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CHARACTERIZATION OF THE NATIONAL PETROLEUM RESERVE
NO. 3 (NPR-3) SITE FOR NATURALLY OCCURRING RADIOACTIVE
MATERIAL (NORM)

Final Report
September 1998

By
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A.S. Hood

January, 1999

Performed Under Contract No. FEW 5AC304

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Idaho National Engineering &
Environmental Laboratory
Idaho Falls, Idaho



National Petroleum Technology Office
U. S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma

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Naturally Occurring Radioactive Material (NORM)

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Work Performed Under Contract FEW 5AC304

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EXECUTIVE SUMMARY

The National Petroleum Reserve No. 3 site (NPR-3) near Casper, Wyoming is being prepared for transfer to private industry. Remediation of the NPR-3 site has already begun in anticipation of this transfer. This document describes the characterization of the NPR-3 site for Naturally Occurring Radioactive Materials (NORM). Data generated on radionuclide concentrations and radon emanation may be used to determine disposal options and the need for remediation at this site.

A preliminary gamma survey of the NPR-3 site was conducted to identify areas of potential NORM contamination. Based on these gamma surveys, two general areas of NORM contamination were found: the North Water Flood area and the BTP-10 produced water discharge stream. A maximum surface exposure rate of $120 \mu\text{R h}^{-1}$ was observed in the North Water Flood area, with the highest readings found along the drainage channel from the area. Exposure rates dropped to background quickly with increasing distance from the center of the drainage. The maximum observed exposure rate in the BTP-10 produced water drainage was $40 \mu\text{R h}^{-1}$.

Soil and sediment sampling were concentrated in these two areas. All samples were analyzed for concentration of ^{226}Ra , ^{228}Ra , and ^{40}K . Maximum ^{226}Ra concentrations observed in the samples collected were 46 pCi g^{-1} for soil and 78 pCi g^{-1} for sediment. Concentrations in most samples were considerably lower than these values. Radon emanation fraction was also measured for a randomly selected fraction of the samples. The mean Rn emanation fraction measured was 0.10, indicating that on average only 10 percent of the Rn produced is released from the medium.

Based on the results of these analyses, NORM contamination at the NPR-3 site is minimal, and appears to be restricted to the two general areas sampled. Concentrations of NORM radionuclides found soils and sediments in these two locations do not justify remedial actions at present. However, continued discharge of NORM-contaminated produced waters from the BTP-10 area will likely result in the continued accumulation of NORM in sediment. It is therefore recommended that the sediments in the BTP-10 discharge stream be monitored periodically for NORM.

ACRONYMS

AEA	Atomic Energy Act
CRCPD	Conference of Radiation Control Program Directors
EPA	Environmental Protection Agency
HpGe	High purity Germanium
ID	Identification
INEEL	Idaho National Engineering & Environmental Laboratory
LDEQ	Louisiana Department of Environmental Quality
LMITCO	Lockheed Martin Idaho Technologies Co.
NORM	Naturally Occurring Radioactive Material
NPDES	National Pollutant Discharge Elimination System
NPR-3	National Petroleum Reserve Number 3 (Teapot Dome, Wyoming)
NRC	Nuclear Regulatory Commission
QA	Quality Assurance
SOP	Standard Operating Procedures
TSCA	Toxic Substances Control Act

1. INTRODUCTION AND BACKGROUND

The potential contamination of oil and gas production and processing facilities with naturally occurring radioactive materials (NORM) has been recognized since the 1930s. Although NORM radionuclides are widely dispersed in the earth's crust, elevated levels of NORM in oil and gas production and delivery equipment and wastes are known to occur, especially in geographic areas where barite (BaSO_4) scales are formed.

More specifically, NORM contamination in oil production equipment and wastes appears to be limited to the following situations (Otto, 1989; Baird et al., 1990):

1. ^{226}Ra and ^{228}Ra co-precipitated in mineral scales on the interior of production tubing and other equipment;
2. sludges and sands from petroleum production equipment, containing isotopes of radium, thorium, and uranium;
3. radon gas (primarily ^{222}Rn) emanating from radium-contaminated materials; and
4. waters or brines produced during the extraction of oil and gas (produced waters).

The primary hazard associated with NORM is the inhalation of radon (Rn) decay products generated by the decay of naturally occurring radium-226 (^{226}Ra). Unlike Ra, ^{222}Rn is a noble gas that is free to diffuse from the solid matrix in which it is formed. Furthermore, ^{222}Rn decays with a half-life of 3.82 days through a series of short-lived alpha- (^{218}Po , ^{214}Po) and beta-emitting (^{214}Pb , ^{214}Bi) daughter products. These Rn progeny are solids that can combine electrostatically to dust particles. In this form, Rn daughters can be deposited in the lung following inhalation, resulting in increased radiation dose to the lung tissue. Exposure to high concentrations of Rn daughters has been documented to cause premature lung cancer in uranium miners. Exposure from gamma photons emitted during alpha and beta decay of Rn and Rn daughter radionuclides may also occur, but present much less of a health hazard than the inhalation of Rn progeny.

Over the next few years, it is expected that the National Petroleum Reserve No. 3 site (NPR-3) near Casper, Wyoming will be sold to private industry, and remediation of the NPR-3 site has already begun in anticipation of this transfer. Although NORM contamination of the

NPR-3 site is not expected to be substantial, characterization of the site with respect to NORM must occur before the need for remediation or NORM contamination can be determined.

If NORM-contaminated soils at the NPR-3 site are to be remediated, disposal options may depend on the Rn emanation fraction from these soils. The Rn emanation fraction is the ratio of the Rn that enters interconnected pore space and is available for transport in the media, to the total number of Rn atoms produced, and is dependent on the physical characteristics of the medium. Pipe scale, for example, generally exhibits a much lower emanation fraction than uranium mill tailings or soils (Rood et al., 1998), and would therefore require a thinner cover compared to uranium mill tailings because the amount of Rn released from the waste material is much less and therefore, requires less attenuation in the cover.

Ultimately, the Rn flux rate from the soil surface or the surface of a waste pile is of importance. This Rn flux rate is dependent on the concentration of the parent Ra in the contaminated material, and on the rate at which the Rn produced can diffuse out of the material. However, Rn flux from a given material is also dependent on soil moisture content, recent precipitation intensity, or passage of a weather front (barometric pumping). A single flux measurement is simply inadequate in terms of characterizing a NORM source. For these reasons, ^{226}Ra concentration and ^{222}Rn emanation fraction measurements appear to be the most relevant parameters in terms of assessing the health risks associated handling and disposal of NORM.

This report describes the collection of environmental samples at the NPR-3 site and the analysis of these samples for NORM radionuclides. Soil and sediment samples were collected from areas identified by gamma exposure surveys as likely to be contaminated with NORM radionuclides. These samples were analyzed for Ra content and Rn emanation fraction. No NORM-contaminated pipe scale was found at the NPR-3 site.

1.1 NPR-3 Site Operational History

The NPR-3 site was established at Teapot Dome, Wyoming on April 30, 1915, by President Woodrow Wilson. The field was leased to Mammoth Oil Company (controlled by H.F. Sinclair) in 1921 for the purpose of developing and exploiting the oil and gas reserves discovered within the NPR-3 site, with production beginning in 1922. The field was shut down in 1927 as a result of a court ruling in what became known as the "Teapot Dome Scandal". As a result of this ruling, operation of the site was turned over to the Navy Department in January

1928. Production at the site resumed in 1976. Since 1992, the field has been operated and managed for the DOE by Fluor Daniel (NPOSR), Inc.

The NPR-3 currently contains about 600 producing wells completed in nine geologic formations, of which the Shannon Formation is the most productive. The NPR-3 field also has numerous shut-in or temporarily abandoned well bores. The field contains 42 injection wells (gas, water, and steam) and two water source wells from the Madison Formation.

The operators of the NPR-3 site do not routinely monitor for NORM contamination with the exception of the surface water discharge monitoring for Ra content as required by Environmental Protection Agency (EPA) permit through the National Pollutant Discharge and Elimination System (NPDES) program. NPDES permit water sampling stations for the NPR-3 site are listed in Table 1, and are shown on the map of the site in Figure 1. Each sampling station listed in Table 1 is prefixed by the letters "SW", indicating the site of surface water monitoring. The number following the SW prefix represents the section of land in which the monitoring site is located. Additional information on the location and other aspects of the NPDES surface water monitoring sites is also provided in Table 1. Surface water sample data from these sites is provided in Table 2 for five semiannual collection dates starting in the summer of 1995. Data presented in Table 2 are for ²²⁶Ra only, which is the only NORM-associated analyte that is required by the EPA by the site NPDES permit.

Table 1. NPDES Surface Water Sampling Locations on the NPR-3 site.

SAMPLE STATION	LOCATION	COMMENTS
SW-2	Section 2, near Shannon's Crossing	Represents the point where most of the produced water enters the drainage.
SW-14	Section 14, 1 mile downstream of SW-22	This stream is intermittent and may be dry during the summer months.
SW-20	Section 20, western boundary of the NPR-3 site	Surface water presumably contains produced water discharged from the adjacent Amoco field.
SW-21	Section 21, northern boundary of the NPR-3 site -- .25 miles downstream of SW-20	Surface water presumably contains produced water discharged from the adjacent Amoco field.
SW-22	Section 22, near South Gate	Surface water flowing onto the NPR-3 site and containing no produced water.
SW-27	Section 27, near eastern border of NPR-3 -- approx. 2 mi. downstream from SW-2	Water sampled here is surface runoff, but mostly produced water.
SW-29	Section 29, near main gate of NPR-3 (Teapot Creek)	Surface water flowing onto site from non-producing areas and contains no produced water.

(See Surface Water Sampling Location Map Figure 1)

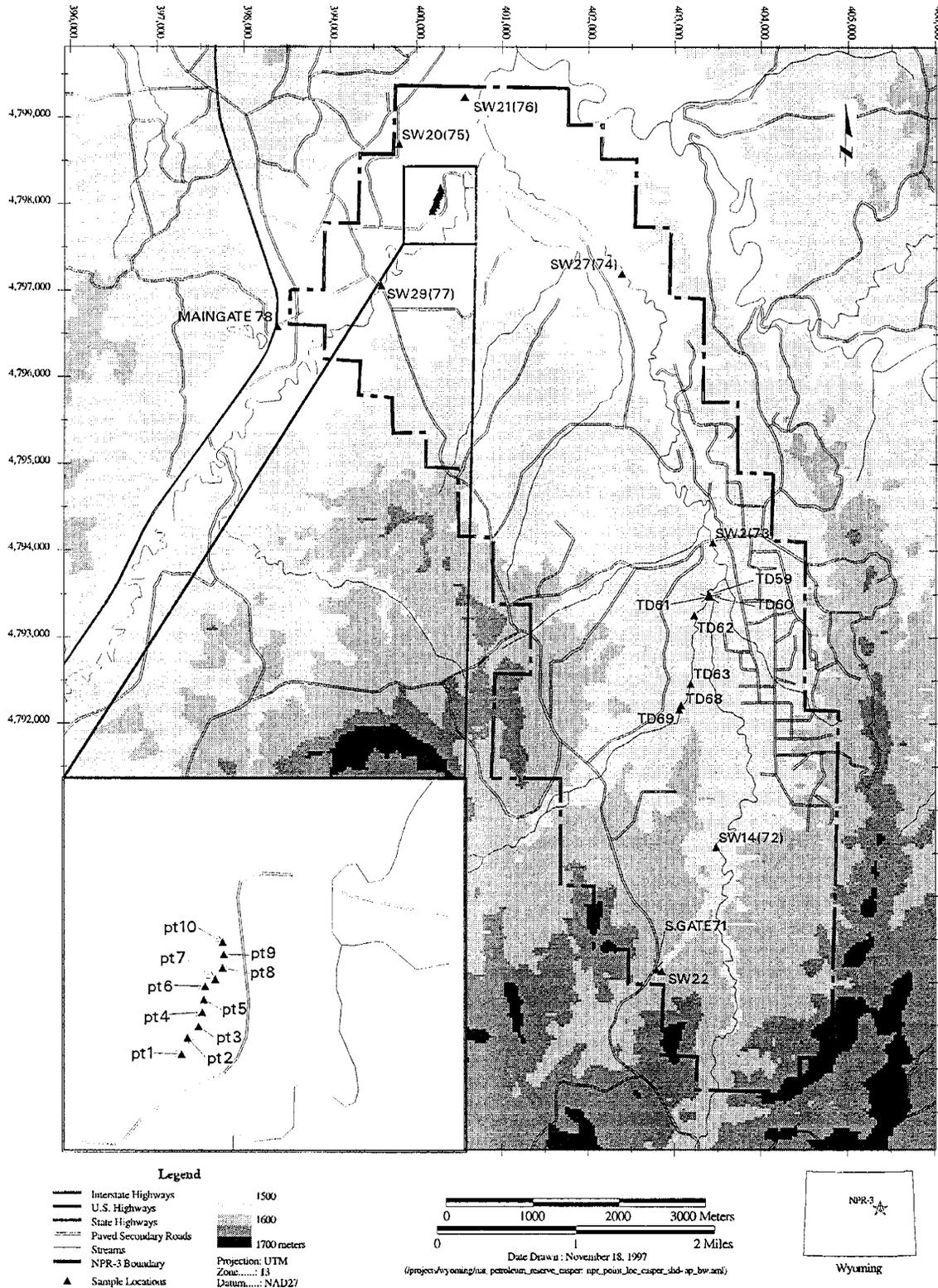


Figure 1. Map of surface water sampling locations – NPR-3 NPDES permit monitoring program.

**Table 2. ²²⁶Ra Concentrations in Surface Water Samples from the NPR-3 site.
(All values pCi L⁻¹)**

Sample ID (location)	Sample Collection Date				
	7/24/95	12/20/95	4/10/96	10/14/96	4/28/97
SW-2	<0.2	10.1	1.7	4.6	6.3
SW-20	4.1	0.5	0.4	0.5	1.3
SW-21	1.0	0.5	<0.2	0.5	1.9
SW-27	3.6	6.8	2.7	2.7	3.5
SW-29	3.6	---	<0.2	<0.2	0.9
SW-22	---	---	---	---	<0.2

Note: SW = Surface Water sample, with the number indicating the section in which the sampling station is located.

1.2 Regulatory Background

Federal regulation of radioactive wastes has been limited to those waste types specifically covered by the Atomic Energy Act of 1953 (AEA) and its amendments. NORM radionuclides, however, are categorically excluded from regulation under the AEA. While the Nuclear Regulatory Commission (NRC) has opted not to seek legislative authority over NORM, the U.S. Environmental Protection Agency (EPA) is in the process of evaluating the need for regulating the handling and disposal of NORM wastes on a national basis. The regulatory authority for EPA regulation of NORM wastes is found under Section 6 of the Toxic Substance Control Act (TSCA), which authorizes the Administrator of the EPA to regulate the disposal of any class of substances for which unregulated disposal would present an unreasonable risk of injury to human health or the environment.

The Conference of Radiation Control Program Directors (CRCPD), a national organization consisting of the directors of regulatory agencies responsible for radiation control in each state, has drafted model regulations for the control of NORM. The intent of the CRCPD in developing this model is to provide states with guidelines for developing regulations and

licensing requirements pertinent to their specific NORM problems. Qualifications and procedures for issuance of both general and specific radioactive material licenses and conditions for regulatory exemption are provided in the CRCPD guidelines. Standards for worker protection and release limits for radioactive material effluent are also described.

Several states including Louisiana and Texas have implemented regulations based largely on the CRCPD guidelines. In Louisiana, for example, the Department of Environmental Quality (LDEQ) has implemented surface gamma exposure rate limits $25 \mu\text{R hr}^{-1}$ above background, and soil contamination limits of $30 \text{ pCi g}^{-1} {}^{226}\text{Ra}$ (including background) averaged over any area of 100 m^2 to a depth of 15 cm, provided that Rn flux from the surface does not exceed $20 \text{ pCi m}^{-2} \text{ s}^{-1}$. Background soil radium concentrations are typically around 1 pCi g^{-1} , and background exposure rates in the NPR-3 area average approximately $10\text{-}20 \mu\text{R hr}^{-1}$.

In Texas, draft regulations recognized that the $5 \text{ pCi g}^{-1} {}^{226}\text{Ra}$ concentration limit established by the federal government for uranium mill tailings could be applied to soils contaminated with NORM, but is not necessarily applicable to NORM in solid scales because of the differing physical properties (Rood et al., 1998). The rationale is related to the expected lower Rn emanation rates from the solid scale material as compared with mill tailings. Compared with the Louisiana rule, the Texas draft regulations provide similar concentration limits for the release of areas for unrestricted use. These include ${}^{226}\text{Ra}$ and ${}^{228}\text{Ra}$ concentration limits of 30 pCi g^{-1} averaged over a maximum depth of 15 cm of soil below the surface.

1.3 Information Needs

Data is needed on concentrations of NORM in environmental media at NPR-3 to determine: (1) the potential level of hazard resulting from these materials to workers or the general public; and (2) the need for remediation of the NPR-3 site prior to closure or transfer of the site to the private sector. Furthermore, data collected at the NPR-3 site can add to the knowledge of the distribution of NORM in petroleum production sites in general. This latter need is facilitated because as a federally owned facility, access to the NPR-3 site is not restricted, and the information gained during this program is more easily applied to other sites within the private as well as the public sector. Questions answered during this project included:

- Where within the NPR-3 site is NORM concentrated?
- In what media are elevated concentrations of NORM found at the NPR-3 site?
- With what processes or activities is NORM contamination associated?

- How do concentrations encountered compare with existing or proposed standards?

The data generated during this study can be used to determine the need for remediating the NPR-3 site for NORM contamination. Information needed to make decisions regarding remediation include Ra content of soil and sediment samples, the Rn emanation fraction from soils and other media, and the geographic or physical extent of NORM contamination at the site. The distribution of soils or sediments with Ra concentrations in excess of 50 pCi g^{-1} will likely require remediation.

2. MATERIALS AND METHODS

2.1 Preliminary Site Survey

Sampling at the NPR-3 site was based on the results of gamma surveys conducted at the site, and samples were collected only from locations where elevated gamma exposures were evident. The preliminary site survey was conducted by LMITCO personnel on June 18, 1997. The purpose of the survey was to determine the general areas within the NPR-3 site at which exposure rates are above background, indicating the likelihood of contamination with NORM.

Prior to conducting the survey, LMITCO personnel were provided with data from previous environmental monitoring conducted at NPR-3 (Table 1). The subsequent survey was focused on areas where previous data or operational experience indicated that NORM contamination were most likely to occur (i.e. locations where pipe cleaning was known to have occurred or where produced waters were discharged to the soil surface). Locations sampled as part of the site NPDES permit were also surveyed, as were roads within the site that had recently been covered with oil sludge. An old solid waste dump site was also surveyed.

Exposure readings from a NaI detector (Ludlum model 12S micro-R-meter, calibrated 6-16-97) were taken at numerous locations throughout the site. Surface gamma exposure rates (within 15 cm of ground surface) in excess of $20 \mu\text{R hr}^{-1}$ were considered to be elevated above background levels. In locations where elevated surface readings were found, more extensive surface readings were taken.

2.2 Sample Collection

Sample collection at the NPR-3 site was concentrated in areas where elevated gamma exposure rates were observed during the preliminary site survey. The resulting sampling was therefore biased in favor of areas of expected NORM contamination. This was done because the goal of the program was to determine the distribution of NORM contamination within the NPR-3 site, and which areas are therefore in need of remediation. Determining the "mean" NORM concentration in soils or sediments within the NPR-3 site was not a goal of the study.

Soil and sediment samples were collected at NPR-3 on August 18-19, 1997. The sites sampled included the North Water Flood area, the BTP-10 produced water discharge stream,

NPDES surface water monitoring sites, and background sites. All samples were collected by LMITCO personnel in accordance with the procedures outlined in the Sampling and Analysis Plan (S&A Plan) developed for this project. A copy of the NPR-3 S&A Plan is attached as Appendix A of this document. Each sample collected was assigned a unique sample identification number.

Pipe scale is not routinely cleaned from pipe at the NPR-3 site, and no scale-contaminated pipe was found during the preliminary survey of the site. Pipe scale samples were therefore not collected at NPR-3 because the accumulation of barite scales in production tubing does not appear to occur at this site.

2.2.1 North Water Flood Area

The preliminary survey of the area known as the North Water Flood showed elevated readings within the drainage located on the west side of this area. Historically, produced water was discharged to a series of three ponds in this area (K. Neilsen, Fluor Daniel, *private communication*). Anecdotal information indicated that some pipe scale removal may have been conducted here in the past. Elevated gamma exposures were found throughout the channel draining this area, with the highest readings in the center of the channel.

The drainage was sampled by marking off a transect of 10 points along the center of the drainage (see insert, Figure 1). The points were approximately 32 meters apart running from south (Point 1) to north (Point 10). At each of these point, a survey was conducted to find the highest gamma rates in a line perpendicular to the north-south transect. The actual center point was therefore located at the location of the highest exposure rate. Additional points were taken laterally from the 10 center points at distances of 2, 4, 8, and 16 meters, until background levels were approached (Figure 2). These samples were used to determine the lateral extent of NORM contamination within the drainage for the North Water Flood area.

Soil samples were collected using a post-hole digger after attempts to collect samples with a soil coring device failed. Samples were collected to a depth 15 cm (6 in.), and were initially placed in an aluminum tray. Care was taken to ensure uniformity of the diameter of the sample hole with depth. Samples were thoroughly homogenized and placed in a one liter Nalgene sample bottle. No preservatives were added to the samples. Sample bottles were labeled and all implements used to collect the sample were cleaned using a rinse bottle or stream water before collecting the next sample.

NPR-3
North Water Flood

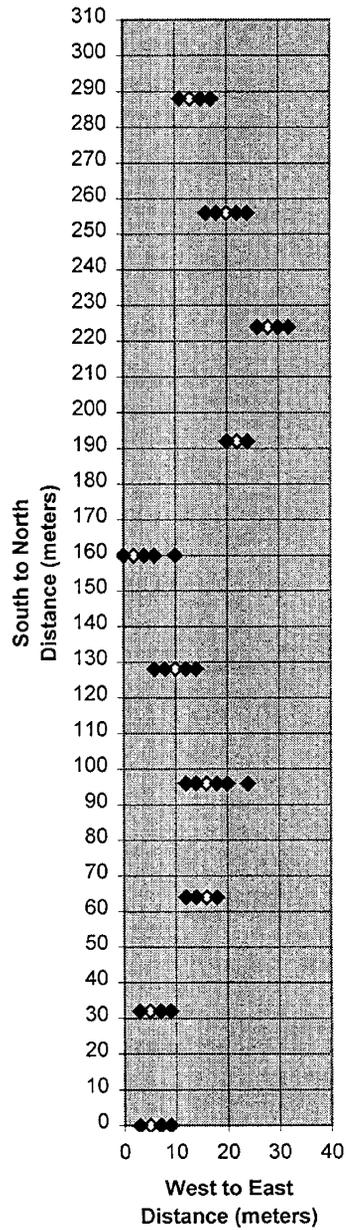


Figure 2. North Water Flood area sampling transect. Center points are indicated by hollow diamonds while solid diamonds indicate locations of lateral points.

After collecting a surface soil sample, an external gamma probe was used to determine gamma exposure rates at the 15 cm depth. If exposure rates indicated that contamination existed below the surface, a second, subsurface soil sample was collected from the 15 cm (6 in.) to 30 cm (12 in) level. This sample was collected from the same hole, taking care to avoid collecting surface material in the subsurface sample. Subsurface soil samples were collected at all 10 center transect points at the North Water Flood area, regardless of down-hole exposure rate.

2.2.2 BTP-10 Produced Water Discharge Stream

Sediment samples were collected from the BTP-10 produced water discharge stream at a series of locations downstream of the discharge point. These included points located approximately 10 and 40 meters downstream from the discharge point (samples TD69 and TD68), and at the first road crossing on the produced water discharge (TD63), approximately 500 m downstream from discharge point (see Figure 1). A sample was also collected from the first drainage (dry) that enters the discharge stream, approximately 1 km downstream from discharge point (sample TD62). Additional samples were collected at the confluence of the discharge stream and Little Teapot Creek (approximately 1.5 km downstream from discharge point), including (1) a point in Little Teapot Creek just before it joins with the discharge stream; (2) a point on the discharge stream just before the confluence with Little Teapot Creek; and (3) one point immediately below the confluence (TD59, TD60, and TD61).

Gamma surveys in this area indicated that NORM contamination was generally restricted to the main channel of the discharge stream, and did not extend laterally up the banks at any of the BTP10 sampling points. The one exception to this was at the road crossing a mile downstream from the discharge point. At this point, the road appears to act as a dam to waters flowing from the discharge stream at high flow rates. At this location, contamination was apparent along the bank of the stream. Soil samples were collected laterally from this sampling point in the same manner as for the North Water Flood soil samples. During a subsequent trip to the NPR-3 site, we observed higher water levels at this site.

Sediment samples were collected with a shovel from as near the center of the channel as possible, and to a depth of approximately 15 cm (6 in.). A sufficient volume (at least 1 L) of sediment was placed in an aluminum tray. The sample was homogenized and placed in a 1 L Nalgene sample bottle. The sample jars were filled completely with sample material. No preservatives were added. Samples bottles were labeled according to the SOPs in the S&A

Plan (Appendix A). All implements used to collect the samples were cleaned using stream water to prevent sample cross contamination.

2.2.3 NPDES Surface Water Sampling Sites

Sediment samples collected from each of the seven surface water (SW) monitoring sites located within NPR-3 (see Table 1 for descriptions of each sampling station). Water samples are routinely collected at these sites by contractor personnel in compliance with the NPDES surface water discharge permit for the NPR-3 site (Figure 1). Our intent in collecting sediment samples at these sites was to compliment the water sampling data; whereas analysis of water samples provides an indication of what is being released at that instant, sediment provides a means for integrating release of NORM radionuclides over time. Gamma exposure rates were measured and recorded for each of these sites, and a single sample was collected from the center of the drainage. Sediment samples were collected at SW sites with water present. In dry locations, soil sampling procedures were applied.

2.2.4 Background Samples

Background soil and sediment samples were collected for comparison with samples collected in NORM-contaminated areas. Background soil samples were collected at four different locations around NPR-3. A background soil sample was collected east of the North Water Flood area. Additional background samples were collected at both the South and North Gates of the NPR-3 site. A final, off-site background soil sample was collected near the interchange of the Highway 258 and Interstate 25. Background sediment samples were taken from Teapot Creek upstream from any NPR-3 activity. In addition, some of the NPDES surface water sampling sites can be considered as background, since they are located upstream from NPR-3. Exposure rate readings were taken and recorded for each site at which background samples were collected.

2.2.5 Quality Assurance Samples

The sampling procedure was repeated *IF* the sample site had been identified as a field replicate site. Replicates are samples that have been divided into two or more portions at some step during the measurement process. Replicate samples were collected for approximately ten

percent of the soil and sediment samples collected at NPR-3. These were selected randomly prior to traveling to the site.

2.2.6 Mineralogy Samples

Additional soil and sediment samples were collected on October 15 in collaboration with James Otton and Robert Zielinski of the U.S. Geological Survey. This included sampling point TD03 of the North Water Flood area, as well as sampling the produced water outflow ~10 meters below the point of discharge. These samples will be analyzed for mineralogical content.

2.3 Sample Preparation and Analysis

All sample analyses were conducted by Energy Laboratories Inc. of Casper, Wyoming. All soil and sediment samples collected at NPR-3 were analyzed for the radium isotopes (^{226}Ra and ^{228}Ra), and naturally occurring ^{40}K using gamma spectroscopy. Samples were not analyzed for uranium or thorium concentration. Potassium-40 is of interest because it contributes to the natural background exposure rate. Typical soils contain 5 to 20 pCi/g of ^{40}K . A high-purity germanium (HPGe) solid-state detector was used for these analyses.

Prior to analysis, samples were dried and ground to a consistent matrix, and were then placed in a sample container for counting. Sample counting was based on the EPA procedure for analysis of gamma emitting radionuclides in drinking water (EPA 1980; "Procedure 901.1 in "Gamma Emitting Radionuclides in Drinking Water"). Differences between the soil and water media are accounted for in the calibration standard. Samples were sealed in their counting containers for a minimum of 20 days before counting to allow ^{222}Rn and progeny to grow into secular equilibrium with the parent ^{226}Ra . The gamma emitting ^{222}Rn daughters, ^{214}Bi and ^{214}Pb , which are also in secular equilibrium with ^{222}Rn , were then counted (Figure 3). Additional details are available in the NPR-3 S&A Plan (Appendix A).

For quality control, a randomly-selected ten percent of the samples were also analyzed for ^{226}Ra using chemical extraction followed by an alpha count. The procedure for this measurement is adapted from EPA procedure 903.0, "Alpha Emitting Radium Isotopes in Drinking Water" (EPA 1980). In such cases, the sample was prepared for a gamma spectroscopy analysis and an aliquot was taken for chemical extraction and alpha analysis before sealing the material in the counting container. Results of the two analysis may then be compared.

Important Isotopes in the ^{226}Ra and ^{228}Ra Decay Series

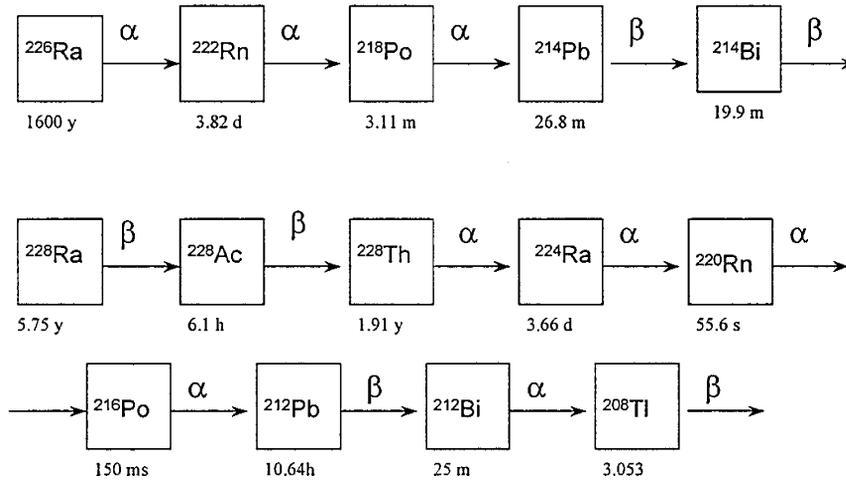


Figure 3. Simplified decay series for ^{226}Ra and ^{228}Ra showing half lives and decay products important to analysis by gamma spectroscopy.

An additional ten percent of the samples were also analyzed for ^{222}Rn emanation. The ^{222}Rn emanation fraction is the ratio of Rn atoms that enters interconnected pore space and is available for transport in the media, to the total number of ^{222}Rn atoms produced. The ^{222}Rn emanation fraction is critical in determining disposal option for any contaminated material leaving the site because health risks are typically from inhalation of ^{222}Rn and ^{222}Rn progeny and not from ingestion of radium or external exposure from gamma emitting progeny. The emanation fraction is strongly dependent on the distribution of parent ^{226}Ra atoms within the host material and several other factors including moisture content, effective porosity, and grain size distribution.

Alteration of the sample from its original condition (such as grinding and milling) will likely alter the ^{222}Rn emanation fraction. The NPR-3 S&A Plan stated that a 0.5 L aliquot of each sample designated for ^{222}Rn emanation measurement was to be analyzed without drying, crushing, or milling the sample. Sample moisture contents varied considerably. Some samples were sediment stream samples while others were surface soil samples. Problems were encountered while preparing the wet samples for ^{222}Rn emanation and for that reason, we deviated from the original protocol and dried all samples. However, crushing and milling of the sample were not performed. Therefore, the ^{222}Rn emanation fractions reported here represent

the “intrinsic” emanation of the material and not the emanation fraction that occurs in a field setting. Emanation fractions in the field will be affected by the soil moisture content.

The emanation measurement was made by evacuating the sample with dry nitrogen gas, sealing it in a container, then counting it immediately afterward using a NaI detector. The 352 keV ^{214}Pb and 609 keV ^{214}Bi are good peaks to observed because of high count yields and high detector counting efficiency. A second count is made several weeks afterward. Counting at two different times allows for calculations of the Rn emanating fraction based on the theoretical ingrowth curve.

Figure 4 shows the theoretical ^{222}Rn ingrowth curve. The sample activities at times t_1 and t_2 (I_1 and I_2) are described by Equations (1) and (2) below.

$$I_1 = I_o + N(1 - e^{-\lambda t_1}) \quad (1)$$

$$I_2 = I_o + N(1 - e^{-\lambda t_2}) \quad (2)$$

Where: I_1 = Activity at time t_1

I_2 = Activity at time t_2

I_o = Bound Rn Activity at time t_o

N = Free, or Emanating Rn Activity at Radioactive Equilibrium

λ = Rn Decay Constant

These two equations can be solved simultaneously for the unknown quantities I_o and N . Substituting A for $(1 - e^{-\lambda t_1})$ and B for $(1 - e^{-\lambda t_2})$ simplifies the equations. The solutions are given in Equation (3). The emanation fraction F is computed from Equation (4).

$$N = \frac{(I_1 - I_2)}{A - B}, \quad I_o = \frac{I_2 A - I_1 B}{A - B} \quad (3)$$

$$F = \frac{N}{N + I_o} \quad (4)$$

It should be noted that it is not necessary to determine the actual sample activities (I_1 and I_2) at times t_1 and t_2 . The net count rates (C_1 and C_2) observed at t_1 and t_2 are proportional to

the activities (I_1 and I_2) through a calibration constant, which cancels out when the final ratio is taken in Equation (4). Thus C_1 and C_2 may be substituted for I_1 and I_2 .

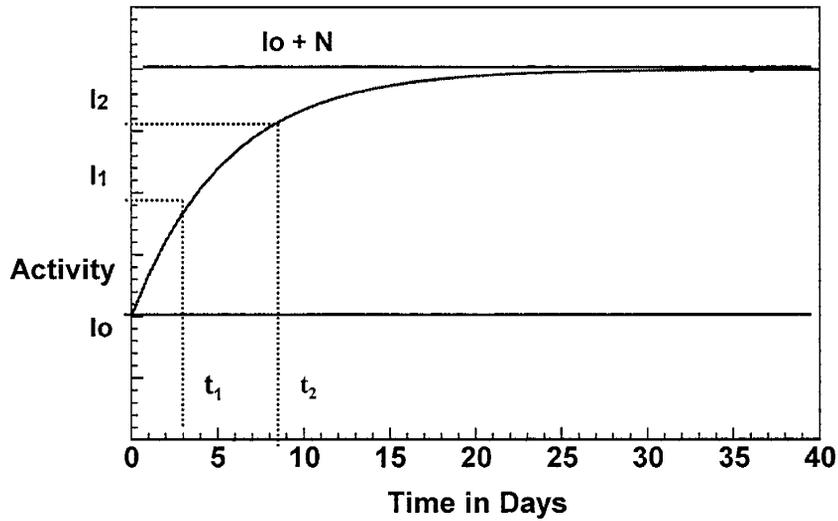


Figure 4. Theoretical radon ingrowth curve defining I_0 , I_1 , and I_2 .

3. RESULTS AND DISCUSSION

3.1 Preliminary site gamma survey

Assuming a local background exposure rate of $15 \mu\text{R h}^{-1}$ for the NPR-3 area, the results of the preliminary site survey showed two general areas of elevated gamma exposure rates; the North Water Flood area, and the area downstream of the BTP-10 produced water cooling station. A summary of the preliminary site gamma survey is provided below in Table 3. These two locations provided the main focus of subsequent sampling efforts.

Gamma exposure rates throughout the North Water Flood area site generally ranged from 2 to 5 times the background rate, with most of the area well below the $25 \mu\text{R h}^{-1}$ (above background) regulatory limit established by Texas and Louisiana for NORM-contaminated materials. However, exposure rates at the “hottest” locations within the North Water Flood area were considerably higher, with a maximum exposure rate of $120 \mu\text{R h}^{-1}$.

The BTP-10 area includes the current produced water cooling station and the discharge stream from this station which eventually converges with Teapot Creek. Exposure rates in the drainage of the BTP-10 area ranged from background to approximately $40 \mu\text{R h}^{-1}$. It should be pointed out, however, that water flowing in the stream may attenuate some of the gamma radiation emanating from the sediment. Scale formed on the concrete side of the discharge facility had a surface exposure rate of $80 \mu\text{R/h}$.

Exposure rates at the NPDES surface water sampling locations and other areas surveyed were generally at or near background levels.

Table 3. Gamma exposure rates at selected locations at the NPR-3 site.

Sample ID Number	EXPOSURE RATE ($\mu\text{R h}^{-1}$)	COMMENTS
B-1-14	14-18	Near SW-14
BTP-10	~80	Produced water cooling station
	40-45	<ul style="list-style-type: none"> Scale deposited on pond outflow retaining wall
	40	<ul style="list-style-type: none"> Immediately below cooling/settling ponds Approximately 400 yards downstream of outflow
T-1-10	12-15	
Section 10	10-15	Water Disposal Facility
Solid Waste Dump	12-18	Located east of the Shop House
Section 3, B-3-3	12-15	Near Water Treatment Facility
Section 3, B-1-3	12-18	Near pipe yard and Chem. Dock
Section 2	10-15	Bad Oil Facility,
SW-2	12-20	Shannon's Crossing
SW-2	12-20	Sludge-covered road near Shannon's Crossing
T-1-34	12-18	
Well B-7 44sh x 27	12-18	
B-1-33	12-16	
B-1-28	12-20	
Section 21		North Water Flood area (historical produced water discharge and pipe cleaning area)
	15	<ul style="list-style-type: none"> near road
	50-120	<ul style="list-style-type: none"> drainage exposure reading
SW-21	12-20	Receives produced water drainage from Amoco field
SW-20	10-12	Receives produced water drainage from Amoco field
B-1-20	12-18	

3.2 North Water Flood Soil Samples

Although dry for many years, the North Water Flood area historically contained a series of produced water cooling and evaporation ponds (K. Neilsen, *personal communication*). Some pipe cleaning has also been reported to have been conducted in this area. A total of 44 surface and 12 subsurface soil samples were collected in the North Water Flood area. Concentrations of ^{226}Ra , ^{228}Ra , and ^{40}K for the surface 44 surface soil samples collected at the North Water Flood area, as determined by gamma spectroscopy, are listed in Table 4. The highest concentrations for ^{226}Ra and ^{228}Ra were 45.8 and 15.5 pCi g⁻¹, respectively. Three samples showed concentrations in excess of the soil contamination limits of 30 pCi/g ^{226}Ra established by the state of Louisiana. Concentrations of ^{228}Ra were generally less than those of ^{226}Ra , although there were some exceptions. Concentrations of ^{40}K were relatively uniform for all soil samples, ranging from a low of 14.3 to a high of 25.7, excluding a single sample that was below the detection limit. The uniformity of ^{40}K was not unexpected, as this radionuclide occurs naturally in soils, and not related to Ra contamination. Concentrations of the two Ra isotopes were correlated in the surface soil samples ($r = 0.92$). Neither ^{226}Ra nor ^{228}Ra were correlated with ^{40}K .

Subsurface soil Ra concentrations are presented in Table 5. In most cases the subsurface concentrations were substantially less than the surface concentrations for both radium isotopes, but were essentially the same for ^{40}K . However, there was one sample that showed 22 pCi g⁻¹ ^{226}Ra in the subsurface but only 4.2 pCi g⁻¹ in the corresponding surface sample. Concentrations of ^{228}Ra were also higher in the subsurface sample at the same sampling location, with a difference of approximately the same factor as seen with ^{226}Ra . As with surface soils, concentrations of the two radium isotopes were correlated in the subsurface samples ($r = 0.98$), but neither ^{226}Ra ($r = -0.66$) nor ^{228}Ra ($r = -0.69$) were correlated with ^{40}K concentrations. The correlation found between the two Ra isotopes indicates that the ratio of the parent ^{238}U and ^{232}Th in the source rock is constant.

Table 4. Radionuclide concentrations and analytical precision values for soil samples from the North Water Flood area as determined by gamma spectroscopy.

Sample ID Number	Surface Exposure ($\mu\text{R/h}$)	Sample Location	^{226}Ra Conc. (pCi g^{-1})	Precision (+/-)	^{228}Ra Conc. (pCi g^{-1})	Precision (+/-)	^{40}K Conc. (pCi g^{-1})	Precision (+/-)
TD-21-003	24	Pt.1, center	2.3	0.3	2.1	0.6	18.3	2.1
TD-21-005	100	Pt.1, 2 m E	35.5	1.4	14.8	3.2	24.4	4.5
TD-21-006	40	Pt.1, 4 m E	6.2	0.5	4.3	1.7	21.5	2.3
TD-21-007	28	Pt.1, 2 m W	2.4	0.3	2.2	0.9	17.8	2.2
TD-21-008	140	Pt.2, center	45.8	1.3	13.2	1.5	22.8	4.2
TD-21-010	60	Pt.2, 2 m E	14.1	0.7	5.6	0.9	16.8	2
TD-21-011	40	Pt.2, 4 m E	5.2	0.5	3.6	1.3	20.7	2.3
TD-21-012	50	Pt.2, 2 m W	7.8	0.6	4.4	1.7	19	2.2
TD-21-013	120	Pt.3, center	28.7	1.3	9.5	1.2	14.3	3.7
TD-21-015	50	Pt.3, 2 m E	5.4	0.4	4.3	1.6	<0.8	N/A
TD-21-016	70	Pt.3, 2 m W	11.2	0.8	5.7	1.3	16.9	2.1
TD-21-017	70	Pt.3, 4 m W	26.2	1.1	6.8	1.3	20.2	2.4
TD-21-018	100	Pt.4, center	42.9	1.5	15.5	2.2	25.7	4.6
TD-21-020	50	Pt.4, 2 m E	8.3	0.5	3.3	0.7	16.3	2.5
TD-21-021	60	Pt.4, 4 m E	13.4	0.7	4.9	0.9	16.6	2
TD-21-022	50	Pt.4, 8 m E	12.6	0.7	4.8	1.9	16.7	2.1
TD-21-023	50	Pt.4, 2 m W	10.5	0.7	4.5	0.8	17.8	2.1
TD-21-024	30	Pt.4, 4 m W	9.1	0.5	3.4	0.7	18.2	2.1
TD-21-025	80	Pt.5, center	4.2	0.4	2.1	0.5	20.1	2.3
TD-21-027	70	Pt.5, 2 m E	3.3	0.4	1.8	0.4	20.5	2.3
TD-21-028	50	Pt.5, 4 m E	12.3	0.7	3.7	0.7	19.3	2.2
TD-21-029	70	Pt.5, 2 m W	6.4	0.2	3.2	0.5	18.5	2.7
TD-21-030	50	Pt.5, 4 m W	12.1	0.2	4.5	0.7	15.7	2.4
TD-21-031	50	Pt.6, center	12.1	0.8	5.7	1.3	15.6	2.4
TD-21-033	40	Pt.6, 2 m E	6.4	0.5	3.5	0.8	18	2.7
TD-21-034	40	Pt.6, 4 m E	5.4	0.5	4.2	1.6	16.9	2
TD-21-035	40	Pt.6, 8 m E	4.7	0.4	<0.8	N/A	18.6	2.1
TD-21-036	30	Pt.6, 2 m W	2.7	0.3	2	0.4	17.5	2.1
TD-21-037	60	Pt.7, center	15.9	0.8	5.7	0.8	16.5	2.6
TD-21-039	35	Pt.7, 2 m E	6.5	0.5	4.6	1.9	19.5	2.3
TD-21-040	40	Pt.7, 2 m W	10.3	0.6	4	0.7	14.9	1.9
TD-21-041	50	Pt.8, center	16.2	0.8	4.9	0.6	14.7	1.9
TD-21-043	40	Pt.8, 2 m E	12.2	0.8	3.6	0.7	19.8	2.4
TD-21-045	40	Pt.8, 4 m E	12.9	0.9	0.5	1.7	18.8	2.9
TD-21-046	35	Pt.8, 2 m W	4	0.4	2.6	0.6	19.9	2.2
TD-21-047	50	Pt.9, center	19.9	0.9	5.5	1.1	16.2	2
TD-21-049	40	Pt.9, 2 m E	9.7	0.6	<0.8	N/A	17.9	2.2
TD-21-051	35	Pt.9, 4 m E	8.5	0.7	4	1.4	16.1	2.1
TD-21-052	35	Pt.9, 2 m W	6.8	0.5	2.8	0.7	17.3	2.1
TD-21-053	35	Pt.9, 4 m W	5.1	0.4	2	0.4	17.4	2.4
TD-21-054	40	Pt.10, center	12	0.8	6.1	1.3	17.1	2.2
TD-21-056	40	Pt.10, 2 m E	9.1	0.6	3.3	0.7	14.3	1.9

TD-21-057	35	Pt.10, 4 m E	5.7	0.4	2.7	0.7	15.4	1.9
TD-21-058	35	Pt.10, 2 m W	10.8	0.6	<0.8	N/A	19.1	2.2

Table 5. Comparison between surface and subsurface radionuclide concentrations for North Water Flood area soil samples. (All values pCi g⁻¹ as determined by gamma spectroscopy).

Location	²²⁶ Ra		²²⁸ Ra		⁴⁰ K	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
Pt.1, center	2.3	1.8	2.1	1.9	18.3	20.9
Pt.2, center	45.8	4.9	13.2	3.4	22.8	19.5
Pt.3, center	28.7	4.9	9.5	3	14.3	20.3
Pt.4, center	42.9	6.3	15.5	2.6	25.7	17.4
Pt.5, center	4.2	22	2.1	8.9	20.1	15.2
Pt.6, center	12.1	3.1	5.7	2.3	15.6	20.4
Pt.7, center	15.9	3.8	5.7	2	16.5	19.8
Pt.8, center	16.2	5.5	4.9	2.7	14.7	17.1
Pt.8, 2 m E	12.2	4.1	3.6	2.8	19.8	19.4
Pt.9, center	19.9	4.1	5.5	2	16.2	22.2
Pt.9, 2 m E	9.7	3.0	<0.8	1.8	17.9	18.5
Pt.10, center	12	1.8	6.1	<0.8	17.1	17.7
MEAN	18.5	5.4	6.7	3.0	18.2	19.0

The trend toward higher Ra concentrations in the top 15 cm in comparison with the second 15 cm depth implies that the NORM contamination was deposited at or near the surface, and is generally maintained near the surface. With time, however, Ra may migrate downward in the soil column.

In comparing concentrations of the three radionuclides examined between subsurface and the corresponding surface soil samples, no correlations were found ($r = -0.129$ for ^{226}Ra , -0.225 for ^{228}Ra , -0.338 for ^{40}K). This lack of correlation held if the one sample in which subsurface Ra concentrations were higher than in the overlying surface soil were not considered.

Correlation between surface gamma exposure rates and ^{226}Ra concentrations in surface soil are illustrated in Figure 5 (correlation coefficient = 0.82). In general, there is good correlation between the surface gamma exposure rate and ^{226}Ra concentration in surface soil. However, there are some significant discrepancies between predicted (as indicated by the correlation line in Figure 5) and observed concentration values. Many of the points that influence the slope of the prediction line are due to high exposure readings that yielded low ^{226}Ra concentrations. Four points in particular had surface exposure readings around $70\text{--}80\text{ R h}^{-1}$ while the measured ^{226}Ra concentrations were only 2 to 3 times background (5 pCi g^{-1}). These discrepancies are apparently due to gamma "shine" from sources adjacent to the point of measurement. While surface exposure measurements are an indication of elevated levels of NORM, they are not a reliable means of estimating ^{226}Ra concentrations in surface soil.

3.3 Sediment Samples

Concentrations of ^{226}Ra , ^{228}Ra , and ^{40}K in sediment samples collected at the produced water discharge stream from BTP-10 and at the various NPDES permit sampling sites are provided in Table 6. Radium concentrations in these samples exhibit substantial variability, relating to the specific location at which each individual sample was collected. The highest Ra concentrations were found in sediment samples collected near the site where produced waters are currently being discharged, with ^{226}Ra concentrations of 77.6 and 68.9 pCi g^{-1} found in the samples collected 10 and 40 m downstream from the discharge point, respectively. These two sampling sites also showed the highest ^{228}Ra concentrations (19 and 24.6 pCi g^{-1}). These compare with background sediment concentrations of around 1.4 and 0.2 pCi g^{-1} for ^{226}Ra and ^{228}Ra , respectively. In comparison with the NPDES surface water sampling sites, the sediment samples from the produced water drainage stream contain substantially more radium.

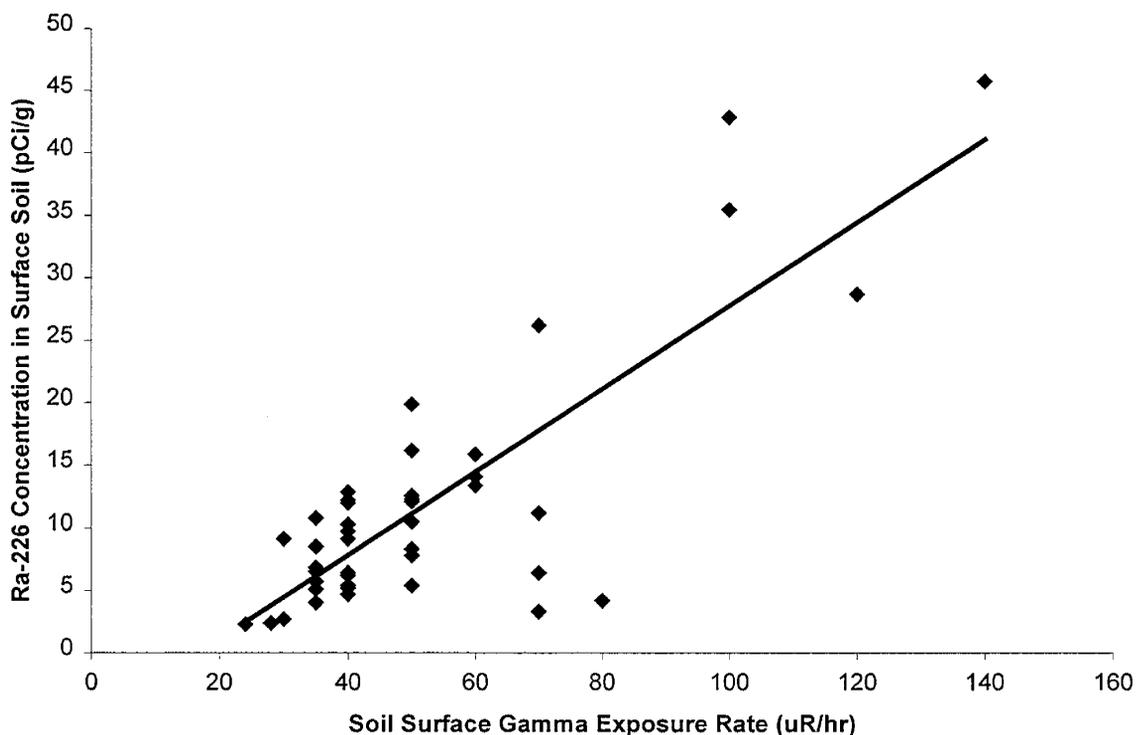


Figure 5. Relationship between ^{226}Ra concentration and gamma exposure in surface soils, North Water Flood.

Concentrations of ^{226}Ra and ^{228}Ra were 23 and 9.9 pCi g⁻¹ at the confluence of the produced water discharge stream and Little Teapot Creek, as compared with background sediment concentrations of about 1.4 and 0.2 pCi g⁻¹ for ^{226}Ra and ^{228}Ra .

As with the soil samples described in Section 3.2, concentrations of ^{226}Ra were highly correlated with concentrations of ^{228}Ra ($r = 0.99$), but neither Ra isotope was correlated with ^{40}K .

3.4 Radon Emanation Measurements

Fourteen samples (8 surface soil, 4 subsurface soil, and 2 sediment) were randomly selected for analysis of Rn emanation, defined as the ratio of the Rn that enters interconnected pore space and is available for transport in the media, to the total number of Rn atoms produced, and is dependent on the physical characteristics of the medium. The results of these analyses are shown in Table 7. Radon emanation fraction in these samples ranged from a low of 0.04 to a high of 0.19, indicating that between 4 and 19 percent of the ^{222}Rn produced in the material is released from the material. The mean of the 14 total samples examined for Rn emanation fraction was 0.10, or ten percent.

Concentrations of ^{226}Ra (as determined by gamma spectroscopy) for each of the samples examined for Rn emanation are also provided in Table 7. Correlation analysis indicated that ^{222}Rn emanation fraction is not correlated with concentration of the parent ^{226}Ra found in the sample ($r = -0.15$). The lack of correlation between Ra concentration and Rn emanation fraction was expected, as Rn emanation fraction is a function of the physical properties (e.g. porosity, moisture content, etc.) of the medium containing the parent Ra rather than the concentration of Ra.

These measurements can be compared to emanation fractions measured for uranium mill tailings. For dry tailings, emanation fractions ranged from 0.05 to 0.35 (NRC, 1984). Depending on the material, these values increased appreciably with added moisture. For example, Grand Junction tailings increased from 0.07 to 0.38 with a moisture saturation ratio change from 0 to 0.4 (the moisture saturation ratio is the ratio of the volumetric moisture content of the sample to the saturated moisture content. Above a saturation level of 0.4, most material's emanation fraction did not change.

Table 6. Radionuclide concentrations in sediment samples as determined by gamma spectroscopy.

Sample ID Number	Surface Exposure ($\mu\text{R/h}$)	Comments	^{226}Ra (pCi g $^{-1}$)	Precision (+/-)	^{228}Ra (pCi g $^{-1}$)	Precision (+/-)	^{40}K (pCi g $^{-1}$)	Precision (+/-)
TD-02-059	25-30	Below confluence of Little Teapot Creek and Produced Water discharge	3.4	0.3	<0.8		13.4	1.6
TD-02-060	12-16	Little Teapot Creek, above confluence with PW discharge	1.5	0.2	1.5	0.5	10.5	1.4
TD-02-061	35-40	PW discharge, above confluence with Little Teapot Creek	20.3	1	8.8	1.6	19.9	2.2
TD-03-062	40	Produced Water discharge, at confluence with dry drainage (Sec. 3)	23	1.2	9.9	2.8	16.7	2.3
TD-10-063		Sec. 10, first road crossing downstream of Produced Water discharge	16.7	0.9	7.7	2.7	19.2	3
TD-10-064	45	Sec. 10, first road crossing downstream of Produced Water discharge, 2 m E	5.8	0.5	4.1	1.9	19.2	2.4
TD-10-065	70	Sec. 10, first road crossing downstream of Produced Water discharge, 4 m E	15.1	0.9	6.7	2.5	24.3	2.6
TD-10-066	60	Sec. 10, first road crossing downstream of Produced Water discharge, 2 m W	8.2	0.6	3.5	0.6	21.6	2.4
TD-10-067	50	Sec. 10, first road crossing downstream of Produced Water discharge, 4 meters West	8.7	0.7	3.7	0.8	24.3	2.7
TD-10-068	40	Sec.10, ~40 meters down from Produced Water discharge point	68.9	3.3	19	4.5	33.3	5.8
TD-10-069	80	Sec.10, ~10 meters down from Produced Water discharge point	77.6	2.5	24.6	2.7	20.4	5.4
TD-22-070	14-18	SW-22, near South Gate	1.4	0.2	1.3	0.5	14.4	1.6
TD-14-072	12-18	SW-14	1.3	0.2	0.9	0.2	12.9	1.6
TD-02-073	10-16	SW-2	1.6	0.2	1.5	0.6	12.2	1.5
TD-27-074	12-16	SW-27, downstream on Little Teapot Creek	1.4	0.2	1.7	0.5	16.6	1.9
TD-20-075	12-16	SW-20, Produced Water from Amoco Field, very oily	3.6	0.5	3.3	0.7	19.8	2.3
TD-21-076	12-16	SW-21, oily	1.5	0.3	1.6	0.4	14.5	1.8
TD-29-077	12-16	SW-29, Teapot Creek coming onto NPR-3	1.5	0.2	1.4	0.5	17.3	2.1

Table 7. Relationship between ^{226}Ra concentration (as determined by gamma spectroscopy) and ^{222}Rn emanation fraction.

Sample ID Number	Sample Type	^{226}Ra concentration (pCi g⁻¹)	^{222}Rn emanation fraction
TD-21-003	Surface soil	2.3	0.107
TD-21-004	Subsurface soil	1.8	0.165
TD-21-006	Surface soil	6.2	0.142
TD-21-014	Subsurface soil	4.9	0.061
TD-21-020	Surface soil	8.3	0.087
TD-21-023	Surface soil	10.5	0.143
TD-21-029	Surface soil	6.4	0.131
TD-21-038	Subsurface soil	3.8	0.042
TD-21-039	Surface soil	6.5	0.110
TD-21-047	Surface soil	19.9	0.056
TD-21-048	Subsurface soil	4.1	0.077
TD-21-058	Surface soil	10.8	0.069
TD-02-059	Sediment	3.4	0.078
TD-02-067	Sediment	8.7	0.194
Mean Rn emanation factor			0.104

Pearson's correlation coefficient = - 0.148 (not correlated)

3.5 Background Samples

A total of seven background samples were collected as part of the NPR-characterization, representing 10 percent of all samples collected. These included 4 surface soil, one subsurface soil, and two sediment samples. All were collected in areas that were presumed to be free of NORM contamination from produced waters or other production activities or wastes. Only one was collected off the NPR-3 site. The analytical results from these background samples are shown in Table 8.

Concentrations of ^{226}Ra in the background samples were nearly uniform, ranging from a low of 1.1 to a high of 1.4 pCi g⁻¹. The range of ^{228}Ra concentrations was only slightly larger (0.9 to 1.6 pCi g⁻¹). In contrast, concentrations of ^{40}K , which is a natural component of soil and sediment, ranged from 1.6 to 2.1 pCi g⁻¹. The two lowest values of ^{40}K were in the only background sediment samples collected. This is likely due to the leaching of K from the material by water.

Table 8. Radionuclide analyses for background samples as determined by gamma spectroscopy.

Sample #	Sample Type	Surface Exposure ($\mu\text{R}/\text{H}$)	Comments	^{226}Ra		^{228}Ra		^{40}K	
				Conc. ($\mu\text{Ci g}^{-1}$)	Precision (+/-)	Conc. (pCi g^{-1})	Precision (+/-)	Conc. (pCi g^{-1})	Precision (+/-)
TD-21-001	Surface Soil	16	NWF	1.3	0.2	1.8	0.7	19.9	2.1
TD-21-002	Subsurface Soil		NWF	1.3	0.2	1.3	0.4	18.1	2.1
TD-22-071	Surface Soil	12-18	SW-22	1.4	0.2	1	0.2	17.7	2.1
TD-30-078	Surface Soil	12-16	North Gate	1.2	0.2	1.2	0.3	16.3	1.9
TD-?-079	Surface Soil	12-16	Off-site (Interstate 25)	1.1	0.2	1.6	0.5	19.8	2.1
TD-22-070	Sediment	14-18	SW-22, near South Gate	1.4	0.2	1.3	0.5	14.4	1.6
TD-14-072	Sediment	12-18	SW-14	1.3	0.2	0.9	0.2	12.9	1.6

3.6 Quality Assurance / Quality Control Samples

As a QA measure, a randomly selected subset of 16 samples was also analyzed for ^{226}Ra concentration using a wet chemistry procedure. The results of the comparison between gamma spectroscopy and wet chemistry analytical procedures is shown in Table 9. These results indicate that analysis by gamma spectroscopy typically results in a slightly higher reported concentration (averaging 17 percent higher) than the wet chemistry procedure. However, the results of the two analytical techniques were found to be highly correlated ($r = 0.99$).

Eight field replicate samples were also collected for analysis. The results of these samples are provided in Table 10. A cursory look at the data in Table 10 indicates good general agreement between field replicates. However, variability between the paired replicate samples appears to be greatest for the samples collected in the most highly contaminated areas, as indicated by surface gamma exposure levels. This is particularly the case with ^{226}Ra .

Table 9. Comparison between analytical results obtained using gamma spectroscopy (GS) and wet chemistry (WC) for determining ²²⁶Ra concentration in soil and sediment samples.

Sample ID Number	Sample Type	GS (pCi g ⁻¹)	Precision (+/-)	WC (pCi g ⁻¹)	Precision (+/-)	Percent Difference
TD-21-013	Surface	28.7	1.3	27.4	1.1	4.5
TD-21-014	Subsurface	4.9	0.5	3.8	0.2	22.4
TD-21-016	Surface	11.2	0.8	10.3	0.5	8
TD-21-021	Surface	13.4	0.7	12.4	0.5	7.5
TD-21-023	Surface	10.5	0.7	11.3	0.5	-7.6
TD-21-039	Surface	6.5	0.5	4.5	0.2	30.8
TD-21-043	Surface	12.2	0.8	12.1	0.7	0.08
TD-21-050	Subsurface	3	0.3	3	0.3	0
TD-21-056	Surface	9.1	0.6	9	0.4	1.1
TD-21-057	Surface	5.7	0.4	4.3	0.2	24.6
TD-02-062	Sediment	23	1.2	19.1	0.4	17
TD-02-067	Sediment	8.7	0.7	8	0.3	8
TD-22-072	Sediment	1.3	0.2	0.7	0.1	46.2
TD-22-076	Sediment	1.5	0.3	0.8	0.1	46.7
TD-22-078	Surface	1.2	0.2	0.8	0.1	33.3
TD-22-079	Surface	1.1	0.2	0.7	0.1	36.4

Pearson's correlation coefficient = 0.99

Mean difference between techniques = 17.5

Table 10. Comparison of field replicate sample analyses.

Sample ID No.	Sample Type	Surface Exposure $\mu\text{R/h}$	^{226}Ra		^{228}Ra		^{40}K	
			Conc. (pCi g ⁻¹)	Prec. (+/-)	Conc. (pCi g ⁻¹)	Prec. (+/-)	Conc. (pCi g ⁻¹)	Prec. (+/-)
TD-21-008	Surface Soil	140	45.8	1.3	13.2	1.5	22.8	4.2
			34.3	1.5	13.1	3.2	21.2	4.2
TD-21-021	Surface Soil	60	13.4	0.7	4.9	0.9	16.6	2.0
			6.9	0.5	3.8	1.2	18.7	2.1
TD-21-034	Surface Soil	40	5.4	0.5	4.2	1.6	16.9	2.0
			4.9	0.4	2.1	0.4	19.2	2.2
TD-21-045	Surface Soil	40	12.9	0.9	0.5	1.7	18.8	2.9
			5.6	0.4	2.8	0.7	17.9	2.0
TD-21-051	Surface Soil	35	8.5	0.7	4.0	1.4	16.1	2.1
			8.9	0.8	3.6	0.6	16.4	2.1
TD-21-058	Surface Soil	35	10.8	0.6	<0.8	--	19.1	2.2
			7.3	0.5	3.8	0.8	15.3	3.1
TD-02-067	Sediment	50	8.7	0.7	3.7	0.8	24.3	2.7
			8.6	0.6	5.1	0.8	22.1	2.3
TD-22-070	Sediment	14-18	1.4	0.2	1.3	0.5	14.4	1.6
			1.3	0.2	1.7	0.7	14.5	1.7

First value is original sample, second value is "replicate"

4. CONCLUSIONS

The characterization of the NPR-3 site described in this report resulted in the identification of elevated concentrations of NORM radionuclides in two general areas. These included the contamination of soils in the North Water Flood area and sediments in the BTP-10 produced water discharge stream. In both of these areas, the concentrations of NORM radionuclides observed were above background, but most samples analyzed showed ^{226}Ra concentrations that were less than the regulatory limits established in states such as Louisiana where NORM in the petroleum industry is regulated.

Radium concentrations in a few of the soil samples collected in the North Water Flood area were above the Louisiana regulatory limits, although average concentrations over the entire sampling area were substantially lower than these limits. It should be pointed out, however, that the sampling procedures employed during this program were designed to ensure that sampling was conducted at the points where contamination levels were the highest, whereas Louisiana regulations involve measurement of average concentrations over a specific area. Furthermore, the activities that are presumed to have resulted in the low-level contamination in the North Water Flood area are no longer occurring, implying that additional contamination of the area is not likely. For these reasons, remediation of the North Water Flood area is not considered necessary.

The high Ra concentrations found in the sediment samples immediately downstream of the current produced water discharge facility (BTP-10) indicate that Ra is accumulating in this area. As produced waters carrying NORM continue to be released, sediment concentrations can be expected to increase in this drainage, even if Ra concentrations in the water discharged to the stream are within the limits established in the site NPDES permit. Radium concentrations in sediments remain an order of magnitude above background for the entire length of the discharge stream, at least until it merges with Little Teapot Creek. Although these concentrations are generally below levels that would cause regulatory concern, continued discharge could, over time, result in the accumulation of NORM radionuclides in sediments that are sufficiently high to require remediation. Periodic monitoring of NORM concentrations in sediments in the BTP-10 discharge stream is therefore recommended so long as the discharge of produced waters continues.

Radon emanation fraction measurements conducted on a subsample of soil and sediment samples collected during this program ranged from 0.04 to 0.19, with a mean of 0.10. This indicates that on average, 10 percent of the ^{222}Rn produced in the soil or sediment may, under the proper environmental conditions, be released from the material. The Rn emanation fraction was not correlated with ^{226}Ra concentration. The values reported here are somewhat higher than those reported for uranium mill tailings, although additional data is necessary before conclusions on the differences between mill tailings and soils can be made.

It was hoped that the activities described in this report would provide evidence that Ra concentrations in soils and other media could be accurately estimated from surface gamma exposure measurements. It is apparent, however, that while surface exposure rate measurements may provide an indication of the presence of elevated levels of gamma-emitting NORM radionuclides, they do not represent a reliable means for estimating ^{226}Ra concentrations in the surface soils.

5. REFERENCES

- Baird, R.D., G.B. Merrell, R.B. Klein, V.C. Rogers, and K.K. Neilson. 1990. Management and disposal alternatives for NORM wastes in oil production and gas plant equipment. Rogers and Associates Engineering Corporation, RAE-8837/2-2.
- Grove Engineering, 1992. Microshield Version 4; Users's Manual, by C.A. Negin and G. Worku. Grove Engineering, Rockville Maryland, 20850
- Nuclear Regulatory Commission, 1984. *Radon Attenuation Handbook for Uranium Mill Tailings Cover Design*. NUREG/CR-3533. Division of Health, Siting and Waste Management, Washington D.C.
- Otto, G.H. 1989. A national survey on naturally occurring radioactive materials (NORM) in petroleum producing and gas processing facilities. Report to the American Petroleum Institute.
- Rood, A.S., D.T. Kendrick, and G.J. White. 1998. Measurement of ^{222}Rn flux, ^{222}Rn emanation, and ^{226}Ra concentration from injection well pipe scale. *Health Physics* 75:187-192.
- U.S. District Court for the District of Columbia. 1990. Settlement Agreement, Natural Resources Defense Council Inc. vs. William K. Reilly, Administrator of the Environmental Protection Agency.

APPENDIX A

Sampling and Analysis Plan of Characterization
Naturally Occurring Radioactive Material (NORM)
at NPR-3 (Teapot Dome)

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ACRONYMS

AEA	Atomic Energy Act
CRCPD	Conference of Radiation Control Program Directors
DMS	Data Management System
DQOs	Data Quality Objectives
EPA	Environmental Protection Agency
HpG	High purity Germanium
ID	Identification
NEEL	Idaho National Engineering & Environmental Laboratory
LDEQ	Louisiana Department of Environmental Quality
LMITCO	Lockheed Martin Idaho Technologies Co.
NORM	Naturally Occurring Radioactive Material
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RPD	Relative Percent Difference
S&A	Sampling and Analysis
TSCA	Toxic Substances Control Act
UMTRA	Uranium Mill Tailings Remedial Action

A-1 INTRODUCTION

The presence of naturally occurring radioactive materials (NORM) in oil and gas production and processing facilities has been known since the 1930s. Although widely dispersed in the earth's crust, elevated levels of NORM in oil and gas production and delivery equipment and wastes appears to be restricted to certain geographic areas, notably those where barite scales (BaSO_4) are formed. Radionuclide contamination in oil production equipment and wastes appears to be limited to the following (Otto, 1989; Baird et al., 1990):

1. ^{226}Ra and ^{228}Ra co-precipitated in some mineral scales on the interior of production tubing and other equipment;
2. sludges and sands from petroleum production equipment, containing isotopes of radium, thorium, and uranium;
3. radon gas (primarily ^{222}Rn) emanating from radium-contaminated materials; and
4. water produced during the extraction of oil and gas (produced waters).

The primary hazard with NORM material containing ^{226}Ra is the inhalation of radon decay products generated by the decay of ^{226}Ra . Radon-222 is a noble gas and has a half-life of 3.82 days. It decays into short-lived alpha (^{218}Po , ^{214}Po) and beta (^{214}Pb , ^{214}Bi) emitting progeny that typically deposit in the lung following inhalation resulting in dose to lung tissue. Exposure to high concentrations of Rn daughters has been documented to cause premature lung cancer in uranium miners. Generally, exposure to gamma photons from elevated levels of NORM is not as great as a health hazard as inhalation of Rn progeny.

Petroleum production at the Naval Production Reserve No. 3 (NPR-3) at Teapot Dome, Wyoming has been occurring since 1922. Over the next few years, it is expected that the NPR-3 site will be sold to private industry. Remediation of the NPR-3 site has already begun in anticipation of this transfer. Although NORM contamination of the NPR-3 site is not expected to be substantial, characterization of the site with respect to NORM must be conducted before the need for remediation can be determined. The collection and analysis of environmental samples described in this Sampling and Analysis Plan are designed to provide the data necessary to make this determination. Furthermore, any information gained through the comprehensive characterization of this federally-owned petroleum production site may be useful in the design of NORM survey and assessment techniques for other, privately-owned production facilities.

As described in Section 3, gamma exposure rates observed at the NPR-3 site ranged from background levels (10-20 $\mu\text{R}/\text{h}$) to approximately 10 times this level. Most areas within the site that appear to be contaminated were therefore only slightly above the 50 $\mu\text{R}/\text{h}$ surface exposure rate limit established by several states (e.g., Texas and Louisiana).

If NORM-contaminated soils at the NPR-3 site are to be cleaned up, disposal options may depend on the radon emanation fraction from these soils. The radon emanation fraction is the ratio of the radon that enters interconnected pore space and is available for transport in the media,

to the total number of radon atoms produced, and is dependent on the physical characteristics of the medium. Pipe scale, for example, generally exhibits a much lower emanation fraction than uranium mill tailings or soils (Rood et al., 1998), and would therefore require a thinner cover compared to uranium mill tailings because the amount of radon released from the waste material is much less and therefore, requires less attenuation in the cover.

Ultimately, the Rn flux at the surface of a waste pile is of primary importance. Radon flux is dependent on the concentration of the parent Ra in the contaminated material, and on the rate at which the Rn produced can diffuse out of the material. However, Rn flux from a given material can be highly variable because it is also dependent on soil moisture content, recent precipitation intensity, or passage of a weather front (barometric pumping). A single flux measurement is simply inadequate in terms of characterizing a NORM source. For these reasons, ^{226}Ra concentration and ^{222}Rn emanation fraction measurements appear to be the most relevant parameters in terms of assessing the health risks associated handling and disposal of NORM.

A-1.1 Site Operational History

The NPR-3 site was established on April 30, 1915, by President Woodrow Wilson. The first reported production from the field was in October 1922. Shale well No. 301-2 produced 830 barrels of oil in a two day flow test. The field was subsequently leased to Mammoth Oil Company (controlled by H.F. Sinclair) in 1921 for the purpose of developing and exploiting the oil and gas discovered within NPR-3. The field was shut down in 1927 as a result of a court ruling on what would become known as the Teapot Dome Scandal. Operation of the site was given to the Navy Department in January 1928. Production resumed in 1976. Since 1992, the field has been operated and managed for the DOE by Fluor Daniel (NPOS), Inc.

The NPR-3 currently contains about 600 producing wells completed in nine geologic formations, of which the Shannon Formation is the most productive. The NPR-3 field also has numerous shut-in or temporarily abandoned well bores, with a variety of depths and casing sizes available for field testing. The field contains 42 injection wells (gas, water, and steam) and two water source wells from the Madison Formation.

A-1.2 Regulatory Background

Federal regulation of radioactive wastes has been limited to those waste types specifically covered by the Atomic Energy Act of 1953 (AEA) and its amendments. NORM radionuclides, however, are categorically excluded from regulation under the AEA. While the Nuclear Regulatory Commission (NRC) has opted not to seek legislative authority over NORM, the U.S. Environmental Protection Agency (EPA) is continuing to evaluate the need for regulating the handling and disposal of NORM wastes on a national basis. The regulatory authority for EPA regulation of NORM wastes is found under Section 6 of the Toxic Substance Control Act (TSCA), which authorizes the Administrator of the EPA to regulate the disposal of any class of

substances for which unregulated disposal would present an unreasonable risk of injury to human health or the environment.

The Conference of Radiation Control Program Directors (CRCPD), a national organization consisting of the directors of regulatory agencies responsible for radiation control in the various states, has drafted model state regulations for the control of NORM. These model regulations are currently in their seventh draft. The intent of the CRCPD in developing this model is to provide states with guidelines for developing regulations and licensing requirements pertinent to their specific NORM problems. Qualifications and procedures for issuance of both general and specific radioactive material licenses and conditions for regulatory exemption are provided. Standards for worker protection and release limits for radioactive material effluent are also described.

Several states including Louisiana and Texas have implemented regulations based largely on the CRCPD guidelines. In Louisiana, for example, the Department of Environmental Quality (LDEQ) implemented exposure rate limits 25 $\mu\text{R/hr}$ above background, and soil contamination limits of 30 pCi/g (including background) averaged over any area of 100 m^2 , provided that radon emanation from the surface does not exceed 20 pCi/ $\text{m}^2\cdot\text{s}$. Background soil radium concentrations are typically around 1 pCi/g, and background exposure rates are approximately 10-20 $\mu\text{R/hr}$.

In Texas, draft regulations recognized that the 5 pCi/g concentration limit established by the federal government for uranium mill tailings could be applied to soils contaminated with NORM, but is not necessarily applicable to NORM in solid scales because of the differing physical properties (Rood et al., 1998). The rationale is related to the expected lower radon emanation rates from the solid scale material as compared with mill tailings. Compared with the Louisiana rule, the Texas draft regulations provide similar (although somewhat less stringent) concentration limits for the release of areas for unrestricted use. These include ^{226}Ra and ^{228}Ra concentration limits of 30 pCi/g averaged over a maximum depth of 15 cm of soil below the surface.

A-1.3 Information Needs

Data is needed on concentrations of NORM in environmental media at NPR-3 to determine: (1) the potential level of hazard resulting from these materials to workers or the general public; (2) the need for remediation of the NPR-3 site prior to closure or transfer of the site to the private sector; and (3) the distribution of NORM in petroleum production sites. This latter need is facilitated because as a federally owned facility, access to the NPR-3 site is not restricted, and the information gained during this program is more easily applied to other sites within the private as well as the public sector.

Questions to be answered include:

- Where within the NPR-3 site is NORM concentrated?
- In what media are elevated concentrations of NORM found at the NPR-3 site?
- With what processes or activities is NORM contamination associated?
- How do concentrations encountered compare with existing or proposed standards?

A-1.4 Purpose of the Sampling and Analysis Plan

This Sampling and Analysis (S&A) Plan has been developed for the NPR-3 NORM Characterization, and describes the information to be gained through the program, how the required information is to be collected, and the anticipated form and content of the final data. The S&A Plan provides detailed procedures describing the work to be performed, how and why the work will be performed, and who will be responsible for conducting the various aspects of the work. Input into the generation of this S&A Plan has been provided by the program sponsor (U.S. Department of Energy), the field personnel responsible for collecting the samples (Lockheed Martin Idaho Technologies Corporation [LMITCO]), and the operator of the NPR-3 site (Fluor-Daniels).

A-1.5 Data Quality Objectives

The Data Quality Objectives (DQOs) process has been developed by the U.S. Environmental Protection Agency (EPA) to provide a means for determining the type, quantity, and quality of data needed to support decision making. For the NPR-3 NORM Characterization, DQOs have been developed to provide the information necessary to determine the extent of NORM contamination at the NPR-3 site, and the need for remediating areas where contamination are found.

DQOs are qualitative and quantitative statements derived from the outputs of the first steps of the DQO process that (1) clarify the study objective; (2) define the most appropriate type of data to collect; (3) determine the most appropriate conditions from which to collect the data; and (4) specify tolerable limits on decision errors which will be used as the basis for establishing the quantity and quality of data needed to support the decision (U.S. EPA, 1994).

The first aspect of the DQO process is the formulation of a problem statement that concisely describes the problem to be studied. The purpose of the present study is to characterize the NPR-3 site for NORM contamination. The data collected must be sufficient to provide the basis for assessing the need for remediation. Stakeholders involved in this study include LMITCO, U.S. Department of Energy (DOE), and Fluor-Daniels. Sample collection and data interpretation will be conducted by LMITCO. The NPR-3 site is owned by DOE and operated under contract with Fluor-Daniels. Input will also be provided by Energy Laboratories Inc., who will be responsible for analyzing the samples collected during this study. Responsibilities for the different aspects of this program are provided in Section 6 of this S&A Plan. The schedule for completion of this project is provided in Section A-7.

The data to be collected during this study will be used to determine the need for remediating the NPR-3 site for NORM contamination. This decision will be based on radium content of soil and sediment samples, the radon emanation and flux from these samples, and the geographic distribution of samples containing NORM. Information required to determine the need for

remediation include radium concentrations and radon release measurements from environmental media that might contain elevated concentrations of NORM radionuclides.

The DQO process also requires definition of the boundaries of the study in terms of (1) the population of interest (i.e. what will be sampled); (2) the geographical area of interest; and (3) the time frame of interest. Environmental media to be sampled during the NPR-3 NORM Characterization include the top 12 inches of soil or sediment within the NPR-3 site boundaries in areas where surface gamma exposure rates are at least twice background levels. All samples will be collected in August of 1997. The geographic distribution of soils or sediments in excess of 50 pCi Ra per gram of material will likely require remediation. Based on surface gamma readings taken at the NPR-3 site, Ra concentrations in soil and sediment samples are expected to be in the range of 1 to 50 pCi/g.

A-2 REGULATORY REQUIREMENTS

All pertinent state and federal regulations for the shipping and disposal of the samples collected for analysis during the NPR-3 NORM Characterization will be complied with. All samples collected during this program will be analyzed by Energy Laboratories Inc., a commercial analytical laboratory located in the Casper area, eliminating the need for shipping. However, because transport of samples from the NPR-3 site to the analytical laboratory in Casper will involve the use of public highways, this transport must comply with U.S. Department of Transportation regulations. Shipping containers will be surveyed with a calibrated gamma exposure rate meter prior to transport. If necessary, the sample shipment will be diluted to ensure that the total activity concentration of the shipments is less than the 2 nCi/g concentration limit imposed by the U.S. Department of Transportation (Code of Federal Regulations 49 CFR 173.403). Proper disposal of samples will be the responsibility of the analytical laboratory, and will be done in accordance with all appropriate federal, state, and local regulations..

A-3 PRELIMINARY SITE SURVEY

On June 18, 1997, G. White, A. Rood, and S. Barndt of LMITCO conducted a gamma radiation survey of the NPR-3 site to determine optimum locations for collecting samples for radiological analysis. Kurt Nielsen of Fluor-Daniels, the operating contractor at the NPR-3 site, was present during the survey. The purpose of the survey was to determine the general areas within the NPR-3 site at which exposure rates are above background, indicating the likelihood of contamination with NORM.

Prior to conducting the survey, LMITCO personnel were provided with data from previous environmental monitoring conducted at NPR-3 (Table A-3.1). The subsequent survey was focused on areas where previous data or operational experience indicated that NORM contamination were most likely to occur (i.e. locations where pipe cleaning was known to have occurred or where produced waters were discharged to the soil surface). Locations sampled as part of the site NPDES permit were also surveyed, as were roads within the site that had recently been covered with oil sludge. An old solid waste dump site was also surveyed.

Exposure readings from a NaI detector (Ludlum model 12S micro-R- meter, calibrated 6-16-97) were taken at numerous locations throughout the site. Surface gamma exposure rates (within 15 cm of ground surface) in excess of 20 $\mu\text{R/hr}$ were considered to be elevated above background levels. In locations where elevated surface readings were found, more extensive surface readings were taken. The results of the survey showed two general areas of elevated surface readings. The first location containing elevated surface readings was within the drainage of the North Water Flood area, where surface exposure rates ranged from 50 to 120 $\mu\text{R/h}$. The second location containing elevated surface readings was the BTP-10 or produced water cooling station. Some of the scale that formed on the discharge outflow between cooling ponds had exposure rates of approximately 80 $\mu\text{R/h}$. The drainage directly below the final cooling pond had exposure readings between 40 and 45 $\mu\text{R/h}$. These two locations will provide the main focus of subsequent sampling efforts. Sediment samples will also be collected from the National Pollutant Discharge Elimination System (NPDES) water sampling stations (see data below). Samples will be analyzed for ^{226}Ra and ^{228}Ra concentrations, and Rn emanation.

A summary of the preliminary survey is provided below in Table A-3.2. Assuming a background exposure rate of 20 $\mu\text{R/h}$, only two areas of elevated exposure were found. These were (1) the North Water Flood area; and (2) the stream bed draining the BTP-10 area. Although the area has been dry for many years, the North Water Flood area historically contained a series of cooling and evaporation ponds for produced waters. Some pipe cleaning was also conducted in this area. The BTP-10 area includes the current produced water cooling station. Produced waters are discharged from this point to a drainage that eventually converges with Teapot Creek. Exposure rates in the North Water Flood area ranged from 50 to 120 $\mu\text{R/h}$, while those in the drainage of the BTP-10 area ranged from background to approximately 40 $\mu\text{R/h}$. Scale formed on the concrete side of the discharge facility had a surface exposure rate of 80 $\mu\text{R/h}$.

Table A-3.1 NPR-3 NPDES Surface Water Monitoring Data (Provided by Fluor-Daniels).

Sample ID (location)	Date Sampled	²²⁶ Ra (pCi/l)
SW-22	4-28-97	<0.2
SW-2	4-28-97	6.3
SW-27	4-28-97	3.5
SW-20	4-28-97	1.3
SW-21	4-28-97	1.9
SW-29	4-28-97	0.9
SW-2	10-14-96	4.6
SW-27	10-14-96	2.7
SW-29	10-14-96	<0.2
SW-20	10-14-96	0.5
SW-21	10-14-96	0.5
SW-29	4-10-96	<0.2
SW-20	4-10-96	0.4
SW-21	4-10-96	<0.2
SW-27	4-10-96	2.7
SW-2	4-10-96	1.7
SW-20	12-20-95	0.5
SW-21	12-20-95	0.5
SW-27	12-20-95	6.8
SW-2	12-20-95	10.1
SW-29	7-24-95	3.6
SW-20	7-24-95	4.1
SW-21	7-24-95	1.0
SW-27	7-24-95	3.6
SW-2	7-24-95	<0.2

Note: SW = Surface Water sample, with the number indicating the section in which the sampling station is located.

Table A-3.2 NPR-3 Preliminary Gamma Exposure Survey Results. B= battery station, SW= surface water

Surface Water Sampling Locations:

- **SW-22:** Located in Section 22 near the South Gate, consisting of surface water flowing onto the NPR-3 site and containing no produced water.
- **SW-14:** Located in Section 14 approximately one mile downstream of SW-22. Note: This stream is intermittent may be dry during the summer months.
- **SW-2:** Located Section 2 near Shannon's crossing, and represents the point where most of the produced water enters the drainage.
- **SW-27:** Located in Section 27 near the eastern border of the NPR-3 site, approximately 2 mi. downstream from SW-2. Water sampled here is surface runoff, but mostly produced water.
- **SW-29:** Located in Section 29 near the Main Gate to NPR-3. This sampling station is in Teapot Creek and includes water that has flowed onto the site from non-producing areas and contains no produced water.
- **SW-20:** Located in Section 20 on the western boundary of the NPR-3 site. Surface water presumably contains produced water discharged from the adjacent Amoco field.
- **SW-21:** Located in Section 21 on the northern boundary of the NPR-3 site approximately 0.25 miles downstream from SW-20. Surface water presumably contains produced water discharged from the adjacent Amoco field.

(See Surface Water Sampling Location Map Figure A-3-1)

General Exposure Readings of Various Locations Within Site:

- B-1-14 (near SW-14): 14 to 18 $\mu\text{R/h}$
 - BTP-10 (produced water cooling station): approximately 80 $\mu\text{R/h}$ (outflow scale), and 40-45 $\mu\text{R/h}$ below the cooling/settling ponds, remained around 40 $\mu\text{R/h}$ 400 yds downstream
 - T-1-10: 12 to 15 $\mu\text{R/h}$
 - Water Disposal Facility in Section 10: 10 to 15 $\mu\text{R/h}$
 - Old solid waste dump located east of the Shop House: 12 to 18 $\mu\text{R/h}$
 - B-3-3, near the Water Treatment Facility in Section 3: 12 to 15 $\mu\text{R/h}$
 - B-1-3, near the pipe yard and Chem. Dock in Section 3: 12 to 18 $\mu\text{R/h}$
 - Bad Oil Facility in section 2: 10 to 15 $\mu\text{R/h}$
 - Shannon's Crossing (SW-2): 12 to 20 $\mu\text{R/h}$
 - Sludged Road near SW-2 and Shannon's Crossing: 12 to 20 $\mu\text{R/h}$
 - T-1-34: 12 to 18 $\mu\text{R/h}$
 - Well B-7 44sh x 27, just north of T-1-34: 12 to 18 $\mu\text{R/h}$
 - B-1-33: 12 to 16 $\mu\text{R/h}$
 - B-1-28: 12-20 $\mu\text{R/h}$
 - North Water Flood (Rattling occurred here) section 21: surface exposure rate near road 15 $\mu\text{R/h}$; drainage exposure reading rate ranged from 50 to 120 $\mu\text{R/h}$
 - SW-21 (Amoco produced water drainage): 12 to 20 $\mu\text{R/h}$
 - SW-20 (Amoco produced water drainage): 10 to 12 $\mu\text{R/h}$
 - B-1-20: 12 to 18 $\mu\text{R/h}$
-

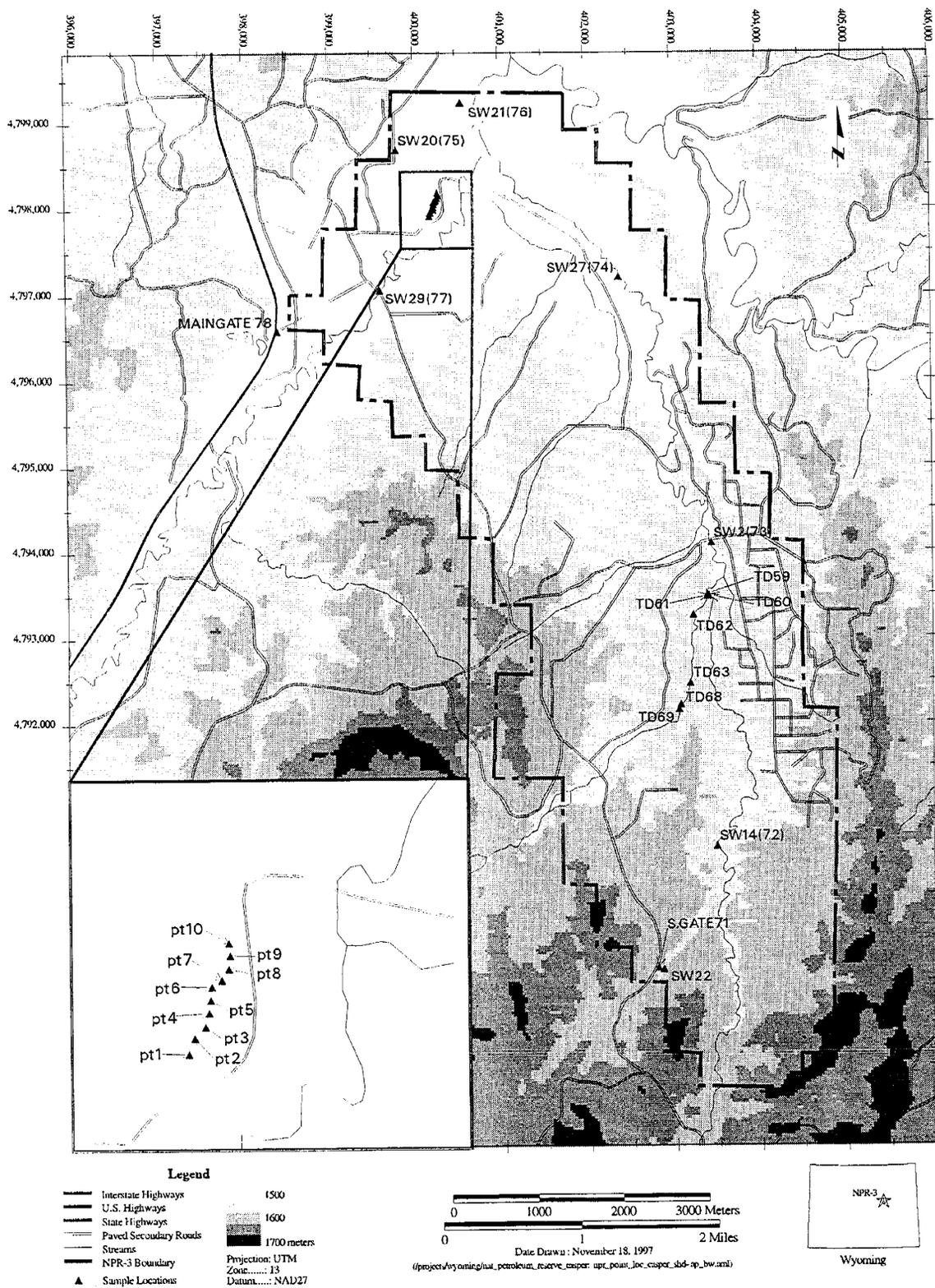


Figure A-3-1. Map of surface water sampling locations – NPR-3 NPDES permit monitoring program.

A-4 Sampling Strategy

The purpose of this section of the Sampling and Analysis Plan is to describe the general strategy behind the sampling design applied to the NPR-3 NORM Characterization. Included are descriptions of the types of samples to be collected and measurements to be performed during this program and the rationale behind the number and location of samples to be collected. Descriptions of how the data resulting from each type of sample or measurement will help provide the information necessary to characterize the NPR-3 site for NORM contamination are also provided.

Sample collection at the NPR-3 site will be concentrated in areas where elevated gamma exposure rates were observed during the preliminary site survey conducted in June (see Section A-3). The resulting sampling is therefore biased in favor of areas of expected NORM contamination. This is done because the goal of the program is to determine the distribution of NORM contamination within the NPR-3 site, and which areas are in need of remediation. Determining the “mean” NORM concentration in soils or sediments within the NPR-3 site is not a goal of the study.

Basing sampling on the results of gamma surveys provide several important benefits to the program. First, gamma surveys help to optimize the sampling program by identifying sample locations where elevated radioactivity levels are present. Only areas with elevated gamma reading will be sampled (except designated background samples). Second, the relative costs of conducting gamma surveys are much less than the costs of analyzing samples; any additional information that can be extrapolated from gamma survey in conjunction with the analytical data will therefore result in a more cost-effective program. Finally, by recording the results of the gamma survey, it will be possible to revisit areas to collect additional or follow-up samples at some later date, provided that either additional funds are made available and additional information becomes necessary or desirable.

Most of the samples collected during this program will be analyzed for radium content. A small fraction of samples will also be analyzed for radon emanation. The radon emanation fraction is the ratio of the radon that enters interconnected pore space and is available for transport in the media, to the total number of radon atoms produced. The radon emanation fraction is critical in determining the disposal options for any contaminated material removed from the site. The emanation fraction is strongly dependent on the distribution of parent radium atoms within the host material and several other factors including moisture content, effective porosity, and grain size distribution.

No samples will be analyzed for uranium or thorium concentration. This decision was based on the assumption that with the likely exception of produced sands, these parent radionuclides should remain essentially immobile in comparison to their radium daughter products. Uranium and thorium are therefore expected to remain within the geologic formation when the more-soluble radium is removed. Second, as a means of optimizing the information that will be generated from this program, we will be relying heavily on the performance of gamma surveys at each field location sampled.

General descriptions of the strategies applied to the collection of the various types of samples are provided below.

A-4.1 NORM Radionuclide Concentration Samples

The purpose of collecting and analyzing samples for concentrations of NORM radionuclides is to evaluate the extent and physical distribution of NORM contamination at the NPR-3 facility. This information is needed before an assessment of the risk associated with these materials may be performed. This will involve the analysis of samples of soil, sediment, and pipe scale for concentrations of both ^{226}Ra and ^{228}Ra . A total of approximately 150 samples (including field QA/QC samples) will be collected for radionuclide analysis at the NPR-3 site.

An approximate breakdown of the numbers and percentage of the different types of radium concentration samples is provided in Table A-4-1 below. Brief descriptions of how each different type of sample will be selected, and the rationale behind choosing these sample numbers is provided below. Detailed procedures for sample collection, analysis, and data management are provided in Section A-5 (Standard Operating Procedures).

Table A-4-1. Approximate number of ^{226}Ra and ^{228}Ra samples to be taken for each sample type of radium concentration sample.

SAMPLES	QA/Qc ^a	TOTAL	% OF TOTAL	SAMPLE TYPE
20	2	22	13	Sediment samples
85	9	94	63	Soil samples
10	1	11	6	Pipe scale samples
20	2	22	13	Miscellaneous "opportunity")
10	1	<u>11</u>	6	Background
		160 = Total ^{226}Ra and ^{228}Ra concentration samples		

^a Represents field replicates of 10 percent of the samples collected

A-4.1.1 Sediment Samples

Samples of sediment will be collected along the main channel of the drainage fed by the produced water cooling and settling ponds (BTP-10), and at each of the surface water sampling sites used routinely to monitor water quality in compliance with the NPR-3 NPDES permit (see Figure A-3-1 for sampling locations).

BTP-10 Outflow Stream Sediment Samples -- Sediment samples will be collected at each of 10 points along the outflow stream fed by the produced water cooling and settling ponds

(Figure A-3-1). These points will be spaced at equal distances from the pond outflow to the point downstream where gamma rate readings revert to background levels.

NPDES Permit Water Monitoring Stations – Additional sediment samples will be collected at each of the surface water monitoring locations routinely sampled by Fluor-Daniels personnel in compliance with the NPDES surface water discharge permit for the NPR-3 site (Figure A-3-1). The intent of these samples is to compliment the water sampling data; whereas analysis of water samples provides an indication of what is being released at that instant, sediment provides a means for integrating release of NORM radionuclides over time.

A-4.1.2 Soil samples

Soil samples will be focused on two general areas: the area surrounding the BTP-10 outflow stream area (see above section on sediment sampling) and the North Water Flood area. Additional samples may be collected if additional areas are found with elevated gamma exposure readings. A comprehensive gamma survey with a properly calibrated exposure rate meter will be conducted of the two areas where general contamination has been identified. A map of surface (15 cm) gamma exposure rates will be generated. Surface samples (top 15 cm or 6 in) will be collected at each location. Subsurface samples (15-30 cm) will be collected at up to 50% of the soil sampling locations, selected randomly from the population of surface soil samples. Gamma exposure will be measured and recorded within each sample hole before subsurface samples are collected. This will be determined using an external gamma probe. Sampling at these two depths essentially follows that proscribed by the Louisiana regulations. Specific procedures for collecting these samples is provided in Section A-5.1.

North Water Flood Area soil samples – Historically, produced water was discharged to a series of three ponds in what became known as the North Water Flood area. Some pipe scale removal was also conducted in this area. Elevated gamma exposures were found throughout the drainage channel from this area, with the highest readings in the center of the channel.

Soil samples will be collected at 10 equally spaced locations along this channel covering the entire distance where elevated gamma exposures are found. Additional samples will be collected on perpendicular transects centered on 4 of these sampling points (numbers 2,4,6, and 8). Along these perpendicular transects, samples will be taken at points 2, 4, 8, and 16 m from the center point provided that surface gamma exposures are above background at the adjacent point along the transect. These samples will be used to determine the lateral extent of NORM contamination within the drainage for the North Water Flood area.

BTP-10 Outflow soil samples – Additional samples will be collected on perpendicular transects centered on 4 of the sediment sampling points (numbers 2, 4, 6, and 8) for the BTP-10 outflow. Along these perpendicular transects, samples will be taken at points 2, 4, 8, and 16 m from the center point provided that surface gamma exposures are above background at the adjacent point along the transect. Sediment will be substituted for soil for any lateral point that is located within the stream. The purpose of these samples is to document the lateral extent of NORM contamination in the area of the discharge stream.

A-4.1.2 Pipe scale samples

Information on the concentration of ^{226}Ra and ^{228}Ra in pipe scale is necessary to determine the degree of risk to workers and to the public from these materials, and to evaluate the need for special disposal requirements. The purpose of collecting pipe scale samples is therefore to determine the concentration of radium isotopes that accumulate within these materials. Pipe scale is not routinely cleaned from pipe at the NPR-3 site, and no scale-contaminated pipe was found during the preliminary survey of the site. However, the site operators have agreed to collect scale samples if pipes are cleaned before LMITCO conducts the soil and sediment sampling at NPR-3. It is unlikely that more than 10 samples will be available, and these will be viewed as “targets of opportunity”. If available, these samples will be analyzed for ^{226}Ra and ^{228}Ra .

A-4.2 Radon Emanation and Flux

The primary hazard with NORM material containing ^{226}Ra is the inhalation of radon decay products generated by the decay of ^{226}Ra . Radon-222 is a noble gas and has a half-life of 3.82 days. It decays into short-lived alpha (^{218}Po , ^{214}Po) and beta (^{214}Pb , ^{214}Bi) emitting progeny that typically deposit in the lung following inhalation resulting in dose to lung tissue. Exposure to high concentrations of radon daughters has been documented to cause premature lung cancer in uranium miners. Generally, exposure to gamma photons from elevated levels of NORM is not as great a health hazard compared to inhalation radon progeny. At NPR-3, gamma exposure rates in contaminated areas were from 2 to 10 times the background rate of $10\ \mu\text{R}/\text{h}$. Exposure rates in elevated areas were typically only slightly above the $50\ \mu\text{R}/\text{h}$ range. Fifty $\mu\text{R}/\text{h}$ has been established by several states (Texas and Louisiana) as cutoff for whether material is defined as NORM or not. If the contaminated ground is to be cleaned up, disposal options may depend on the radon emanation fraction. For example, pipe scale (which is reported to have a much lower emanation fraction compared to uranium mill tailings) would require a thinner cover compared to uranium mill tailings because the amount of radon released from the waste material is much less and therefore, requires less attenuation in the cover.

Ultimately, the radon flux at the surface of a waste pile is of primary importance. However, radon flux is highly variable and dependent on soil moisture content, recent precipitation intensity, or passage of a weather front (barometric pumping). A single flux measurement is simply inadequate in terms of characterizing a radon source. For these reasons, ^{226}Ra concentration and ^{222}Rn emanation fraction measurements appear to be the most relevant parameters in terms of assessing the health risks associated handling and disposal of NORM.

A-4.3 “Targets of Opportunity”

Although the preliminary site gamma survey conducted in June was considered to be thorough, it is possible that additional contaminated areas may be found during the sampling effort. A total of up to 20 additional samples may be collected if such additional contaminated areas are encountered. These may include soil, sediment, scale or production waste.

A-4.4 Background samples

A total of up to 10 background soil samples will be collected in areas surrounding the NPR-3 site that do not have elevated gamma readings. These samples will be analyzed for Ra content to provide a point of comparison with samples collected from contaminated areas. Sediment samples collected from NPDES monitoring sites in streams entering the NPR-3 site (but not containing produced waters from the adjacent Amoco site) will be used as background sediment samples.

A-4.5 Quality Assurance/Quality Control (QA/QC) Samples

A total of 10% field QA/QC samples has been assumed throughout the sampling program to verify the quality of the results observed. Field replicate samples will be determined randomly prior to sample collection. Because Energy Laboratories Inc. is an EPA-certified laboratory, laboratory QA/QC procedures will be those in place at the contract laboratory. QA/QC procedures are discussed in detail in Section A-8 of this document.

A-5 STANDARD OPERATING PROCEDURES (SOPs)

The purpose of this section is to provide detailed procedures to be applied to the different aspects of the NPR-3 NORM Characterization in the form of Standard Operating Procedures, or SOPs. Included are SOPs for Sample Collection (Section 5.1), Sample Analysis (Section 5.2), Sample Identification and Tracking (Section 5.3), Data Management (Section 5.4), and Waste Disposal (Section 5.5). Many of these procedures were used in an earlier study of NORM in oil facility waste and equipment. Each SOP contained in this S&A Plan includes detailed descriptions of the rationale for using the specific procedures.

The samples to be collected during the NPR-3 NORM Characterization represent a variety of different types. In some cases, the form taken by the samples will be similar to those collected for the UMTRA Program or other previous large-scale radionuclide assessment programs. Where NORM Program samples are similar to those collected for other programs, sample collection and analysis procedures have been adopted with the appropriate modifications

A-5.1 Sample Collection SOPs

Specific procedures for the collection of each type of sample are provided below. These procedures are to be used by LMITCO field by personnel charged with collecting NPR-3 NORM Characterization samples whenever possible. Any deviation from the sample collection SOPs described herein must be documented and explained by the field collection personnel in the sample collection documentation that accompanies the sample to the analytical laboratory. All samples collected during the NPR-3 NORM Characterization will be collected by personnel of Lockheed-Martin Idaho Technologies (LMITCO). All personnel participating in the collection of samples shall be familiar with the appropriate sample collection SOPs prior to working in the field. These procedures describe:

- How field personnel determine the specific location at which a sample will be collected (including how to survey the site at which the sample will be collected);
- How the sample will be collected by field personnel;
- The quantity (in terms of either volume or mass) of the sample to be collected;
- The sample containers to be used in the field for the collection and shipment of the samples;
- Any applicable QA/QC procedures that must be followed during sample collection; and
- Any ancillary information that must be recorded by the field personnel.

A-5.1.1 Sediment sample collection SOPs

Sediment samples will be collected in the main drainage leading from the produced water cooling and settling ponds (BTP-10) and at the NPDES permit surface water sampling locations. Equipment needed to collect sediment samples are shown in Table A-5-1. Collection of all sediment samples will be performed by LMITCO personnel.

Table A-5.1 Sampling equipment and supplies needed for collection soil and sediment samples at NPR-3.

<u>Quantity</u>	<u>Description</u>
<u>Soil Samples:</u>	
1	soil core sampler
138	1-liter Nalgene wide mouth plastic sample jars
1	rinse bottle and paper towels for cleaning sampler between cores
1	tray for mixing soil sample
1	trowel
1	Exposure rate survey meters and check sources
1	Sonin distance meter
1	Compass
138	Sample labels
	Shipping Containers
	Sample Collection Forms
	Sample Shipping Forms
1	Log book
1	Site map indicating sampling locations (Figure A-3-1)
	Random number table
<u>Sediment Samples:</u>	
1	sediment corer
44	1-liter Nalgene wide mouth plastic sample jars
1	rinse bottle and paper towels for cleaning sampler between cores
1	tray for mixing soil sample
1	trowel
	Shipping containers
1	Sonin distance meter
1	Compass
44	Sample labels
	Sample collection forms
	Sample shipping forms
1	Carboy for decon water
1	Scrub brush
1	Decon bucket
1	Log book
1	Site map indicating sampling locations (Figure A-3-1)
	Random number table

BTP-10 Sediment Sample Collection SOPs – Sediment samples will be collected from 10 locations along the drainage channel leading from the produced water facility according to the following procedure:

1. Conduct a comprehensive gamma survey of the drainage channel. Gamma readings will be taken at a height of no more than 15 cm above the ground or water surface using a calibrated micro-R-meter. The survey will be conducted downstream from the discharge point until surface gamma readings approach background levels. A rough map will be produced, and the total length of the discharge stream containing elevated gamma readings will be estimated. Sediment sampling locations will then be selected at equal distances over this entire length. (i.e. point 1 will be near the discharge point, point 2 at a distance of 1/9 of the total length of elevated gamma rate, etc.).
2. Collect sediment samples: A sediment corer will be used to collect surface sediment samples. Samples should be collected as near the center of the channel as possible, and to a depth of approximately 15 cm (6 in.). A sufficient volume (at least 1 L) of sediment will be placed in an aluminum tray.
3. Homogenize and place in sample bottle: The sediment will be mixed in the aluminum tray using a garden trowel. One L of the homogenized sediment will then be placed in the Nalgene sample bottle. The jar should be filled completely with soil sample. The procedure will be repeated IF the sample site has been identified as a field replicate site. No preservatives will be added.
4. Label the sample bottle: (See Sample Identification and Tracking SOPs, section 5.3).
5. Complete all appropriate paperwork: (See Sample Identification and Tracking SOPs, section 5.3).
6. Clean shovel, tray, and trowel: All implements used to collect the samples should be cleaned using stream water to prevent sample cross contamination.

NPDES Surface Water Sampling Site Sediment Samples – Sediment samples will also be collected at each of the surface water sites routinely sampled by Fluor-Daniels personnel in compliance with the NPDES discharge permit for the NPR-3 site. The procedure to be used is as follows:

1. Measure gamma exposure level: A calibrated micro-R-meter will be used to measure gamma exposure at the location to be sampled. Gamma readings will be taken at a height of no more than 15 cm above the ground or water surface using a calibrated micro-R-meter.
- 2-6. Follow the procedures described in steps 2 through 6 above for the collection of BTP-10 sediment samples.

A-5.1.2 Soil Sample Collection SOPs

Soil sampling will be focused on two locations: the North Water Flood area and the area adjacent to the BTP-10 outflow stream where the preliminary survey indicated elevated gamma exposure rates. All soil samples will be collected by LMITCO personnel. The equipment needed for the collection of these samples are shown in Table A-5-1.

North Water Flood Area Soil Sampling SOPs – The following procedures will be used to collect soil samples at the North Water Flood area:

1. Conduct gamma survey and map contaminated area: . Gamma readings will be taken at a height of no more than 15 cm above the ground or water surface using a calibrated micro-R-meter throughout the contaminated area. A rough map of the contaminated area will be drawn indicating exposure levels. The survey will follow the drainage channel from the area to the point where surface gamma rate approaches background.
2. Select sampling locations: Soil samples will be collected at 10 points located at equal distances along the main drainage channel from the North Water Flood area. Additional samples will be collected at points 5 m on either side of the main drainage channel sampling points. NO!!! Additional sampling points will also be taken if areas of exceptionally high gamma readings are found.
3. Collect surface soil sample: A soil coring device will be used to extract a sample of the top 15 cm (6 in.). The sample will be placed in an aluminum tray.
4. Homogenize and placed the sample in the bottle: The soil sample will be thoroughly mixed in the aluminum tray using a garden trowel. One L of the homogenized soil will then be placed in a Nalgene sample bottle. The jar should be filled completely with soil sample. The procedure will be repeated IF the sample site has been identified as a field replicate site. No preservatives will be added.
5. Label the sample bottle: (See Sample Identification SOPs, section ??).
6. Complete all appropriate paperwork: (See Sample Identification SOPs, section ??).
7. Clean shovel, tray, and trowel: All implements used to collect the samples should be cleaned using a rinse bottle or stream water.
8. Repeat steps 3 through 7 IF the surface soil sample has been identified as a field replicate site.
9. Measure gamma exposure rate at 15 cm depth: An external gamma probe will be used to determine gamma levels at the 15 cm depth.
10. If exposure rates indicate that contamination is found below the surface, a second sample will be collected of soil from the 15 cm (6 in.) to 30 cm (12 in) level. This sample will be collected from the same hole using the procedures outlined in steps 3 through 10.

BTP-10 Sediment Sample Collection SOPs – Soil samples will be collected at points 5 meters to either side of each of the 10 sediment sample collection points for the BTP-10 drainage. Sampling procedures will follow those outlined in steps 3 through 10 above for collecting soil samples at the North Water Flood area.

A-5.1.3 Pipe scale sample collection SOPs

Because the accumulation of barite scales in production tubing is not much of a problem at NPR-3, the site does not have a designated area where pipe is routinely cleaned. When scale is removed, it is typically done in place. A maximum of ten samples of pipe scale will be collected from site operators, if pipe scale is available. Analyses of these samples will be incorporated into an earlier study involving the collection of pipe scale samples from throughout the country to help determine the geographic distribution of NORM.

A-5.1.4 Background samples

Background soil and sediment samples will be collected for comparison with samples collected in NORM-contaminated areas. For soils, background samples will be taken near the NPR-3 site, in the predominately upwind direction. Background sediment samples will be taken from Teapot Creek upstream from any NPR-3 activity. In addition, some of the NPDES surface water sampling sites can be considered as background, since they are located upstream from NPR-3. Exposure rate readings will be taken and recorded for each site at which background samples are collected. General sample collection procedures described above will be used for both sediment and soil background samples.

A-5.1.5 Other “targets of opportunity” samples

If other “target of opportunity” samples become available, they will be collected using procedures described above, to the extent practicable.

A-5.2 Sample Analysis SOP's

All samples collected at the NPR-3 site will be analyzed for radium concentrations, and a fraction of the samples will also be analyzed for radon emanation. All analyses will be conducted by Energy Laboratories Inc. of Casper, Wyoming.

A-5.2.1 Radionuclide Analyses

Soil, sediment, and scale samples collected at NPR-3 will be analyzed for the radium isotopes, ^{226}Ra , ^{228}Ra , and naturally occurring ^{40}K using gamma spectroscopy. Potassium-40 is of interest because it contributes to the natural background exposure rate. Typical soils contain 5 to 20 pCi/g of ^{40}K . A high-purity germanium (HPGe) solid-state detector will be used for this analysis. Energy Laboratories Inc., the analytical laboratory performing all sample analyses for this program, is responsible for providing a detailed description of the laboratory procedures to be used. The following provides a general outline of the analytical procedure for radionuclide analysis.

Samples will be dried and ground to a consistent matrix before being placed in a sample container for counting. The grain size and matrix density of the sample should be similar to the grain and matrix density used in the calibration standard. Sample counting is based on the EPA procedure for analysis of gamma emitting radionuclides in drinking water (EPA Procedure 901.1 in “Gamma Emitting Radionuclides in Drinking Water” EPA 1980). Differences between the soil and water media are accounted for in the calibration standard.

Samples must be sealed in their counting containers for a minimum of 20 days before counting to allow ^{222}Rn to grow into secular equilibrium with the parent ^{226}Ra . The gamma emitting ^{222}Rn daughters, ^{214}Bi and ^{214}Pb , which are also in secular equilibrium with ^{222}Rn , will then be counted (Figure A-5-1). Typically, the 609 keV and 1764 keV ^{214}Bi photopeaks are counted for determination of ^{226}Ra , and the 611 keV ^{228}Ac photopeak or the 2614 keV ^{208}Tl photopeak are

counted for determination of ^{228}Ra . Potassium-40 is determined by counting the 1460 keV photon (Table A-5-2).

For quality control, 10% of the samples will also be analyzed for ^{226}Ra using chemical extraction followed by an alpha count. The procedure for this measurement is adapted from EPA procedure 903.0, "Alpha Emitting Radium Isotopes in Drinking Water" (EPA 1980). In such cases, the sample will be prepared for a gamma spectroscopy analysis and an aliquot will taken for chemical extraction and alpha analysis before sealing the material in the counting container. Results of the two analysis will then be compared.

A-5.2.2 Radon Emanation Measurement

Approximately 10% of the soil and sediment samples collected will be assessed for radon emanation fraction measurement. Alteration of the sample from its original condition (such as grinding and milling) will likely alter the radon emanation fraction. The sample will not be dried, crushed or milled before counting. For these reasons, a 0.5 L aliquot of each sample designated for ^{222}Rn measurement will be extracted before sample preparation for gamma spectroscopy. The sample aliquot will not be dried, crushed, or milled before the Rn emanation measurement. Moisture content of the sample should be held at its original field value as reasonable achievable. After counting, determine the moisture content of the sample by drying and weighing the sample.

The emanation measurement is typically made by evacuating the sample with dry nitrogen gas, sealing it in a container, then counting it immediately afterward using a NaI detector. The 352 keV ^{214}Pb and 609 keV ^{214}Bi are good peaks to observed because of high count yields and high detector counting efficiency. A second count is made several weeks afterward. Counting at two different times allows for calculations of the radon emanating fraction based on the theoretical ingrowth curve.

Table A-5-2. Primary gamma photons and their energies for radium isotopes of interest and ^{40}K .

Isotope	Gamma emitting daughters in secular equilibrium	Important Gamma Photon Energies (keV)	Intensity (%)	Comments
^{226}Ra	^{214}Bi	609 1764	46.1 15.6	allow about 20 days for ^{222}Rn to grow into Secular Equilibrium used for radon emanation coefficient measurements
^{222}Rn	^{214}Pb	352	37	
^{228}Ra	^{208}Tl ^{228}Ac	2614 611	99.79 11.0	
^{40}K	--	1460	10.67	

Important Isotopes in the ^{226}Ra and ^{228}Ra Decay Series

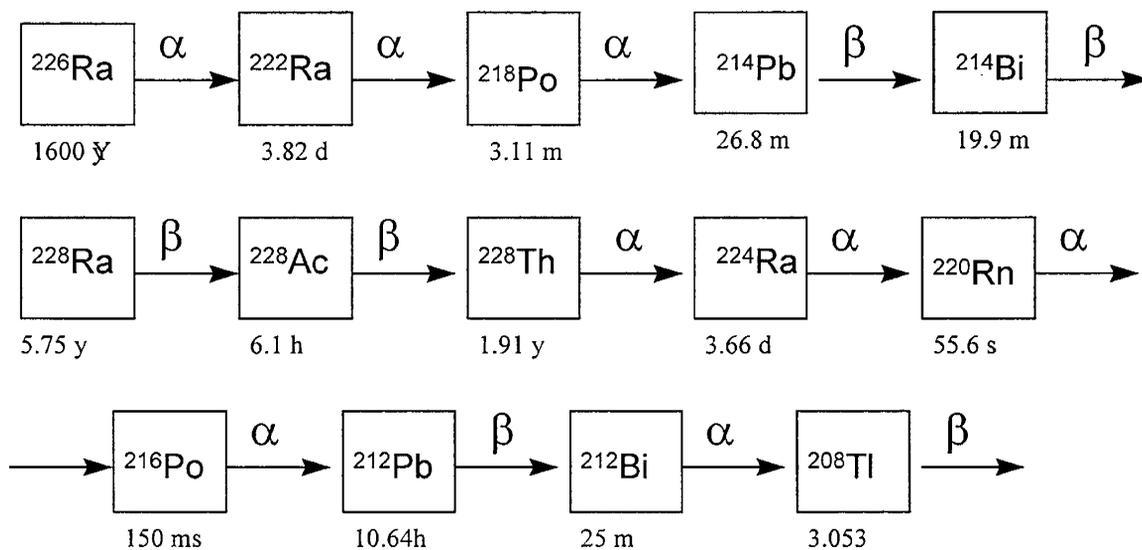


Figure A-5-1. Simplified decay series for ^{226}Ra and ^{228}Ra showing half lives and decay products important to analysis by gamma spectroscopy.

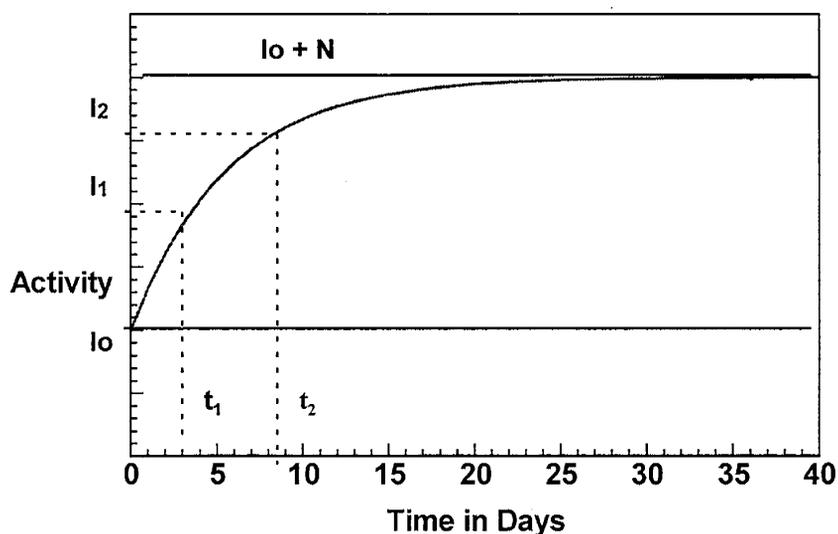


Figure A-5-2. Theoretical radon ingrowth curve defining I_0 , I_1 , and I_2

Figure A-5-2 shows the theoretical radon ingrowth curve. The sample activities at times t_1 and t_2 (I_1 and I_2) are described by Equations (1) and (2) below.

$$I_1 = I_0 + N(1 - e^{-\lambda t_1}) \quad (1)$$

$$I_2 = I_0 + N(1 - e^{-\lambda t_2}) \quad (2)$$

Where:

- I_1 = Activity at time t_1
- I_2 = Activity at time t_2
- I_0 = Bound Radon Activity at time t_0
- N = Free, or Emanating Radon Activity at Radioactive Equilibrium
- λ = Radon Decay Constant

These two equations can be solved simultaneously for the unknown quantities I_0 and N . Substituting A for $(1 - e^{-\lambda t_1})$ and B for $(1 - e^{-\lambda t_2})$ simplifies the equations. The solutions are given in Equation (3). The emanation fraction F is computed from Equation (4).

$$N = \frac{(I_1 - I_2)}{A - B}, \quad I_0 = \frac{I_2 A - I_1 B}{A - B} \quad (3)$$

$$F = \frac{N}{N + I_0} \quad (4)$$

It should be noted that it is not necessary to determine the actual sample activities (I_1 and I_2) at times t_1 and t_2 . The net count rates (C_1 and C_2) observed at t_1 and t_2 are proportional to the

activities (I_1 and I_2) through a calibration constant, which cancels out when the final ratio is taken in Equation (4). Thus C_1 and C_2 may be substituted for I_1 and I_2 .

A-5.3 Sample Identification and Tracking SOPs

The purpose of this section of the NPR-3 NORM Characterization Program Sampling and Analysis Plan is to establish procedures for identifying and handling all samples from the time the sample is collected until the analysis is complete, and for recording the information necessary to accompany each sample. Included are SOPs for Sample Labeling at the time of collection (Section 5.3.1), Sample Documentation and Recordkeeping (Section 5.3.2), and Sample Management (Section 5.3.3). These SOPs are designed to allow for the tracking of samples and to convey information regarding the samples. No formal chain-of-custody procedures are to be applied to this program because the sampling and analysis described in this document is not being conducted in response to any regulatory requirements.

A-5.3.1 Sample labeling

The purpose of a sample label is to establish and maintain the identity of the sample. A sample label will be completed in the field by the sample collection personnel for each sample collected, and shall remain with the sample through analysis. The following information shall be recorded in waterproof ink on the waterproof sample label:

1. Sample ID number: A unique sample ID number will be assigned to each sample collected. The sample ID number shall be displayed prominently on the sample label, and shall be in the form of a ten- or eleven-digit alphanumeric code. The following form will be used:

TD##YY456R

where:

- The first two digits (TD) represent the Teapot Dome facility
- The next two numbers represent a two digit section number
- The next two digits (YY) represent a two letter code for the type of sample collected. These should fit into one of six categories, listed below:
 - SC = pipe scale samples
 - SO = soil samples
 - SD = sediment samples
- The next three digits represent sequential numbers assigned in the field to each individual sample. The sequence should start at 001 for each sample type collected at NPR-3, and should proceed in the order in which the samples are collected.

- The final digit (R) represents field replicate samples collected for the purposes of QA/QC, and should be placed only on those samples that have been designated as replicate samples. Non-QA/QC samples should not have any letter or number in the 11th position.

An example of a sample ID number is TD02SD001, representing sediment sample number 1 collected in section 2 at NPR-3.

2. **Sampling Location:** This information must adequately identify the physical location within the NPR-3 facility at which the sample was collected. The purpose for including this information is to allow for the relocation of the sample site at a later date.
3. **Sample Type:** Applicable types of sample include pipe scale, soil, or sludge.
4. **Time and Date of Collection:** The time the sample was collected must be recorded using a 24-hour clock (e.g. 1445 for 2:45 p.m.). The date of collection must be noted by day-month-year (e.g. 18-AUG-97).
5. **Sampler:** The individual in charge of collecting the sample must be identified so that any questions regarding the collection of the sample may be properly directed.

An example of a sample label is provided in Figure A-5.3.

A-5.3.2 Sample documentation and recordkeeping

Recordkeeping and documentation of field activities is a necessary component of any monitoring and assessment program. A written record of all field data, activities, and observations is important for several reasons, including:

- Ensuring the timely, correct, and complete analysis for all parameters required for a given sample;
- Satisfaction of applicable the QA/QC requirements; and
- Ensuring that all essential information acquired in a consistent manner, and is preserved for current use and future reference.

Maintaining standardized records facilitates the collection of the data required to conduct site activities. Field logbooks will be used for this program, and standardized forms will also be used to ensure that the necessary information is recorded consistently for each sample collected. These forms will be completed by the sample collection personnel in the field at the time the samples are collected. As with the sample labels, these forms will be completed using waterproof ink. If weather conditions prohibit the use of ink, a pencil may be used, but the reason for its use must be noted on the form. If an error is made on any of the sample forms, a correction will be made by drawing a single line through the error and entering the correct information. All such corrections must be initialed and dated. An example of the data collection form is provided in Figure A-5-4. Serial numbers will not be used on the forms for this program.

Figure A-5-3 Example Sample Label

NPR-3 NORM CHARACTERIZATION LOCKHEED MARTIN IDAHO TECHNOLOGIES IDAHO NATIONAL ENGINEERING LABORATORY P.O. BOX 1625, IDAHO FALLS, ID 86415-2213 ATTN. G.J. WHITE (208)526-9501		
SAMPLING LOCATION:		
SAMPLE TYPE:		
DATE COLLECTED:	TIME COLLECTED:	SAMPLER:
SAMPLE IDENTIFICATION NUMBER: — — — — — - — — — —		

Figure A-5.4 Example Sample Collection Form

NPR-3 NORM CHARACTERIZATION
SAMPLE COLLECTION FORM

Sample Identification Number _____ - _____
Collection Date _____ Collection Time _____
 Day Month Year

Sampler _____
 Name Affiliation

Sample Form Checked By _____ Name
Sample collection SOP followed (Ref. #) _____
Specific Location of Sample _____
Sample Type _____ Sample Quantity _____
Pertinent Field Measurements and Observations _____

Does the sample contain oily material? _____
If the above question is yes the complete the following (Laboratory only)
Sample mass before removal of oily material _____ grams
Sample mass after removal of oily material _____ grams
Net mass of oily material _____ grams
Person responsible for removal of oily material _____
 Affiliation _____

Sample Destination **Energy Laboratories Inc., P.O. Box 3258, 2393 Salt Creek Highway,
Casper, WY 82501 (307) 235-0515**

Much of the information to be provided on the sample collection forms will be identical to that provided on the sample label. This will include:

1. Names of additional personnel on sampling team;
2. Name and address of the facility at which the sample was collected (NPR-3);
3. Location within the NPR-3 facility at which the sample was collected;
4. Type of sample collected (e.g., soil, sediment, scale, etc);
5. Quantity of sample collected (in terms of approximate sample mass or volume);
6. Sample depth (for soil, sediment samples);
7. Time (24-hour) and Date (day-month-year) of sample collection;
8. Sample ID number;
9. Field measurements and observations associated with each sample collected (e.g., counts/min, estimated radium concentration, etc.);
10. Sample destination (Energy Laboratories Inc., P.O. Box 3258, 2393 Salt Creek Highway, Casper, WY 82501), and mode of transportation; and
11. Gamma survey results, including sketch of facility grounds indicating locations of elevated gamma readings.

The sample collection form should be signed by the collector and the individual who performs the QA check on the completed form. A copy of this form shall accompany each sample sent to the analytical laboratory. The laboratory shall file the form and submit all sample collection forms to LMITCO at the completion of all analytical activities associated with the program.

A-5.3.3 Sample management:

Although no formal chain of custody procedures will be used, some basic standard sample handling procedures will be applied, and are described in this section. The purpose of establishing sample management procedures is to enable the tracking of samples. Each sample tracking system must ensure that (1) all samples are collected according to the Sampling and Analysis Plan; and (2) samples can be traced from sample collection through laboratory analysis, and to the point when the data are entered into the Data Management System.

As part of the tracking system, these procedures provide a traceable record from analytical laboratory results back to the proper field sample, through the following sequence of events:

- Field sampling;
- Shipping;
- Receipt of samples at the Analytical Laboratory;
- Sample preparation; and
- Sample analysis.

The sample shipping record identifies the samples shipped to the laboratory. The sample shipping form should include the following information:

- Sample ID Number(s) contained in the shipment;
- Number of containers used in the shipment;
- Shipped By/Received By: Indicate the individual who ships the samples and the individual accepting the possession and custody of the sample(s). Also, include the date and time of the transfer;
- Maximum surface gamma readings for each container.

An example of the shipping form is provided in Figure A-5.5.

Figure A-5.5 Sample Shipping Form

NPR-3 NORM CHARACTERIZATION

SAMPLE SHIPMENT FORM

Shipped By:
Name: _____
Affiliation: _____
Address: _____

Received By:
Name: _____
Affiliation: _____
Address: _____

Date Shipped: _____
 Day Month Year

Date Received: _____
 Day Month Year

Number of Containers: _____

Shipped _____

Received _____

Sample I.D. Numbers:

_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

Maximum Container Surface Gamma Readings: _____

A-5.4 Data Management SOPs

The need for sample and document management procedures is mandated by several areas of concern, including:

- To establish the authenticity of the evidence collected;
- To facilitate interpretation of sampling and analysis results; and
- To standardize data entries for input into the data management system.

Data management and analysis has two major objectives:

1. To ensure rapid and error-free transmission of data from the point of generation through several layers of verification and validation to the point of placement final report; and
2. To provide a data management system (DMS) that accommodates the final storage and archiving of the data generated during the program.

Because samples analyzed as part of the NPR-3 NORM Characterization will be of a number of distinct types, data management issues must be clearly identified and addressed by developing and adhering to data management procedures. Consistent implementation of these data management procedures by all participants of the program will ensure reliable, consistent, and effective flow, treatment, and storage of the data.

The program will include two types of data: field sampling data and analytical laboratory data.

A-5.4.1 Field sampling data

Data associated with field sampling includes any measurements conducted in the field, such as external gamma measurements on pipe scale or soil samples, etc., as well as supplementary information such as the locations of field samples, detailed field conditions, and instrument methods employed. This information must be available to the analytical laboratory for use in interpreting the analytical data. Existing data from the earlier gamma survey are included.

Procedures have been developed for receiving, logging, and entering the appropriate field information. The form and content of all Sample Log Sheets have been determined, and a standard set of measurements will be taken for each sample type consistent with the Sample Log Sheets. The Sample Log Sheets and the Chain-of-Custody (COC) Records must be reviewed and prepared for data entry.

A-5.4.2 Laboratory data

Data associated with the analytical laboratory includes any and all data resulting from analyses conducted at the analytical laboratory as well as any data generated at other analytical laboratories as part of the QA/QC procedures. Where appropriate, procedures for entering or reformatting the instrument output into a standardized format for providing basic analytical data for each of the analytical methods have been developed.

Laboratory and field data will be delivered by the analytical laboratory in an ASCII readable format. Copies of all sample forms shall be sent to LMITCO. Analytical results shall also be sent to LMITCO upon completion for entry into the database.

A-5.5 Waste Disposal SOPs:

Energy Laboratories Inc. is responsible for the proper disposal of all samples following analysis. This disposal shall be in full compliance with all appropriate federal, state, and local regulations.

A-6. Responsibilities

The purpose of this section of the Sampling and Analysis Plan is to define the responsibilities of the various organizations involved with the NPR-3 NORM Characterization. The primary responsibility for each task within the program (e.g. sample collection, analysis, data management, QA/QC, report writing, program management, etc.) has been assigned, and the key individuals involved from each organization has been identified wherever possible.

A-6.1 Program Development and Overall Responsibility

Lockheed Martin Idaho Technologies Corporation (LMITCO), a contractor for the U.S. Department of Energy at the Idaho National Engineering and Environmental Laboratory (INEEL), is charged with the overall responsibility for the NPR-3 NORM Characterization. This responsibility includes the development of the overall program, including the writing of this Sampling and Analysis Plan, and the coordination between participating organizations. Within LMITCO, the following key individuals have been identified:

LMITCO Project Manager: R. E. Rice has been identified as the Project Manager from LMITCO. As such, he is responsible for the overall management of the project. His duties include maintaining an interface with DOE-ID, submitting monthly progress reports to DOE, managing and tracking the Program budget, and solving management level problems relating to the Program.

LMITCO Principal Investigator: Dr. G. J. White has been designated as the Principal Investigator from LMITCO. The Principal Investigator is responsible for all technical aspects of the project, including technical management of the portion of the program conducted by the analytical laboratory. The technical responsibility includes preparation of the Sampling and Analysis Plan, field testing of the Plan, technical coordination with DOE representatives and with the analytical laboratory, managing the data resulting from the Program, and preparation of the final report.

LMITCO Co-Principal Investigator: A. S. Rood has been designated as Co-Principal Investigator and will work with Dr. White on all aspects of the program.

A-6.2 Sample Collection

Sample collection will be the responsibility LMITCO. Responsibility for determining sampling site locations will also be the responsibility of LMITCO, although NPR-3 personnel will provide input based on logistics and safety considerations. Sampling locations within the facilities will be determined by LMITCO personnel using guidelines described in the Sampling and Analysis Plan. The principle investigator has been identified as having the primary responsibility for coordinating sample collection.

A-6.3 Sample Analysis

All analysis of samples collected for the NPR-3 NORM Characterization, electronic form, ASCII and hardcopy of results, will be the responsibility of the analytical laboratory. A Program Manager at the analytical laboratory will be identified as having responsibility for all analyses.

A-6.4 Equipment and Materials

The purpose of this section of the Sampling and Analysis Plan is to identify the equipment and materials needed to collect each type of sample, and the organization responsible for providing it.

This information is provided in Table A-5.1. Equipment and materials needed to analyze the samples are not included in Table A-5.1, as all analytical needs are the responsibility of the analytical laboratory.

A-6.5 Training

LMITCO field personnel responsible for the collection of samples will be trained prior to collecting samples. This training will include:

- application of the appropriate SOPs;
- conducting the required gamma surveys;
- filling out the appropriate paperwork; and
- packing and shipping the samples.

A-6.6 Data Management

All data management activities for the NPR-3 NORM Characterization will be the responsibility of LMITCO. The Principal Investigator (G. J. White) will be the individual responsible for this task. Analytical data management will be coordinated with the analytical laboratory.

A-6.7 Reporting Requirements

Brief monthly progress reports for the NPR-3 NORM Characterization will be submitted to DOE-FE and DOE-ID. The responsibility for the preparation of these reports will be with the LMITCO Project Manager (R. E. Rice). These reports will describe the current status of the project, accomplishments achieved since the previous report, expected accomplishments prior to the next report, and the program budget. The monthly reports will include input from the analytical laboratory, which will be coordinated by the LMITCO Principal Investigator.

The Final Report containing the data and resulting conclusions will be prepared by LMITCO, as described in the Scope of Work. Input to the report will be provided by the analytical laboratory.

The overall responsibility for preparing this report has been assigned to the LMITCO Project Manager (R. E. Rice).

A-6.8 Waste Disposal

Disposal of unused sample material is the responsibility of the analytical laboratory.

A-7. Schedule

The tentative schedule for the completion of the NPR-3 NORM Characterization is as shown in Table A-7.1.

Table A-7.1. Sampling and analysis schedule for the NORM Characterization Program.

TASK	START DATE	COMPLETION DATE
Preliminary Site Survey	06/17/97	06/19/97
Complete Sampling and Analysis Plan	06/01/97	07/31/97
Collect Samples	08/01/97	09/30/97
Sample Analysis	08/15/97	11/30/97
Prepare Final Report	12/01/97	09/30/98

A-8. Quality Assurance/Quality Control

The important QA/QC elements that will be applied to the NPR-3 NORM Characterization are listed and described below.

1. **QA objectives for measurement** - Detailed descriptions of QA objectives and the procedures to be implemented to meet these objectives during the NPR-3 NORM Characterization are described here. The QA portion of the QA/QC program includes descriptions of the frequency and types of field replicate samples, laboratory split and blank samples, etc. to be analyzed for QA purposes.

For most environmental sampling, it is recommended that control samples be collected. The results from control sites (locations not exposed to contaminants of interest but, ideally, exposed to all other contaminants reaching the monitoring location) are statistically compared with the exposed samples to determine whether contamination has occurred.

- **Field Replicate Samples:** Replicates are samples that have been divided into two or more portions at some step during the measurement process. From the time the replicate sample is produced, each portion of the original sample is carried through the remaining steps of the measurement process as a separate subsample. Field replicates are replicate samples that are collected in the field such that two (or more) presumably duplicate samples are provided. Field replicate samples must be collected in such a manner that they are equally representative of the parameter(s) of interest at a given point in time. Replicate samples can be used to estimate the overall precision of the data collection activity. EPA recommends that field replicates be collected for at least five percent of the sample collected (USEPA, 1987). Because of the wide range of values expected, co-located field replicate samples will represent ten percent of the samples collected during the NPR-3 NORM Characterization.
- **Laboratory Replicate Samples:** Laboratory replicates represent samples collected in the field that are either (1) split in the laboratory at one or more points during the analytical process, with each resulting subsample continuing independently through the remainder of the analytical procedure; or (2) samples that are analyzed twice by the same process. Although laboratory replicate samples must be split in the laboratory for most types of analyses, samples undergoing radionuclide analyses may often simply be counted a second time, followed by a comparison of the two analytical runs. This allows for the adequate determination of analytical precision while avoiding the need for splitting the samples. Laboratory replicates will be the responsibility of the analytical laboratory, and shall be performed according to their standard, approved procedures.
- **Laboratory Split Samples:** These are replicate samples divided into two portions, sent to different laboratories, and subjected to the same environmental conditions and steps in the measurement process. They serve as an oversight function in assessing the analytical portion of the measurement system. Laboratory split samples will be the responsibility of the

analytical laboratory and shall be performed according to their standard, approved procedures.

2. Sampling Procedures - Standard Operating Procedures for the collection of each type of sample collected for analysis as part of the NPR-3 NORM Characterization are provided in Section 5.1 (Sample Collection SOPs) of this Sampling and Analysis Plan.

3. Sampling Identification and Tracking SOPs - Standard Operating Procedures for the identification and tracking of samples collected as part of the NPR-3 NORM Characterization are provided in Section 5.3 (Sample Identification and Tracking SOPs) of this Sampling and Analysis Plan.

4. Calibration Procedure and Frequency - LMITCO field personnel will be responsible for all calibration of field instrumentation, including gamma survey meters.

5. Analytical procedures - Standard Operating Procedures for the analysis of most types of samples collected as part of the NPR-3 NORM Characterization are provided in Section 4.2 (Sample Analysis SOPs) of this Sampling and Analysis Plan. Existing analytical SOPs developed by the designated analytical laboratory for previous radionuclide monitoring programs will be incorporated into the design of this program. As such, they represent proven techniques and may be applied as written to the NPR-3 NORM Characterization.

6. Data reduction, validation and reporting - Data reduction and validation of sample analysis results is the responsibility of the designated analytical laboratory. Analytical data will be transferred in a timely manner to LMITCO in ASCII file and hardcopy form. Data validation for electronic data transfer from ASCII file to a relational data base is the responsibility of LMITCO.

7. Internal quality control - Quality control (QC) procedures for data involve four major activities; sample tracking, data verification, data validation, and data qualification.

- **Sample Tracking:** Procedures for identifying and tracking all field samples and sample containers are provided in Section 5.3 of the Sampling and Analysis Plan. When samples are actually collected and the data entered into the data base, the records will be compared to ensure that the sample was either part of the sample design or a field QA sample. When samples are analyzed in the laboratory, the records will again be compared to ensure that the laboratory sample can be directly traced to a field sample.
- **Data Verification:** All data entered manually must either be entered by two different operators or be subject to visual verification. Data values will also be screened using software designed to ensure that they fall within possible value ranges.
- **Data Validation:** Software procedures that perform statistical and graphical techniques will be used to identify suspicious values. In addition, software will be used to check all important fields for reasonableness.
- **Data Qualification:** Qualifying variables called "flags" will be used for the purpose of identifying field or laboratory conditions that may adversely affect the quality of the data. Flags will also be included to document the results of a third-party audit. In addition,

variables to assess the overall quality of the data (based on design, field, analytical, and document control evaluations) may be required.

8. Assessment of Laboratory Data Precision, Accuracy, and Completeness - Analytical accuracy is a measure of the nearness of an analytical result to the true value, and will be evaluated by analyzing reference standards where applicable for the specific analytical method employed. Analytical precision is a measure of the agreement between two or more measurements, and will be evaluated by analyzing duplicate samples where applicable. Completeness refers to the process of obtaining the required data as outlined in this Sample and Analysis Plan, and is defined as the percentage of measurements made which are judged to be valid. Completeness will be evaluated by dividing the total number of valid results by the total number of reported results. A completeness goal of 90% has been applied to the data collected for this program.

9. Corrective Actions - Data generated by the analytical laboratory will be monitored and reviewed by the laboratory for conformance with established QA/QC requirements. If data falls outside accepted limits, the sample will be either rerun or the "out-of-control" condition will be documented by the laboratory via a nonconformance report. The nonconformance report will indicate the source of the nonconformance and any proposed or initiated corrective action. All personnel participating in field work at the NPR-3 site will first participate in a site safety training session provided by Fluor-Daniels.

A-9. Safety and Health

As required by DOE policy, all aspects of field and laboratory activities in which INEEL are involved must be covered by an approved Safety Plan. The purpose of this Field Safety Plan is to describe the safety procedures and requirements that will be applied to the field portions of the NPR-3 NORM Characterization in which employees of the INEEL will be involved. Laboratory safety procedures will be the responsibility of the designated analytical laboratory.

It is anticipated that the primary radiological health hazard associated with this activity will be from radon and its short lived daughter products. The atmospheric transport pathway is therefore the primary concern. The source of the radon is ^{226}Ra primarily associated with a barite scale that forms deposits on the pipe, and which may be found incorporated into the soil as residual contamination from pipe cleaning processes. Because the radium may be incorporated into the crystalline structure of the pipe scale, the radon emanation fraction may be small, effectively retaining the gamma-emitting daughters of radon and producing localized gamma fields.

All field personnel will wear safety equipment in accordance with site policy at the NPR-3. This includes the use of hard hats, safety glasses, and steel-toed boots.

A-10. References

- Baird, R.D., G.B. Merrell, R.B. Klein, V.C. Rogers, and K.K. Neilson. 1990. Management and disposal alternatives for NORM wastes in oil production and gas plant equipment. Rogers and Associates Engineering Corporation, RAE-8837/2-2.
- Grove Engineering, 1992. Microshield Version 4; Users's Manual, by C.A. Negin and G. Worku. Grove Engineering, Rockville Maryland, 20850
- Otto, G.H. 1989. A national survey on naturally occurring radioactive materials (NORM) in petroleum producing and gas processing facilities. Report to the American Petroleum Institute.
- Rood, A.S., D.T. Kendrick, and G.J. White. 1998. Measurement of ^{222}Rn flux, ^{222}Rn emanation, and ^{226}Ra concentration from injection well pipe scale. Health Physics 75:187-192
- U.S. District Court for the District of Columbia. 1990. Settlement Agreement, Natural Resources Defense Council Inc. vs. William K. Reilly, Administrator of the Environmental Protection Agency.

