm (10.2) γB=100cpm α=NA
126							
127							
128							
129				129.0			
130	5/11 10029 1430	37 22 17	10	dense, brown (10YR 3/3) gravelly sand, coarse gravel, med. to coarse sand, trace silt and trace pebbles, wet	SW	NA	HNU=0 ppm (10.2) γB=60 cpm α=NA
131							
132							Borehole staying open ahead of casing. Sample at 135-136.5 ft taken ahead of casing.
133							
134				134.0			

NOTES:

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FERNALD RI/FS

Dft 2/5/89

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VISUAL CLASSIFICATION OF SOILS

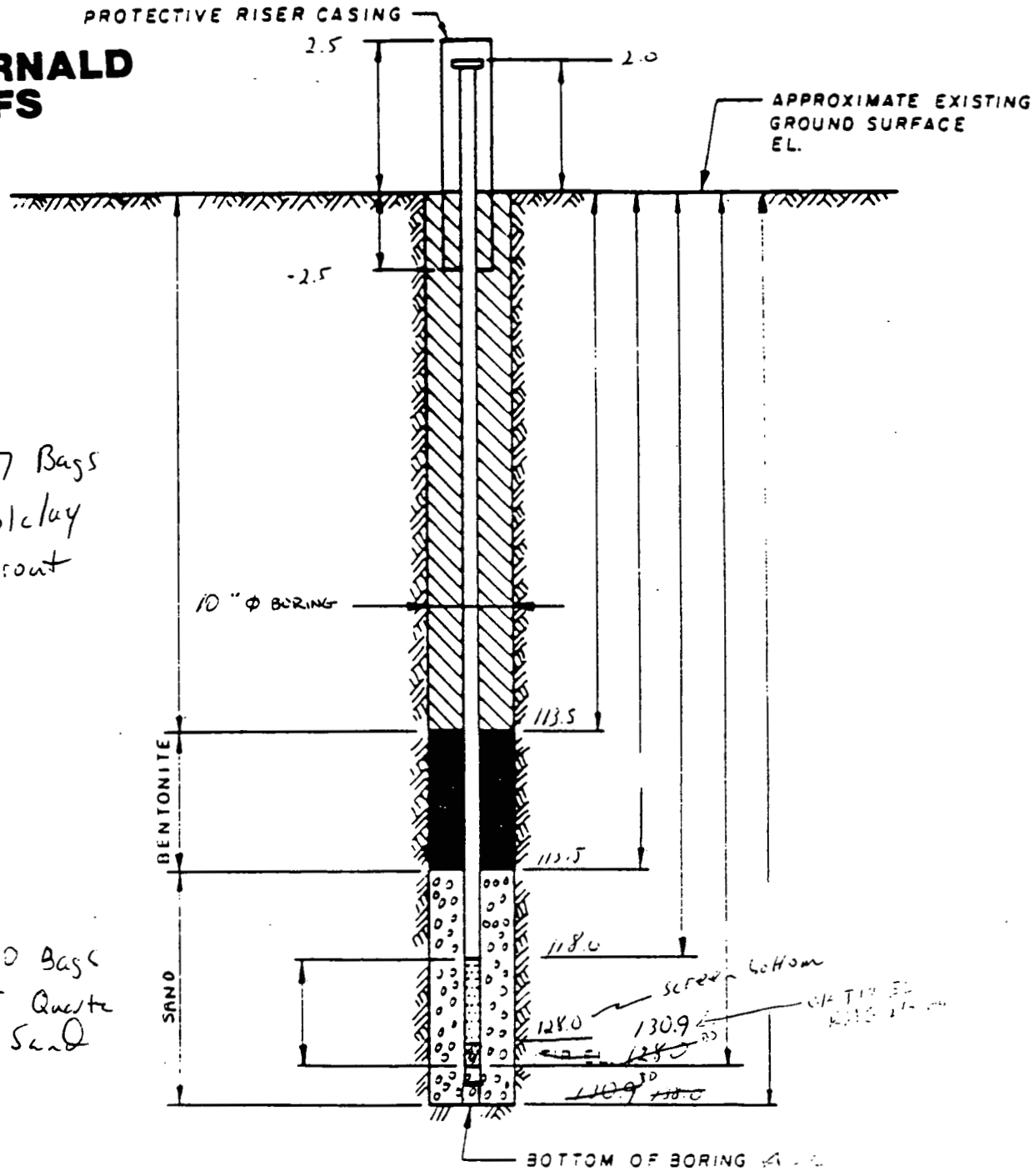
PROJECT NUMBER: 602.03.02.01	PROJECT NAME: FMPC RI/FS	
BORING NUMBER: 491	COORDINATES:	DATE: 5/11/88
ELEVATION:	GWL: Depth 15.1 Date/Time 5/12/88-0730	DATE STARTED: 5/7/88
ENGINEER/GEOLOGIST: T. Sullivan	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: Cable Tool		PAGE 10 OF 10

DEPTH (FT.)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 IN.)	RECOVERY (IN.)	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	REMARKS
136	5/11 10020 1516	42 45 50/4"	13	very dense, brown (10YR 4/1) med. sand and fine to coarse gravel, some silt and clay, wet.	gm	NA	HNU=0ppm (10.2) PB=50cpm α=NA
137				0.5" lens of yellow-brown (10YR 5/6) clay at 135.5 ft. 135.5			Fossiliferous limestone rock fragment caught in mouth of spoon.
138	5/12 0755	33 53/3"	NA	Attempted sample at 137.8 ft, drove spoon 0.8 ft. to 138.6 ft. - NO RECOVERY			
139			1.5				Angular limestone fragments in cuttings.
140	5/12 10031 0855	50/4"		gray-green (5Y 4/1) clay, trace angular limestone fragments, dry. 138.6	cl		HNU=0ppm (10.2) PB=50cpm α=NA
141				soft, gray-green (5Y 4/1) friable, extremely weathered, shaly limestone, dry.	LS		Could only drive spoon 0.3 ft., sample at 138.5-138.8 ft.
142							
143							
144				Bedrock at 138.6 ft.			
145							
146				*Drilled out to 140 ft. so the casing would not get stuck in the bedrock.			
147							
148							
149							

NOTES: Drove casing from 130-132.5 ft. after collecting 135-136.5 ft. sample. Casing would not drive past 132.5 ft. - bedrock (?). 134
Cleaned out casing to 137.8 ft., attempted sample at 137.8-138.6 ft, spoon would only drive 0.8 ft. No Recovery. Cleaned out casing to 138.5 ft., attempted sample at 138.5-138.8 ft., spoon would only drive 0.3 ft.

402-11-86

FERNALD RI/FS



DRAWING NUMBER	
CHECKED BY	
APPROVED BY	
DATE	5/13/88
DRAWN BY	

NOTES:

1. RISER PIPE IS 4 IN ID SCHEDULE PIPE, THREADED, FLUSH-JOINTED.
2. SCREEN IS 4 IN I.D SS PIPE CONTINUOUS SLOT SCREEN (0.010 IN SLOT SIZE).
3. LOWER END OF SCREEN IS CAPPED.
4. ELEVATION OF WATER LEVEL
5. WATER LEVEL READING ON

Measurements in feet

Bentonite pelleted surface seal

INSTALLATION DETAILS
MONITORING WELL 491

PREPARED FOR 4091

	Initial	Date
1st Key In	JPC	7/6/88
2nd Key In		
Hard Copy Verification		

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FERNALD RI/FS

PIEZOMETER INSTALLATION SHEET

PROJECT NAME Fernald RI/FS FIELD ENG./GEO. DAVIES DATE 5/19/88
PROJECT NO. 601 3.2 CHECKED BY R Colombaitis DATE 2/7/89
BORING NO. 491
PIEZOMETER NO. 491 DATE OF INSTALLATION 5/17 Hissal 5/18/88

BOREHOLE DRILLING

DRILLING METHOD CABLE TOOL
DRILLING FLUID (S) USED:
FLUID H_2O FROM 0 TO 138 Ft
FLUID _____ FROM _____ TO _____

TYPE OF BIT Steel hammer
CASING SIZE (S) USED:
SIZE 10" FROM 0 TO 140 Ft
SIZE _____ FROM _____ TO _____

PIEZOMETER DESCRIPTION

TYPE Monitoring well
DIAMETER OF PERFORATED SECTION 4 inch
PERFORATION TYPE:
SLOTS ☐ HOLES ☐ SCREEN ☒
AVERAGE SIZE OF PERFORATIONS 0.010 inch
TOTAL PERFORATED AREA 10 Ft.

RISER PIPE MATERIAL Stainless steel
RISER PIPE DIAMETERS:
O.D. [illegible] I.D. [illegible]
LENGTH OF PIPE SECTIONS 10 Feet
JOINING METHOD Screw ends tight

PROTECTION SYSTEM

RISER PROTECTIVE PIPE LENGTH 5 Feet
PROTECTIVE PIPE O.D. 10 inch

OTHER PROTECTION locking cover on vented protective casing
cap on well

ITEM	DISTANCE ABOVE/BELOW GROUND SURFACE (Ft)		ELEVATION ( )	
TOP OF RISER PIPE	~~2.0~~ 2.0 Ft			
GROUND SURFACE	0.0			
BOTTOM OF PROTECTIVE PIPE	2.5 Ft			
BOREHOLE FILL MATERIALS:				
GROUT/SLURRY	TOP 0	BOTTOM 113.5	TOP	BOTTOM
BENTONITE	TOP NA	BOTTOM NA	TOP	BOTTOM
SAND	TOP 113.5	BOTTOM 135.5	TOP	BOTTOM
GRAVEL	TOP NA	BOTTOM NA	TOP	BOTTOM
PERFORATED SECTION	TOP 118.0	BOTTOM 128.0	TOP	BOTTOM
PIEZOMETER TIP	130.9			
BOTTOM OF BOREHOLE	140.0 RWB 2/7/89			
GWL AFTER INSTALLATION				

WAS THE PIEZOMETER FLUSHED AFTER INSTALLATION? YES ☐ NO ☑
WAS A SENSITIVITY TEST PERFORMED ON THE PIEZOMETER? YES ☐ NO ☑

136

REMARKS Being drilled to ~~138~~ 140.0 Ft cased to 135.5 Ft when 1st casing pulled back. Sand pack to 113.5 Ft, Volclay grout to surface, 2 Buckets bentonite pellets placed around protective casing both inside and outside