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RADIONUCLIDE INVENTORY DISTRIBUTION PROJECT DATA EVALUATION AND VERIFICATION WHITE PAPER

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DISCLAIMER

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ACRONYMS AND ABBREVIATIONS

Am	americium
CAI	corrective action investigation
CAS	Corrective Action Site
CAU	Corrective Action Unit
cm	centimeter(s)
Co	cobalt
Cs	cesium
DCG	Derived Concentration Guide
DOE	U.S. Department of Energy
DQO	Data Quality Objective
DRI	Desert Research Institute
EG&G	Edgerton, Germeshausen, and Grier Energy Measurements, Inc.
EPA	U.S. Environmental Protection Agency
Eu	europium
FFACO	*Federal Facility Agreement and Consent Order*
FGR	Federal Guidance Report
g/m^3	gram(s) per cubic meter
Ge	germanium
GIS	Geographic Information System
IRL	Inverse Relaxation Length
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
m	meter(s)
microR/hr	microRoentgen(s) per hour
mrem/IA-yr	millirem(s) per industrial access year
NAEG	Nevada Applied Ecology Group
nCi/m^2	nanocurie(s) per square meter
NDEP	Nevada Division of Environmental Protection
NSTec	National Security Technologies, LLC
NTS	Nevada Test Site
PARCC	precision, accuracy, representativeness, completeness, and comparability

ACRONYMS AND ABBREVIATIONS, CONTINUED

pCi/g	picocurie(s) per gram
PIC	pressurized ionization chamber
Pu	plutonium
QA	quality assurance
QC	quality control
REECo	Reynolds Engineering and Electrical Co.
RESRAD	Residual Radioactivity
RIDP	Radionuclide Inventory and Distribution Program
SAFER	Streamlined Approach for Environmental Restoration
Sr	strontium
TEDE	total effective dose equivalent
Th	thorium
TLD	thermoluminescent dosimeter
U	uranium
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WCP	Waste Consolidation Project

EXECUTIVE SUMMARY

Testing of nuclear explosives caused widespread contamination of surface soils on the Nevada Test Site (NTS). Atmospheric tests produced the majority of this contamination. The Radionuclide Inventory and Distribution Program (RIDP) was developed to determine distribution and total inventory of radionuclides in surface soils at the NTS to evaluate areas that may present long-term health hazards. The RIDP achieved this objective with aerial radiological surveys, soil sample results, and in situ gamma spectroscopy.

This white paper presents the justification to support the use of RIDP data as a guide for future evaluation and to support closure of Soils Sub-Project sites under the purview of the *Federal Facility Agreement and Consent Order*. Use of the RIDP data as part of the Data Quality Objective process is expected to provide considerable cost savings and accelerate site closures. The following steps were completed:

- Summarize the RIDP data set and evaluate the quality of the data.
- Determine the current uses of the RIDP data and cautions associated with its use.
- Provide recommendations for enhancing data use through field verification or other methods.

The data quality is sufficient to utilize RIDP data during the planning process for site investigation and closure. Project planning activities may include estimating 25-millirem per industrial access year dose rate boundaries, optimizing characterization efforts, projecting final end states, and planning remedial actions. In addition, RIDP data may be used to identify specific radionuclide distributions, and augment other non-radionuclide dose rate data. Finally, the RIDP data can be used to estimate internal and external dose rates.

Additional, enhanced RIDP data use is possible. Recommendations include finalizing the existing database and making it accessible to the Soils Sub-Project working group, evaluating Corrective Action Unit (CAU) 371 and CAU 372 data against the RIDP data, evaluating the use of conservative correction factors in estimating internal dose rates for application at other Soils Sub-Project sites, evaluating the use of conservative correction factors in estimating external dose rates for application at other Soils Sub-Project sites, and evaluating CAUs for closure through the Streamlined Approach for Environmental Restoration process.

1.0 INTRODUCTION

1.1 Purpose and Objectives

The purpose of this white paper is to provide justification to support the use of the Radionuclide Inventory and Distribution Program (RIDP) data as a guide for future evaluation and to support closure of Soils Sub-Project sites under the purview of the *Federal Facility Agreement and Consent Order* (FFACO). Use of the RIDP data as part of the Data Quality Objective (DQO) process is expected to provide considerable cost savings and accelerate site closures. To determine if RIDP data are usable, the following steps were completed:

- Summarize the RIDP data set and evaluate the quality of the data.
- Determine the current uses of the RIDP data and cautions associated with its use.
- Provide recommendations for enhancing data use through field verification or other methods.

1.2 Scope

The scope of this white paper is to validate the RIDP data set in order to justify its use to support future closure of Soils Sub-Project sites under the FFACO. To accomplish this scope, a description and analysis of data collection methods and techniques, data storage systems, data quality evaluations and verification activities, cautions associated with the data, and guidelines for current data use are provided. This paper also provides recommendations for additional verification methods.

1.3 Contents

This white paper is divided into the following sections:

Section 1.0 Introduction – provides the purpose, scope, and contents of this white paper.

Section 2.0 Background – summarizes the purpose, objectives, and history of the RIDP, and describes the RIDP database.

Section 3.0 Data Summary – describes the data sources, including aerial radiological surveys, soil samples, and in situ measurements, used to develop the final RIDP values.

Section 4.0 Data Assessment – presents the results of data quality analyses, including pilot studies, calibration analysis, evaluation of detection capabilities and duplicate values, quality control (QC) procedures, and laboratory quality assurance (QA).

Section 5.0 Data Cautions and Use – provides a list of the cautions associated with the RIDP data if further verification is not completed and a set of guidelines for appropriate use of the data given the current level of QA.

Section 6.0 Conclusions and Recommendations – states why the RIDP data can be used for future closure of Soils Sub-Project sites and provides recommendations for possible additional verification methods.

Section 7.0 References – provides a list of references cited in this white paper.

Appendix A RIDP Data Conversion Process – outlines the method used to convert the RIDP data to units of picocuries per gram (pCi/g).

2.0 BACKGROUND

2.1 RIDP Purpose and Objectives

The RIDP was developed to determine distribution and total inventory of radionuclides in surface soils associated with testing at the Nevada Test Site (NTS). Its objective was to evaluate areas of the NTS that may have been sufficiently contaminated to present long-term health hazards. The RIDP achieved this objective by using aerial radiological surveys, soil sample results, and in situ gamma spectroscopy.

2.2 History of the RIDP

Testing of nuclear explosives caused widespread contamination of surface soils on the NTS. Atmospheric tests produced the majority of this contamination. The RIDP conducted a thorough investigation of contaminated surface soils at the NTS using an in situ gamma spectroscopy technique developed in the 1970s by Lawrence Livermore National Laboratory (LLNL). The project began in 1981, and the final measurements were collected in 1986. A total of 3,850 measurements were collected from all areas of the NTS where aboveground tests had been conducted and where other localized sources of contamination may have been present, such as waste dumps. Areas not investigated included rugged highland areas and craters where the RIDP vehicle could not safely access the sites.

Aerial radiological survey data collected between 1976 and 1984 were used to plan locations for the in situ measurements. In addition, soil samples were collected to calibrate the in situ measurement system by establishing the radionuclide contaminant distribution with depth. Results of soil samples also provided ratios of non-gamma emitters to gamma emitters.

Edgerton, Germeshausen, and Grier Energy Measurements, Inc. (EG&G) and the Desert Research Institute (DRI) performed five years of field work and three years of analysis. Data collection and analysis were carried out under the Basic Environmental Compliance and Monitoring Program of the U.S. Department of Energy (DOE). The results were published in five reports (McArthur and Kordas, 1983; 1985; McArthur and Mead, 1987; 1988; 1989). A summary report was also published (McArthur, 1991) that provided estimated levels of soil radioactivity at the NTS, including quantities of the 16 most significant man-made radionuclides produced by nuclear weapons testing.

2.3 RIDP Database

The RIDP in situ gamma spectroscopy data were originally archived. DRI imported the archived data into a Microsoft Access database in 2006 (Gray et al., 2007). RIDP values for man-made radionuclides were reported in nanocuries per square meter (nCi/m^2), while naturally occurring radionuclides (e.g., potassium-40, thorium [Th]-232, uranium [U]-238) were reported in units of pCi/g.

National Security Technologies, LLC (NSTec), created a Microsoft Access database to support additional analyses and assessments, enhanced data development, calculations of 25-millirem per industrial access year (mrem/IA-yr) dose rate boundaries, and spatial Geographic Information System (GIS) analysis. The RIDP locations were grouped using GIS selection tools. The hard copy reports were reviewed to ensure that correct ratios and Inverse Relaxation Lengths (IRLs) were applied to each measurement for point-by-point analyses. Subsequently, aerial radiological survey results, dose-based limits, soil sample results, Corrective Action Unit (CAU) 370 data, and recent LLNL data were added to the database for data comparisons. The recent LLNL data had been collected to verify a modeling code to predict radioactive fallout from nuclear weapons detonations. The LLNL data provided limited opportunities for detailed comparisons but supported the RIDP and recent aerial radiological survey results for CAU 371.

3.0 DATA SUMMARY

The following data sources were used to develop the RIDP data set:

- Aerial radiological surveys – The results of these surveys were used to select locations for in situ field measurements.
- Soil samples – Results were used to determine depth distribution of various radionuclides in soil for calibration of the in situ measurement system. In addition, radiochemical analysis of soil samples provided information about radionuclides that do not emit gamma rays and therefore cannot be measured by in situ spectroscopy.
- In situ measurements – Field measurements of external exposure rate and radionuclide activities were collected by in situ gamma spectroscopy.

3.1 Aerial Radiological Surveys

Aerial radiological surveys were performed from a helicopter to improve upon previous surveys that had been conducted using fixed wing aircraft and to more clearly define contaminant boundaries and relative levels of contamination on the NTS. The aerial surveys provided greater accessibility to contaminated areas, increased measurement sensitivity, and improved spatial resolution. The RIDP used the results of these surveys to develop a statistically based sampling plan for in situ measurements.

The aerial surveys were used to bias sample locations to areas with higher contamination. In general, the RIDP collected more in situ measurements on a tighter grid in areas that had been shown by the aerial surveys to have higher contamination. In areas further away from a ground zero and that were shown by the aerial surveys to have lower contamination levels, fewer in situ measurements were collected with larger grid spacing.

3.2 Soil Samples

At most of the sites investigated by the RIDP, radionuclides are concentrated in the top several centimeters (cm) of soil. However, at some locations, activation products, such as europium (Eu), extend deeper than fission products (e.g., cobalt [Co] and cesium [Cs]). Determination of the contaminant distribution with depth is necessary for in situ measurement system calibration.

The RIDP collected soil samples at selected locations for analysis by gamma spectroscopy. Samples were collected in increments of 0–2.5 cm, 2.5–5 cm, 5–10 cm, and 10–15 cm. At selected sites, such as SEDAN, where it was suspected that radioactivity extended deeper into the soil, samples were collected in six increments to a depth of 30 cm. Soil samples were usually collected in areas where in situ measurements were taken and along perpendicular transects through a ground zero.

The activity of each radionuclide was determined to decrease exponentially with depth, with the rate of decrease characterized by an IRL (α) expressed in units of cm^{-1}. The method for calculating IRLs from soil sample results varied during the project but generally relied on the following equation:

$$S_{z'} = S_o e^{-(az')}$$

Where:
S_0 is the activity per cm^3 at the soil surface
α is the IRL in cm^{-1}
z′ is the contaminant depth

Average calculated IRLs for each radionuclide were used for analysis of the in situ measurements. In some instances, depth distributions near a ground zero were different from those farther away. The measurements from the ground zero regions were therefore analyzed using a different set of IRLs.

Soil samples from the top increment at each location were also radiochemically analyzed for strontium (Sr)-90, plutonium (Pu)-238, Pu-239/240, Cs-137, and americium (Am)-241. The ratios of Sr-90 to Cs-137, Pu-238 to Am-241, and Pu-239/240 to Am-241 were then calculated and applied to the RIDP measurements for the associated gamma-emitting radionuclides. The RIDP reports and the DRI database used these values to calculate total inventory for these radionuclides.

The analyses in this white paper required that the correct ratio and IRL be applied to each RIDP measurement. This was accomplished through a review of the hard copy reports and GIS tools. The ratio and IRL for each RIDP measurement were developed for this white paper and included in the enhanced Microsoft Access database described in Section 2.3 to convert RIDP data to units of pCi/g as outlined in Appendix A. An internal QA of this process was completed; however, a more formal QA should be performed prior to release of the enhanced database to the Soils Sub-Project working group.

The IRLs were also required to assess external dose rates. External dose rates were calculated using coefficients provided by Beck (1980). Beck's coefficients were developed for surface deposition of radionuclides resulting from aboveground nuclear weapons testing. Nuclear weapons test sites are unique because the contamination is distributed exponentially with depth. In addition, the depth distribution is different for different radionuclides and at different locations. Beck's coefficients allow the most applicable conversion factors for each RIDP measurement. Other dose rate assessment codes, such as the Residual Radioactivity (RESRAD) model, do not take into account the exponential distribution with depth known to exist at the NTS. A number of analyses in this white paper use the Beck coefficients to assess external dose rates at RIDP locations by calculating the exposure for each radionuclide, summing those exposures, and converting to effective dose equivalent rates.

3.3 In Situ Measurements

In situ measurements were collected with a collimated high-purity germanium (Ge) detector mounted on an off-road vehicle and suspended approximately 7.4 meters (m) above the ground (Figure 1). The detector had a circular field of view with a radius, or sample size, of approximately 10 m for Am-241, 12 m for Cs-137, and 21 m for Co-60. Other components of the measurement system, including an amplifier, power supply, pulse-height analyzer, and desktop computer, were located inside the vehicle. The vehicle was positioned near a measurement point, and the detector was cantilevered out over the measurement location. The operator entered a description of the location into the computer and began the spectrum acquisition. During the 15-minute acquisition period, a pressurized ionization chamber (PIC) set at 1 m above the ground under the detector measured the external exposure rate. At the end of the acquisition period, the detector was retracted, and the vehicle was moved to the next location.

The system was maintained and operated by EG&G. During each measurement, pulses from gamma rays reaching the detector were sorted into a 4,096-channel energy spectrum. At the end of the 15-minute count period, the spectra were transferred to the computer, where a spectral analysis program computed the concentrations of various radionuclides. Finally, the spectra were transferred to magnetic tape for further future analysis. As each measurement was completed, the spectra were sent to LLNL for analysis by a modified version of GAMANAL (Gunnink and Niday, 1971), a more sophisticated spectral analysis program than the one used in the field.

FIGURE 1. VEHICLE USED TO COLLECT IN SITU MEASUREMENTS

4.0 DATA ASSESSMENT

Precision, accuracy, representativeness, completeness, and comparability (PARCC) are used to evaluate data quality. These PARCC criteria had not been developed at the time of the RIDP; however, the concepts behind the PARCC criteria can be used to assess the RIDP data by using the data quality information collected at the time. The discussions in the following sections indicate how the PARCC parameters were evaluated.

Prior to field activities, an extensive series of calibrations and test measurements were performed on the detectors to ensure accuracy. In addition, the energy calibration of each detector was checked three times per day during field operations. Consistency of these measurements ensured precision over time. Approximately 30 percent of the 8,550 spectra recorded during the RIDP were laboratory calibration runs to verify the angular response and effective area of the detector. Another 23 percent of the spectra were field calibrations.

Laboratory QA procedures during the RIDP included inter-laboratory comparisons (comparability), analysis of blind reference samples (accuracy), and comparisons of hidden replicates (precision). A QA "referee" managed sampling protocols, reviewed data results, and provided summary statements of data quality. In addition, LLNL conducted an assessment of pilot measurements collected prior to 1980. Finally, for this white paper, NSTec has evaluated other data sets and compared them to the RIDP data to further assess the RIDP data quality. These results are presented in Section 4.7.

4.1 Pilot Measurements and Project Improvements

Pilot studies for the RIDP were conducted prior to 1980. Difficulties were encountered with instrument calibration and storage. LLNL was asked to perform the following tasks for DOE to expand the program:

- Perform an assessment of the methodology and results.
- Perform an engineering evaluation of the equipment.
- Provide recommendations for improvement.

A summary of previous data, including Field Instrument for Detection of Low-Energy Radiation data and soil sample results, was developed by the Nevada Applied Ecology Group (NAEG) and stated that soil sample results prior to 1980 were questionable due to laboratory analytical problems (Anspaugh and Kordas, 1980).

In addition, obtaining a representative set of soil samples to accurately reflect site conditions and the associated potential dose rate is difficult. Estimating the total effective dose equivalent (TEDE) from soil samples is problematic due to the heterogeneous nature of soil contamination. This is known as the "hot particle problem." The hot particle problem leads to incorrect dose rate estimates depending on whether or not a "hot particle" is captured in the sample or sample aliquot. The distribution of Pu isotopes in soil has been found to vary by a factor of 10 between individual 1-gram aliquots from a single soil sample (Los Alamos Scientific Laboratory, 1971). In situ methods are not subject to these errors because the sample size, or the measurement field of view, is large relative to an individual soil sample. The large field of view integrates contributions from discrete particles and trinity glass, and represents a more realistic exposure scenario than soil samples.

In 1976, EG&G built the vehicle and supporting equipment for taking in situ measurements at the NTS. However, EG&G chose not to operate the system. DRI took over the system, extensively modified the electrical components, and began taking measurements in 1978 on Frenchman and Yucca Flats. However, these measurements were of unknown validity or were unreported. DRI then collected measurements around the perimeter of the NTS until the project was halted in 1980.

LLNL reported that until 1980, very little of the data collected by NAEG and DRI was reliable. The scope of the project was unclear, no schedule had been developed for the project, and criteria such as what should be measured and to what accuracy, as well as basic reporting standards, were poorly defined and changed frequently. Additional problems with calibration procedures, spectral analysis software, and equipment configuration were noted. Protocols to address these issues were integrated into the RIDP.

To continue the project, LLNL endorsed the use of the in situ measurement method, supplemented by judicious soil sampling to determine ratios of radionuclides and depth distributions for calibration of the in situ detectors. It was recommended that aerial radiological surveys be used to guide the more detailed, ground-based measurements.

The RIDP also integrated lessons learned from soil sampling conducted at the NTS and Tonopah Test Range, closure work performed at Eniwetok Atoll, and activities conducted by NAEG.

4.2 Calibration Analysis

Details regarding calibration of the in situ detector are provided by Anspaugh (1976), Beck et al. (1972), and Tipton et al. (1978). The equation used to convert counts in a given energy range to specific radionuclide activities in units of nCi/m^2 requires several parameters, including detector response at various energies, detector response with respect to the angle of gamma rays interacting with the detector, gamma ray attenuations in air and soil, soil density and moisture content, and radionuclide depth distribution.

Detector response was determined empirically using calibrated sources. The consistency of detector response was checked three times per day during field operations. Mass attenuation coefficients for the energies of interest were obtained by interpolation of values given by Beck et al. (1972). IRLs of various radionuclides were derived from soil sample results. Contaminant distribution with depth is a sensitive parameter, and the RIDP made efforts to select this parameter to minimize errors. The following parameters values were assumed:

- Air density: 0.001204 grams per cubic centimeter (g/cm^3)
- Wet soil density: 1.5 g/cm^3
- Soil moisture: 10 percent

McArthur and Kordas (1983) evaluated the effect of soil moisture content and density values on calculations and found that, for Am-241, a 20-percent difference in actual soil moisture from assumed soil moisture results in a 3-percent error, and the small error leads to conservative results when the actual value is lower than the assumed value. This error is smaller for other radionuclides. Additional studies documented in DOE’s Environmental Measurements Laboratory Procedures Manual, HASL-300, indicate the insensitivity of these parameters (Helfer and Miller, 1988).

Since the RIDP derived sensitive parameters, such as IRL, through empirical methods and used assumed values only for relatively insensitive parameters, RIDP measurement errors were minimized. The IRL is a measure of how uniformly the contaminant is distributed with depth; therefore, this is a sensitive parameter for both RIDP and direct soil sampling methods. The RIDP found these distributions varied by radionuclide and location. A static soil sample depth will concentrate some values and dilute others. This is a potential source of error for both RIDP and soil sample data and thus a potential basis for non-comparable data.

4.3 Detection Capability Evaluation

Detection capabilities for individual measurements were not reported in the RIDP database. To be of value, the RIDP system must be sensitive enough to detect contaminants at or below decision levels. The detection capabilities of the RIDP measurements were estimated for this white paper using a reporting protocol observed in the RIDP reports that identified measurements that were at or near detection capabilities as “upper-limit values.” The results of a query against this reporting protocol were verified against maps presented in the RIDP reports, and an average upper-limit value was established for each radionuclide. Table 1 provides the maximum upper-limit value for each radionuclide and compares them to the draft Derived Concentration Guides (DCGs) established for internal dose rates at CAU 370. By summing the maximum upper limit-values for all radionuclides, a total dose rate of 0.02 mrem/IA-yr is found, which is less than 0.1 percent of the 25-mrem/IA-yr limit. As a result, it can be stated that the RIDP system can detect radionuclides to determine internal dose rates below decision levels.

TABLE 1. RIDP SENSITIVITY FOR INTERNAL DOSE RATE CALCULATIONS

RADIONUCLIDE	DERIVED CONCENTRATION GUIDE (pCi/g)	MAXIMUM UPPER-LIMIT VALUE (pCi/g)	DOSE RATE (mrem/IA-yr)
Am-241	5.63 E+03	5.15	9.14 E-04
Co-60	2.70 E+06	1.03	3.82 E-07
Cs-137	1.63 E+06	1.36	8.35 E-07
Eu-152	6.99 E+06	3.62	5.18 E-07
Eu-154	5.09 E+06	6.16	1.21 E-06
Eu-155	3.42 E+07	5.43	1.59 E-07
Pu-238	6.30 E+03	6.70	1.06 E-03
Pu-239	5.72 E+03	99.10	1.73 E-02
Sr-90	4.52 E+05	3.49	7.73 E-06
Th-232	1.86 E+03	2.31	1.24 E-03
U-235	2.45 E+04	2.89	1.18 E-04
U-238	2.55 E+04	11.33	4.44 E-04
		Total Dose Rate	2.11 E-02

As with other methods used to measure radioactivity, RIDP detection capability is related to background radiation in a given area. It is an indication of how well an instrument can discern contamination from background radiation. Generally, the higher the local background radiation levels, the higher the detection capability of a given instrument.

Detection capabilities of the RIDP measurements for external dose rates were determined by calculating the average and the standard deviation of the upper-limit values for Co-60, Cs-137, Eu-152, and Eu-154. Average external dose rates plus two standard deviations were then calculated for each radionuclide. These isotope-specific external dose rates were summed to determine a conservative sensitivity estimate. This determination indicates that the RIDP measurement sensitivity for external dose rate is approximately 4 mrem/IA-yr. This was calculated from non-decay-corrected values. Over time, the value will decrease and, essentially, the RIDP data will become more sensitive.

The RIDP sensitivity estimate for determining external dose rates was compared with estimated thermoluminescent dosimeter (TLD) sensitivity. TLD sensitivity was estimated using results of TLD stations across the NTS. This is analogous to the RIDP estimate because the RIDP upper-limit values were also derived across the NTS, where background radiation varies. An average background TLD external dose rate plus two standard deviations was calculated. This resulted in an estimated TLD measurement sensitivity for external dose rate of approximately 16 mrem/IA-yr, which is much closer to the 25-mrem/IA-yr limit than the RIDP sensitivity estimate. Both the RIDP estimate and the TLD estimate are at a 95-percent confidence interval. In most areas, the actual values are lower than the estimate. This evaluation reflects on the accuracy, precision, and relative sensitivity of the RIDP data.

4.4 Duplicate Measurement Quality

McArthur and Kordas (1983) reported QA results for duplicate measurements. The average deviation from the mean of duplicate sets was 8.6 percent. Maximum deviations were not presented. For this white paper, NSTec also performed an assessment of the RIDP data to determine duplicate measurement quality. A total of 454 duplicate RIDP measurements were assessed. Only 35 of the duplicate measurements varied from each other by more than 25 percent. All of the less precise values were at or near the calculated detection capability; therefore, as shown in Section 4.3, any errors at these levels have an insignificant impact on RIDP-calculated dose rates. The analysis of duplicate measurements indicates that higher values result in better agreement between values. This indicates that at levels that could impact total dose rate calculations, the RIDP data are precise.

4.5 Quality Control Measurement Analysis

The RIDP collected measurements in real time to evaluate data quality. These measurements were collected with PICs set 1 m above the ground. The PICs directly measured the external exposure rate in microroentgens per hour (microR/hr). The RIDP also measured radionuclide-specific contaminant levels and used these measurements to calculate an expected exposure rate in real time. During data acquisition, the expected exposure rate that was calculated from the in situ measurements was compared to the PIC measurements. If the RIDP measurements led to an expected exposure rate that was different from the PIC-measured exposure rate, which indicated a potential measurement problem, another measurement was taken, and, if needed, the instrument was recalibrated. While somewhat informal and based on judgment, this process improved RIDP measurement accuracy.

4.6 Laboratory Quality Assurance

Reynolds Engineering and Electrical Co. (REECo) analyzed soil samples during the RIDP. Each RIDP report, except the first, contains an appendix that addresses QA issues for soil samples, and describes any changes in procedure since the previous report. Each appendix explains problems with the data sets and how they were addressed, and concludes with a summary statement. Each appendix also presents replicate, inter-laboratory, and other supporting QA data.

The QA procedures in each report included the following elements:

- Analysis of replicate aliquots from samples, a measure of data precision
- Analysis of independently calibrated reference blinds for a related program, a measure of data accuracy
- Duplicate gamma spectroscopy measurements of samples by LLNL, a measure of data comparability

In addition, to resolve uncertainties and provide further assurance of data reliability and comparability, samples were typically analyzed by two independent labs, for a total of four labs.

The sections below summarize specific data quality findings and limitations in each RIDP report. While the raw laboratory QA data are not readily available, the summary discussions provided in the RIDP reports are adequate to determine data quality and usability for the limited purposes of estimating IRLs and ratios. The analyses indicate there are no specific problems with the data that would preclude further development of the RIDP data or the evaluation of RIDP data quality. RIDP soil sample results will not be used directly in the DQO process or for future project planning activities.

4.6.1 McArthur and Kordas, 1985 (RIDP Report #2)

Inconsistencies were noted in REECo soil sample results. Possible causes included the "hot particle problem," errors in technique, and errors in data transcription or sample labeling. There was "reasonably good agreement" among the four analytical labs, except for samples with low analytical results. For samples treated by chemical separation, inconsistencies were attributed to the hot particle problem and small final aliquots, which were the result of efforts to keep activity levels in the laboratory low.

The authors concluded that the REECo data were satisfactory for RIDP purposes because RIDP used averages of many measurements and because the program objectives specified a final inventory determination within a factor of two. However, they recommended that a "more extensive and formalized QA program is desirable," and referred to a new QA program to develop for future use.

4.6.2 McArthur and Mead, 1987 (RIDP Report #3)

The QA program for this series of analyses included the same elements as the previous program (including analysis by four labs, two of them independent) with the addition of blind and background samples and hidden replicates. In addition, a "referee" was provided by Los Alamos National Laboratory (LANL) and assigned to manage blind and replicate samples so that they remained unknown to the analyst. The referee also kept a log of sample numbers. REECo included additional internal performance tests using actual samples.

The referee evaluated sample results and flagged questionable data for further investigation. The flagged data were first reviewed for transcription and typographical errors. The hot particle problem was then investigated.

The results of the QA evaluation indicated that there was good reproducibility based on blind sample results. The replicate sample results were considered acceptable. Exceptions included a few samples with hot particles, two samples for which an explanation of the discrepancy was not determined, and an unexplained high bias for Am-241 results collected from SEDAN.

The authors concluded that the data set is a reliable and accurate representation of radioactivity in the samples tested.

4.6.3 McArthur and Mead, 1988 (RIDP Report #4)

For this series, samples from SCHOONER were collected under a modified QA program (i.e., modified labeling procedures) to accommodate a new independent laboratory. Other elements remained the same, including inter-laboratory comparisons, analysis of blind reference samples, and comparisons of hidden replicate samples. A LANL referee managed blinds and replicates, and evaluated the test results.

The results of the QA evaluation using only SCHOONER samples (though they had low activity levels) indicated acceptable agreement for blind reference samples and replicate samples. For the entire data set, a few of the REECo results and one of the independent lab results were flagged as questionable but were not rejected. The data set as a whole was judged as reliable. The authors suggested that the flagged results should be used with care, and that the practice of averaging measurements reduces errors associated with individual analyses.

4.6.4 McArthur and Mead, 1989 (RIDP Report #5)

The QA program did not change for this series. Problems with some of the flagged sample results were attributed to the hot particle problem. Other causes were not determined but may be attributed to errors in transcription, labeling, computation, calibration, or contamination.

This series of analyses also included a comparison of results for fine and coarse soil fractions (previously, only fine soil fractions were analyzed). This comparison showed that, as previously assumed, most of the radioactivity is in the fine soil fractions. This is not site-dependent and is a consistent feature of radioactive contamination resulting from nuclear weapons testing.

Based on the analysis of blind and replicate samples, the overall data set was judged to be reliable. It was noted that flagged data should be used with caution.

4.7 Comparisons to Other Data Sets

To further assess RIDP data quality for this white paper, NSTec has compared the RIDP data to data collected by other methods. The results of these evaluations are presented below.

4.7.1 1994 Aerial Radiological Survey Data

RIDP results for Am-241 and strong gamma-emitting contaminants of concern were compared to aerial radiological survey data collected in 1994 (Hendricks and Riedhauser, 1999). Am-241 aerial radiological survey data are presented in units of counts per second, and strong gamma-emitting radionuclides are quantified as estimated exposure rates. Aerial radiological survey data, by nature, represent average contaminant levels over wide areas.

The aerial radiological survey data are presented as ranges of results, or bins. There are six bins for Am-241 aerial radiological survey data and ten bins for total man-made aerial radiological survey data. The RIDP results were grouped according to the ranges or bins in which they were located. GIS selection tools were used to determine which RIDP values were geographically located within each bin. The RIDP values within each of the bins were averaged and compared to the middle value of each aerial radiological survey range.

Figures 2 and 3 illustrate these comparisons and demonstrate a linear relationship based on wide-area averages of RIDP data. The purpose of this evaluation was an initial indication of whether the RIDP data are of reasonable quality to undergo additional assessment and evaluation. The results indicate that the RIDP data are of reasonable quality to proceed with the additional quality assessments discussed later in this white paper.

The additional assessments presented in this white paper establish RIDP data quality more firmly than the initial positive indication provided by these wide-areas average comparisons. Additional data development may allow a coefficient to be applied to the aerial radiological survey data to estimate dose rates in areas where there is sparse RIDP measurement coverage. The result of such an estimate would only provide a wide-area average.

Since the actual variability of contaminants in soils is quite high, such a process would be developed with conservative assumptions. This limitation exists for application of a correction factor whether the factor is applied to RIDP data or to newly collected data. In either case, application of a correction factor to aerial radiological survey data to make closure decisions requires a full understanding of the actual variability of contaminant levels within a site-specific survey bin and, based on that variability, calculating an appropriately conservative correction factor to estimate dose rates.

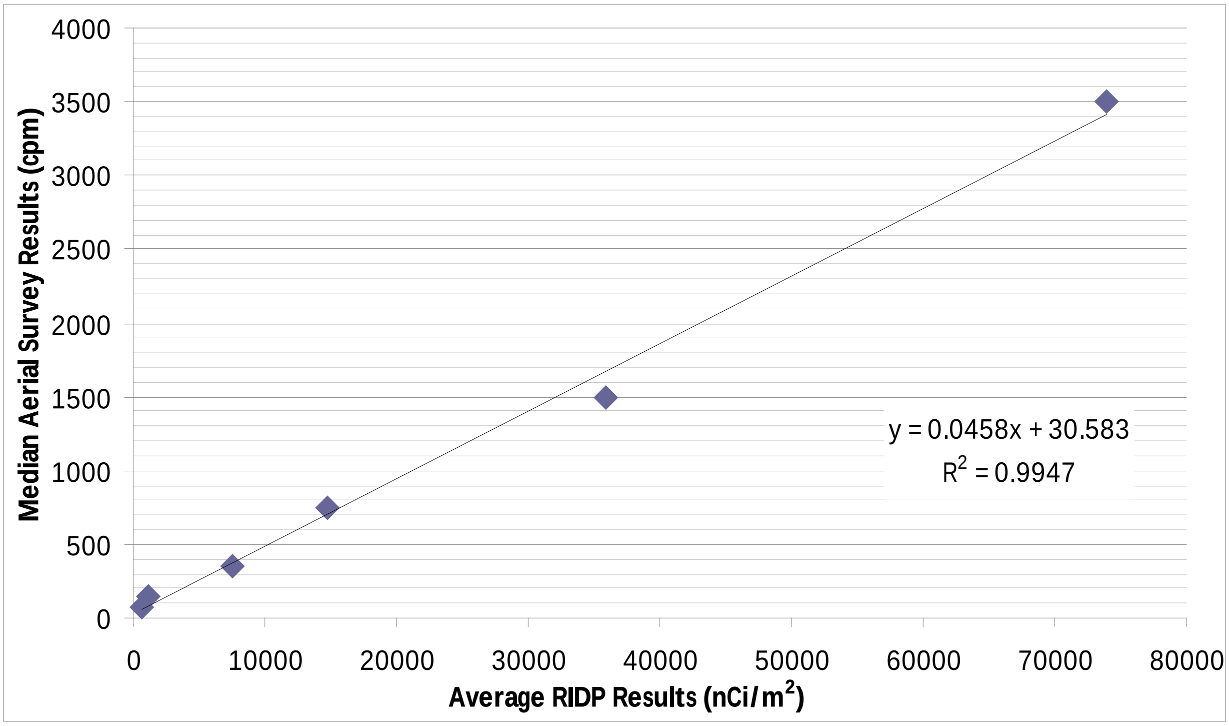

FIGURE 2. 1994 AERIAL RADIOLOGICAL SURVEY DATA COMPARED TO RIDP RESULTS FOR AM-241

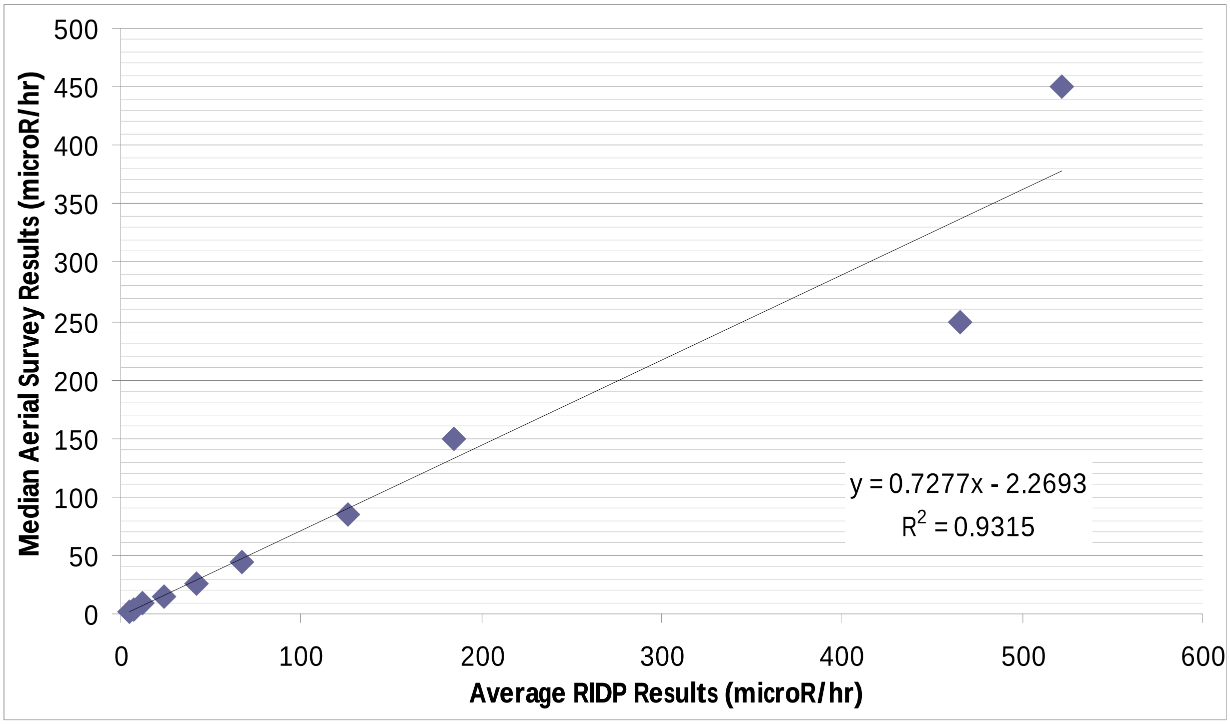

FIGURE 3. 1994 AERIAL RADIOLOGICAL SURVEY DATA COMPARED TO RIDP RESULTS FOR TOTAL MAN-MADE RADIONUCLIDES

4.7.2 Corrective Action Unit 370 Investigation Results

For this white paper, the RIDP data have been compared to the CAU 370 corrective action investigation (CAI) results, and the data show excellent agreement. Evidence demonstrating the currency and accuracy of the RIDP data are presented below.

Dose rate assessments for CAU 370 involved calculating internal and external dose rates separately; therefore, the following comparisons and discussion are also separated in this way.

4.7.2.1 Corrective Action Unit 370 Internal Dose Rates

Soil sample results for CAU 370 were used to assess internal dose rates. The RESRAD code models dose rates based on the concentrations of radionuclides in soil and was used to convert soil sample results in units of pCi/g to dose rates in units of mrem/IA-yr. The RESRAD code was also used to determine draft DCGs for CAU 370.

To compare the RIDP results to the CAU 370 soil sample results for the primary, internal dose-driving radionuclides, the RIDP data have been converted to units of pCi/g using the method in Appendix A. Figures 4–6 compare the converted RIDP data to the CAU 370 soil sample results averaged across each CAU 370 soil sample plot for Am-241, Pu-238, and Pu-239.

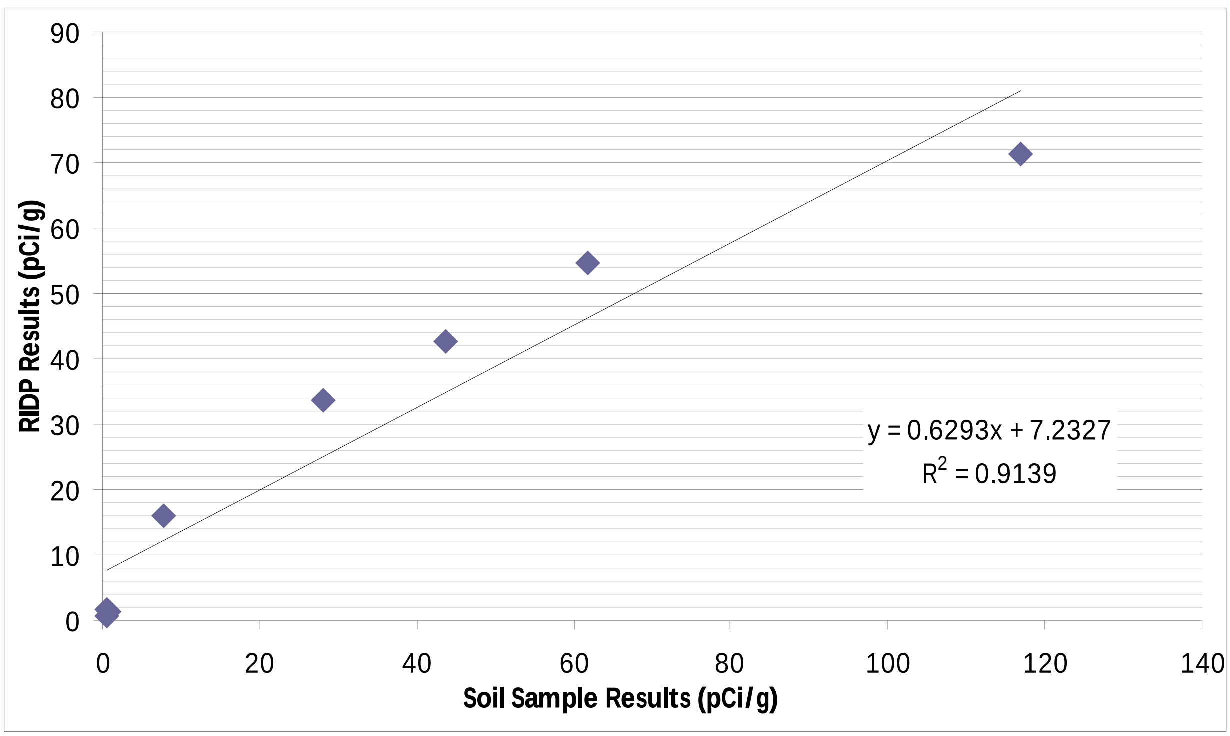

FIGURE 4. CAU 370 CAI RESULTS FOR AM-241 COMPARED TO RIDP DATA

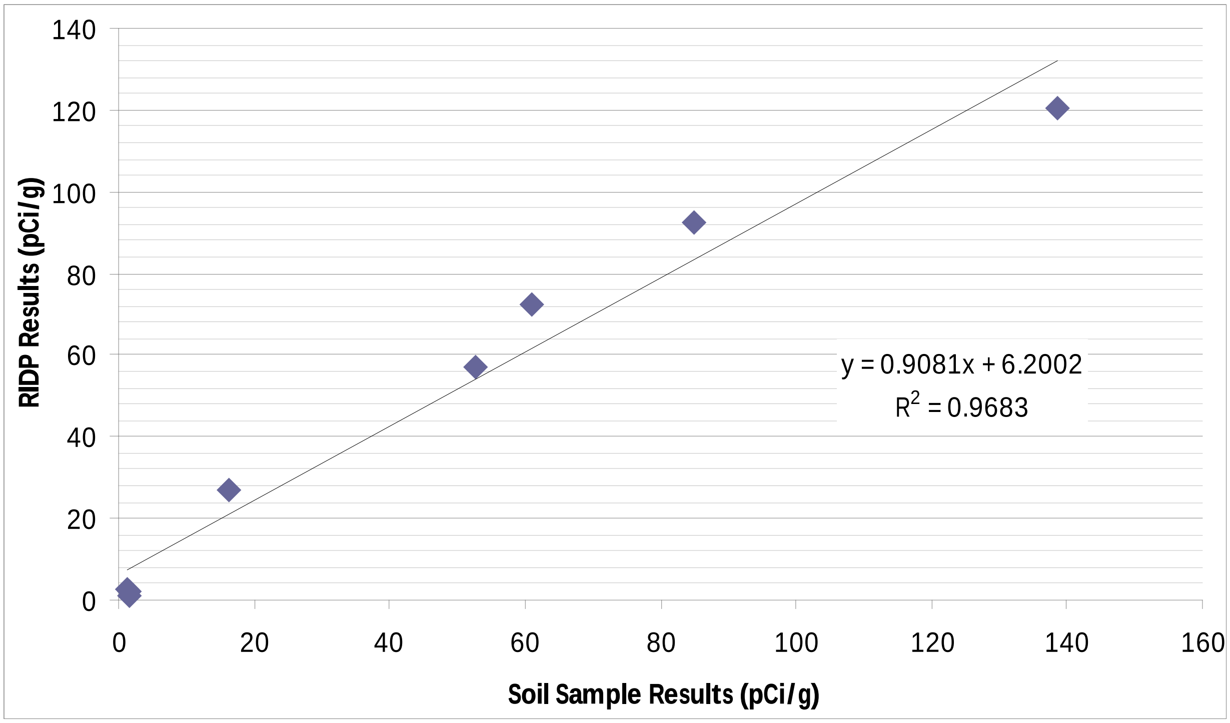

FIGURE 5. CAU 370 CAI RESULTS FOR PU-238 COMPARED TO RIDP DATA

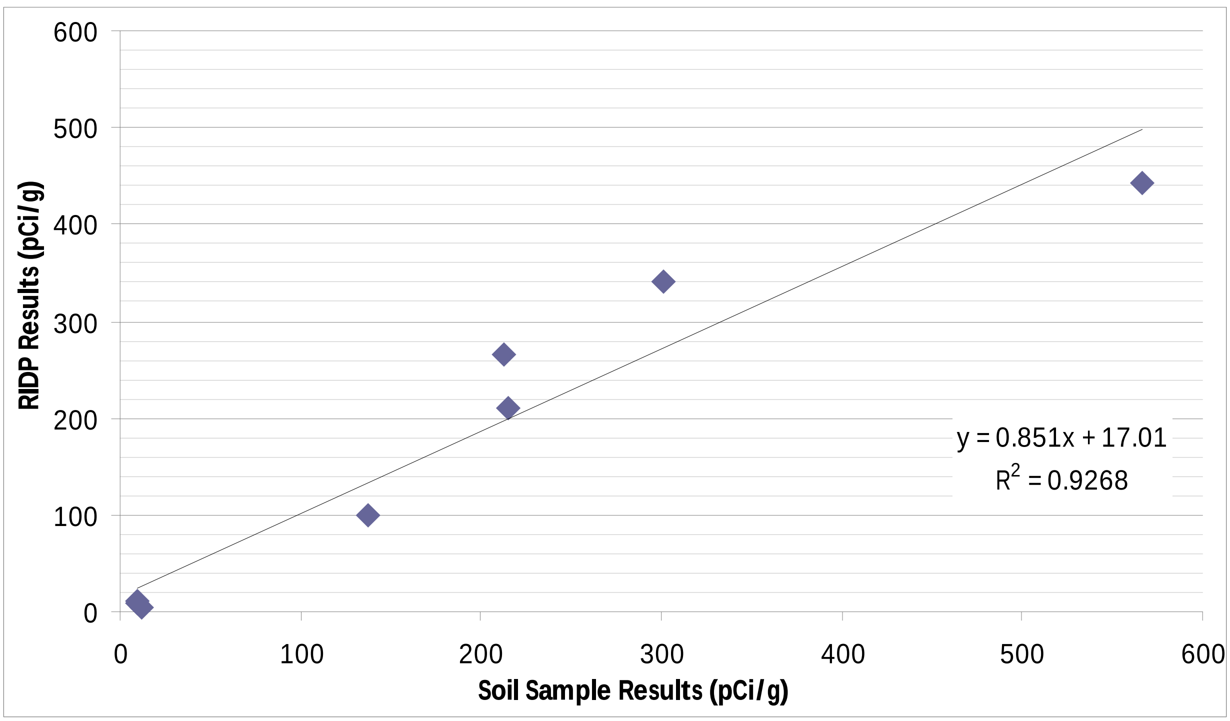

FIGURE 6. CAU 370 CAI RESULTS FOR PU-239 COMPARED TO RIDP DATA

The graphs in Figures 4–6 show that the data are well correlated; however, converted RIDP measurements expressed in units of pCi/g vary from the average CAU 370 soil sample results at each sample plot. The difference between the converted RIDP values and the average CAU 370 soil sample values potentially results from the following sources:

1) **RIDP Ratios:** Soil samples collected during the RIDP provided ratios to determine contaminant values for radionuclides that the RIDP did not directly measure. Ratios were determined through a limited number of soil samples collected by the RIDP at subject locations. Ratios were then applied across each entire subject area. Applying ratios that were calculated using only a few soil samples to many RIDP measurements may result in some error.

2) **IRLs:** This parameter is based on contaminant distribution with depth. This distribution is known to vary by radionuclide and by location, especially near ground zero locations. IRLs were determined through a limited number of soil samples collected by the RIDP at subject locations. IRLs were then applied to RIDP measurements across each entire subject area. Applying IRLs that were calculated from only a few soil samples to many RIDP measurements may result in some error.

3) **CAU 370 Plot Data:** Relatively high variability may result when a sample mean is calculated from multiple soil samples, even when the samples are collected from locations close to each other. In addition, variability in contaminant distribution with depth may cause variability in sample results, even across a single sample plot. A uniform sampling depth of 5 cm may concentrate values at some locations and dilute values at others. This variability can produce the differences in results between the two characterization methods.

The magnitude of the differences between converted RIDP results and CAU 370 soil sample results caused by each potential source listed above cannot be easily quantified with existing data. The converted RIDP data involve potential error; however, average soil sample values also have associated error. To provide context to the differences between the two data sets, internal dose rates based on converted RIDP data and internal dose rates based on the average CAU 370 soil sample results plus or minus two standard deviations were compared and plotted in Figure 7. Internal dose rates were calculated for both data sets using the draft DCGs established for CAU 370. The error bars shown in Figure 7 are associated with the four CAU 370 sample results collected in each sample plot and were calculated at the 95-percent confidence level.

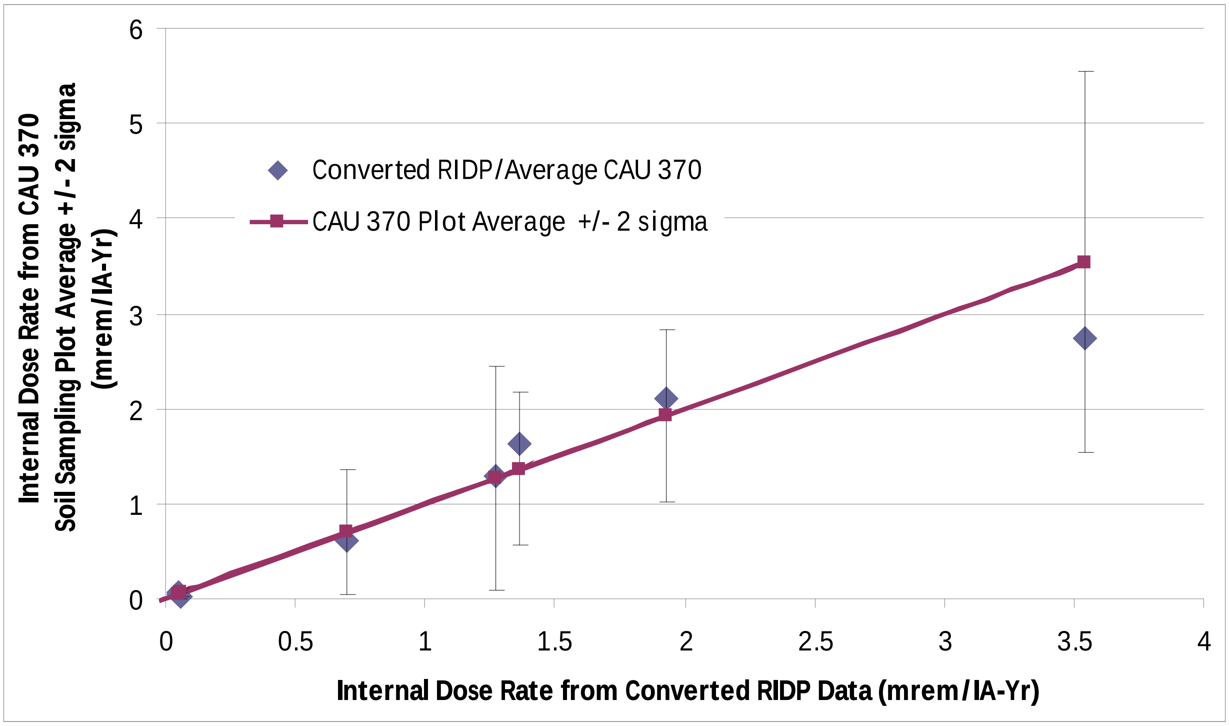

FIGURE 7. COMPARISON OF INTERNAL DOSE RATES

The maximum difference between internal dose rates calculated from RIDP values and from average CAU 370 soil sample results is 0.8 mrem/IA-yr. The difference was calculated at the 95-percent confidence level based on two results. This difference is insignificant at the relatively low contaminant levels found at CAU 370 and is more than accounted for by the error associated with the average soil sample value itself.

The deviation (95-percent confidence level) of internal dose rate based on CAU 370 soil sample data alone was also calculated. A maximum deviation of 2 mrem/IA-yr occurred at sample plot M. While the uncertainty in the average internal dose rate based on CAU 370 soil sample data is higher than the difference between internal dose rates calculated from RIDP values and from average CAU 370 soil sample results, it cannot be concluded that RIDP provides a more precise measure of internal dose. It can only be concluded that using converted RIDP values to determine internal dose rates is as accurate as using the average CAU 370 soil sample values across the sample plots at CAU 370.

The term missing from this evaluation is a propagated RIDP error based on uncertainties in RIDP measurements, IRLs, and RIDP ratios. Calculating such an error is outside the scope of this white paper and may not be possible based on available data (i.e., historical RIDP data and CAU 370 data); however, as explained further in Section 5.2.2, such a calculation may not be needed to effectively use the RIDP data for guiding decision making.

Am-241, Pu-238, and Pu-239 comprise the greatest component of internal dose rate. Complete analysis of internal dose rate requires an evaluation of contribution from other radionuclides, such as Eu-152, Eu-154, Sr-90, and Cs-137. Direct comparisons between converted RIDP measurements and CAU 370 average soil sample results were completed. The results showed poor correlation for Sr-90, reasonable correlation for Cs-137, and some clear outliers for Eu-152 and Eu-154.

There was also variability in CAU 370 soil sample results across sample plots. The sources of these differences are the same as those noted above for Am-241, Pu-238, and Pu-239. Sr-90 differences also result from a technically invalid assumption on the part of the RIDP that a ratio between Cs-137 and Sr-90 would yield accurate Sr-90 concentration values. This is not a valid assumption and is discussed in Section 5.1.

Eu-152 is a soil activation product produced when the neutrons resulting from nuclear fission interact with soil. As such, Eu-152 contamination extends to greater depths than other radionuclides and in some cases increases with depth. Eu-152 contaminant distribution with depth is more variable than Am-241, Pu-238, and Pu-239, which also causes greater differences in the direct comparisons of converted RIDP data and CAU 370 soil sample data for these radionuclides.

Again, the sources of these differences are related to uncertainty in both RIDP data and CAU 370 soil sample results. The differences between the two characterization methods are expected. However, errors in the data sets and differences between the two data sets are inconsequential to the calculation of internal dose rates for these radionuclides.

To support this conclusion, the following analysis was completed:

- The internal dose rate resulting from these radionuclides was calculated using converted RIDP data and CAU 370 average soil sample results. This calculation was based on the draft CAU 370 DCGs for internal dose.
- The maximum difference between these internal dose rate values was determined.
- The internal dose rate resulting from these radionuclides was determined for all RIDP measurements across the NTS, and the maximum was selected. This calculation was based on the draft CAU 370 DCGs for internal dose.
- It was assumed that the maximum percentage difference determined at CAU 370 would apply to the highest internal dose rate identified across the NTS.
- The resulting worst-case internal dose rate resulting from these radionuclides was 0.5 mrem/IA-yr.

The differences between the converted RIDP values and the CAU 370 soil sample results could be investigated, and the sources of the differences could be identified and roughly quantified. However, the above analysis clearly demonstrates that additional research would not add value because these radionuclides do not contribute to internal dose rates. Therefore, accurate measurements are not needed for these radionuclides.

4.7.2.2 Corrective Action Unit 370 External Dose Rates

Internal and external dose rates were measured and calculated separately and by two different methods during the CAU 370 CAI. External dose rates were determined during the CAU 370 CAI using TLDs. TLDs measured the total exposure over the time period they were placed in the field. The data were then converted to units of mrem/IA-yr to determine external dose rate for CAU 370. RIDP data were evaluated to determine accuracy in determining external dose rate through a number of methods that yielded varying results. Table 2 lists the CAU 370 TLD measurements and external dose rates calculated several ways using RIDP data and other CAU 370 data.

TABLE 2. SUMMARY COMPARISON OF EXTERNAL DOSE RATE RESULTS

			Calculated Dose Rates Based on Activity per Unit Mass		*Calculated Dose Rates Based on RIDP Measurements Directly*		*Calculated Dose Rates Based on Direct Reading Instrumentation*	
RIDP ID	**CAU 370 Sample Plot ID**	**CAU 370 External Dose Rate TLD (mrem/IA-yr)**	**CAU 370 Soil Samples (mrem/IA-yr)**	**Converted RIDP (mrem/IA-yr)**	**Direct RIDP (Beck) (mrem/IA-yr)**	**Direct RIDP (A&D) (mrem/IA-yr)**	**1994 Aerial Survey (mrem/IA-yr)**	**CAU 370 Field Survey (mrem/IA-yr)**
KE0003	A	**173**	257	239	188	447	343	149
KE0008	C	**132**	171	173	135	316	206	81
KE0009	E	**10**	16	14	13	33	62	14
KE0014	J	**10**	11	16	14	31	62	2
KE0020	P	**21**	12	15	13	32	62	14
KE0021	M	**153**	183	169	125	276	206	104
KE0052	F	**141**	206	153	120	283	343	104
KE0053	H	**166**	144	141	109	255	206	104

RIDP ID: Location ID of the RIDP in situ measurement
CAU 370 Sample Plot ID: CAU 370 CAI soil sample plot. A large plot was used in an attempt to replicate the large field of view (sample size) acquired by the RIDP in situ measurements.
CAU 370 External Dose Rate TLD: The dose rate calculated using the TLDs hung at each sample plot. This value was used to calculate external dose rate for CAU 370.
CAU 370 Soil Samples: The dose rate calculated using the CAU 370 soil sample results and the dose conversion factors in Federal Guidance Report (FGR) 12 (U.S. Environmental Protection Agency [EPA], 1993), the same factors used in The RESRAD code.
Converted RIDP: The dose rate calculated using RIDP values converted to pCi/g and the dose conversion factors in FGR 12 (EPA, 1993).
Direct RIDP (Beck): The dose rate calculated using the RIDP measurements directly and the dose conversion factors developed by Beck (1980).
Direct RIDP (A&D): The dose rate calculated using the RIDP measurements directly and the dose-based limits in Anspaugh and Daniels (1995).
1994 Aerial Survey: The dose rates calculated using the aerial survey values converted to and normalized to 2,250 hours for the industrial use scenario.
CAU 370 Field Survey: The dose rate measured with field instrumentation during the CAU 370 CAI.

Table 2 demonstrates that each approach to calculating external dose rates has strengths and weaknesses. The following three distinct comparisons were made to evaluate the effectiveness of various approaches to use the RIDP data:

1) The first set of comparisons uses calculated dose rates based on activity per unit mass (pCi/g). The CAU 370 soil sample data were converted to external dose rates in units of mrem/IA-yr using the conversion factors in the RESRAD code. These values were compared to the CAU 370 TLD-measured dose rates, and the comparison is shown in Figure 8.

   The RIDP data were converted to units of pCi/g using the method in Appendix A and then converted to external dose rates in units of mrem/IA-yr using the conversion factors in the RESRAD code. These values were also compared to the CAU 370 TLD-measured dose rates, and the comparison is shown in Figure 9.

   Figures 8 and 9 show good comparison between the calculated and measured dose rates. The RIDP results show a slightly closer correlation to the TLD measurements than the CAU 370 soil sample results. The two data sets indicate that at least one TLD result may be biased high.

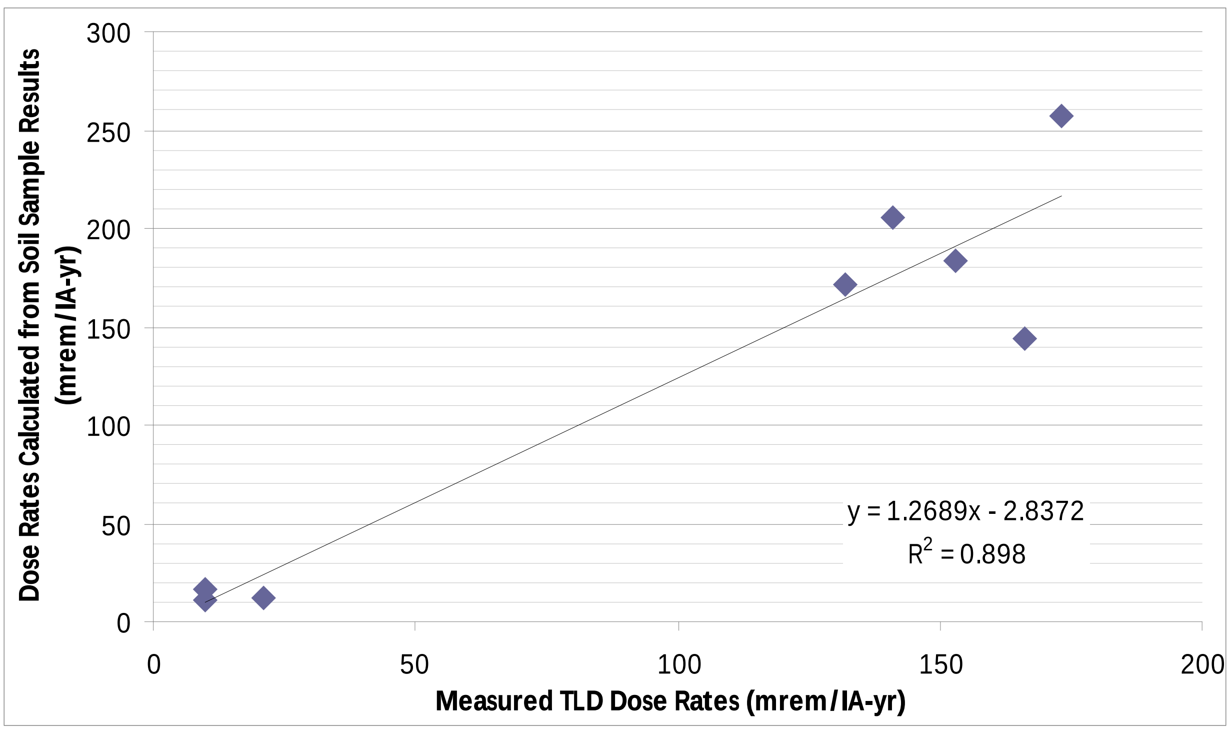

FIGURE 8. CAU 370 TLD RESULTS COMPARED TO CAU 370 SOIL SAMPLE RESULTS

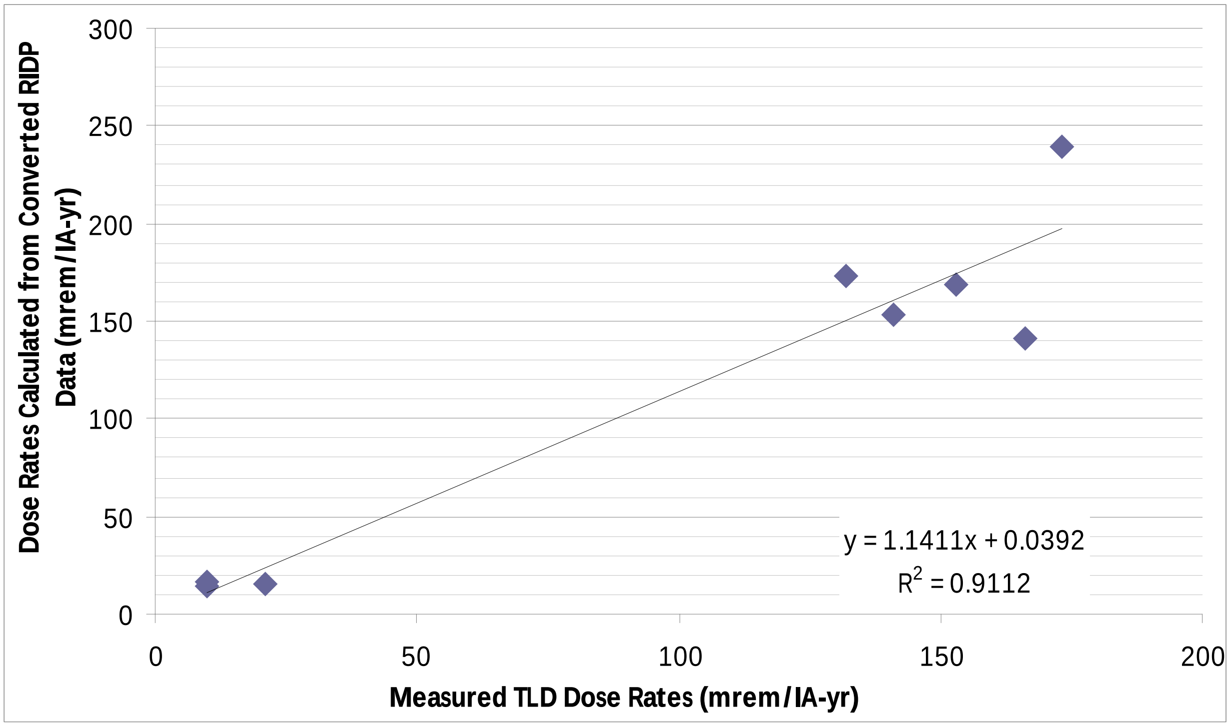

FIGURE 9. CAU 370 TLD RESULTS COMPARED TO CONVERTED RIDP DATA

2) The second set of comparisons uses external dose rates calculated directly from RIDP data in units of activity per unit area (nCi/m^2) without first converting the RIDP data to units of pCi/g. Figures 10 and 11 compare the CAU 370 TLD-measured dose rates to the calculated external dose rates. This comparison was done using two approaches.

The first approach used conversion factors from Beck (1980) calculated for exponentially distributed radionuclides in soil. The Beck factors allow for a direct conversion from the RIDP data reported in nCi/m^2 to exposure rates without the use of the RESRAD code or other modeling codes. Exposure rates were converted to dose rates using the following conversion factors:

- Exposure to dose-in-air: 0.87 rad/R (United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], 1988)
- Dose-in-air to effective dose equivalent: 0.7 rem/rad (UNSCEAR, 1988)

Figure 10 illustrates the comparison of CAU 370 TLD-measured dose rates to the RIDP data converted using the Beck coefficients. The data are well correlated. This approach to external dose rate calculation also indicates that at least one TLD result may be biased high.

While the external dose rates calculated using the Beck coefficients are not as strongly correlated as the values calculated using converted RIDP values and FGR 12 dose rate conversion factors, they yield closer absolute value comparisons. The data show that using the Beck coefficients is the better approach. This is because the Beck coefficients were specifically derived for soil contamination at nuclear weapons test sites and account for the exponential contaminant distribution with depth, which the FGR 12 values do not.

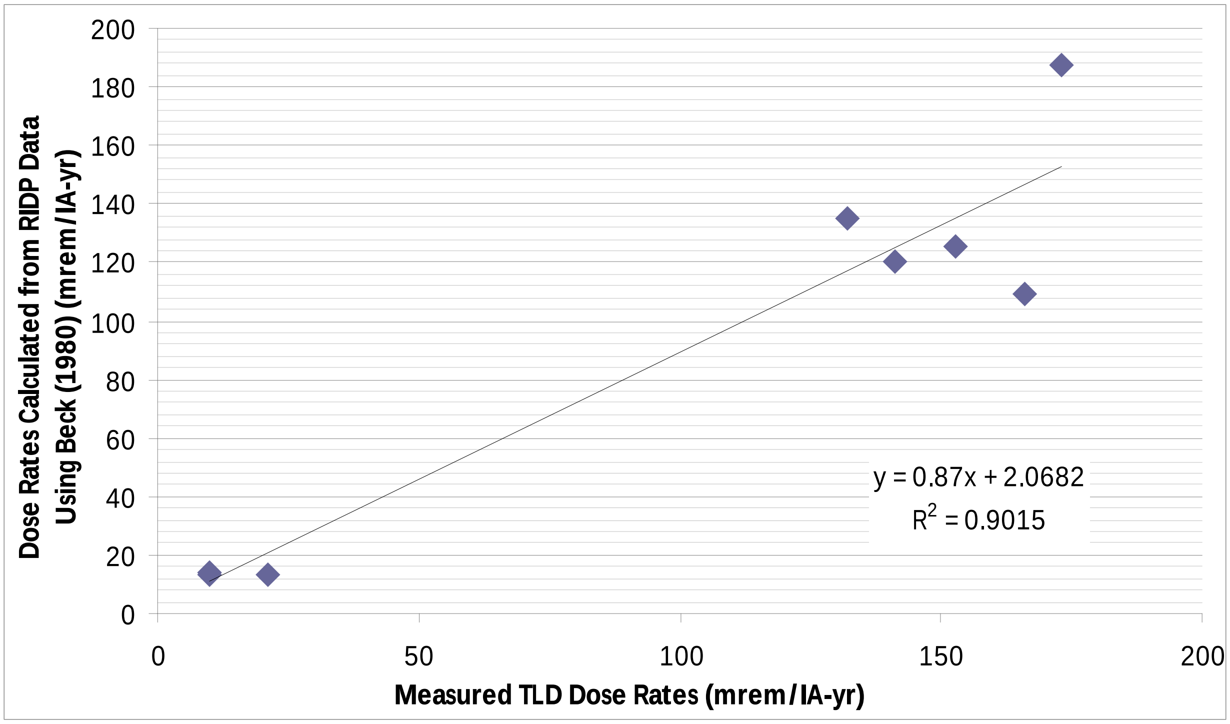

FIGURE 10. CAU 370 TLD RESULTS COMPARED TO RIDP DATA USING BECK (1980) CONVERSION FACTORS

The second approach used the dose-based limits derived by Anspaugh and Daniels (1995). Figure 11 compares the CAU 370 TLD-measured dose rates to the RIDP data using this approach. The data are highly correlated, but the calculated external dose rates are higher than the TLD-measured dose rates. This is due to the intentional conservatism in the Anspaugh and Daniels dose-based limits. In addition, this method did not easily allow the internal dose component from gamma-emitting radionuclides to be removed. These factors cause a high bias in the calculated data. Given this high bias, external dose rates based on the Anspaugh and Daniels limits that are currently available should be used as a screening and planning tool only.

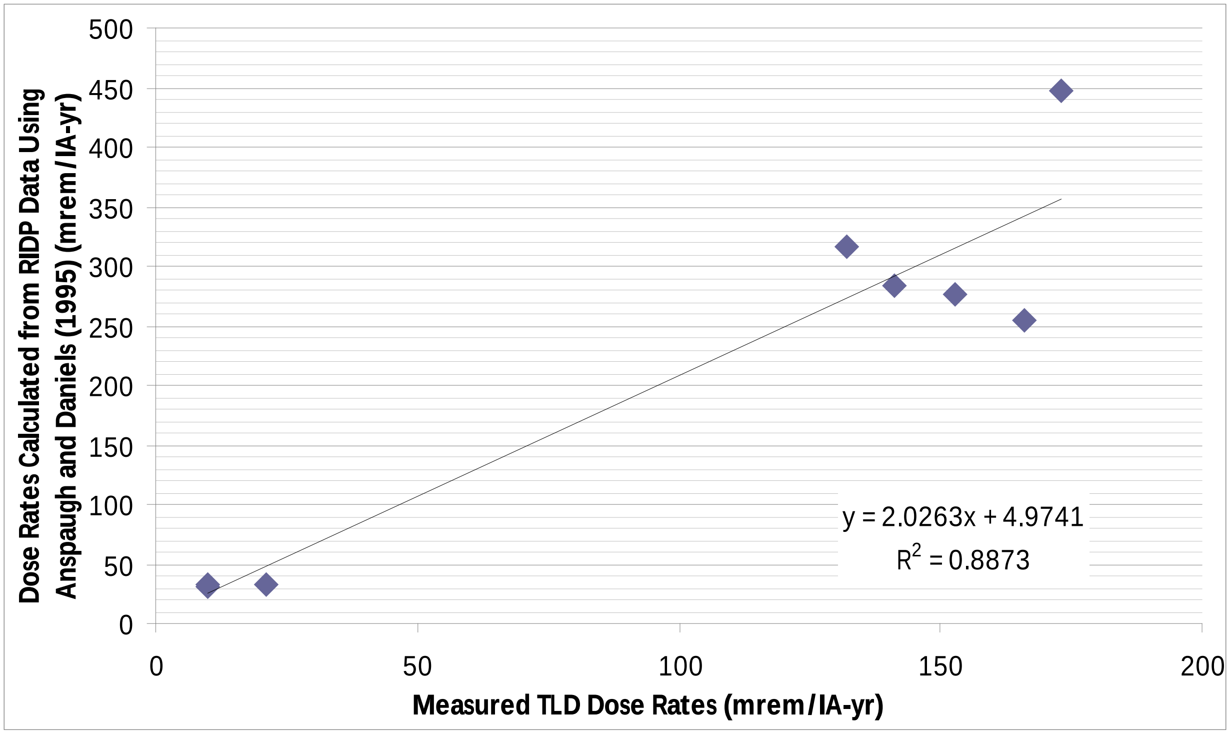

FIGURE 11. CAU 370 TLD RESULTS COMPARED TO RIDP DATA USING ANSPAUGH AND DANIELS (1995) DOSE-BASED LIMITS

3) The third set of comparisons made to evaluate the effectiveness of the RIDP data uses external dose rates calculated directly from RIDP data using the Beck (1980) coefficients. These values are compared to the results of direct-reading field surveys conducted during the CAU 370 CAI and to the 1994 aerial radiological survey data.

   Figure 12 compares the RIDP data to the CAU 370 direct-reading field survey data. Figure 13 compares the RIDP data to the 1994 aerial radiological survey data. Both the CAU 370 direct-reading field survey data and the aerial radiological survey data show good correlation to the external dose rate values calculated using RIDP measurements directly and applying Beck's exposure conversion factors.

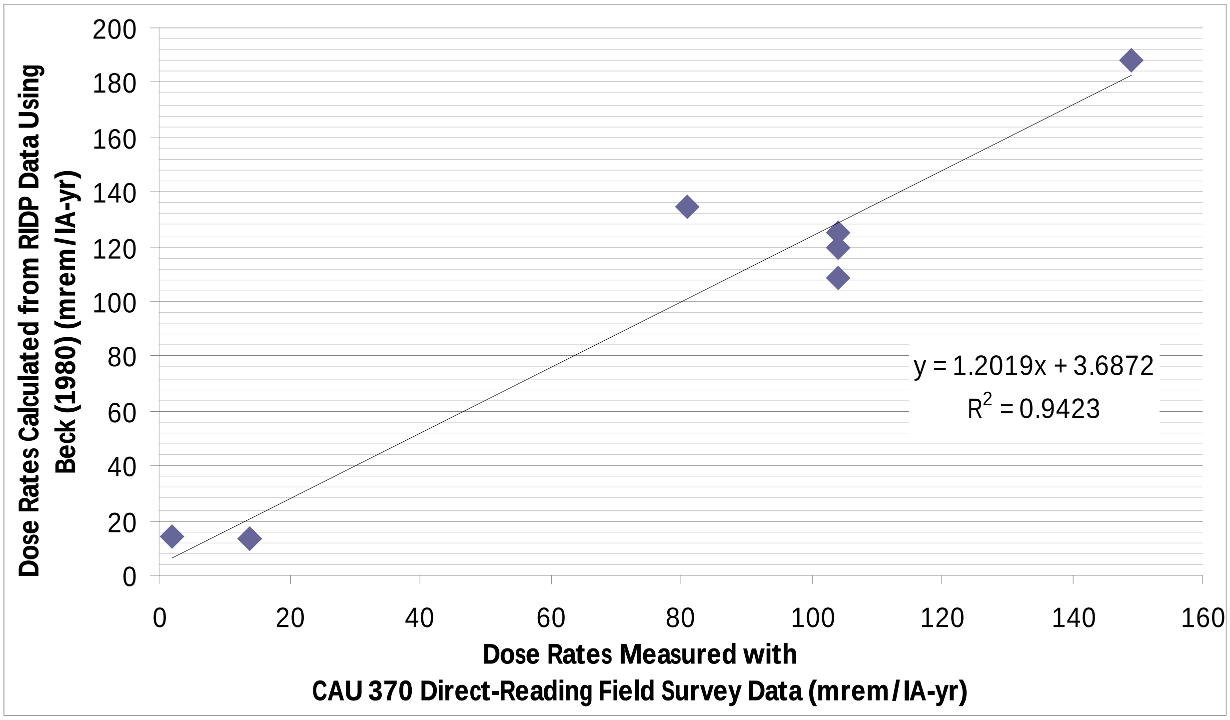

FIGURE 12. CAU 370 DIRECT-READING FIELD SURVEY RESULTS COMPARED TO RIDP DATA USING BECK (1980) CONVERSION FACTORS

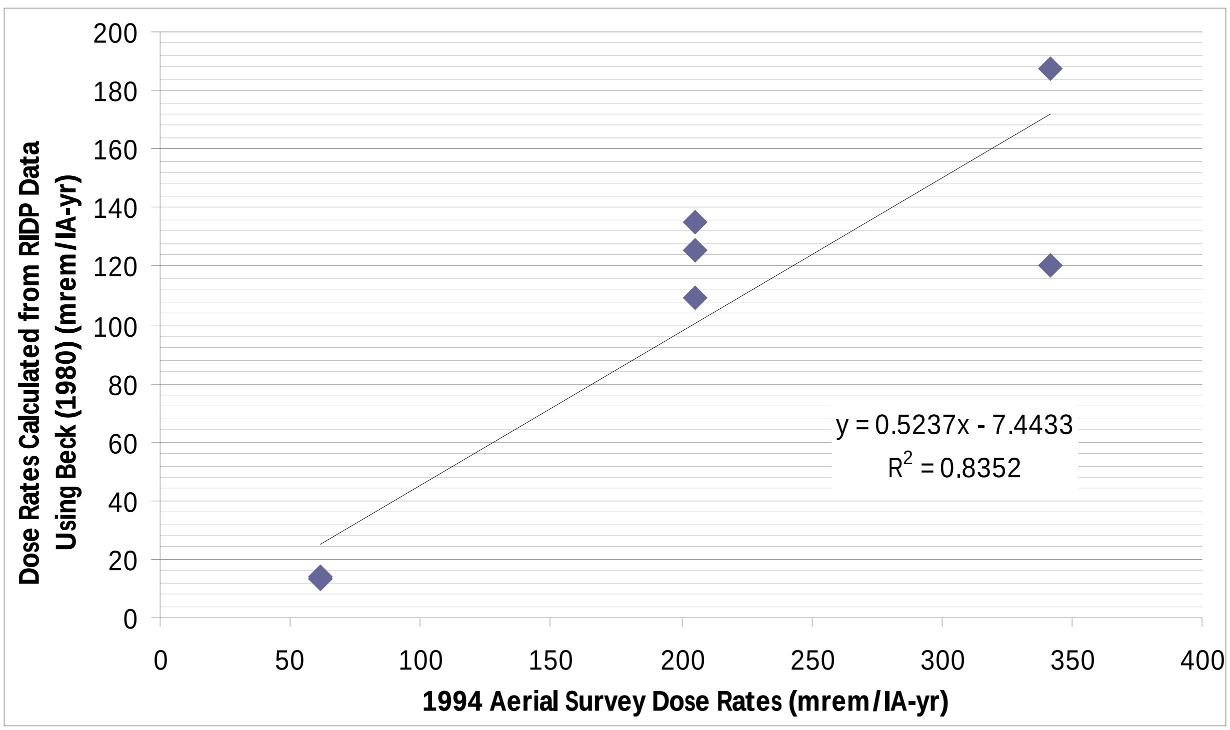

FIGURE 13. 1994 AERIAL SURVEY RESULTS COMPARED TO RIDP DATA USING BECK (1980) CONVERSION FACTORS

The three sets of data comparisons presented above demonstrate that the RIDP data can be used to accurately determine external dose rates. Additional sampling at CAU 370 did not yield better results than the RIDP data. In fact, the RIDP data converted to pCi/g yielded a stronger comparison to the TLD data than the actual CAU 370 soil sample data; however, neither data set yielded equivalent results. Both sets of results were higher than the TLD values.

The RIDP values used directly to calculate external dose rates using Beck's coefficients provided the best correlation to the TLD data of any of the data comparisons and scored well on a paired t-test (a statistical test used to determine differences between data sets). The results presented above show that the use of RIDP data to determine external dose rates at CAU 370 yield reasonably accurate results.

The largest differences between external dose rates calculated with RIDP and TLD measurements occurred at locations where the TLDs measured dose rates greater than 25 mrem/IA-yr. The IRL at these locations is also 0.05 cm^{-1}. An IRL of 0.05 cm^{-1} represents the far end of the exponential depth distribution assumption, and deviations in actual depth distribution from calculated depth distribution will produce larger errors in dose rates in this region of the curve.

In an effort to further investigate this error and its implications to NTS-wide use of the RIDP data for calculation of external dose rates, comparisons between TLD data and RIDP data were made across the NTS where RIDP measurements were relatively close to environmental TLD monitoring locations. This evaluation indicated that most of the larger deviations between these two values occurred at locations where the applied IRL is 0.05 cm^{-1}. Understanding the source of RIDP error relative to TLD values will allow quantification of the error and a method to mitigate the risk associated with the error. Additional discussion is provided in Section 5.2.2.

4.7.2.3 Corrective Action Unit 370 Internal and External Dose Rates Summary

The final assessment completed was to determine the 25-mrem/IA-yr dose rate boundary using RIDP values and compare it to the 25-mrem/IA-yr boundary determined with the results of the CAU 370 CAI. The RIDP 25-mrem/IA-yr boundary was established by using direct RIDP measurements and the Beck coefficients. The internal dose rate was determined using RIDP values converted to pCi/g as outlined in Appendix A and the draft DCGs established for CAU 370. As Figure 14 shows, the location of the 25-mrem/IA-yr boundary is the same using either data set.

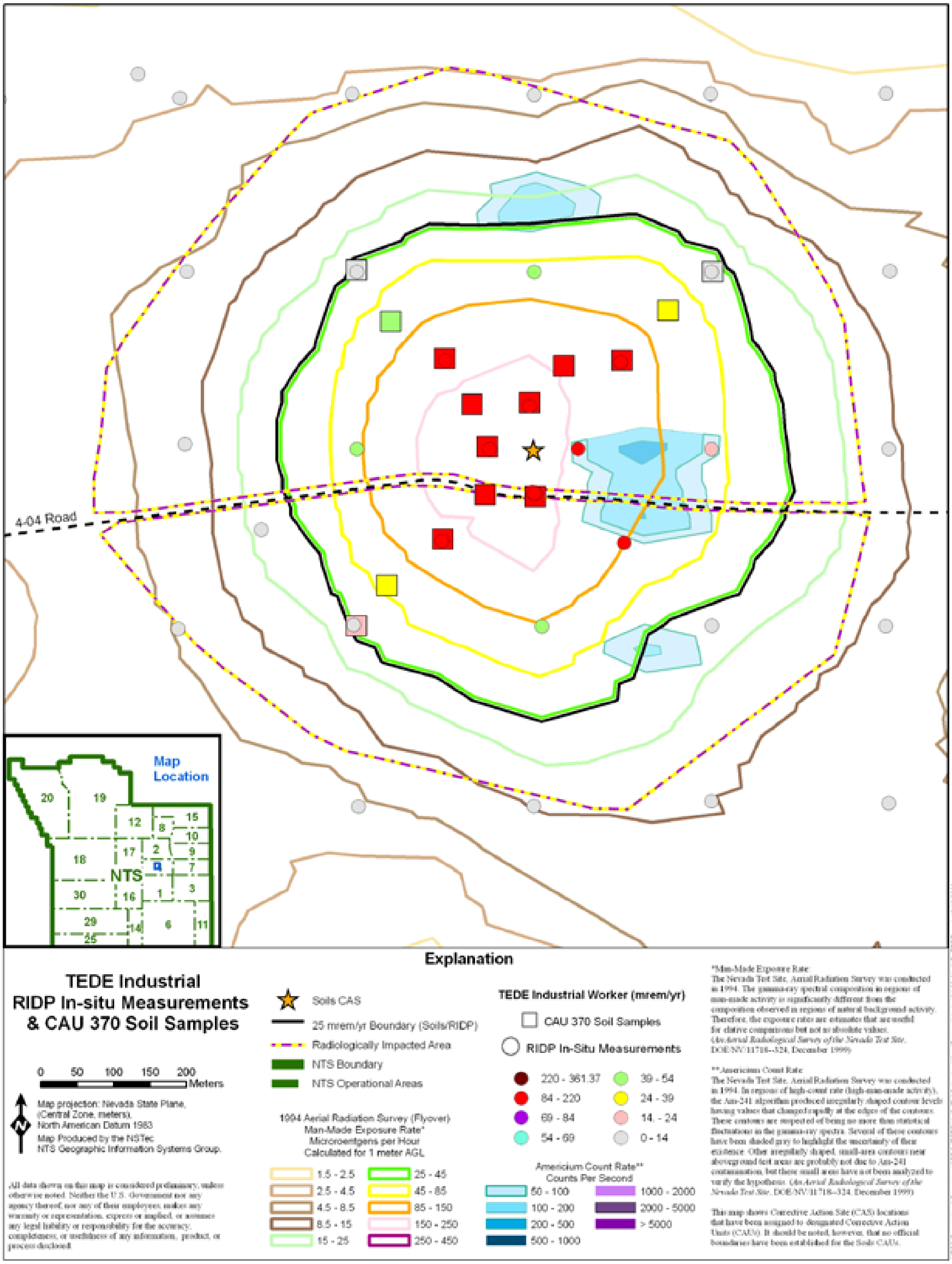

FIGURE 14. RIDP 25-MREM/IA-YR DOSE BOUNDARY FOR CAU 370

5.0 DATA CAUTIONS AND USE

5.1 RIDP Data Cautions

The RIDP data are currently usable, but the following cautions on RIDP data use have been identified. These cautions can be managed through conservative assumptions and some additional research or limited characterization:

- Some ratios of Pu-238 and Pu-239/240 to Am-241 are higher than expected, such as for measurements collected in the WILSON area. However, these high ratios, if incorrect, would result in deriving higher than actual activities, so the results using the existing ratios would be conservative.
- Applying the ratios of Sr-90 to Cs-137 to calculate aged Sr-90 contamination is not reliable. The ratios of Pu-238 and Pu-239/240 to Am-241 are based on the physics of radioactive decay, but the ratios of Sr-90 to Cs-137 are not. These two radionuclides are produced independently of each other and are not in the same decay chain. This means that different ratios would be expected at different sites, with little if any process knowledge to evaluate the ratios. Additionally, Sr-90 is more mobile in the environment than Cs-137, resulting in additional potential changes in the ratio over time. However, Sr-90 is not a contributor to internal dose rate, even under the most conservative assumptions, as outlined in Section 4.7.2.1. Because Sr-90 does not contribute to internal dose, an accurate measurement is not needed.
- Some site cleanup carried out under the Waste Consolidation Project (WCP) was performed concurrently with the RIDP, and RIDP measurements were collected before and after cleanup activities at several sites. The RIDP did not identify appreciably different values before and after these cleanup activities were performed. RIDP may not have detected significant differences because the scope of the cleanup only included minimal amounts of slightly contaminated debris or soil hot spots that were not near RIDP sampling locations. However, because clean up activities occurred after the RIDP, sites that were cleaned up under the WCP should be noted and the RIDP data evaluated. Sites where cleanup occurred after the RIDP can be flagged for additional data cautions.
- The RIDP data cannot capture recent contaminant migration. Sites where migration might be an issue may require additional, focused characterization in the known migration channels.

5.2 RIDP Data Use

The RIDP data are currently usable for a number of applications given the level of QA reviews performed to date. Enhanced uses of RIDP data may be possible with additional calculations and verification.

5.2.1 Current RIDP Data Use

Project Planning: Evaluations of the RIDP data indicate it may be used for project planning without additional field verification. Project planning activities may include estimating 25-mrem/IA-yr dose rate boundaries, optimizing characterization efforts, projecting final end states, and planning remedial actions. Figure 15 provides an example of the 25-mrem/IA-yr dose rate boundary at the GALILEO site. This example highlights a secondary plume that does not follow the pattern observed at CAU 370 of decreasing dose rate with distance from ground zero and indicates that the secondary plume may require an additional land use restriction. The 25-mrem/IA-yr dose rate boundaries have been estimated for all areas of the NTS. Figure 16 provides an example of how RIDP data may be used to optimize characterization efforts.

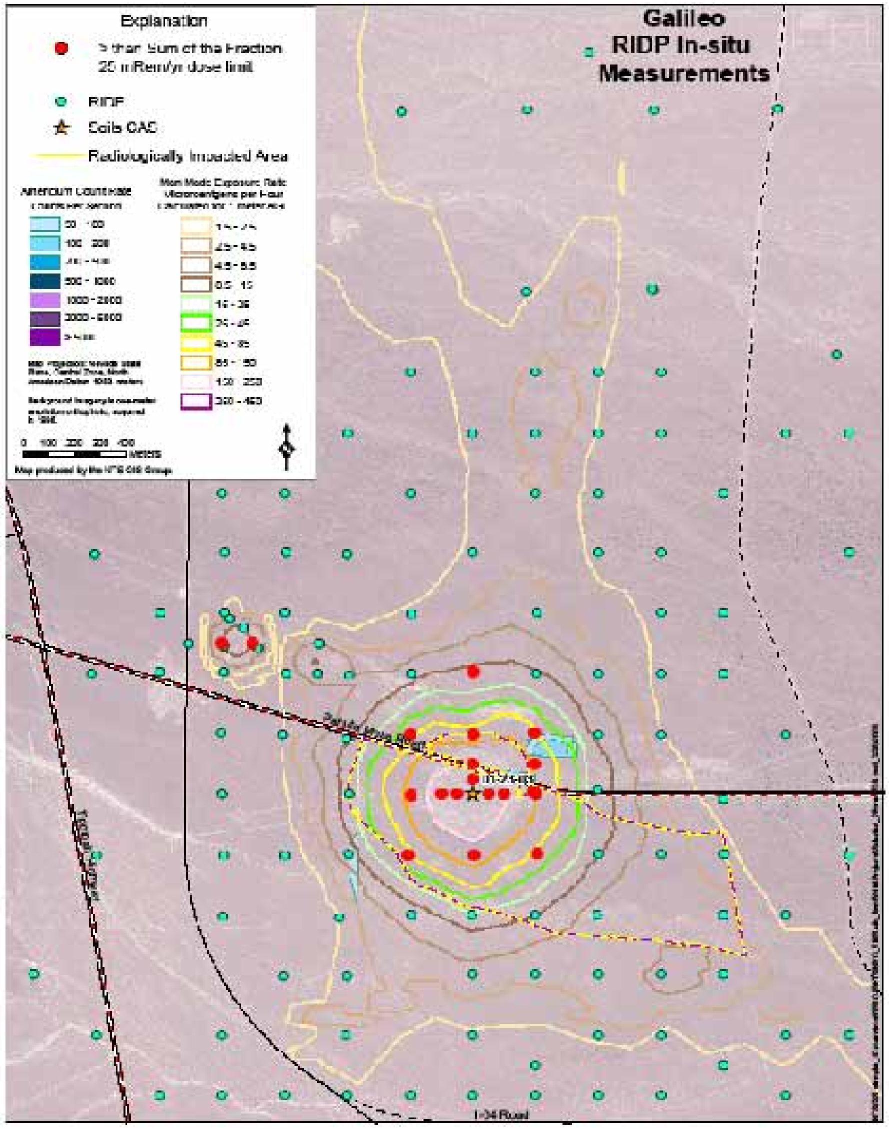

FIGURE 15. EXAMPLE OF ESTIMATED 25-MREM/IA-YR DOSE RATE BOUNDARIES

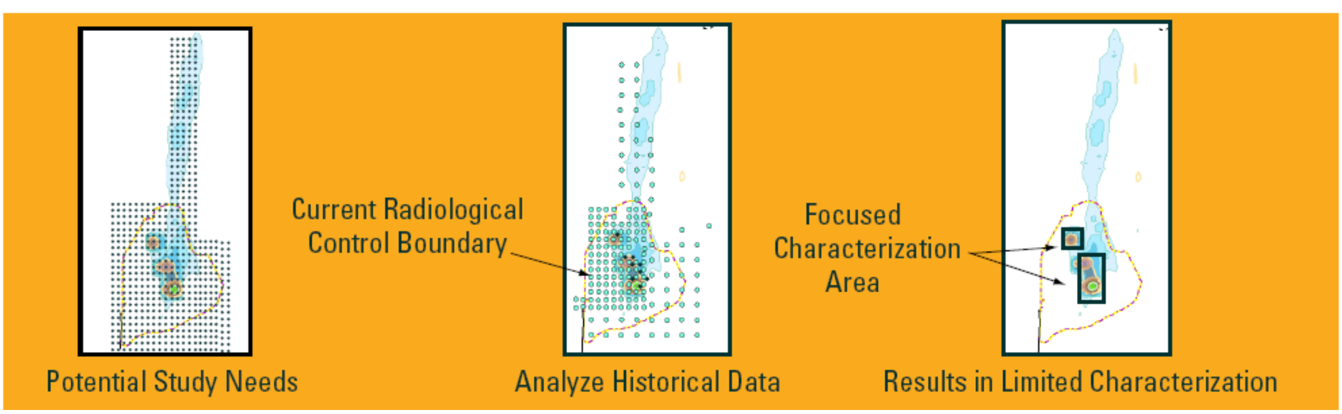

FIGURE 16. USING HISTORICAL DATA TO OPTIMIZE CHARACTERIZATION

Augmenting TLD Data: Approximately 90 percent of the dose rate at CAU 370 is due to external gamma exposure from radionuclides with short half-lives relative to Am-241 and Pu-239. Data collection at CAU 370 used TLDs to determine external dose rates. TLD data cannot be easily corrected for decay. RIDP data can be used to identify specific radionuclide distributions, thus augmenting the CAU 370 data set to allow for decay corrections and dose rate projections for any future date. Less risk will be involved for closure at sites where the dose rate and 25-mrem/IA-yr boundary is steadily decreasing. This approach provides a way to show that the TLD or calculated RIDP dose rate errors steadily decrease over time.

Calculating Dose Rates and Estimating the 25-mrem/IA-yr Boundaries: The RIDP data collected in the CAU 370 area provide reasonably accurate dose rate values for both internal and external dose rates. The RIDP data lead to the same decisions as the newly collected data for CAU 370; therefore, the RIDP data should be used to estimate the 25-mrem/IA-yr boundaries during the DQO process. The estimated boundaries can potentially limit additional characterization requirements. Figure 16 outlines this characterization optimization.

5.2.2 Enhanced RIDP Data Use

Several opportunities for enhanced RIDP data use are appropriate based on the evaluations presented in Section 4.7. The evaluations show good agreement between RIDP data and CAU 370 data. The evaluations also help roughly define the magnitude and potential sources of RIDP error. This information can be used to establish some conservative approaches for RIDP data use that will mitigate the risks associated with potential RIDP error without drastically increasing areas of land use restrictions. Three examples of how enhanced RIDP data use may be pursued follow.

Internal Dose Rate Estimates: There is error associated with internal dose rate estimates based on both RIDP data and soil sample results. Section 4.7.2.1 indicates that internal dose rates calculated using converted RIDP values are likely to be accurate within the inherent deviation in soil sample plots. This is expected to be the case due to the variation between soil sample values. Using the process outlined in Section 4.7.2.1, internal dose rates at all RIDP locations across the NTS were calculated. A query was run to determine how many RIDP locations exceeded 25 mrem/IA-yr with an internal dose component greater than 25 percent of the total dose, or 6.25 mrem/IA-yr. Only 47 RIDP locations resulted from this query. The maximum difference between CAU 370 dose rates calculated with soil samples and calculated with converted RIDP values was 50 percent. This error was applied to the 47 values to gain a rough idea of the increase in the size of land use restriction areas using the conservative application of potential error. The adjusted values only resulted in 16 additional points exceeding 25 mrem/IA-yr with an internal dose component greater than 6.25 mrem/IA-yr. This informal and brief evaluation highlights that conservative assumptions may be applied with little impact to the size of land use restriction areas. Using this type of conservative estimate may allow these areas to be characterized with limited additional sampling. This approach would be presented during the DQO process. The outcome of using the RIDP data would reduce worker risk associated with sampling in contaminated areas, accelerate schedules, and reduce project costs.

External Dose Estimates: There is error associated with estimating external dose rates based on TLDs and the RIDP data. Section 4.7.2.2 indicates that RIDP values associated with IRLs of 0.05 cm^{-1} can lead to differences between TLD measurements and RIDP-calculated dose rates in some areas. The risk associated with this potential error can be limited by selecting a more conservative Beck coefficient. Many of these locations are at or near ground zero locations, so using a more conservative coefficient to determine dose is unlikely to increase the 25-mrem/IA-yr dose rate boundaries.

Additional Streamlined Approach for Environmental Restoration (SAFER) Plan: Estimated dose rates for each RIDP measurement location have been calculated in support of this white paper using the process described in Section 4.7.2.3. This information was used to determine Corrective Action Site (CAS) areas that did not exceed a dose rate of 25 mrem/IA-yr. Approximately 20 CAS areas do not have RIDP locations with calculated dose rates greater than 25 mrem/IA-yr. This information can be used to select candidate sites that may be appropriate for closure under the SAFER process. The evaluation of these CASs for inclusion into a proposed SAFER closure will consider similarities to CAU 370, proximity to operating facilities, whether migration is likely, and existing fencing or posting. After the CASs are evaluated against these criteria, DQOs will be prepared that include an evaluation of the RIDP data and a determination of any additional data needs.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following sections provide conclusions based on the evaluations presented above and recommendations for future actions.

6.1 Conclusions

Evaluations presented in this white paper indicate the RIDP data may be used under the limitations set forth in Section 5.1 and for the uses outlined in Section 5.2. Task 1 presented below should be implemented prior to the release of the RIDP data as a shared Microsoft Access database.

Enhanced RIDP data use is possible though the implementation of the recommendations provided in the following section.

6.2 Recommendations

Recommended activities presented below assume that the enhanced data uses suggested in Section 5.2.2 will be implemented.

6.2.1 Task 1: Database Finalization

- Review calculations and the resulting data for query logic and accuracy of calculated output under a formalized approach. A graded approach to software quality assurance will be used to verify that the calculations are appropriate and accurate.
- Migrate the database to a platform for multi-user access.

6.2.2 Task 2: Evaluation of CAU 371 and CAU 372 Data

- Determine 25-mrem/IA-yr boundaries using RIDP data.
- Determine sources of potential error either in the RIDP measurements or projected uncertainty associated with characterization and dose assessment for CAU 371 and CAU 372.
- Document any adjustments to the 25-mrem/IA-yr boundaries to account for errors or uncertainty.
- Perform an assessment similar to that presented in this white paper for CAU 371 and CAU 372 data and document the results.

6.2.3 Task 3: Calculation of Internal Dose Rates

- Formalize the initial evaluation in Section 5.2.2 to determine how conservative applications of various assumed errors may affect the size of required land use restrictions.
- If conservative assumptions do not greatly increase the estimated size of land use restrictions, select more conservative correction factors and apply them to the RIDP data to be used during the DQO process.

6.2.4 Task 4: Calculation of External Dose Rates

- Formalize the initial evaluation in Section 5.2.2 to determine how conservative applications of various assumed errors may affect the size of required land use restrictions.
- If conservative assumptions do not greatly increase the estimated size of land use restrictions, select more conservative correction factors and apply them to the RIDP data to be used during the DQO process.

6.2.5 Task 5: Evaluation of Sites for a SAFER Closure

- Select sites as outlined in Section 5.2.2.
- Evaluate sites under the criteria suggested in Section 5.2.2 and other criteria that may be developed.
- Determine a list of candidate sites that appear to have an obvious closure path, low dose rates, and low project risks.
- Evaluate the sufficiency of RIDP data to develop a list of sites that will require limited additional characterization.
- Change the closure process from complex to SAFER.
- Prepare DQOs that evaluate the RIDP data.

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APPENDIX A
RIDP DATA CONVERSION PROCESS

In situ gamma spectroscopy data were collected during the RIDP. Instrument calibration factors were determined so that the raw gamma count rate could be converted into radionuclide-specific activities. In this case, radionuclide-specific peaks were identified, and raw gamma count rates were converted to units of activity per unit area (nCi/m^2). In order to compare these data to dose-based DCGs, the data must be converted to units of activity per unit mass (pCi/g).

The discussion below outlines the approach to data conversion using the IRL as determined through actual soil samples at the NTS supporting the RIDP project and equation 5 from HASL-300.

Equation 5 from HASL-300, the cumulative activity, or inventory I, integrated to a depth z' is:

$$I_{z'} = \int_0^{z'} dz = \frac{S_0}{\alpha}\left[1 - e^{-(\alpha z')}\right] = I_0\left[1 - e^{-(\alpha z')}\right]$$

Where:
S_0 is the activity per cm^3 at the soil surface
α is the IRL in cm^{-1}
z' is the contaminant depth

The RIDP data provide α. $I_{z'}$ and I_0 will be represented as a fraction in the following analysis. The RIDP values presented in units of total activity per unit area represent the total activity integrated to an infinite depth. In order to develop a specific activity value (pCi/g), the following procedure is used to avoid "diluting" values by integrating to too great a depth, and thereby calculating values that would underestimate potential dose. The goal is to establish an appropriate depth to which it should be assumed the contamination is largely distributed. The RIDP values represent total activity in the column beneath the unit area reported. In other words, it is the surface representation of the total activity integrated to an infinite depth. The total contamination is assumed to be distributed to a depth that captures 90 percent of the total inventory in the column based on the exponential distribution of the contaminant. This is conservative in that 100 percent of the activity is assumed to reside in only 90 percent of the volume. All radionuclides of concern, other than activation products, reside in the top several cm of soil and fall off very rapidly with depth, so the method is conservative for these radionuclides. Activation products tend to be present to deeper levels, so the method is very conservative for those radionuclides. Equation 5 above is solved for z', which will then be used to convert activity per unit area to activity per unit volume. A soil density of 1.6 g/cm^3 was used in the RIDP calibrations and is used for this conversion.

Solving for z':

$$\frac{I}{I_0} = \left[1 - e^{-(\alpha z')}\right]$$

Then:

$$1 - \frac{I}{I_0} = e^{-(\alpha z')}$$

Then, assuming a 90-percent contaminant capture depth:

$$.1 = e^{-(\alpha z')}$$

Then, solving for z':

$$\frac{Ln(.1)}{\alpha} = -z'$$

The RIDP data contain the appropriate α for each region of in situ values, thus the procedure for solving for z' is to write a query to carry out the function above. The value of z' will then be multiplied by the RIDP value in activity per unit area. These values will then be divided by the soil density to arrive at the activity per unit mass (pCi/g).