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**Determination of the Radioactive
Material and Plutonium Holdup
in Ducts and Piping in the
325 Building**

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Executive Summary

This report describes the measurements performed to determine the radionuclide content and mass of plutonium in exposed ducts, filters, and piping in the 325 Building at the U.S. Department of Energy Hanford Site in Washington State. This information is needed to characterize facility radiation levels, to verify compliance with criticality safety specifications, and to allow more accurate nuclear material control using nondestructive assay (NDA) methods. Gamma assay techniques typically employed for NDA analysis were used to determine the gamma-emitting isotopes in the ducts, filters, and piping. Passive neutron counting was selected to estimate the plutonium content because high gamma levels from fission and activation products effectively mask any gamma emissions from plutonium. A high-purity germanium detector was used to measure the mixed fission and activation radionuclides. A neutron slab detector containing five ^3He proportional counters was used to determine the neutron emission rates and estimate the mass of plutonium present. Both measurement systems followed the methods and procedures routinely used for nuclear waste assay and safeguards measurements.

The chronological order of events included a review of previously published documents on holdup assays at other sites and reviews of standards and regulatory guidelines relating to holdup and holdup measurement techniques. Reviews of facility historical radiation survey reports and discussions with facility personnel significantly helped in identifying potential holdup areas. A radiological survey mapping of the pipes and ductwork was performed prior to the actual holdup measurements. During this activity, NDA measurement locations were identified and permanently marked, and a unique naming protocol was established. This work was conducted in February 1996.

The fission and activation product inventories in the ducts and piping were measured using gamma-ray NDA techniques. A well-shielded and collimated gamma detector was used to view specific locations on the ducts and piping. The intrinsic germanium detector was used to measure the characteristic gamma-ray spectra of the fission and activation products in the 325 Building. From the gamma-ray intensities measured and the decay scheme of identified radionuclides, it is possible to obtain reasonably accurate measurements of the activity of gamma-emitting nuclides. Almost all the gamma activity present originates from the fission product ^{137}Cs and the activation product ^{60}Co . Radiations from other nuclides present were effectively masked by the intense gamma rays from the mixed fission and activation products. This was particularly true in attempting to directly measure for transuranic (TRU) materials. The small quantities of plutonium present did not produce sufficient gamma activity to be detected in the presence of so much fission and activation product activity. Transuranic activity was determined by measuring neutrons using a ^3He neutron detector. The fast neutrons emitted by plutonium are highly penetrating in metals and can easily be detected, even for gram quantities of plutonium surrounded by several inches of steel shielding.

Special data analysis techniques had to be used to estimate the plutonium content of the ducts since they were not in a standard counting geometry. The mass estimates may be too high if there is a significant number of neutrons produced by alpha-neutron interactions with low-atomic-number materials in the ducts and pipes, particularly alpha-emitters in intimate contact with fluorine, aluminum, boron, or beryllium.

beryllium. This is of concern if the high-efficiency particulate air (HEPA) filters contain finely divided plutonium oxide powder on borosilicate glass filter media. To be conservative, yet realistic, the neutron detector was calibrated using a known mass of weapons-grade plutonium (6 weight percent ^{240}Pu) in the form of an oxide. This source was well characterized by previous NDA measurements to verify its mass.

The estimates of plutonium mass are highly dependent on the assumptions made in analyzing the data. Specifically, the estimates depend on the isotopic and chemical form of the plutonium, the distribution of plutonium, the amount of intervening shielding surrounding the plutonium, and the general neutron background in the surrounding areas. Assumptions are that the plutonium is in the form of weapons-grade plutonium oxide and at least 10 years old. This is a conservative assumption because much of the plutonium processed in the 325 Building is in the form of higher-burn-up material that emits more neutrons per gram (hence, the mass would be less for the same neutron emission rate).

Estimated plutonium mass gram equivalents in the basement ductwork and filters are 31 grams. The radioactive liquid waste system (RLWS) line has 12 grams. The laboratory vacuum system (LVS) has 2 grams equivalent plutonium. RPS has 3 grams equivalent plutonium. Total plutonium mass holdup estimates for basement areas range from 48 grams, assuming that the plutonium is weapons-grade plutonium, to a best estimate of 27 grams plutonium, assuming 11% ^{240}Pu . Estimated plutonium mass gram equivalents for all laboratories range from 385 to 581 grams. Individual laboratory estimates are listed in chapter 5.

Total estimated plutonium gram equivalent holdup and material in process for the facility is 410 grams.

In summary, the results of this survey indicate that no significant levels of plutonium, from a criticality safety perspective, reside in the ductwork, laboratory vacuum system lines, RLWS pipes, or any one laboratory in the 325 Building.

Acronyms

DOE	U.S. Department of Energy
EBR-II	Experimental Breeder Reactor
FFTF	Fast Flux Test Facility
HPGe	high-purity germanium detector
LLNL	Lawrence Livermore National Laboratory
MCA	multichannel analyzer
NDA	nondestructive assay
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
RAM	radioactive material
RLWS	radioactive liquid waste system
RPS	retention process sewer
SNM	special nuclear materials
TRU	transuranic



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1.0 Introduction

This section provides a brief description of the facilities in the 325 Building to provide an overview of radionuclides that may be present in the various process equipment and ancillary ductwork and piping. The equipment and methods used to provide estimates of the radionuclide inventories are discussed briefly.

1.1 Facility Description

The 325 Building Applied Chemistry Laboratory is operated by the Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE).^(a) The Applied Chemistry Laboratory is a Category II nuclear facility located within the 300 Area. Work recently performed, under way, or planned for the near future includes a variety of activities including: process research, development and demonstrations; analytic chemistry research and services; and treatment of radioactive, hazardous, or mixed radioactive and hazardous wastes. Work is divided among a variety of locations including: two hot cell complexes, glove boxes, fume hoods, and laboratory benches, depending on the radioactive or hazardous nature of the work. A single project frequently involves working in more than one of these locations, such as sample preparation or dilution in the hot cell or glove box, followed by analytical measurements in a fume hood.

The 325 Building is a concrete structure three stories high with a basement. The structure houses offices, analytical laboratories and shops, as well as a plutonium storage vault and several highly shielded hot cells with associated truck locks. A wide variety of activities involving spent nuclear fuel, separation processes, waste analysis, analytic chemistry services, etc. are conducted in the facility. The facility has contained large inventories of transuranics, fission and activation products, tritium, and radium in the past. These materials are located in the laboratory and hot cell areas in the building. The First Floor contains the offices, shops, and laboratories, as well as the 325A hot cells (High Level Radiochemistry Facility) and 325B hot cells (Shielded Analytical Lab.). The Second Floor contains more offices, and the third Floor contains ventilation equipment and access to the top of the cells. The Basement contains more offices and laboratories as well as the storage vault and process equipment piping and ductwork for the laboratories.

Analytical services are provided for all projects in the 325 Building, as well as services for outside customers. General chemical laboratories are equipped with work space on laboratory benches and fume hoods. Large pieces of equipment, such as spectrometers, are usually placed in separate glove boxes for contamination control. Entire rooms and laboratories may be devoted exclusively to glove boxes and

(a) Pacific Northwest National Laboratory is operated by the Battelle Memorial Institute for the U.S. Department of Energy under contract DE-AC06-76RLO 1830.

have few or no laboratory benches. However, some analytical equipment is maintained free of contamination and is housed in separate areas without any fume hoods or laboratory benches. Because of the constantly changing work requirements, the arrangement of laboratories and equipment in the laboratories is constantly changing as some projects are completed and new projects are started, or as project needs change. At the present time, 20 to 40 different projects are simultaneously conducted in the 325 Building.

1.1.1 Past Work Activities

In the recent past, there have been a number of activities related to the separation of plutonium from spent nuclear fuels, including separation of plutonium from high exposure fuels. Some of the typical activities that have taken place in the last few years (waste-related, fuel-related, and others) are described below

Waste-Related Activities

- Characterize chemical, radiochemical, and physical properties from Hanford single-shell and double-shell waste tanks. Particular emphasis is given to waste stream suitability for processing at the Hanford Waste Vitrification Plant (HWVP).
- Evaluate ion-exchange resins for the recovery of selected radionuclides from vitrification wastes produced by the HWVP.
- Develop flowsheets for processing selected Hanford wastes.
- Provide a treatment service for hazardous waste or mixed (hazardous and radioactive) waste generated at PNNL. This includes grouting, neutralization, distillation, and new and emerging technologies for chemical waste treatment and destruction of waste.
- Determine the potential for rapid exothermic reactions between ferrocyanide and nitrate or nitrite in wastes from single-shelled tanks at Hanford.
- Evaluate the performance of a resorcinol/formaldehyde ion-exchange resin for removal of ^{137}Cs from Savannah River alkaline waste.
- Develop and demonstrate a process for preparing waste sludge from West Valley Nuclear Services Company for vitrification feeds. Develop processes for secondary treatment of wash or supernatant liquids to reduce the level of radioactivity to as low as reasonably achievable (ALARA).
- Prepare organic standards and investigate organic extractions. Work may involve gallon quantities of solvents such as acetone, hexane, toluene, iso-octane, carbon tetrachloride, Freon 112, and methylene chloride.

Fuel-Related Activities

- Develop and test flowsheets for the removal of transuranics and other selected radionuclides from dissolved fuel from light-water reactors in support of processes being developed by Westinghouse Hanford Company.
- Provide analytical chemistry support for fuels-related programs such as the Materials Characterization Center and Tuff Repository Program.
- Prepare and analyze samples for x-ray diffraction, scanning electron microscope, or Auger electron analysis. Samples include oxidized and nonoxidized spent fuel from light-water reactors and fission product deposits from fuel rods.
- Investigate oxidation kinetics of spent light-water reactor fuel.
- Conduct Fast Flux Test Facility (FFTF) fuel analyses.

Other Activities

- Provide as-needed analyses of liquids and solids associated with the Hanford Site characterization and remediation efforts and plant operations for compliance with the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).
- Analyze performance evaluation samples submitted by the EPA, the Environmental Monitoring Laboratory, and other organizations as a routine part of laboratory quality control programs.
- Prepare standard solutions of radionuclides from stock batches for research and development of analytical procedures and for quality control.
- Investigate tritium release from tritium-containing materials such as beryllium and lithium oxide. Examine releases by both carrier gas extraction and vacuum extraction.
- Study tritium permeation through reactor target rods.
- Separate and process medically useable radioisotopes.
- Recover ^{238}Pu from irradiated ^{237}Np .

1.1.2 Present and Future Work Activities

Recently, there has been a major effort to greatly reduce nuclear and radioactive material inventories within the 325 Building to reduce the facility from Hazard Category II to Category III status. Material

from old programs has been repackaged and shipped out of the building. The amount of material used in current and future programs has been severely restricted. Current and future programs include the following:

- *N Reactor Fuel Characterization* - Most of this work is in the 327 Building, but some may take place in the 325 Building involving only a few grams of ^{235}U at a time, with a maximum of about 50 g of ^{235}U in the building. There will be small amounts of plutonium associated with the fuel.
- *Waste Characterization Studies* - There is high potential for increased work activity for waste characterization studies in the 325 Building. This will include small quantities of transuranics as well as fission products.
- *Fuel Leaching/Dissolution Studies* - There is ongoing work with Light Water Reactor (LWR) fuels and N Reactor fuels, with the possibility of Navy reactor fuel work. The amount of nuclear material involved is small, about 0.5 kg for each study.
- *Medical Isotope Production* - Most of this work currently involves production of ^{90}Y , but other isotopes may be considered in the future.
- *Radium Production and Radium Repository programs* - There are several radium production programs being considered for work in the 325 Building, including purification of ^{223}Ra from Fernald. The laboratory has been exploring the potential for becoming a repository for radium needles and repackaging the material for reuse. Small but significant amounts of radium have been processed in the past in the 325 Building.
- *^{233}U Purification* - There is the possibility of a limited-production demonstration of a process for separating ^{233}U from irradiated thorium. Initial work would involve about 100 g of ^{233}U .
- *^{238}Pu Chemistry Studies* - There are about 15 g of ^{238}Pu in the 325 Building involved in several studies. Because of its very high neutron emission rate, this could seriously impact estimated ^{239}Pu inventory estimates based on neutron counting.
- *Plutonium Dissolution Studies (CEPOD)* - A significant amount of material has recently been removed and shipped from the 325 and 324 Buildings, but there may be some hold-up left. There is the possibility of extended work for removing the plutonium from ash.
- *^{238}Pu Heat Sources* - There is the possibility of the introduction of significant quantities of ^{238}Pu in heat sources in the near future. This could seriously impact ^{239}Pu estimation from neutron counting because of the very high neutron backgrounds.
- *Strontium Capsules* - There are significant quantities of strontium in the 325 Building, including encapsulated material in storage drums and material removed from B Cell.

- *Tritium* - In addition to the past tritium work, there is a proposal for continuing post-irradiation examination of tritium materials as well as further work on fusion programs.

1.1.3 Possible Problem Areas

As indicated from the discussions above, there are several potential problem areas that could interfere with the accurate determination of holdup of plutonium and other transuranic (TRU) materials, as well as the determination of the holdup of fission products and other non-TRU isotopes in the 325 Building. A wide variety of neutron-emitting materials may be present, including ^{238}Pu , ^{244}Cm , and other isotopes with high neutron-emission rates. In areas with high neutron counts, it is necessary to make certain that the neutrons are from ^{239}Pu and associated plutonium isotopes; otherwise, erroneously high plutonium estimates will result. The isotope ^{244}Cm used in waste vitrification studies presents a serious problem because milligram quantities emit as many neutrons as kilogram quantities of plutonium. With its weak gamma emissions, it will be difficult to accurately measure ^{244}Cm behind massive shields. It may also be necessary to perform a greater number of gamma spectra measurements to allow better determination of plutonium isotopic compositions using the gamma analysis codes. Also, any mass spectrometric data would be of use for more accurately predicting neutron emission rates and hence better mass correlations with neutron emission rates.

There are several areas that need particular attention because in the past large quantities of transuranics were processed in these areas:

- **Room 604** - Plutonium was calcined in this room, and there may be significant holdup in the air ducts and waste lines in this area.
- **Room 410** - In a former glove box and ancillary locations in the room, a chemist processed significant quantities of alpha-emitters, including plutonium, ^{238}Pu , ^{244}Cm , and even ^{252}Cf . Accurate plutonium measurements may be difficult because of interference by the other isotopes which have very high neutron emissions. Attention needs to be given to the ducts and piping in this area.
- **300 Hallway and laboratories** - In the 1960s, the laboratories along the hallway and the hallway itself were contaminated with plutonium. Much of the air ducts and ventilation was replaced, but a careful survey was necessary to make certain that plutonium was not contained in sections of ducts or pipes that were not replaced.
- **325A hot cells** - Both ^{237}Np and ^{238}Pu separation processes were conducted in the 325A hot cells. A spill of ^{238}Pu solution in C-Cell resulted in a significant amount of contamination of the rear face of the cell. There may be enough ^{237}Np or ^{238}Pu present to interfere with plutonium holdup estimates from neutron counting.
- **Laboratory vacuum system** - During an outage, the building vacuum system was pressurized by accident. There is a distinct possibility that americium was dispersed into the vacuum system lines. During the vacuum system reversal, about 1 gram of ^{241}Am was spread into laboratories on the 500 hallway.

- **325 basement** - There is a high probability that the sumps and piping in the basement below the hot cells contain spent fuel debris or transuranics from disassembly and separation processes conducted in the hot cells.
- **FFTF fuels glove boxes** - A chemist processed large quantities of plutonium for use in the fuel program for the FFTF. Since much of the plutonium was in the form of plutonium dioxide powder, there was a good possibility that the interior of the ducts and ventilation system and filter boxes contained significant quantities of plutonium.
- **Sealed sources** - An 80-g PuBe source and a 156- μg ^{252}Cf source located in Room 44 and an AmBe source stored in Room 42 contribute to a significant neutron background on the east side of the basement.

1.2 Radiological Survey

Holdup measurements are required in all facilities where special nuclear materials (SNM) may exist in building systems. Potential criticality safety issues have been identified at other DOE facilities and have been addressed in PNL-MA-25, *Criticality Safety*, as action items.^(a) The major objective of this project is to identify and quantify radioactive materials that may contain transuranic (TRU) holdup in various ducts, processes, and equipment in the 325 Building. The radiological mapping survey was used 1) to locate potential sources of radioactive materials/special nuclear materials (RAM/SNM) at specified locations; 2) to provide a baseline reference point for trend analysis on data from future measurements; 3) to augment ongoing radiological surveys; and 4) to provide supporting documentation regarding criticality safety and provide data for nuclear material accountability.

A radiological survey of all 325 Building cell ductwork, radioactive liquid waste system (RLWS) pipes, and laboratory vacuum system lines in the basement was conducted in February 1996. The survey readings were taken by PNNL radiological control technicians. Guidelines for holdup assay are stated in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guides 5.23 and 5.37 (1984, 1983) and the Los Alamos Nuclear Safeguards Training Program (LANL 1992).

1.2.1 Radiological Survey Equipment

Equipment used for the survey included a Geiger-Mueller (GM) counter with an extendable probe and a marking device for permanently labeling measurement locations. The potential hazards identified were possible contamination and high-dose-rate areas. Personnel safety issues were addressed and covered in the radiological work procedure specific to this work. The radiological survey procedure followed regulatory guidelines. Preliminary radiation survey measurements of the facility were used to budget the measurement time, to emphasize high-holdup areas, and to determine nondestructive assay locations.

(a) Pacific Northwest Laboratory (PNL). August 17, 1994. *Criticality Safety*. Controlled technical manual, PNL-MA-25, Pacific Northwest Laboratory, Richland, Washington.

1.2.2 Delineation of Assay Sites Procedure

The procedure used to establish assay locations is given below.

1. In each room suspected of having material holdup, detector positions (assay sites) were chosen so that the material holdup could be measured with both the neutron slab detector and the HPGe detector, if necessary.

Each room usually contained several types of holdup areas. For example, Room 45 in the basement contained most of the exposed RLWS pipes, the vacuum system lines, and the HEPA filters for all the hoods and glove boxes in the first floor laboratories.

2. Each assay site was marked with a permanent marker to ensure reproducible assay positions.

For ducts and RLWS pipes, dose rate measurements were taken at successive 2-ft intervals, beginning 1 ft in from the start of the duct or pipe. Where dose rates remained constant over long sections of piping or ductwork, measurements were spaced out over larger distances but usually multiples of 2 ft. Interval points were marked and identified using permanent ink or equivalent.

"Hot spots" were also identified, surveyed, and marked. Dose rate information was recorded on a floor plan schematic provided by the task leader.

3. Each site was uniquely labeled to facilitate unambiguous reference to that site in the assay log. A labeling convention was established.

Labeling proceeded sequentially for each room, beginning with room number/letter designation followed by the interval identification number. For example, the location of the first measurement point in room 45 was 45-1. Measurements began in the basement of the 325 Building in February, 1996, and progressed to the first floor laboratories during March.

1.3 Gamma Assay

Gamma-ray assay is based on the activity observed from specific energy peaks detected from the isotopes present. Equipment for gamma holdup measurements consisted of the following components:

- tungsten or lead collimator
- high-purity germanium (HPGe) detector - efficiency ~20%
- angular response of the detector/collimator reference (see Figures 1.1 and 1.2)
- Canberra Genie-PC AIM Data Analysis and Acquisition System.

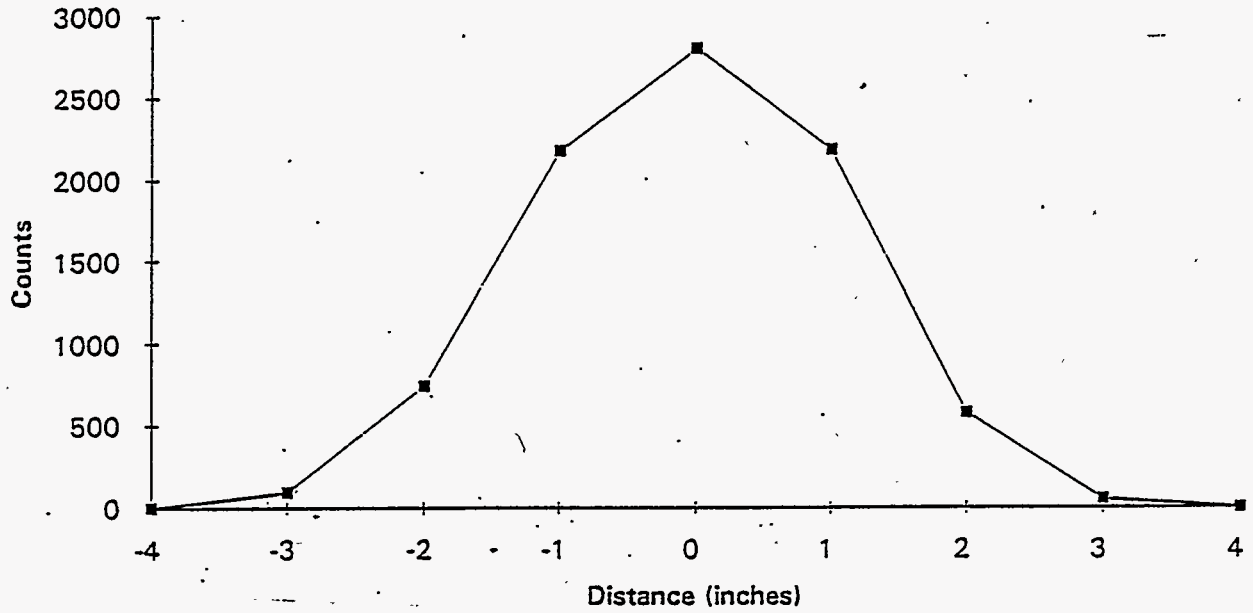


Figure 1.1. Point Source Measurements by Collimated High-Purity Germanium Detector at Selected Distances from Source

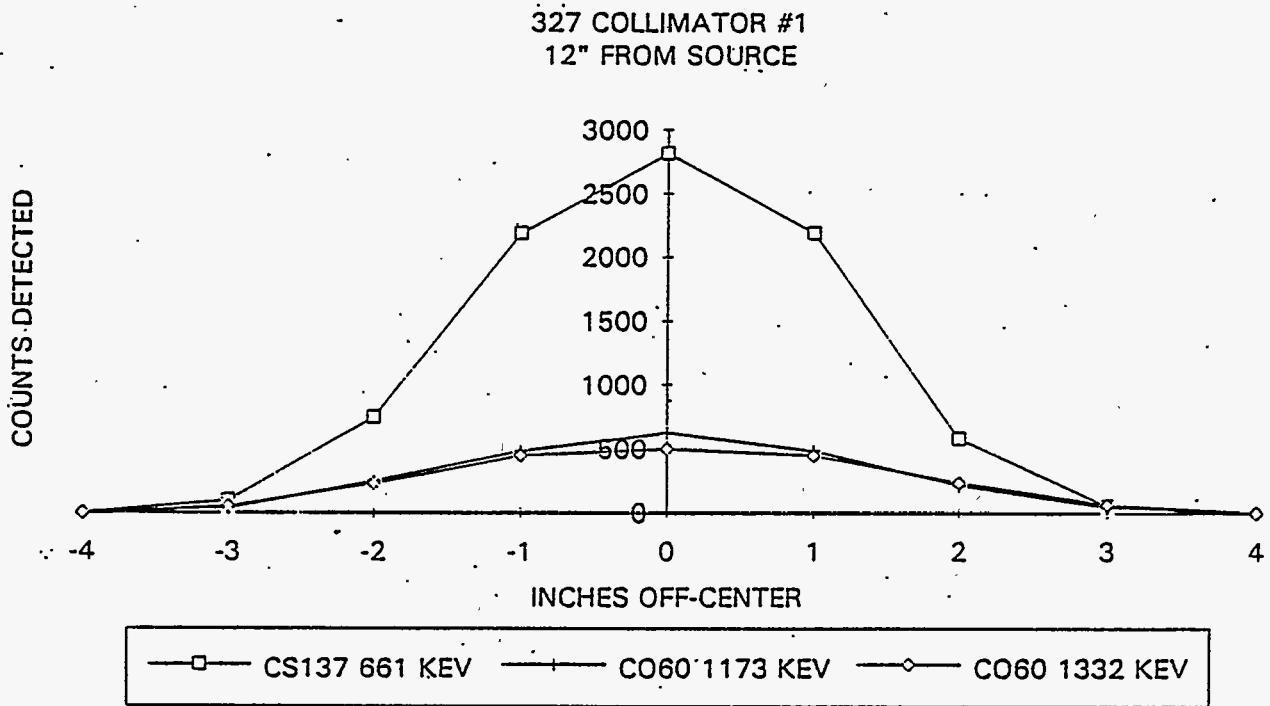


Figure 1.2. Distribution of Gamma-Ray Activity Along Horizontal Measurement Axis of the HPGe Detector

The HPGe detector was shielded and collimated from other surrounding source material. A tungsten collimator was used with the gamma-ray detector. Additional shielding was also needed to eliminate background gamma rays originating behind the detector. The collimator provided sufficient shielding and directionality for the holdup measurement geometry. The detector's field of view was defined by the tungsten collimator. Calibration of the gamma system was performed with the same collimation setup used during the holdup measurement campaign.

Initial calibrations for the holdup measurement system were performed for point, line, and area source geometries. These point, line, and area geometry calibration constants described the distribution in the detector's field of view. The correction factors were specific to the detector and collimation setup and were used to correct for the detector's radial response to the incident radiation of interest. These corrections were used in the corresponding measurements to convert the results to activity or grams of material. This procedure used a single point source to determine these correction factors. Point source measurements were conducted at several horizontal positions, as indicated in Figure 1.1. Figure 1.2 illustrates the gamma detector's response along the horizontal measurement axis. The gamma detector's relative efficiency for that geometry was determined. One reference standard centered in front of the detector at a fixed distance was measured to determine the detector's absolute response to the incident radiation.

Formulae required to determine calibration constants are as follows:

$$L = 2s \frac{\sum_{i=0}^n C_i}{C_0} - s \quad (1.1)$$

where L = effective length of the detector field of view at distance r_0
 s = length of the horizontal increment
 C_i = net count rate at horizontal position i
 C_0 = net count rate with the source centered in front of the detector.

$$a_0 = \frac{\pi s^2}{4} \quad (1.2)$$

where a_0 is the incremental area at horizontal position 0

$$a_i = \pi [(i + 0.5)s]^2 - \pi [(i - 0.5)s]^2 \quad (1.3)$$

where a_i is the incremental area at horizontal position i

$$A = \frac{\sum_{i=0}^n (a_i C_i)}{C_0} \quad (1.4)$$

where A is the effective area of the detector field of view at distance r_0

$$K_p = \frac{m_0}{C_0 r_0^2} \quad (1.5)$$

$$K_l = \frac{m_0}{L C_0 r_0} \quad (1.6)$$

$$K_a = \frac{m_0}{A C_0} \quad (1.7)$$

where K_p = point source calibration constant (g·s/cts·cm²)
 K_l = line source calibration constant (g·s/cts·cm²)
 K_a = area source calibration constant (g·s/cts·cm²)
 m_0 = mass of the reference source (g)
 C_0 = net count rate of the reference standard centered in front of the detector face at distance r_0 (cts/s).

Once calibration constants are determined, quantitative estimates can be made for point sources, line sources, and area sources.

1.3.1 Point Source Calibrations

A point source is a small deposit centered in a large detector field-of-view. Its calibration is determined with Equation 1.8:

$$m = K_p C r^2 \quad (1.8)$$

where m = mass of isotope of interest (g)
 K_p = point source calibration constant (g·s/cts·cm²)
 C = net count rate (cts/s)
 r = source-to-detector distance (cm).

1.3.2 Line Source Calibrations

A line source is a narrow uniform deposit, centered in a wide detector field-of-view, which spans the width of the detector field-of-view. Its calibration is found with Equation 1.9:

$$m = K_l C r l \quad (1.9)$$

where m = mass of isotope of interest (g)
 K_1 = line source calibration constant (g·s/cts·cm²)
 C = net count rate (cts/s)
 r = source-to-detector distance (cm)
 l = length of a line source (cm).

1.3.3 Area Source Calibrations

An area source is a uniform deposit that fills the detector field-of-view. Its calibration is found with Equation 1.10:

$$m = K_a C a \quad (1.10)$$

where m = mass of the isotope of interest (g)
 K_a = area source calibration constant (g·s/cts·cm²)
 C = net count rate (cts/s)
 a = area of an area source (cm²).

The equipment was moved to the 325 Building and checked for physical damage. A combination standard traceable to the National Institute for Standards and Technology (NIST) was measured periodically during the measurement campaign to demonstrate that the instrumentation was properly functioning and that the calibrations determined in the laboratory were still valid.

1.4 Neutron Assay

Accurate determination of the fissile material and radioisotope content in the ducts, filters, and piping of the 325 Building is a very difficult problem. Nondestructive assay techniques for fissile materials usually employ gamma spectroscopy to identify and quantify each gamma-emitting nuclide, such as plutonium. However, the large amounts of fission products present completely obscure any gamma rays emitted by plutonium. Fortunately, the neutrons emitted by plutonium are highly penetrating and can easily pass through several inches of the steel or lead shielding used to reduce gamma doses, although the neutrons may be degraded in energy. With some degree of uncertainty, the amount of plutonium can be determined using appropriate calibration standards and neutron detectors. Passive neutron counting is a recognized technique for nondestructive assay of plutonium and is described in Chapter 14, "Principles of Neutron Counting" in *Passive Nondestructive Assay of Nuclear Materials*, NUREG/CR-5550 (Reilly et al. 1991).

Neutrons emitted by plutonium originate from two main sources:

- spontaneous fission of even-numbered plutonium isotopes
- alpha-neutron reactions with any low-atomic-number materials in intimate contact with the plutonium.

Most of the neutrons originate from ^{238}Pu , ^{240}Pu , and ^{241}Am , which is the decay product of the short-lived nuclide ^{241}Pu . Thus, it is important to know not only the isotopic composition of the plutonium, but also the time since chemical separation of the ^{241}Am content to be able to estimate the neutron contribution from ^{241}Am . In many practical situations, the number of neutrons produced by alpha-neutron reactions can exceed the spontaneous fission production from plutonium. Any alpha-emitter in contact with low-atomic-number nuclides will produce neutrons. For example, transuranics that are in intimate contact with beryllium, boron, aluminum, sodium, or even concrete will produce neutrons. High neutron emission rates can result from finely divided plutonium oxide dust on borosilicate glass or aluminum spacers in HEPA filters. The neutron emission rates can be tens to hundreds of times higher than for pure plutonium metal.

It is conceivable, although not likely, that the material may not contain any plutonium, but will still emit neutrons from alpha-neutron reactions from americium or other transuranic material with high alpha activity. The exact amount of plutonium present can be determined from the neutron measurements if we know the following:

- the exact isotopic composition of the plutonium
- the time since chemical separation to allow calculation of ^{241}Am progeny
- chemical composition of the plutonium
- presence of low-atomic-number impurities in contact with alpha-emitters
- other transuranics present that may also emit neutrons, such as ^{244}Cm .

We can make some simplifying assumptions that will limit the range of calculated values of the amount of plutonium that may be present. For instance, we can assume that the plutonium will be low-exposure plutonium. Neutron emission rates of weapons grade (less than 6% ^{240}Pu) or N-Reactor plutonium are quite low, typically about 150 neutrons per second per gram of plutonium. Higher-exposure plutonium would emit more neutrons and result in a smaller actual mass for a given measured neutron emission rate.

Plutonium metal is chemically unstable, and any small pieces would eventually convert into an oxide or oxide-hydroxide mixture in moist air. The oxide is the most chemically stable form of plutonium and would be the most likely form to be found. The neutron emission rates of oxylates, nitrates, and hydroxide mixtures will be somewhat similar to that from pure plutonium oxide. Assuming any plutonium present would be in the form of an oxide will result in conservative estimations. Any other chemical form, particularly fluorides, would emit more neutrons and result in a smaller actual mass for a given measured neutron emission rate. However, oxides are the most probable chemical form found in reactor spent fuel.

2.0 Scope and Objectives

The objectives of this work are threefold:

- provide a baseline radiological survey of the ducts and piping
- determine an upper limit of plutonium inventory and an estimate of the most probable amount of plutonium that may be present
- locate and quantify the amount of fission product, activation, and TRU materials that are present in ducts, RLWS lines and other facility processes, as a baseline for future reference.

This work is limited in scope to the nondestructive assay of the contents of the ducts, filters, and piping in the 325 Building and low-level waste that resided in those locations at the time measurements were taken.

2.1 Definition of the Problem

Over many years of operation of the 325 Building, the internal ducts, filter boxes, and piping and drain lines from the hot cells and laboratories have become contaminated with large amounts of fission and activation products and small amounts of plutonium and other transuranic nuclides. The fission and activation product inventory is large enough in some locations that it presents a radiation hazard, and in some locations steel and lead shielding have been added to critical areas to reduce radiation doses. It is conceivable that enough plutonium and transuranic material has accumulated to be of concern for criticality safety and safeguards controls.

The purpose of this work is to attempt to quantify the amounts of radionuclides in the internal ducts, filter boxes, and pipes leading from the hot cells. Of particular concern are the liquid waste lines that may have accumulated fuel debris, with the potential build-up of quantities of plutonium. Because of its high activity, the radioactive cesium and cobalt are relatively easy to locate. However, the high gamma levels will mask the gamma emissions from plutonium and other transuranics. The problem is further exacerbated by the streaming of neutrons down ducts and openings from the hot cells. Inventories of plutonium, curium, and other neutron-emitting nuclides in the hot cells will create variable backgrounds in the basement in the areas around the ducts and pipes. It is extremely difficult to accurately assess plutonium inventories in the presence of variable neutron backgrounds. Passive neutron measurements are further complicated by the storage of over 500 g of ^{238}Pu oxide stored in Room 52 in the basement of the 325 Building. The neutron emission rate from the ^{238}Pu oxide is orders of magnitude higher than from other sources we are attempting to measure.

2.2 Planning and Solution

A review of the radiological conditions was made, including gamma surveys to determine hot spots in the ducts and piping. Excessive gamma dose rates from fission products preclude the use of gamma assay equipment routinely used to determine plutonium mass. The high dose rates from fission products would interfere with the plutonium isotopic analysis. Therefore, neutron assay techniques would be more reliable for locating and quantifying fissile material. A neutron slab detector based on a design from the Los Alamos National Laboratory (LLNL) Safeguards Assay Group was selected for measurements to determine the amount of plutonium that could be present. The amount of plutonium in the ducts and RLWS pipes can be estimated by:

- calibrating the neutron detector with appropriate calibration standards
- measuring the neutron flux around the ducts, filter boxes, and piping
- carefully analyzing the data to relate the measured neutron fluxes to mass of plutonium.

The gamma-emitting nuclides were readily identified by standard gamma-assay techniques because in most instances the nuclides are not heavily shielded in the ducts and pipes. In most situations, the amount of shielding is well known and the radioactive material localized. A well collimated intrinsic germanium detector was used to quantify gamma-emitters. Where space permits, measurements are made at more than one orientation and the results averaged to give an accurate estimate of the contents inside ducts and pipes.

3.0 Measurements

The measurements were conducted according to the following documents:

- Pacific Northwest Laboratory Quality Assurance Plan QAP FO-1, *QA Plan for Safeguards Nondestructive Assay Measurements*
- Pacific Northwest Laboratory Nondestructive Assay Measurement Procedure MCA-510, *Holdup Assay Measurements* (see Appendix A).

3.1 Measurement and Test Equipment

The neutron and gamma assay systems are "user to calibrate" equipment. The individual components are configured and tested as a system, and then the entire system is calibrated with appropriate calibration/verification standards. The neutron and gamma assay systems are calibrated with check sources and calibrations standards traceable to the NIST.

3.2 Calibration Standards

Calibration standards are used in a measurement system to establish the relationship between the basic instrument response and the attributes of interest. The quality of the calibration is ensured by selecting the appropriate standard. The standard must be a physically and chemically stable item for which the attributes of interest are well characterized and for which other properties affecting the measurement are known. In this case, the count rate from neutrons, the amount of shielding, and the orientation and distance from the detector to the neutron source are related to the mass of weapons-grade plutonium. The mass of other forms of plutonium can be inferred from the calculated neutron emission rates. The calibration of the gamma assay equipment is more straightforward. The counting efficiency of the gamma spectrometer with a collimator can be measured using calibration sources of known activity and photon emission rates. The viewing angle and efficiency can be determined directly from measurements, as shown in Figure 1.2.

Records indicate that the material in the hot cells and laboratories was from a wide variety of sources, including both low-exposure and high-exposure reactor fuel samples. For these measurements, it was assumed that the plutonium would be low-exposure plutonium oxide with relatively low neutron emission rates (typically 150 neutrons/second/gram of plutonium). To give conservative results, any high neutron yields from alpha-neutron reactions were ignored. The neutron energy spectrum from plutonium dioxide is shown in Figure 3.1, taken from the document *Neutron Spectra of Plutonium Compounds*, BNW-1262 (Brackenbush and Faust 1970).

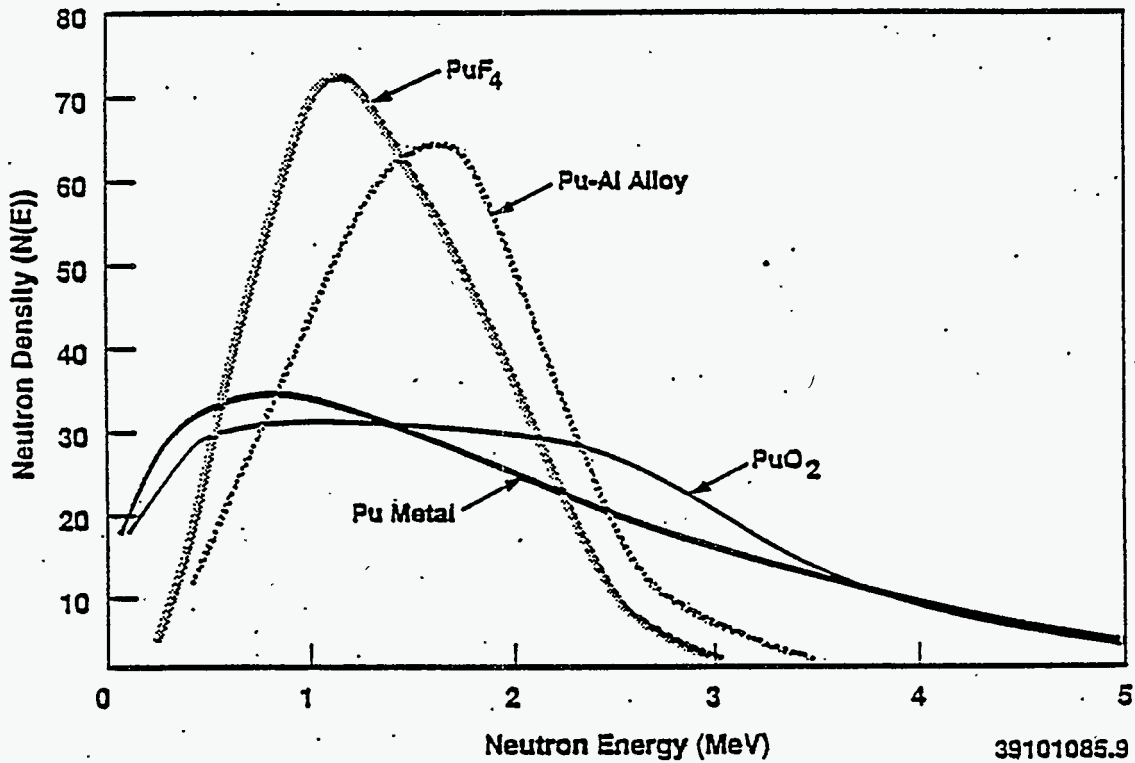


Figure 3.1. Neutron Energy Spectra from Plutonium Compounds

Two neutron sources were selected for use in calibrating/verifying the neutron detector assay system. The first was a small 0.3- μg ^{252}Cf neutron calibration source. This source's neutron dose rates have been determined by comparison with other neutron sources whose calibrations are directly traceable to NIST. This source has a neutron energy spectrum very similar to that of plutonium dioxide. (See *^{252}Cf Shielding Guide*, DP-1246 [Stoddard and Hootman 1971] or NBS Special Publication 633 [Schwartz and Eisenhauer 1982].) This source was used to determine the angular efficiency of the slab detector in the laboratory prior to the holdup measurements at the 325 Building.

A sample of weapons-grade plutonium oxide was selected as the reference material standard for determining the basic instrument response for the attributes of interest. Specifically, the mass of plutonium in the reference material was related to the neutron count rate in the neutron detector. Weapons grade plutonium has a lower neutron emission rate than the higher exposure reactor-grade plutonium samples and should yield conservative (i.e., higher) plutonium mass estimates. The plutonium oxide sample (LLNL ash sample RA 146A) selected for the reference standard contains 108 grams of plutonium with the isotopic composition given in Table 3.1. The reference standard has been measured by several nondestructive assay (NDA) systems used for measuring safeguard mass confirmatory standards. Data for this sample from high-level neutron coincidence counting and calorimetry with isotopic compositions obtained from gamma spectroscopy are in good agreement with the book values assigned by LLNL when the material was shipped to PNNL.

Table 3.1. Isotopic Composition of Plutonium Ash Reference Material,
Weight Percent Isotope

	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
Weight Percent Isotope	0.13825	93.452	6.101	0.2793	0.019	0.220
	$\pm 1.53\%$	$\pm 0.15\%$	$\pm 2.21\%$	$\pm 1.22\%$	n/a	$\pm 1.4\%$

Note: Calculated age from ratio of $^{241}\text{Am}/^{241}\text{Pu}$ is 12.3 ± 0.33 years.

3.3 Measurement and Quality Control

The measurement personnel had the complete responsibility for monitoring and evaluating the quality of the data. Any indication that the system was out of calibration (e.g., significant gain shifts in the position of the thermal neutron peak or high gamma levels that produce pile-up in the neutron events) required the stoppage of work until the problem was resolved. Before NDA measurements were initiated, the overall system was calibrated. To verify the proper operation of the neutron assay system, the entire system was assembled in the laboratory and components checked for proper operation. Then, verification measurements were performed using a known mass of plutonium before and after the measurements in the 325 Building. All of the spectral data collected during the measurements were recorded on computer files and can be retrieved if questions should arise.

A measurement control check was performed daily before the equipment was used, and the results recorded. For the neutron assay system, the detector was positioned at a fixed location 12 in. from an AmBe reference source stored in Room 42 in the basement. The measurement control check was used to check the position of the thermal neutron peak and verify that the integral of the neutron events for a 300-second count remained constant throughout the duration of the measurements. For the gamma assay system, the germanium detector was exposed to a calibration source containing a known activity of radioactive material. An analysis of photopeak areas and channel number is used to verify that the gain and sensitivity has remained constant. These procedures are recorded in Appendix A, and the data are archived on magnetic storage media.

3.3.1 Preparations for Measurement and Test Equipment

The approach to the problem of NDA assay was to select a very sensitive neutron detector to measure the neutrons emitted by any TRU (plutonium) contained in the ducts, filter boxes, and pipes. The detector requirements included sufficient sensitivity to measure sub-gram quantities of plutonium at accessible measurement locations. A slab neutron detector was selected for the measurements because of its sensitivity and directionality.

3.3.2 Neutron Slab Detector System

The neutron detector system consists of

- a neutron slab detector containing several ^3He proportional counters inside a polyethylene moderator
- ancillary NIMbin electronics (preamplifier, shaping amplifier, high voltage power supply)
- a multichannel analyzer (MCA) to display and record the neutron spectra from the detector.

The neutron slab detector consists of an array of five cylindrical ^3He proportional counters, 1 in. in diameter by approximately 22 in. long, which are filled with four atmospheres of ^3He to detect slow neutrons. The proportional counters are inside a slab of polyethylene moderator at a depth of 2 in. from the front face and 4 in. from the back face. The tubes are carefully selected to have the same gain and are connected in parallel to a preamplifier and high voltage supply. The nominal operating voltage is +1400 volts. The polyethylene slab is 6 in. deep, 16 in. wide, and 24 in. long. The detector is a standard design used for NDA safeguards assay and is described in Section 14.4.2 of NUREG/CR-5550, *Passive Nondestructive Assay of Nuclear Materials* (Reilly et al. 1991).

The NIMbin electronics include a high-voltage power supply to provide a regulated voltage of +1400 volts DC to operate the proportional counters and a shaping amplifier to convert the signals from the preamplifier to pulses that can be processed by the MCA. An MCA was used to display the spectra, so that any possible gamma interference or instrument malfunction could be detected immediately. Data from the MCA (Canberra Series 35 Plus) were recorded on a laptop computer with a hard disk for permanent data storage. Data from the computer was also backed up on floppy disks as a precaution. If there is any question about a measurement, the spectral data can be retrieved and examined later.

3.3.3 Gamma Assay System

A 20% efficient HPGe detector was used to determine radionuclide identification and quantities present at various measurement locations. The gamma assay system is composed of the latest innovative hardware and software commercially available.

3.4 Pretest Verifications

Pretest verifications consisted of testing the electronic equipment, making angular response measurements, and calibrating the slab detector with plutonium oxide.

3.4.1 Testing of Electronics

The neutron slab detector and supporting electronics were assembled in the laboratory, and all of the electronic components were checked to assure proper operation in the field. The electronics were placed in the NIMbin and the cables connected for the signals, high voltage, and preamplifier power. The methods

in the NIMbin and the cables connected for the signals, high voltage, and preamplifier power. The methods used to verify the proper operation of the equipment in the laboratory generally followed the methodology given in *Neutron Dosimetry at Commercial Nuclear Plants*, NUREG/CR-3610 (Brackenbush et al. 1984), which describes the setup of neutron spectrometry equipment using ^3He proportional counters. The output signals from the shaping amplifier was examined by exposing the detector to a ^{252}Cf neutron source in the laboratory and observing the pulses with an oscilloscope to examine the pulse shape. Adjustments are made to correct for amplifier gain and pole zero to minimize pulse overshoot or undershoot, so that the pulse returns to the baseline in the shortest possible time to reduce pulse pile-up and allow operation in high count rates. Because this adjustment depends on the cable capacitance, the entire system was tested, including the long cables that were to be used. If any component failed, there were backup units that were also checked.

The equipment was calibrated as a complete system before the 325 Building measurements were initiated. Following safeguards measurement procedures, the system was calibrated at the system level. It is not necessary, or even desirable, to calibrate the individual components of the system, because proper operation of the system and accurate interpretation of the results cannot be obtained from individual component electronic calibration. System malfunctions usually can be easily identified from the spectra recorded during the measurements. Proper operation of the system was verified with measurements using a known mass of plutonium.

The calibration/verification measurements consisted of measuring the angular response and response to room-scattered neutrons using the 0.3- μg ^{252}Cf neutron source in the ESB Building at PNNL. The response of the detector would then be known at any angle and distance to a fission source. The mass of the plutonium was then correlated to the neutron count rate from the slab detector by exposing the detector to the 108-g plutonium oxide source in the 324 Building.

Figure 3.2 shows a typical spectrum obtained from the ^3He proportional counters in the slab detector exposed to a neutron source. In this graph, the ordinate is the logarithm of the number of counts from the detector, and the abscissa is the energy deposited in the detector by gamma rays and neutrons.

There is a clear separation between gamma events, shown on the left side of the plot, and neutron events. Gamma events can be eliminated by setting a region of interest and integrating only neutron events, as shown in Figure 3.2.

However, pulse pileup can occur in intense gamma fields, when several gamma pulses are counted within the resolving time of the electronics. This produces a gamma continuum that can extend into the neutron event region. The slab detector was exposed to a ^{137}Cs gamma source in the ESB laboratory to determine the operating range in high radiation fields. There is no significant gamma pile-up that could interfere with the neutron detector at gamma exposure rates up to 1 R/h. The detector can function in gamma fields as high as 35 R/h, but there is serious gamma pile-up, and the region of interest must be adjusted. The spectral data were recorded, so that all of the measurements can be reviewed later, if necessary.

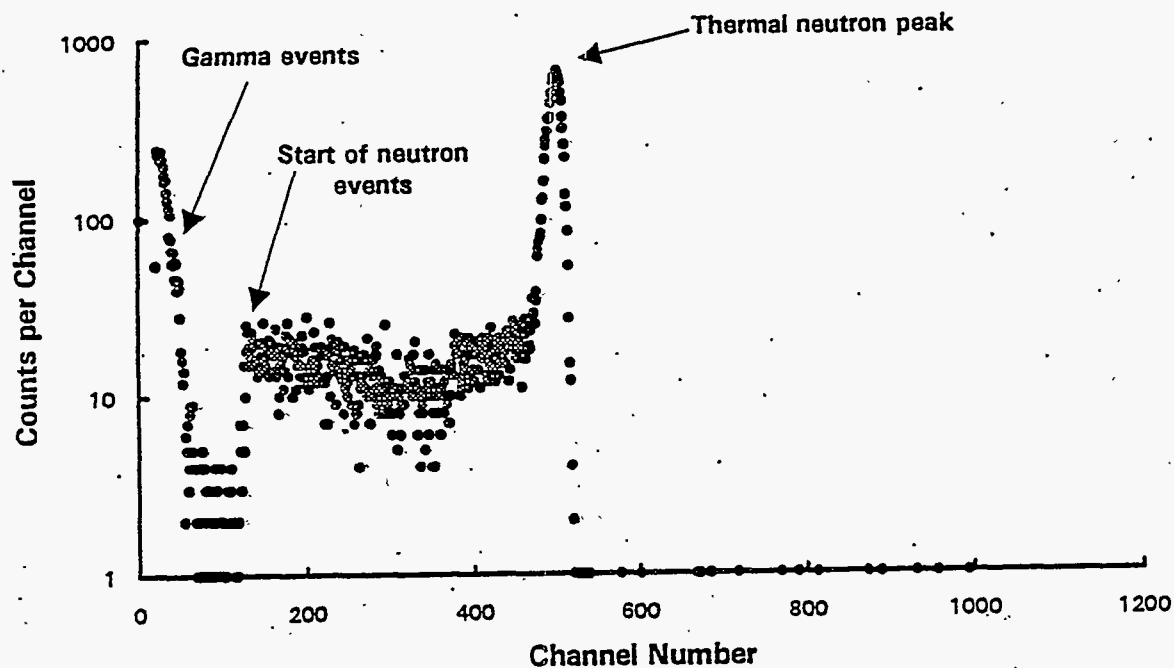


Figure 3.2. Energy Deposition Spectrum from the ^3He Proportional Counters Exposed to a Neutron Source

3.4.2 Angular Response Measurements

The first set of calibration/verification measurements were made in the ESB Building laboratory, using the $0.3\text{-}\mu\text{g } ^{252}\text{Cf}$ neutron source to set up the system electronics and determine the angular response of the slab detector. The response of the detector as a function of polar and azimuthal angles is given in Figures 3.3 and 3.4, respectively. Angles are measured in reference to an axis normal to the center of the front face of the slab detector. (The front face has the five ^3He tubes located at 2 in. below the surface of the plastic moderator.) The azimuthal angles are measured in the plane passing through the longest axis of the rectangular slab; polar angles are measured in a plane at right angles to the longest axis of the rectangular slab. These measurements were made in the ESB Building laboratory at a height of 4 ft above the floor. The angular responses were measured with the slab detector positioned vertically on a turntable; the neutron source was at a distance of 6 ft (2 m) from the center of the ^3He tubes. The graphs demonstrate that the angular counting efficiency does not change dramatically if the source is slightly off-axis, and that neutrons entering the back side of the detector are counted at about 50% of the efficiency of those entering the front.

3.4.3 Calibration of Slab Detector with Plutonium Oxide

The slab detector was also calibrated in the 324 Building by exposing the detector to a 108-g sample of plutonium oxide (LLNL sample RA 146A) at a height of 4 ft above the floor and in a vertical configuration. The 108-g plutonium source has been described previously in Section 2.0. As will be

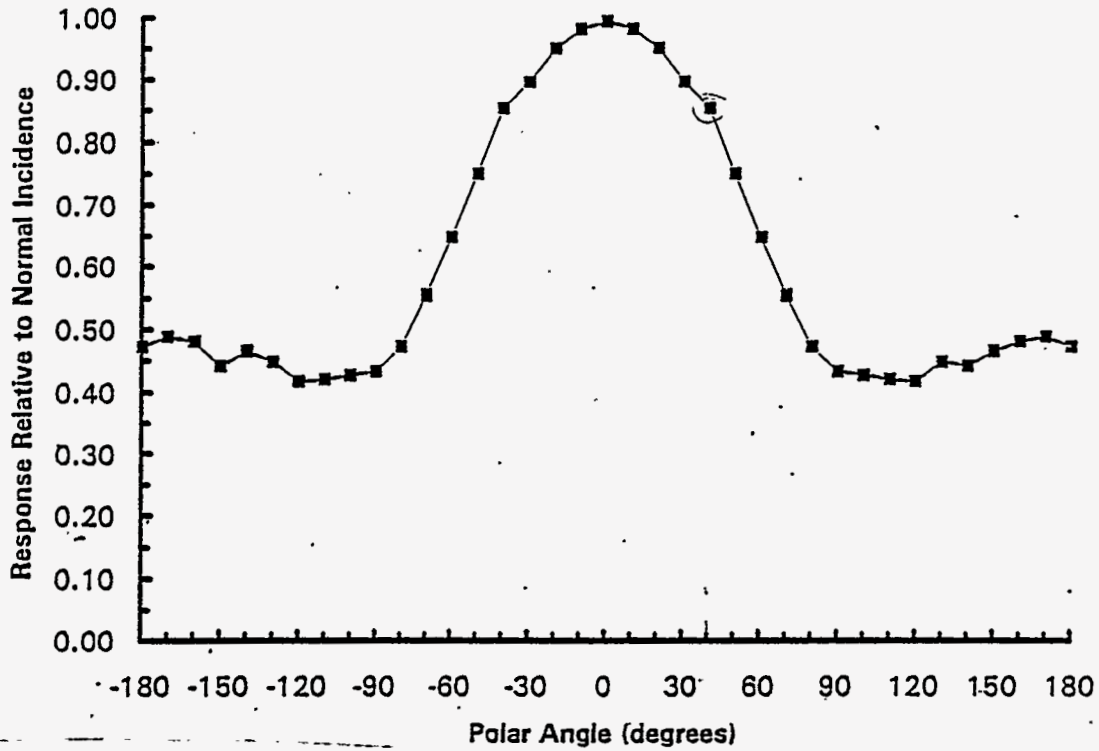


Figure 3.3. Relative Angular Response of the Slab Neutron Detector as a Function of Polar Angle

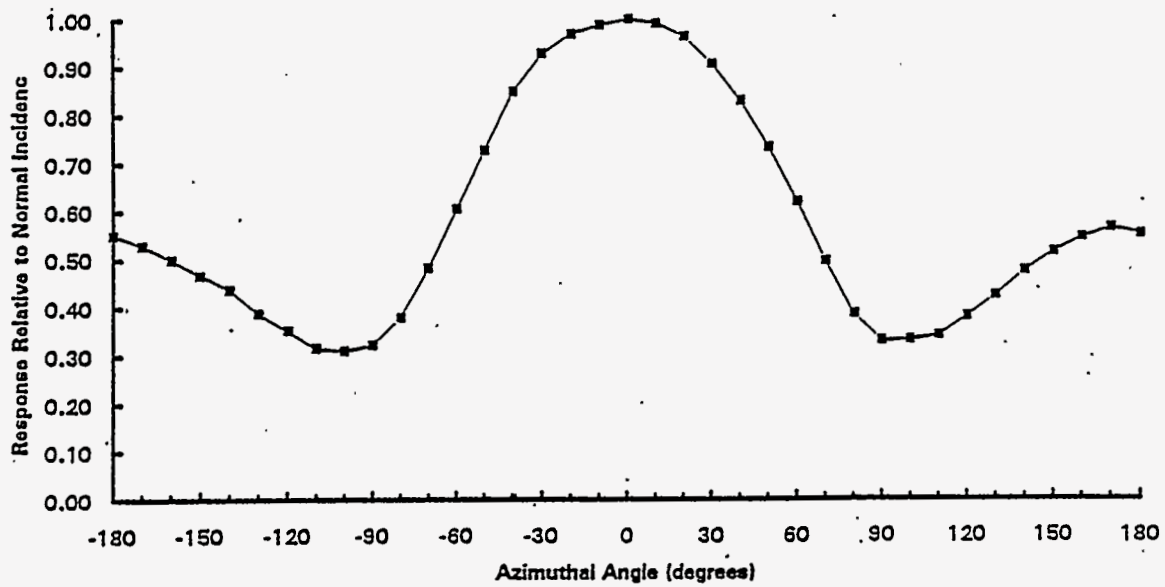


Figure 3.4. Relative Angular Response of the Slab Neutron Detector as a Function of Azimuthal Angle

explained in Section 4.0 on data analysis, it is possible to correct for the effects of room-scattered neutrons from the series of measurements that relate distance to the measured neutron count rate. After these measurements were completed, it was possible to relate the mass of weapons-grade plutonium to the measured count rate, the distance from the detector, and the angle of incidence. As will be explained in the data analysis in Section 4.0, it is even possible to correct for the effects of neutrons scattered within the facility from inverse square measurements performed in the 324 Building.

Measurements were also made in the 324 Building using various thicknesses of steel and aluminum to estimate the effects of shielding. The shields were approximately 2-ft square and were positioned near the plutonium source to effectively shield it from the slab detector. The can of plutonium oxide containing the 108 g of plutonium was positioned on its side on the floor inside a "cave" of steel and lead bricks. Measurements were then made with the bare source and with the source covered with large slabs of iron and aluminum positioned on top of the can containing the plutonium oxide. The steel and lead cave prevented neutrons from scattering around the edges of the intervening shield materials. Results of the shielding measurements are given in Table 3.2. Note that the neutrons were not absorbed like gamma rays in steel shields; the neutrons scattered within the shield and were lower in energy. These data indicate that even 2 in. of steel or aluminum does not greatly influence the measured neutron flux.

Table 3.2. Effect of Steel and Aluminum Shielding Materials Placed Between the Plutonium and the Slab Neutron Detector

<u>Shield Material</u>	<u>Thickness (in.)</u>	<u>Attenuation Factor</u>
Steel	None	1.00
	1	0.85
	2	0.75
	3	0.68
	4	0.6
	6	0.49
Aluminum	None	1
	0.5	0.94
	1.5	0.84
	2	0.8
	3.5	0.68
	4	0.65

3.5 Neutron Measurements in the 325 Building

Operational and background checks were made for neutron levels.

3.5.1 Operational Check

After the preliminary measurements were completed in the laboratory and the system was functioning properly, the holdup measurements commenced in the 325 Building basement in Room 45. Here, the neutron detector was connected to the MCA via 100-foot-long cables, so that the operator could remain in one area while the detector was positioned near the various ducts and piping. Before the measurements were started, an AmBe reference source stored in Room 42 was used as an operational source check of the system. The neutron slab detector was positioned 12 in. from the source to the front face of the detector. The neutron event spectrum, similar to that shown in Figure 3.2, was measured and recorded every day to verify that the detector and ancillary electronics were functioning properly. After the operational check indicated that the system was still functioning properly, it was ready for neutron measurements on the ducts and pipes.

3.5.2 Background Measurements

Background measurements were performed with the HPGe detector and the neutron counter.

High-Purity Germanium Detector

Background measurements were taken with the HPGe at various measurement locations. A solid plug replaced the collimator and a background measurement was taken for the same counting time as the collimated measurement. The background contribution was subtracted from the collimated measurement with analysis conducted on the resulting background-corrected spectrum.

A small, low-power neon laser was used to align the gamma detector to the desired measurement location on the duct, RLWS line, or other measurement location of interest. Detector-to-source distance was measured using a SONIN sonic measuring unit. Accuracy of the distance measurement was ± 0.5 cm.

Neutron Measurement System

Other neutron sources in the building could contribute significantly to the neutron count rate, so careful background measurements were made before any measurements were made on the ducts or pipes. If the neutron count rates were too high, it would be necessary to modify the measurement plan.

The detector was designed to have a directional response, so that fission neutrons entering from the back side would be counted with only half the efficiency of those entering from the front of the slab detector. Background measurements were made on the periphery of the area around the ducts and filter boxes. The slab detector was positioned in a vertical orientation to measure the general background. At

a given position, a measurement was taken; then, the slab detector was rotated 180° and the measurement repeated. This procedure gave pairs of neutron count rates with the detector facing the source and pointed away from the suspected neutron source. These data allowed the average room background at each location to be determined, as explained in Section 4.0 on data analysis.

4.0 Analysis of Data

Data was analyzed for both the calibration/verification measurements and for measurements taken in the 325 Building.

4.1 Analysis of Calibration and Verification Measurements

The calibration or verification measurements made before the 325 Building holdup measurements allow one to correlate the mass of weapons-grade plutonium to the measured neutron count rate and account for scatter of neutrons from the walls, floor, and ceiling of the room. This method of correcting for scatter from inverse square measurements is presented in the NBS Special Publication No. 633 (Schwartz and Eisenhauer 1982). The response of any moderated neutron detector can be modeled as a response to neutrons coming directly from the source and a response to neutrons scattered from the floor, walls, and ceiling of the room. If the detector is more than 1 m from the floor and walls, the scattered component can be assumed to be a constant. This can be expressed mathematically by Equation 4.1:

$$C = \frac{M}{r^2} B \quad (4.1)$$

where C = the count rate (cts/s)
M = the mass of plutonium in grams (directly proportional to the neutron source strength)
B = the neutron background in the room due to scatter from the floor, walls, and ceiling
r = the distance (in feet) from the plutonium source to the centerline of the proportional counters.

Multiplying by r^2 gives Equation 4.2:

$$Cr^2 = MBr^2 \quad (4.2)$$

In the limit that r^2 approaches zero, the term Br^2 approaches zero while the term Cr^2 approaches a constant. Plotting the product of the count rate times the distance squared versus the distance squared produces a straight line if the detector is not too close to the source or walls. An example of the inverse square plot from the 108-g plutonium oxide source is shown in Figure 4.1. A straight line has been fitted to the data points. The intercept on the ordinate axis is proportional to the neutron source strength or mass of plutonium, and the difference between the intercept and the value on the straight line gives the contribution to room scatter. In some small rooms, the scatter can be as high as 50% of the count rate at distances of 6 ft (2 m) from the neutron source. Thus, it is important to correct for the effects of room scatter.

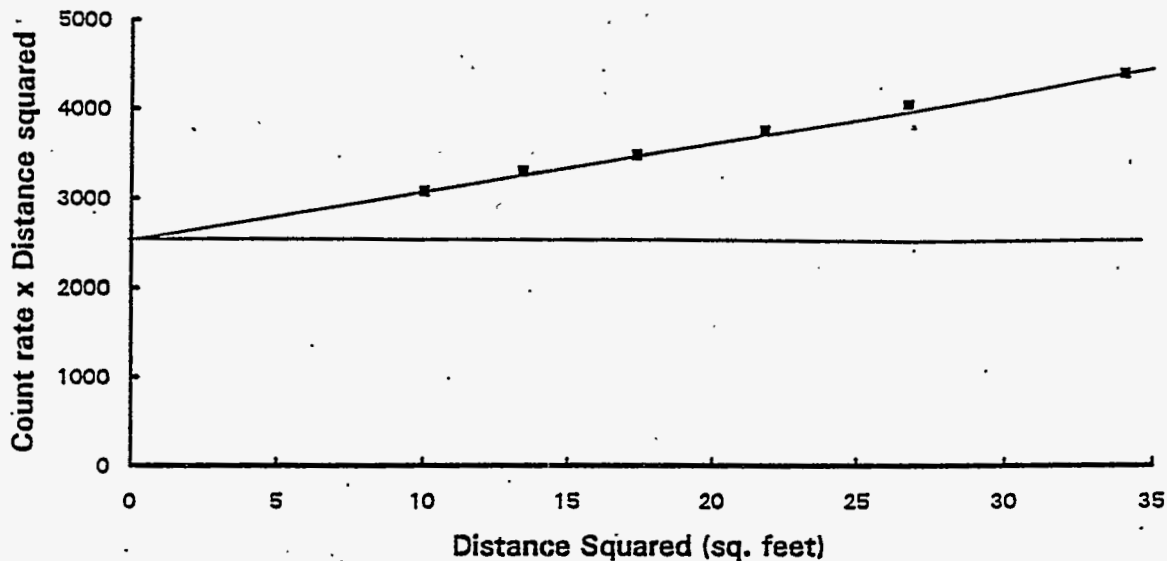


Figure 4.1. Example of Inverse Square Measurements with Neutron Slab Detector Exposed to a Plutonium Oxide Source Containing 108 Grams of Plutonium

This technique can be used to correlate the detector count rate to the mass of plutonium. Consider the case where the can of plutonium oxide was 4 ft (1 m) above the floor and the slab neutron detector was positioned vertically. The least squares fit gives the values for the slope and y-intercept of a straight line fitted to the inverse square data points in Figure 4.1. Dividing the slope and intercept values by the mass of plutonium (108 g) gives the results normalized to 1 g. The normalized y-intercept is 0.507, and the normalized slope is 23.66. Putting these values into Equation 4.1 gives an expression for the count rate per gram of plutonium for the slab detector, oriented vertically at 4 ft above the floor. This is expressed mathematically by Equation 4.3:

$$\text{cts/s/g} = 0.507 + \frac{23.7}{r^2} \quad (4.3)$$

where r is the horizontal distance in feet between the plutonium source and the centerline of the ^3He proportional counters at 4 ft above the floor.

4.2 Analysis of 325 Building Measurements

The estimate of the amount of plutonium holdup in the 325 Building depends on the assumptions made concerning the following factors:

- the composition, age, and location or distribution of the plutonium

- the position of shielding materials around the plutonium sources
- the neutron background in the area around the plutonium sources.

4.2.1 Basic Assumptions Used for Calculations

It is possible that there is very little plutonium in the ducts and piping. Many of the measured neutrons could originate from alpha-neutron reactions in low-atomic-number materials, such as borosilicate glass in HEPA filters, and from the many sealed sources and samples stored in the basement and first-floor laboratories. It is more probable that the neutrons originate from plutonium and other transuranics (such as ^{241}Am) in the ducts and piping, and great care must be taken in distinguishing between room background and plutonium source neutrons. For all the calculations, the following assumptions were used:

- The neutron emissions were from plutonium and its decay product, ^{241}Am , in the form of an oxide, which is the most stable chemical form. Nitrates, oxylates, hydrated oxides, and hydroxides would produce similar neutron yields. Neutrons from other transuranics were ignored. This results in conservative estimates for the mass of plutonium.
- There is little interference from other plutonium compounds, such as fluorides, or from alpha-neutron reactions with low-atomic-number elements, such as beryllium, boron, aluminum, or sodium. It is difficult to judge whether there is a significant contribution from alpha-neutron reactions without more sophisticated measuring equipment that can measure two neutrons in coincidence from a single fission event. (Alpha-neutron events would produce only random coincidences.)
- Each plutonium source is treated separately and does not interact with other plutonium sources (i.e., there is no multiplication).
- Any multiplication effects were ignored, which is a good assumption for gram quantities of plutonium. There may have been some increase in the neutron emissions from the 108-g plutonium sample used as the verification standard, but any errors introduced will be small in comparison with other sources of error or uncertainty.
- Any plutonium holdup is low-exposure plutonium with very little ^{240}Pu . The weapons-grade plutonium from LLNL (ash sample RA 146A) is assumed to be representative of the plutonium in the holdup material. This is a reasonable assumption and will produce conservative estimates. Any plutonium present with a higher ^{240}Pu content will emit more neutrons per gram; consequently, the mass of plutonium will be overestimated.

4.2.2 Neutron Background

Before the measurements on the ducts and pipes were initiated, some measurements were made to determine the neutron backgrounds of the periphery of the area. When a source was located, two measurements were made: one measurement with the front face of the detector pointing towards the suspected plutonium source, and a second measurement with the slab detector pointing away from the source.

Measurements were made with the slab neutron detector oriented at right angles to the suspected source, i.e., the long axis of the slab was perpendicular to the source. In general, the effective "field of view" was about 3 to 4 ft at a distance of 1 to 2 ft from the suspected plutonium source. The following discussion demonstrates how it is possible to estimate the effects of room background with the slab detector oriented at right angles to a suspected plutonium source in the ducts or piping.

Consider the example of a bottom prefilter box on the west side of the SERF cell in the 327 Building basement. The slab neutron detector was positioned directly to the side of the prefilter box at a distance of 12 in. from the surface of the iron shield placed around the box. With the front face of the slab detector pointed towards the prefilter box, the measured neutron count rate was 8.84 ± 0.27 cts/s. When the detector was rotated 180° so that the front of the detector was pointed away from the filter, the measured count rate was 4.48 ± 0.19 cts/s. We can be reasonably certain that there were no neutron sources directly in front of the slab detector when it was pointed away from the filter box.

Fission neutrons entering from the back of the detector were counted with about 53% of the efficiency of neutrons entering from the front face, as shown by the experimental data for angular efficiency discussed in Section 3.4.3. Let x represent the counts from the source and y represent the counts from room background. The count rate measured with the vertical slab detector pointed toward the suspected source is the sum of the counts from neutrons entering the front and 50% of the neutrons entering from the back:

$$x + 0.50y = 8.84 \text{ cts/s} \quad (4.4)$$

Likewise, the count rate measured with the vertical detector pointing away from the prefilter box and facing the room is the sum of the neutrons entering from the front (or room background neutrons) and 50% of the neutrons entering from the back side:

$$y + 0.50x = 4.48 \text{ cts/s} \quad (4.5)$$

Solving the two simultaneous equations for x and y gives:

$$\begin{aligned} y &= 0.08 \text{ cts/s for neutrons from room background} \\ x &= 8.80 \text{ cts/s for neutrons emanating from the filter box.} \end{aligned}$$

Thus, we must correct the measured count rates by subtracting away 0.08 cts/s due to the neutron background in the room. This is a selected example in which the plutonium in the filter box is well isolated and the count rates are much higher than the general room background. In every other measured location, the count rate with the slab detector pointed towards the suspected plutonium source is similar to the count rate with the detector pointed away from the source. The background-corrected count rates are given in the data table in the spreadsheet calculations in Appendix C.

4.2.3 Calculated Mass of Plutonium

Once the contribution from room background is calculated (or estimated from measurement in the general area), it is possible to use Equation 4.3 to estimate the effects of room scatter and determine the mass of weapons-grade plutonium (6% ^{240}Pu) in the source, if the distance to the center of the plutonium source is known. In the case of the prefilter box, discussed in the previous section, the dimensions of the box were 31.5 in. long by 31 in. high: the box was shielded by 2.5 in. of iron. The center of the slab neutron detector was 12 in. from the surface of the iron shield covering the filter box. If we assume that the plutonium is uniformly spread over the filter, the plutonium source can be modeled as a point source at a distance of $31.5/2 + 2.5 + 12 = 30.25$ in. (2.52 ft) from the center of the detector. Substituting a distance of 2.52 ft into Equation 4.3 gives:

$$0.507 + \frac{23.7}{(2.52)^2} = 4.24 \text{ cts/s/g} \quad (4.6)$$

Dividing the measured count rate of 8.80 cts/s by 4.24 cts/s/g of plutonium gives a value of 2.1 g of plutonium in the filter box. It may be somewhat suspect because alpha-neutron reactions from finely divided alpha-emitters on borosilicate glass fiber can produce elevated neutron levels. Because the neutron emission rates from higher-exposure plutonium are higher than for weapons-grade plutonium, the value of 2.1 g of plutonium is an upper limit on the amount of plutonium that may be in the prefilter box.

5.0 Results

The results of this survey indicate that no significant levels of plutonium reside in the exposed ductwork or piping in the basement of the 325 Building. There are, however, significant quantities of plutonium remaining in the laboratory fume hoods and gloveboxes. Section 5.1 presents neutron measurement results; Section 5.2 similarly summarizes the gamma measurement results. Appendix C contains the complete set of data and analyses for the neutron measurements.

5.1 Neutron Measurement Results

Neutron measurements of the 325 Building ductwork, laboratory vacuum system lines and RLWS pipes were taken at suspected source locations using the neutron slab detector. Neutron measurements were also taken on each fume hood and glovebox where fissile material had been processed. Two sets of plutonium mass estimates were determined using an assumed weapons-grade isotopic composition for the maximum plutonium mass and a reactor fuel isotopic composition (11% ^{240}Pu) for the most likely mass. An exception is the Laboratory Vacuum System (LVS) where the most likely mass of plutonium is based on 16% ^{241}Am , 83.5% ^{239}Pu , and 0.5% ^{238}Pu from radiochemistry results of the LVS slab tank samples. Table 5.1 details the results of the neutron measurements for the exposed HEPA filters, ducts, RLWS lines, and LVS lines in the basement of the 325 Building. Table 5.2 lists the neutron measurement results for the RLWS lines in the basement. Results for each fume hood and glove box measured are listed by room number in Table 5.3 and include any source material present at the time of the measurements. Special attention was given to "hot spots" with high gamma activity, which were assumed to be spent fuel debris in the pipes or ducts.

Totals for all neutron measurement locations are

maximum	637 ± 190 g
most likely	386 ± 120 g.

A summary of plutonium holdup by system and location is presented in Table 5.4. The largest quantities of holdup are found in the glove boxes in the first floor laboratories. However, a significant portion of that, approximately 195 g, is source material in containers identified by fissile material labels.

5.2 Gamma Measurement Results

A summary of radionuclide curie content in the RLWS line is presented in Table 5.5. The data identifies the measurement location and estimated activity level at each location. Appendix B contains figures that show the measurement locations. Figure 5.1 shows a plot of the ^{137}Cs content of the RLWS lines. Radionuclide content at other gamma measurement locations is presented in Table 5.6.

Table 5.1. Plutonium Holdup in Ductwork, LVS, HEPA, RPS, and RLWS Lines in 325 Basement

Location	Maximum Plutonium (g) ^(a)	Most Likely Plutonium (g) ^(a)	Process
30a-1	0.05	0.03	Duct
31-1	0.15	0.08	Duct
32-1	8.36	4.56	HEPA
32-2	0.60	0.33	HEPA
32-3	0.62	0.34	HEPA
32-4	4.85	2.65	HEPA
32-5	0.63	0.34	RLWS
32-6	0.00	0.00	RLWS
32-7	2.71	1.48	Duct
32-8	6.35	3.47	Duct
33-1	0.03	0.02	RLWS
45-1	0.50	0.27	HEPA
45-2	0.10	0.05	HEPA
45-3	0.27	0.15	HEPA
45-4	0.23	0.13	Duct
45-5	0.22	0.12	Duct
45-6	0.09	0.05	Duct
45-7	0.35	0.19	HEPA
45-8	5.27	2.88	HEPA
45-9	0.10	0.10	LVS
45-10	0.27	0.15	Duct
45-11	0.00	0.00	HEPA
45-12	0.01	0.01	LVS
45-13	3.17	1.73	RPS
45-14	0.00	0.00	LVS
45-15	0.68	0.68	LVS
45-16	0.32	0.32	LVS
45-17	0.14	0.14	LVS
45-18	0.43	0.43	LVS
45-19	0.05	0.05	LVS
45-20	0.09	0.09	LVS
45-21	0.07	0.07	LVS
45-22	0.08	0.08	LVS
45-23	0.03	0.03	LVS
62-1	0.06	0.03	HEPA
62-2	0.05	0.03	HEPA
62-3	0.11	0.06	Duct
Total	37.04	21.14	

(a) Maximum and most likely plutonium mass estimates are based on 6 and 11 weight percent ²⁴⁰Pu, respectively.

Table 5.2. Plutonium Holdup in RLWS Pipeline in 325 Building Basement

<u>Location</u>	<u>Maximum Plutonium (g)^(a)</u>	<u>Most Likely Plutonium (g)^(a)</u>
RLWS-4	0.01	0.01
RLWS-5	0.02	0.01
RLWS-6	0.01	0.01
RLWS-7	0.05	0.03
RLWS-8	0.03	0.02
RLWS-9	0.02	0.01
RLWS-10	0.03	0.02
RLWS-11	0.00	0.03
RLWS-12	0.01	0.01
RLWS-13	0.04	0.02
RLWS-14	0.05	0.03
RLWS-15	0.08	0.04
RLWS-16	0.11	0.06
RLWS-17	0.41	0.22
RLWS-23	5.31	2.90
RLWS-24	1.19	0.65
RLWS-25	3.16	1.73
RLWS-26	0.34	0.19
RLWS-27	0.22	0.12
RLWS-28	0.16	0.09
RLWS-31	0.26	0.14
Total in RLWS Line	11.51	6.28

(a) Maximum and most likely plutonium mass estimates are based on 6 and 11 weight percent ²⁴⁰Pu, respectively.

Table 5.3. Plutonium Holdup in Laboratory Hoods and Glove Boxes

<u>Location</u>	<u>Maximum Plutonium (g)^(a)</u>	<u>Most Likely Plutonium (g)^(a)</u>	<u>Labeled Source Material (g)</u>
Room 303			
Hood 4	0.01	0.01	
Room 305			
Hood 1	0.20	0.11	
Hood 2	0.16	0.09	
Glove Box 11	0.00	0.00	
Glove Box 9	50.94	50.94	49.0 (12.5% ²⁴⁰ Pu)
Glove Box 10	9.66	9.66	
Room 309			
Hood 1	0.21	0.11	
Hood 2	0.18	0.10	
Hood 3	0.32	0.17	
Hood 4	0.45	0.25	
Hood 5	2.37	1.29	
Hood 6	4.16	2.27	
Hood 7	4.90	2.68	
Hood 8	3.72	2.03	
Room 312			
Hood 1	0.17	0.09	
Hood 2	0.12	0.07	
Hood 3	0.11	0.06	
Glove Box 1	0.09	0.05	
Glove Box 2	0.10	0.05	
Port	0.07	0.04	
Room 313			
Hood 1	0.01	0.01	
Hood 2	0.00	0.00	
Hood 3	0.52	0.28	
Hood 4	0.60	0.33	
Room 317			
Hood 1	0.00	0.00	
Hood 2	0.04	0.02	
Room 320			
Hood 1	0.00	0.00	
Hood 2	0.05	0.03	

Table 5.3. (contd)

<u>Location</u>	<u>Maximum Plutonium (g)^(a)</u>	<u>Most Likely Plutonium (g)^(a)</u>	<u>Labeled Source Material (g)</u>
Room 330			
Hood 1	0.00	0.00	
Hood 2	0.00	0.00	
Hood 3	0.00	0.00	
Hood 4	0.00	0.00	
Room 401			
Hood 1	0.04	0.02	
Hood 2	0.09	0.05	
Room 406			
Hood 1	0.75	0.41	
Hood 2	0.62	0.34	
Hood 4	0.76	0.42	
Glove Box	27.60	15.07	
Room 410			
Hood 1	0.70	0.38	
Hood 2	0.57	0.31	
Hood 3	0.45	0.25	
Hood 4	0.76	0.42	
Hood 5	0.83	0.45	
Hood 6	2.11	1.15	
Room 416			
Hood 1	0.16	0.09	
Hood 2	0.14	0.08	
Hood 3	0.61	0.33	
Hood 4	0.51	0.28	
Room 419			
Hood 1	0.05	0.03	
Hood 2	0.07	0.04	
Hood 3	0.06	0.03	
Hood 4	0.00	0.00	
Hood 5	0.00	0.00	
Room 500			
Hood 1	6.85	3.74	
Hood 2	23.82	13.01	
Hood 3	0.67	0.37	
Hood 4	0.79	0.43	

Table 5.3. (contd)

Location	Maximum Plutonium (g) ^(a)	Most Likely Plutonium (g) ^(a)	Labeled Source Material (g)
Room 504			
Hood 1	12.19	12.19	15g (²³⁸ Pu)
Glove Box 2	11.30	6.17	
Glove Box 3	21.61	11.8	46.6 (6.43% ²⁴⁰ Pu)
Glove Box 4	8.57	4.68	
Room 506			
Hood 1	10.75	5.87	
Hood 2	9.89	5.40	0.5 ²⁴¹ Am, 5.6 ²⁴³ Am
Hood 3	17.50	9.56	
Glove Box 31	57.79	36.20	29.0 (12.9% ²⁴⁰ Pu)
Glove Box 35	9.49	5.18	9.0 ²³³ U
Glove Box 37	8.93	4.88	
Room 507			
Hood 1	3.99	2.18	
Hood 2	2.83	1.55	
Hood 3	1.62	0.88	
Hood 4	4.56	2.49	
Hood 5	22.11	12.07	
Room 510			
Hood 1	4.50	2.46	
Hood 2	4.50	2.46	
Hood 3	4.37	2.39	
Hood 4	13.55	7.40	
Room 511			
Hood 1	2.39	1.30	
Hood 2	1.37	0.75	
Hood 3	4.33	2.36	
Hood 4	3.57	1.95	
Room 515			
Glove Box 1	5.35	2.92	
Glove Box 2	4.50	2.46	
Room 516			
Hood 1	1.66	0.91	
Hood 2	1.74	0.95	
Hood 4	3.50	1.91	
Glove Box 2	3.59	1.96	
Glove Box 7	5.15	2.81	6.6 (8% ²⁴⁰ Pu)

Table 5.3. (contd)

<u>Location</u>	<u>Maximum Plutonium (g)^(a)</u>	<u>Most Likely Plutonium (g)^(a)</u>	<u>Labeled Source Material (g)</u>
Room 517			
Hood 1	0.82	0.45	
Hood 2	0.52	0.28	
Hood 3	0.38	0.21	
Hood 4	2.08	1.14	
Hood 5	1.42	0.78	
Room 528			
Hood 4	9.17	5.01	
Glove Box	56.26	30.72	
Room 604			
Glove Box 36	38.63	21.09	1 (5.98%), 1 (12%), 1 (19.05%)
Glove Box 38 "A"	44.49	24.29	13.0 (6.61% ²⁴⁰ Pu)
Glove Box 38 "B"	19.09	10.42	32.2 (6.61% ²⁴⁰ Pu)
Room 701			
Hood 1	0.00	0.00	
Hood 2	0.00	0.00	

(a) Maximum and most likely plutonium mass estimates are based on 6 and 11 weight percent ²⁴⁰Pu, respectively.

Table 5.4. Summary of Plutonium Holdup in the 325 Building

<u>Location</u>	<u>Grams of Pu (6%)</u>	<u>Grams of Pu (11%)</u>
RLWS	12.2	6.6
LVS	2.0	2.0
Ducts	10.2	5.6
HEPA	21.0	11.5
RPS	3.2	1.7
Total in Basement	48.6	27.4
Total in Labs	588.2	358.9
Total Holdup + Material in Process	636.8	386.3

**Table 5.5. Radionuclide Content By Direct Gamma Ray Measurement
Using a Collimated High-Purity Germanium Detector, Curies**

Location	²⁴¹ Am	²³⁹ Pu	¹³⁷ Cs	¹⁵⁴ Eu	⁶⁰ Co	¹⁵² Eu
RLWS 1	0.00E+00	0.00E+00	6.50E-06	0.00E+00	1.74E-07	6.57E-08
RLWS 2	0.00E+00	0.00E+00	6.50E-06	0.00E+00	1.74E-07	6.57E-08
RLWS 3	0.00E+00	0.00E+00	6.50E-06	0.00E+00	1.74E-07	6.57E-08
RLWS 4	0.00E+00	0.00E+00	6.50E-06	0.00E+00	1.74E-07	6.57E-08
RLWS 5	0.00E+00	0.00E+00	4.55E-05	0.00E+00	1.22E-06	4.60E-07
RLWS 6	0.00E+00	0.00E+00	1.95E-04	0.00E+00	5.22E-06	1.97E-06
RLWS 7	0.00E+00	0.00E+00	3.90E-05	0.00E+00	1.04E-06	3.94E-07
RLWS 8	0.00E+00	0.00E+00	4.55E-05	0.00E+00	1.22E-06	4.60E-07
RLWS 9	0.00E+00	0.00E+00	6.50E-06	0.00E+00	1.74E-07	6.57E-08
RLWS 10	0.00E+00	0.00E+00	1.30E-04	0.00E+00	3.48E-06	1.31E-06
RLWS 11	0.00E+00	0.00E+00	1.30E-04	0.00E+00	3.48E-06	1.31E-06
RLWS 12	0.00E+00	0.00E+00	1.30E-04	0.00E+00	3.48E-06	1.31E-06
RLWS 13	0.00E+00	0.00E+00	1.63E-04	0.00E+00	4.35E-06	1.64E-06
RLWS 14	0.00E+00	0.00E+00	3.25E-05	0.00E+00	8.69E-07	3.28E-07
RLWS 15	0.00E+00	0.00E+00	5.85E-04	0.00E+00	1.56E-05	5.91E-06
RLWS 16	0.00E+00	0.00E+00	1.30E-05	0.00E+00	3.48E-07	1.31E-07
RLWS 17	0.00E+00	0.00E+00	2.60E-05	0.00E+00	6.95E-07	2.63E-07
RLWS 18	0.00E+00	0.00E+00	2.60E-05	0.00E+00	6.95E-07	2.63E-07
RLWS 19	0.00E+00	0.00E+00	3.90E-04	0.00E+00	1.04E-05	3.94E-06
RLWS 20	0.00E+00	0.00E+00	3.90E-05	0.00E+00	1.04E-06	3.94E-07
RLWS 21	0.00E+00	0.00E+00	3.25E-05	0.00E+00	8.69E-07	3.28E-07
RLWS 22	0.00E+00	0.00E+00	9.75E-05	0.00E+00	2.61E-06	9.85E-07
RLWS 23	0.00E+00	0.00E+00	1.63E-05	0.00E+00	4.35E-07	1.64E-07
RLWS 24	0.00E+00	0.00E+00	1.30E-05	0.00E+00	3.48E-07	1.31E-07
RLWS 25	0.00E+00	0.00E+00	1.30E-04	0.00E+00	3.48E-06	1.31E-06
RLWS 26	0.00E+00	0.00E+00	3.25E-05	0.00E+00	8.69E-07	3.28E-07
RLWS 27	0.00E+00	0.00E+00	1.95E-05	0.00E+00	5.22E-07	1.97E-07
RLWS 28	0.00E+00	0.00E+00	1.30E-05	0.00E+00	3.48E-07	1.31E-07
RLWS 29	0.00E+00	0.00E+00	1.95E-05	0.00E+00	5.22E-07	1.97E-07
RLWS 30	0.00E+00	0.00E+00	2.60E-05	0.00E+00	6.95E-07	2.63E-07
RLWS 31	0.00E+00	0.00E+00	1.95E-05	0.00E+00	5.22E-07	1.97E-07

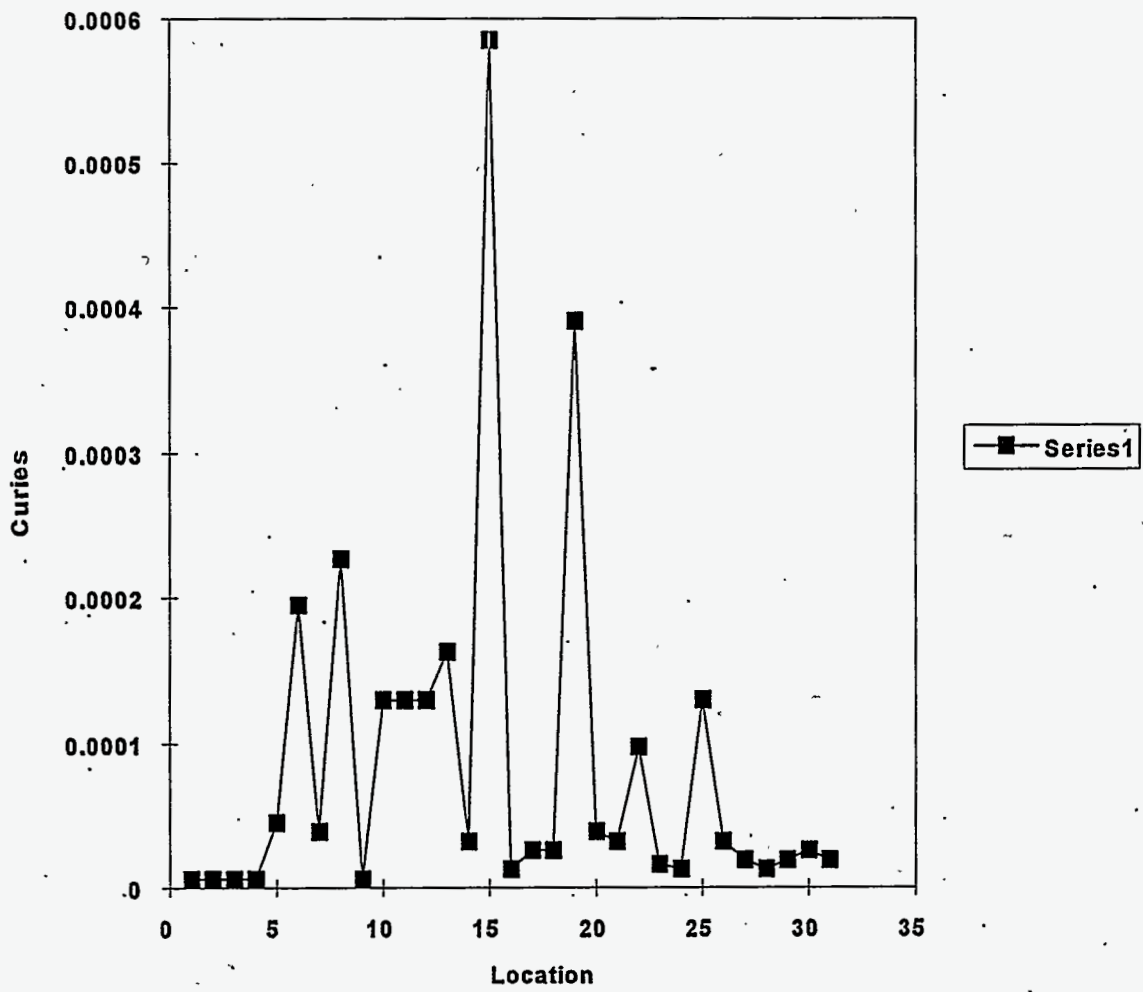


Figure 5.1. Cesium-137 Found in RLWS Lines (by RLWS Number), Curies

Table 5.6. Radioactive Liquid Waste System Pipeline Activity Profile, Curies

Location	²⁴¹ Am	²³⁹ Pu	¹³⁷ Cs	¹⁵² Eu	¹⁵⁴ Eu	⁶⁰ Co
Laboratory Vacuum System Line						
E5	8.12E-04	0.00E+00	4.45E-06	1.31E-06	2.90E-06	0.00E+00
F5	9.64E-03	0.00E+00	8.21E-05	3.61E-06	8.95E-06	0.00E+00
C6	1.69E-03	0.00E+00	3.63E-05	0.00E+00	4.74E-07	0.00E+00
H6	2.28E-03	0.00E+00	2.24E-05	2.34E-06	5.69E-06	0.00E+00
HS(45-9)	6.83E-03	0.00E+00	5.22E-04	1.56E-05	4.25E-04	0.00E+00
B416H4	0.00E+00	0.00E+00	5.23E-07	0.00E+00	0.00E+00	6.15E-08
B416H2	0.00E+00	0.00E+00	4.56E-07	0.00E+00	0.00E+00	0.00E+00
B416H1	0.00E+00	0.00E+00	3.16E-07	0.00E+00	0.00E+00	2.28E-07
Plenum Duct "Hot Spot"						
PLEN-HS	0.00E+00	0.00E+00	1.37E-04	0.00E+00	2.50E-06	0.00E+00
303-H4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
309-H2	0.00E+00	0.00E+00	1.29E-05	0.00E+00	0.00E+00	0.00E+00
309-H6	1.07E-05	0.00E+00	4.47E-05	0.00E+00	0.00E+00	1.25E-07
313-H4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
317-H1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
317-H2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500-H1	0.00E+00	0.00E+00	7.69E-05	0.00E+00	4.93E-07	2.54E-07
500-H2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
504-H1	4.21E-05	4.23E-01	1.19E-04	0.00E+00	3.39E-07	5.12E-07
506-H3	0.00E+00	4.61E-02	2.78E-06	0.00E+00	0.00E+00	0.00E+00
510-H3	0.00E+00	0.00E+00	5.06E-06	0.00E+00	0.00E+00	0.00E+00
528-H4	0.00E+00	0.00E+00	2.70E-07	0.00E+00	0.00E+00	2.43E-07
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glove Boxes						
305-GB3	4.89E-04	1.22E-01	1.01E-05	1.52E-06	2.30E-06	9.22E-07
305-GB6	1.80E-05	9.07E-02	6.73E-07	0.00E+00	0.00E+00	0.00E+00
305-GB7	1.16E-05	0.00E+00	1.36E-07	0.00E+00	0.00E+00	0.00E+00
406-GB3	3.30E-04	0.00E+00	1.65E-04	0.00E+00	2.50E-07	0.00E+00
406-GB4	2.15E-03	8.96E-02	3.82E-04	0.00E+00	4.19E-07	0.00E+00
406-GB5	1.54E-03	1.53E-01	9.52E-06	0.00E+00	0.00E+00	0.00E+00
406-GB6	5.14E-03	7.79E-02	3.91E-05	0.00E+00	0.00E+00	0.00E+00
506-GB1	4.01E-04	0.00E+00	5.95E-05	0.00E+00	0.00E+00	2.53E-07
506-GB4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
528-GB2	1.16E-04	2.69E-02	4.42E-06	0.00E+00	0.00E+00	0.00E+00
528-GB3	1.80E-04	3.80E-02	6.27E-06	0.00E+00	0.00E+00	0.00E+00

6.0 References

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Appendix A

Basic Holdup Assay Measurements Procedure MCA-510

Appendix A

Basic Holdup Assay Measurements Procedure MCA-510

1. The assay system components are set up in the laboratory and pretest verifications are performed.
2. Perform energy calibration and measurement control procedure, completing Exhibit A (see Figure A.1).
3. Perform calibrations for the assay scenario.
4. Move instrumentation to location and verify that no damage has occurred. Perform an energy calibration and measurement control procedure, completing Exhibit A.
5. Determine ambient background(s) at the counting location and evaluate counting technique(s).
6. Perform measurements with intermittent control checks, record data and location, and assign nondestructive assay (NDA) log numbers.
7. Transfer data and analyze, using software acquisition and analyses codes and computer spreadsheets. Retain the original data for archive, logging the file name on the Exhibit B, Pacific Northwest Laboratory (PNL) NDA Analysis Log/Report (see Figure A.2).
8. Evaluate the data results and determine the appropriate correction factors, including the detector filters. Initial basic assumptions are made of the source material, one being that the sample self-attenuation is negligible. Actual attenuation correction factors can be applied after measurements are made and more reasonable assumptions are determined as to the material matrix and configuration. All counts measured are corrected by the attenuation correction factors (CF).

Generally, a density value in grams per cubic centimeter (g/cm^3) is derived for the item based on gross weight of the container minus the container weight and/or shielding and/or packaging materials. This matrix density value is used for the attenuation corrections for the gamma energies measured.

9. Perform the analysis, review the results, and issue a report.

PNL NONDESTRUCTIVE ASSAY MEASUREMENT PROCEDURE

Procedure No.: NDA-510 Revision: 1 Effective Date: July 26, 1994 Page 31 of 34

EXHIBIT A

M & TE SET-UP AND MCA ENERGY CALIBRATION CHECKLIST

Date _____ Location _____ Work Pkg # _____ Operator _____ Time _____

List Assayed Items(s) and NDA Log #:

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

SET-UP CHECKLIST

- | | | |
|-----|---|-----|
| (1) | Review RWP, CSP | () |
| (2) | Gamma Detector Filled With LN, Stabilized | () |
| (3) | Filters on Detector Y / N List _____ | () |
| (4) | Gamma Detector # _____ | () |
| (5) | HV Supply Settings; Pos _____ Neg _____ | |
| (6) | Neutron Detector Mod/Ser. _____ | |
| (7) | HV Supply Settings; Pos _____ Neg _____ | |

ENERGY CALIBRATION

(7) Spectroscopy Amplifier Settings:

Model No. _____	
Course Gain _____	30
Threshold _____	AUTO
Polarity Input _____	NEG
Polarity Output _____	POS
Shaping Time _____	2 μ sec
Fine Gain _____	
Shaping Multiplier _____	1

(8) Energy of Sources & Peak Settings

⁶⁰ Co, 1332.5 keV	_____	CH 2665
¹³⁷ Cs, 662.0 keV	_____	CH 1324
¹⁵² Eu, 344.0 keV	_____	CH 688
¹⁵⁴ Eu, 265.0 keV	_____	CH 530
¹⁵⁴ Eu, 1275.0 keV	_____	CH 2550
¹³³ Ba, 81.0 keV	_____	CH 162
¹³³ Ba, 356.0 keV	_____	CH 712

(9) Systems Adjustments and Noise:

With Oscilloscope at 10 μ sec/div ()

- | | |
|------------------|-----|
| Check Pole Zero | () |
| Check Peak Shape | () |

(10) ADC Settings

Model/Serial No. _____	
Gain _____	4096
Range _____	4096
Digital Off Set	NONE
Coincidence Gate II	NONE

(11) MCA Identification

Model/Serial No. _____

(12) Neutron System

Model/Serial No. _____	
Counter Model/Serial No. _____	
Threshold Setting _____	

(13) Gamma Measurement Control

Initial PreTest		Count Time _____
Peak Energy _____		Net Area _____
_____		_____
Final Post Test		Count Time _____
Peak Energy _____		Net Area _____
_____		_____

SPECIALIST REVIEW/DATE _____

Figure A.1. Calibration Checklist

PNL NONDESTRUCTIVE ASSAY MEASUREMENT PROCEDURE

Procedure No.: NDA-510 Revision: 1 Effective Date: July 26, 1994 Page 32 of 34

EXHIBIT B

PNL NDA ANALYSIS ASSAY LOG/REPORT

DATE: _____ NDA LOG # _____
TRU U MFP Activation SAMPLE # _____
WEIGHT #/G _____

MEASUREMENT SYSTEMS/METHODS:

- ___ Gamma Energy Analysis GEA
- ___ Calorimeter
- ___ Gamma Isotopics
- ___ Passive Neutron Coincidence Well Counting
- ___ Active Neutron Well Counting
- ___ Passive Neutron Counting / Spectrometry
- ___ Segmented Gamma Assay (Transmission Corrected)
- ___ Combined Neutron Coincidence/Segmented Gamma Assay (Transmission Corrected)
- ___ Far Field Assay Techniques
 - ___ Barrels
 - ___ Process Hold-up, HEPA Filters
 - ___ Waste Boxes
 - ___ Project Specific
 - ___ Other _____

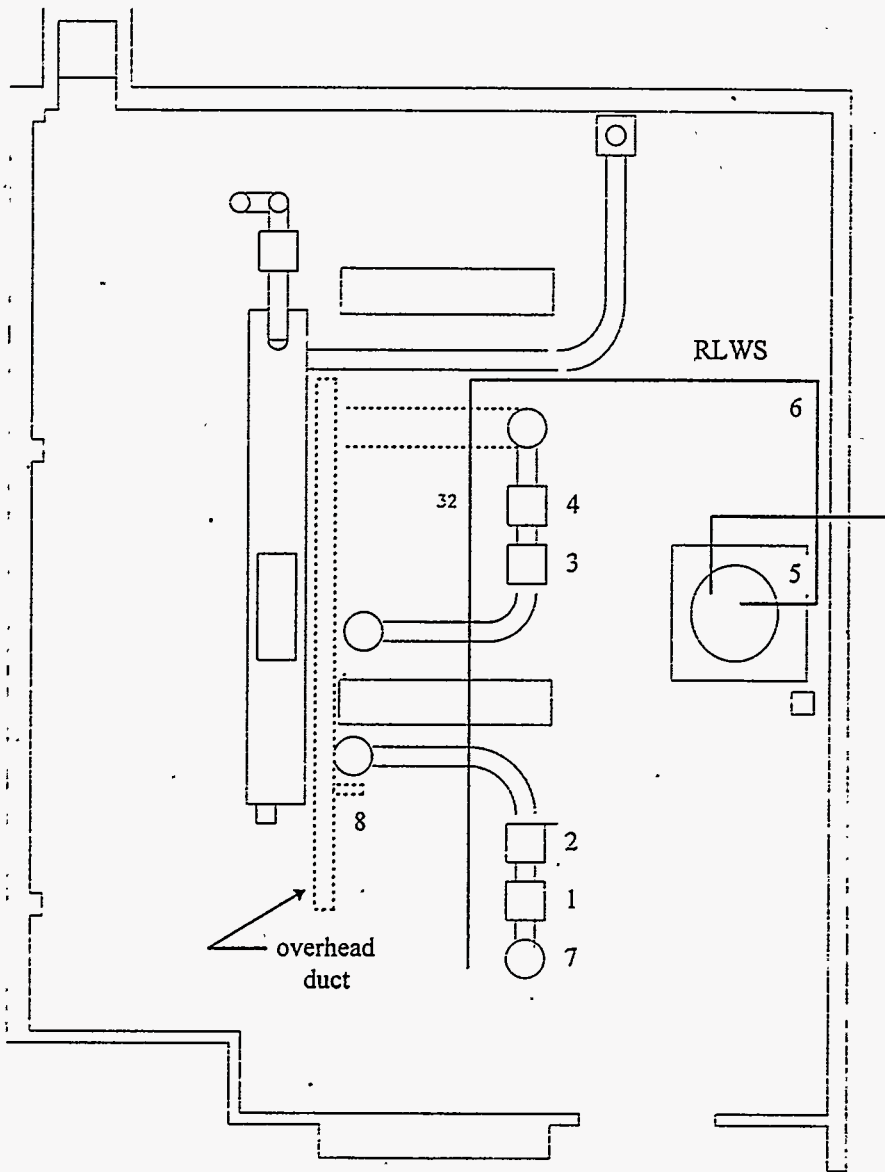
Measurement Information	
	Dose Rate _____

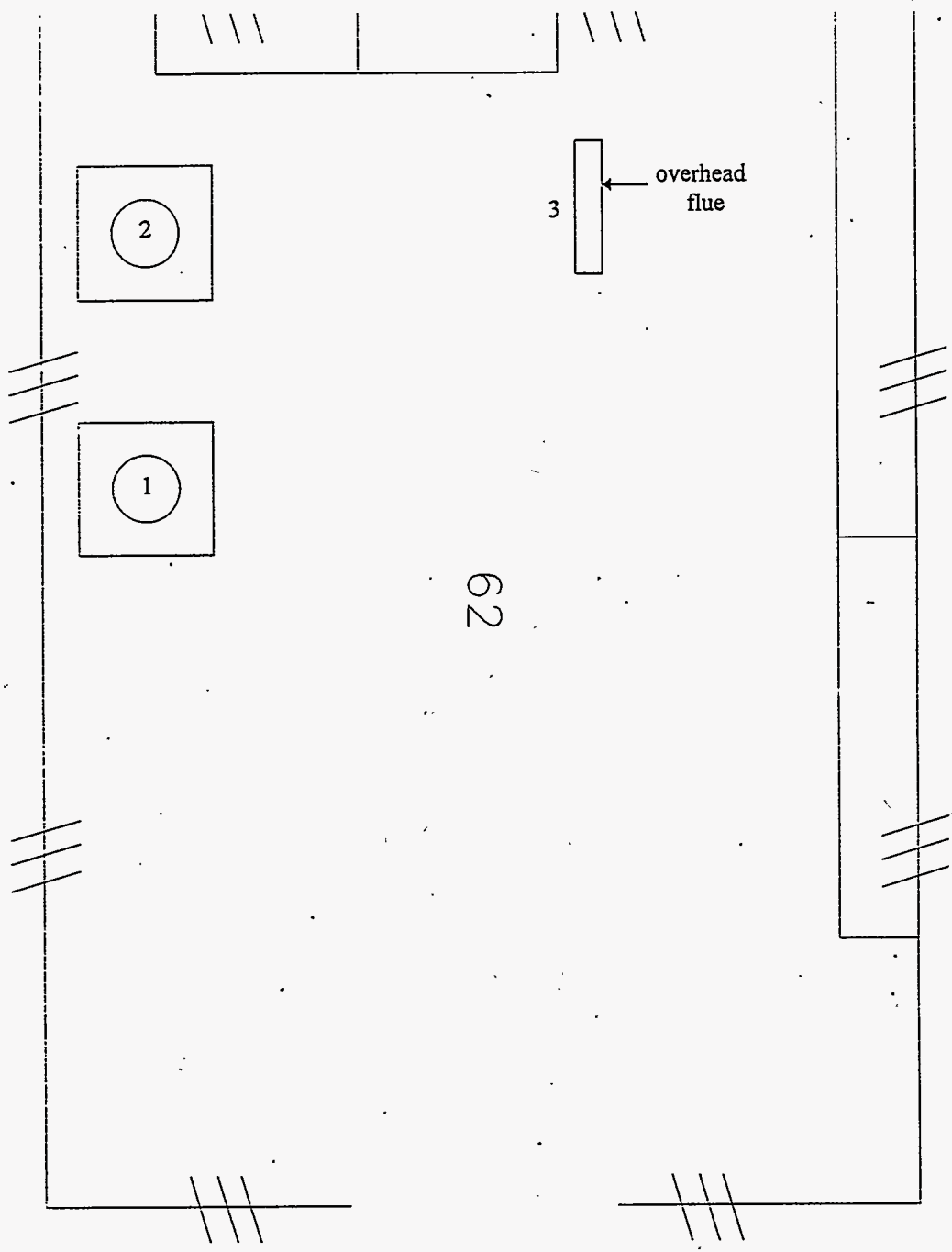
ASSAY RESULTS: Report attached Y / N Issue Date _____
ISOVER Report Y / N Issue Date _____
DATA ARCHIVED: Disk(s) Directory / Prefix _____
File Names _____
Specialist Review _____

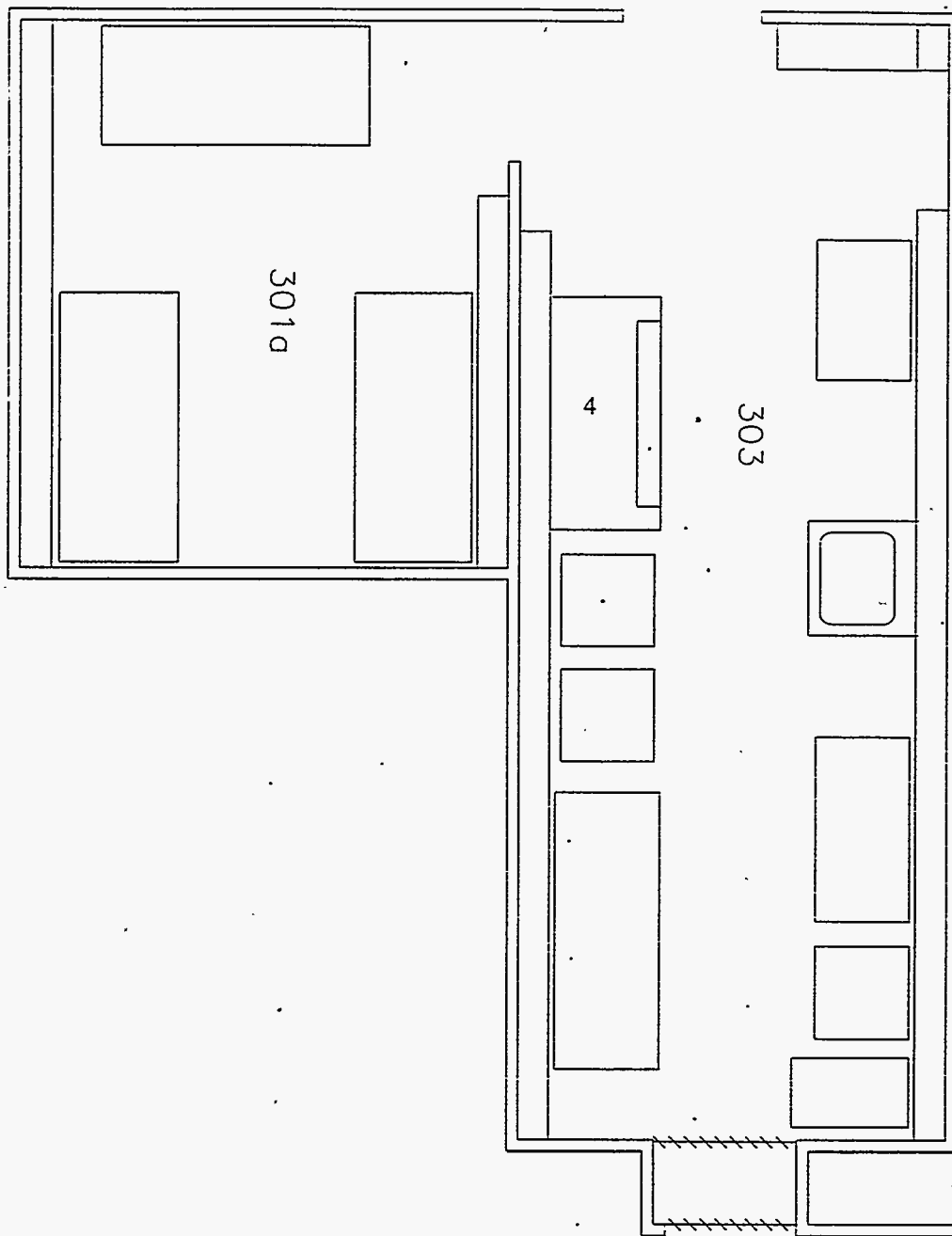
Figure A.2. Assay Log/Report Form

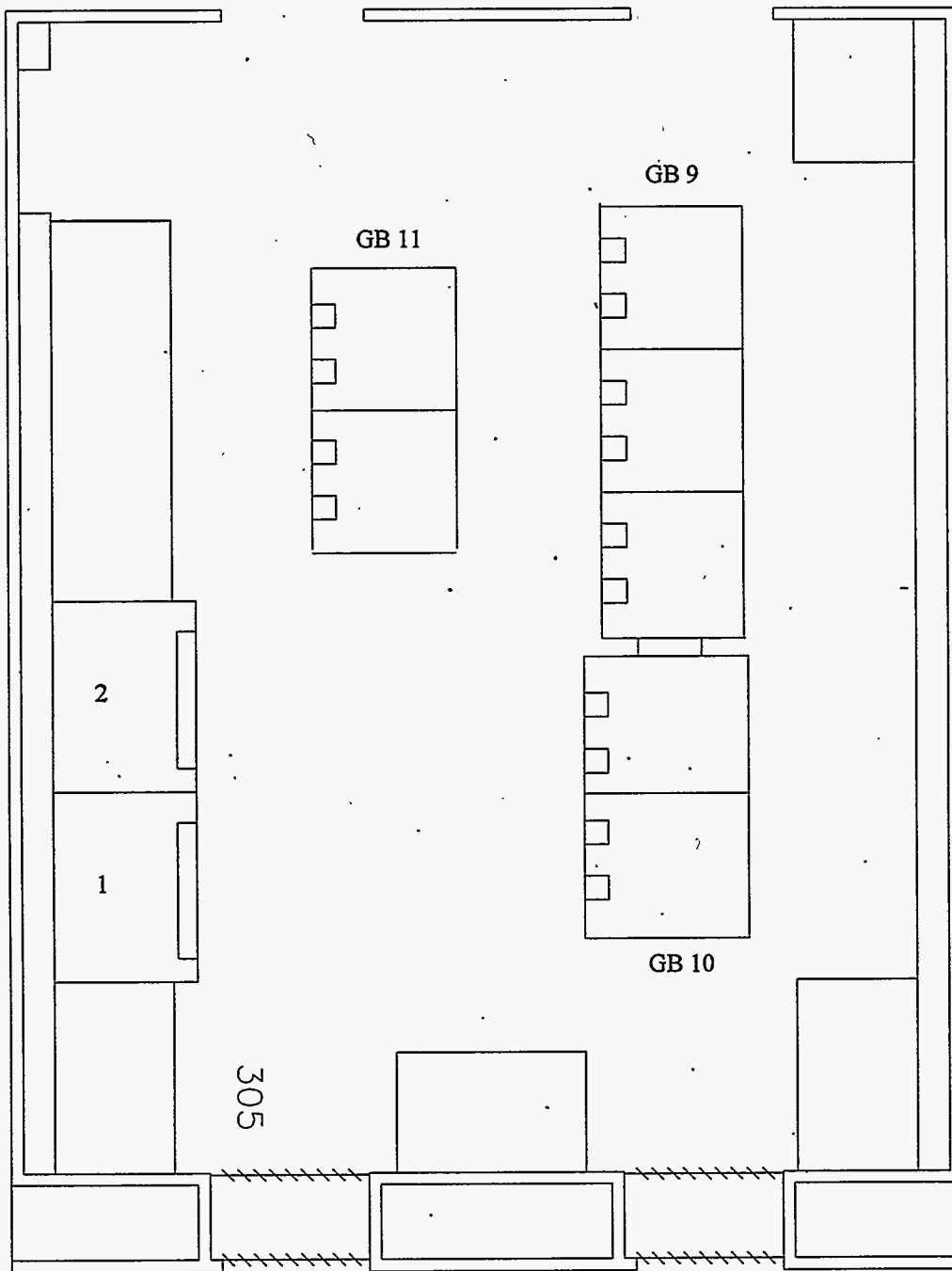
Appendix B

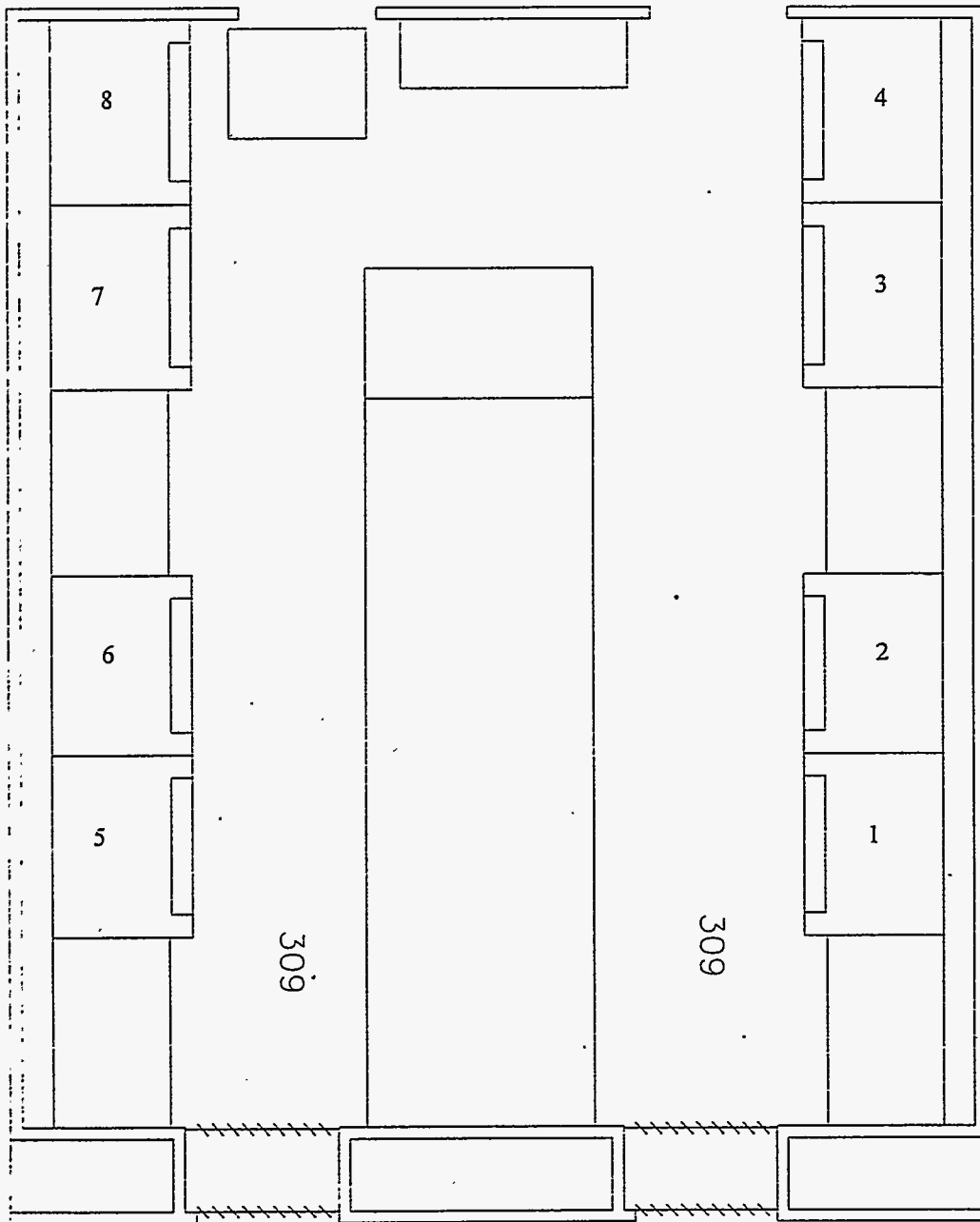
Schematics of NDA Measurement Locations

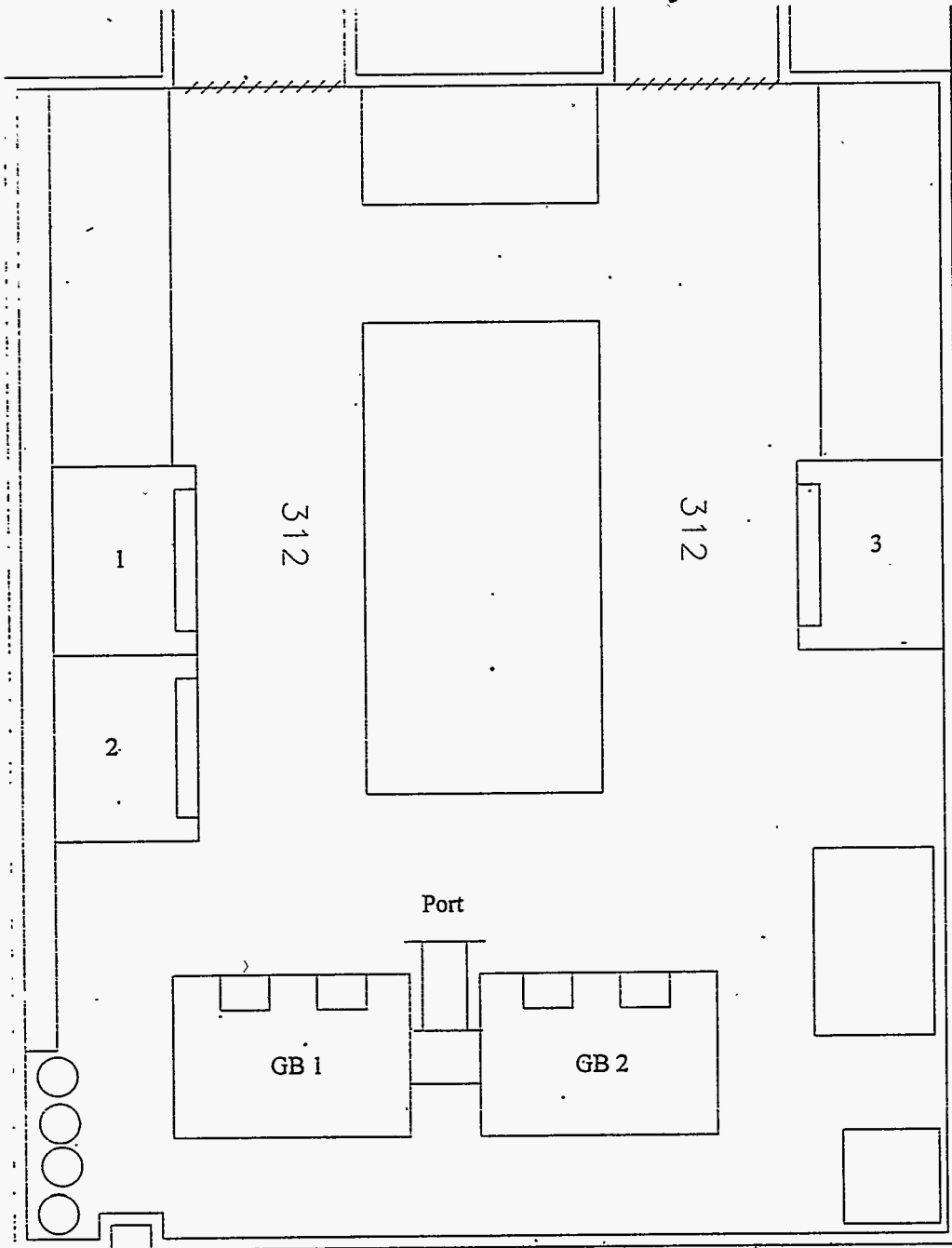




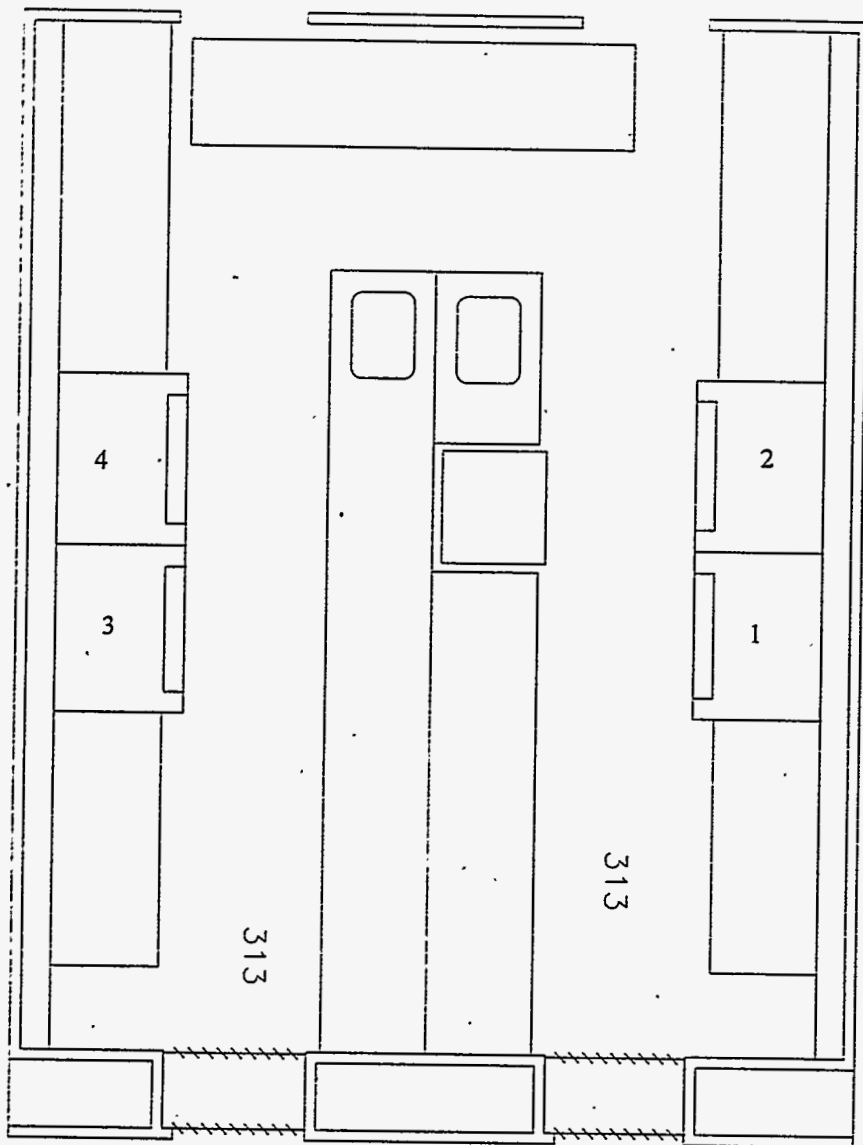


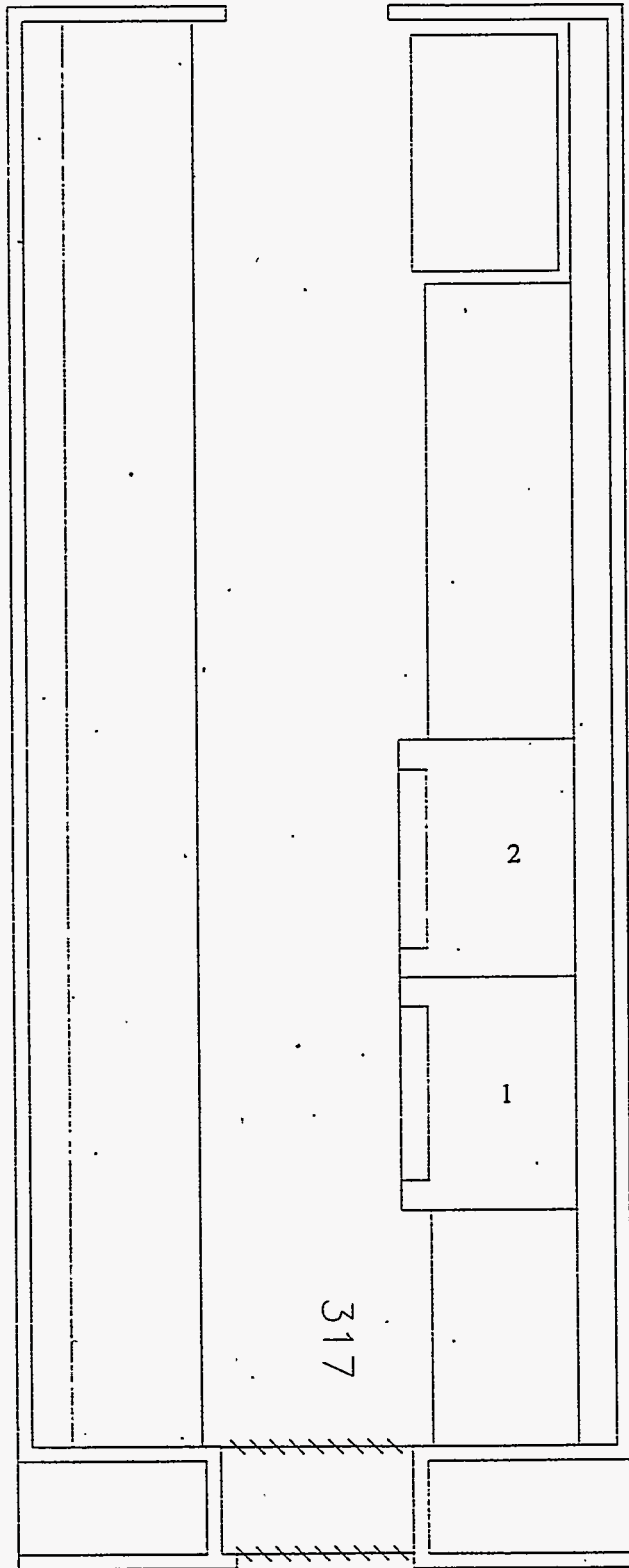




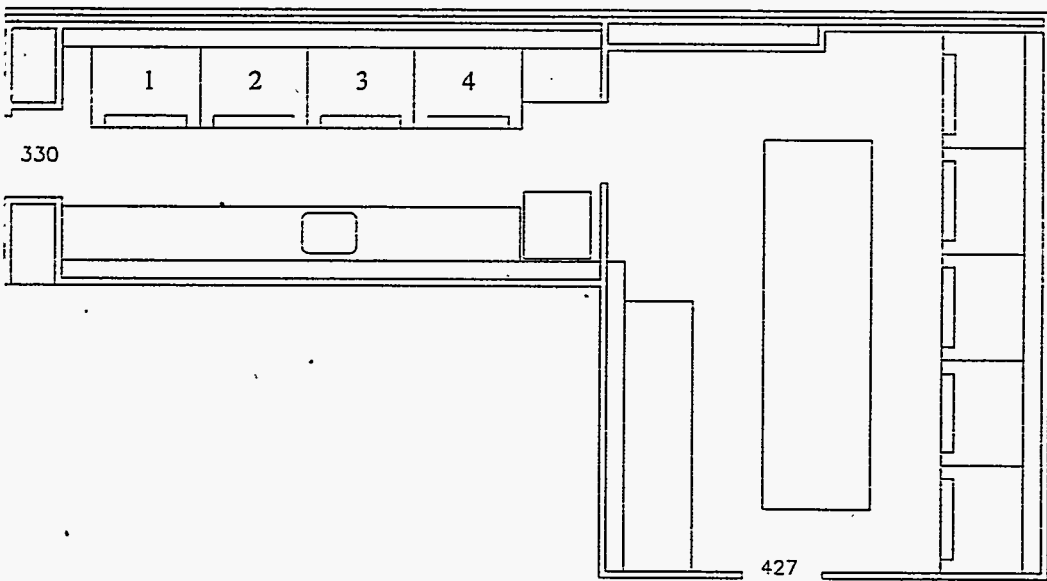
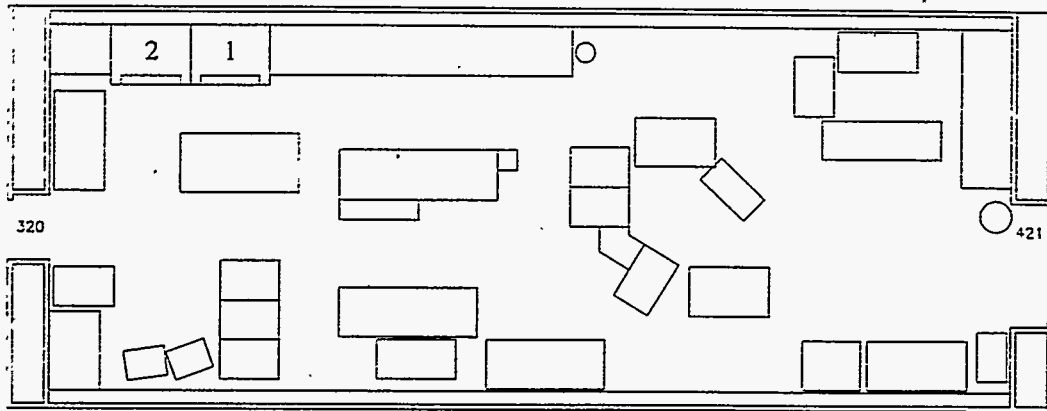


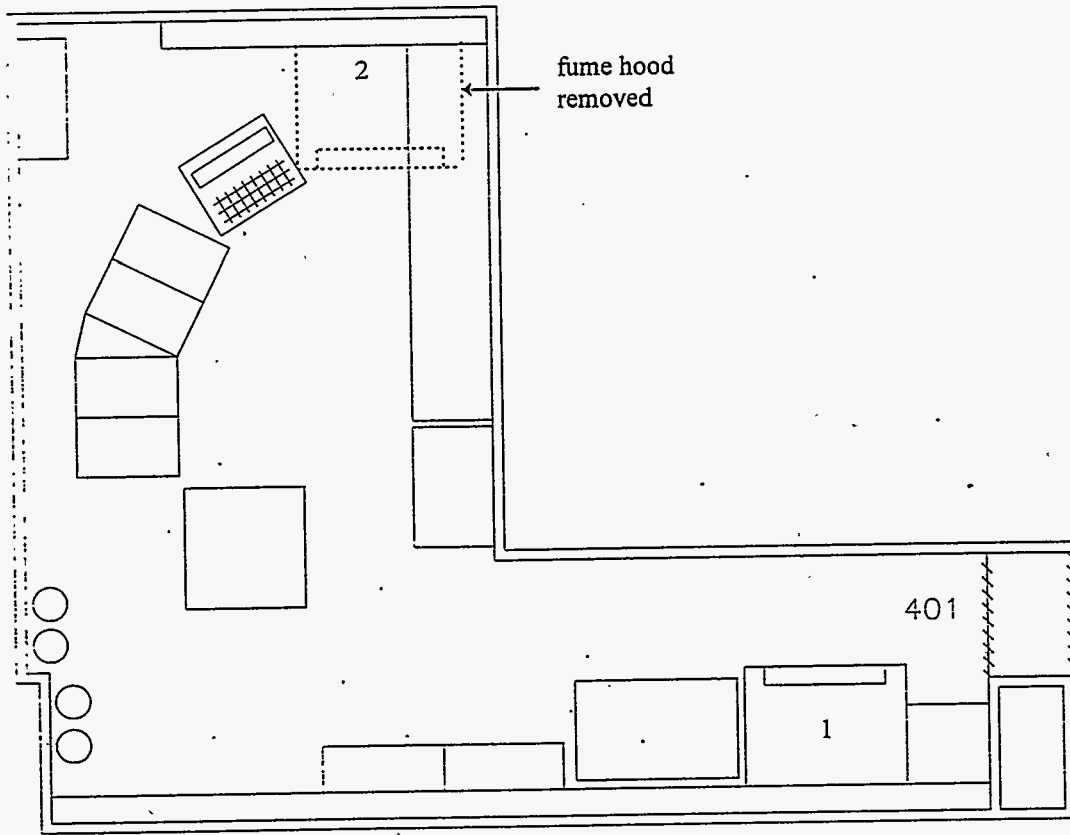
B.6

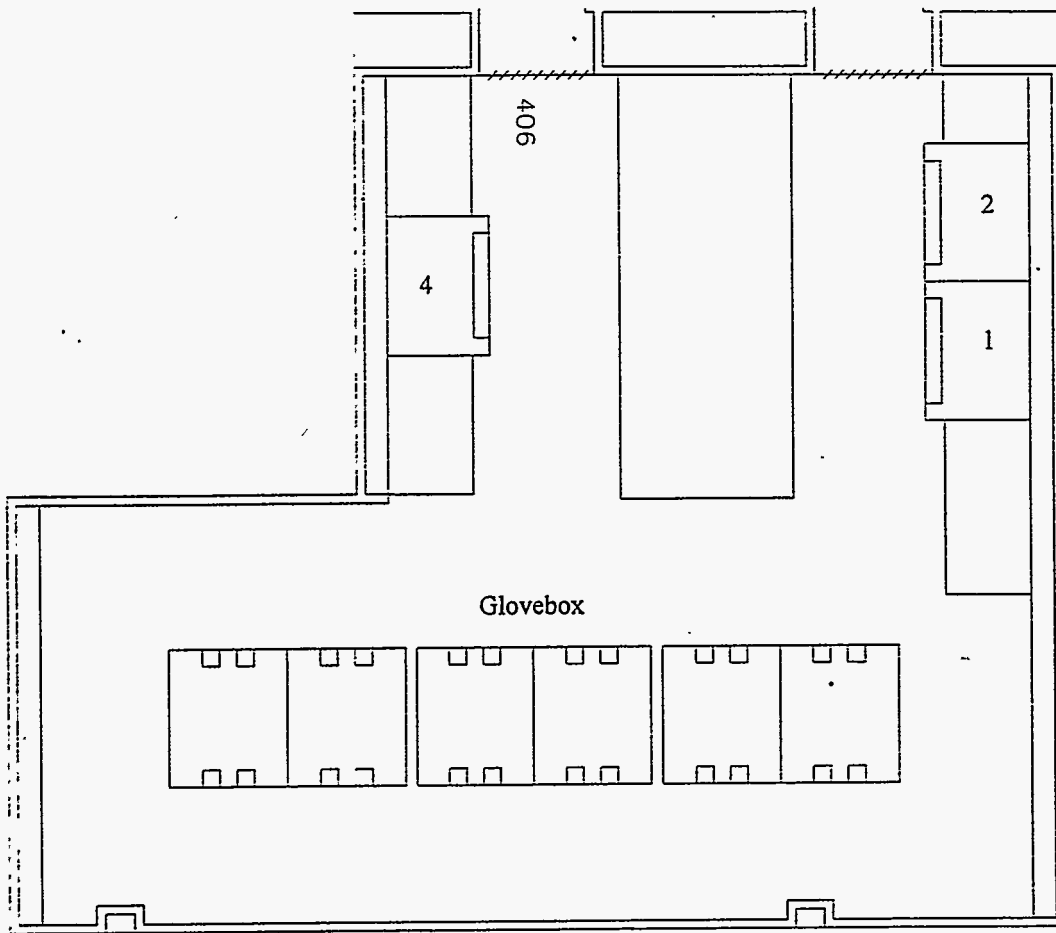


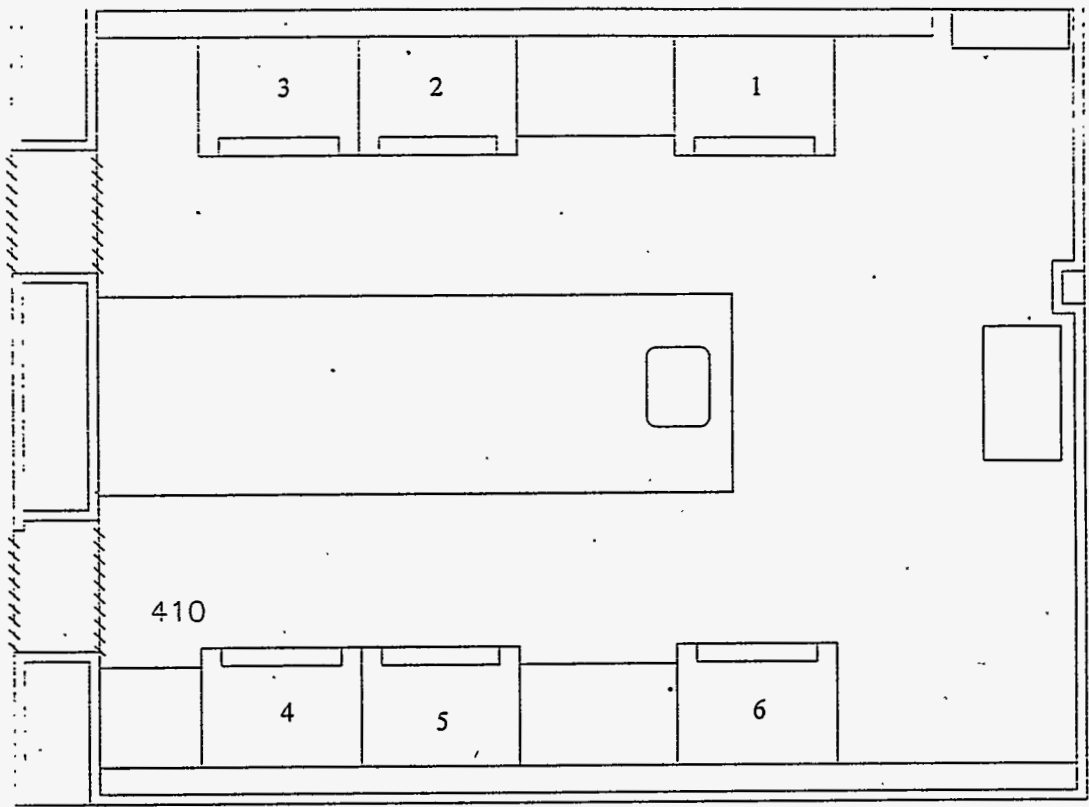


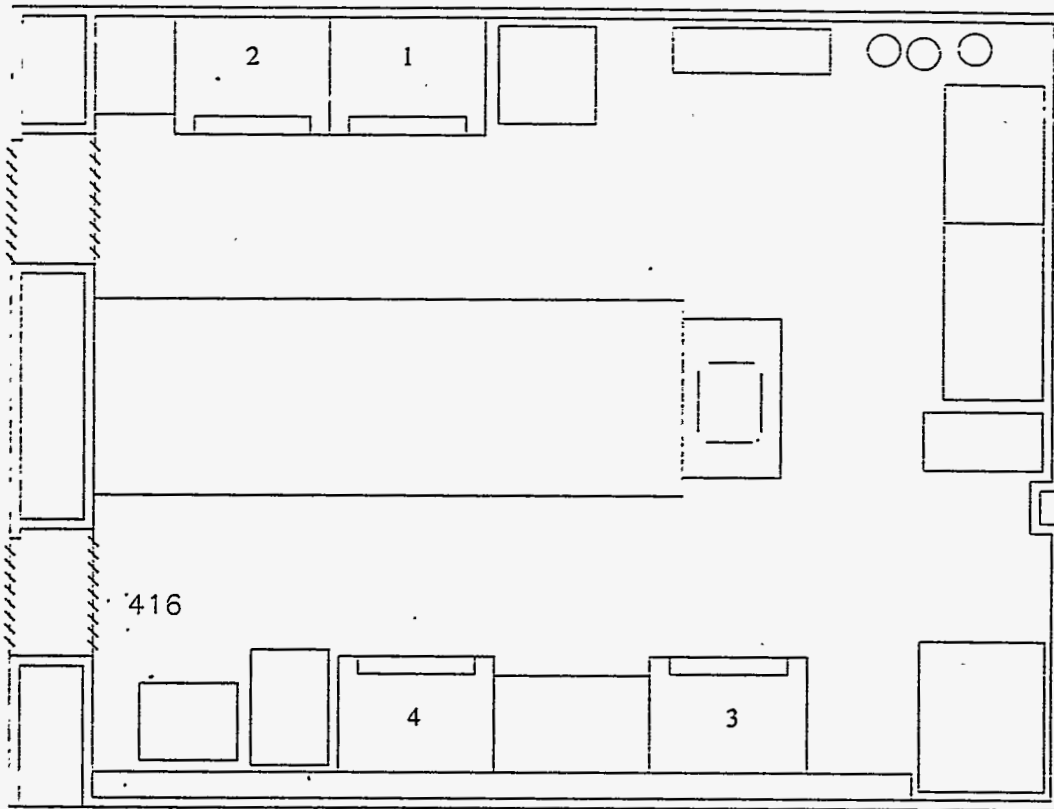
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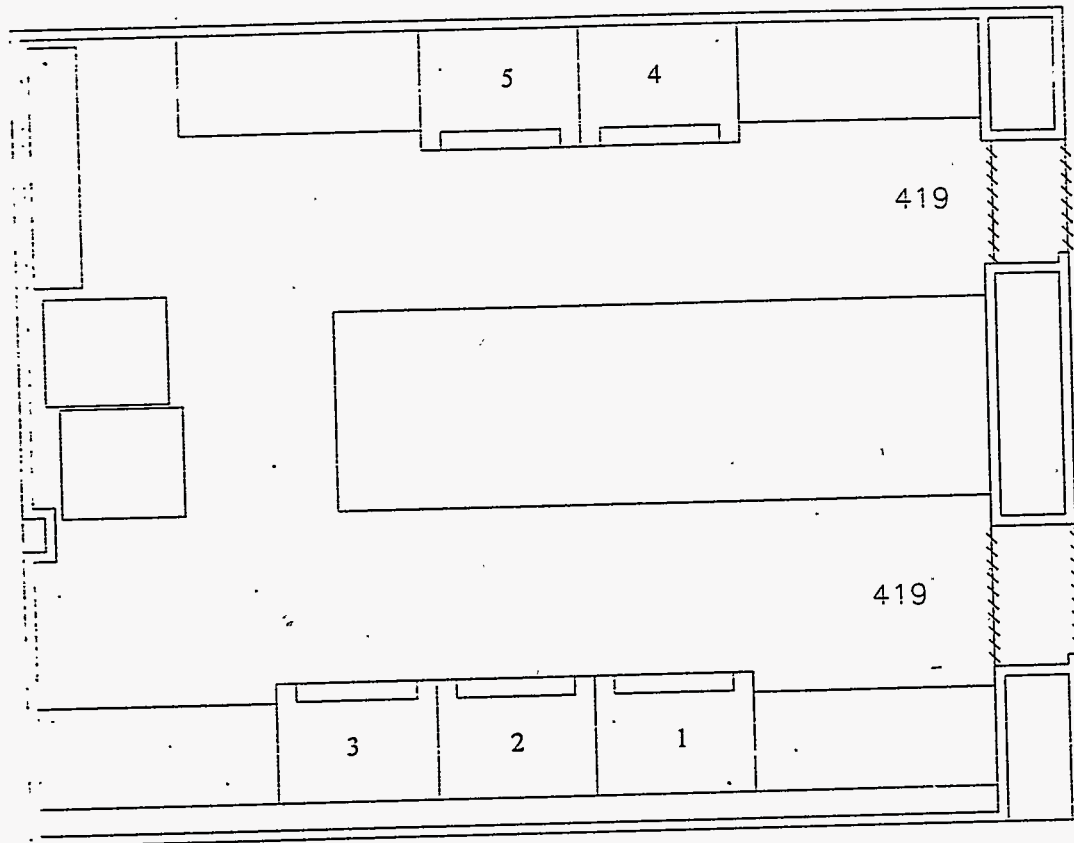


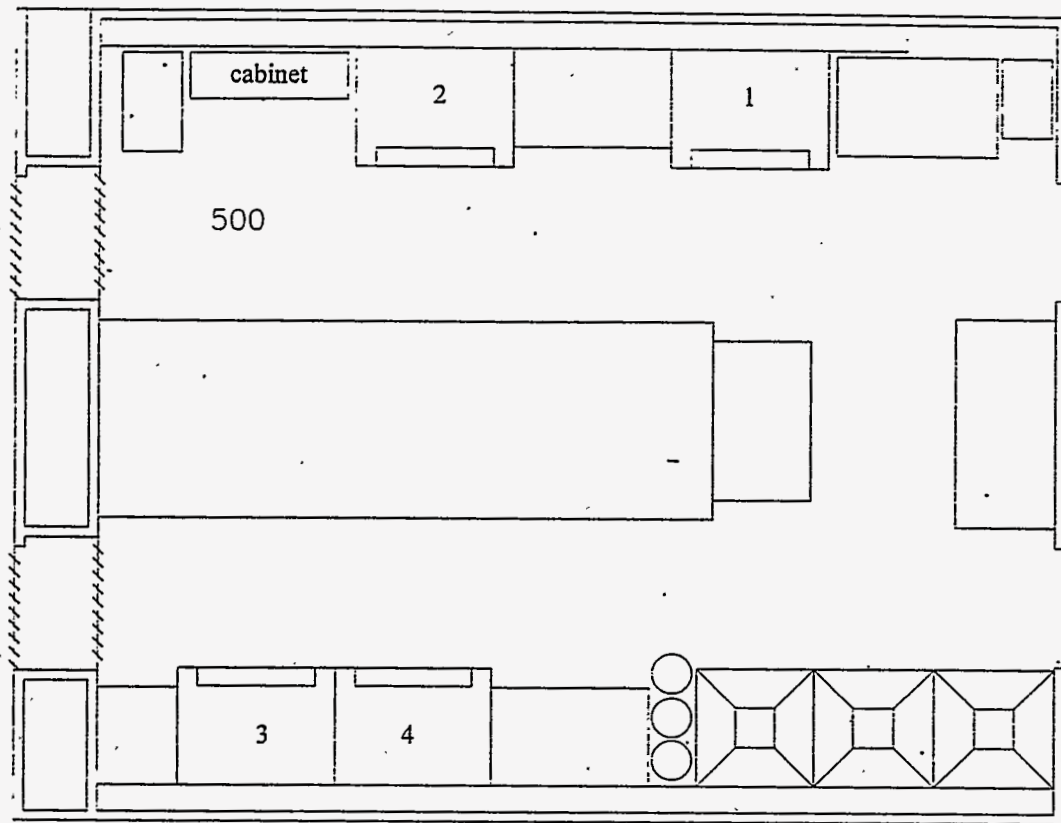


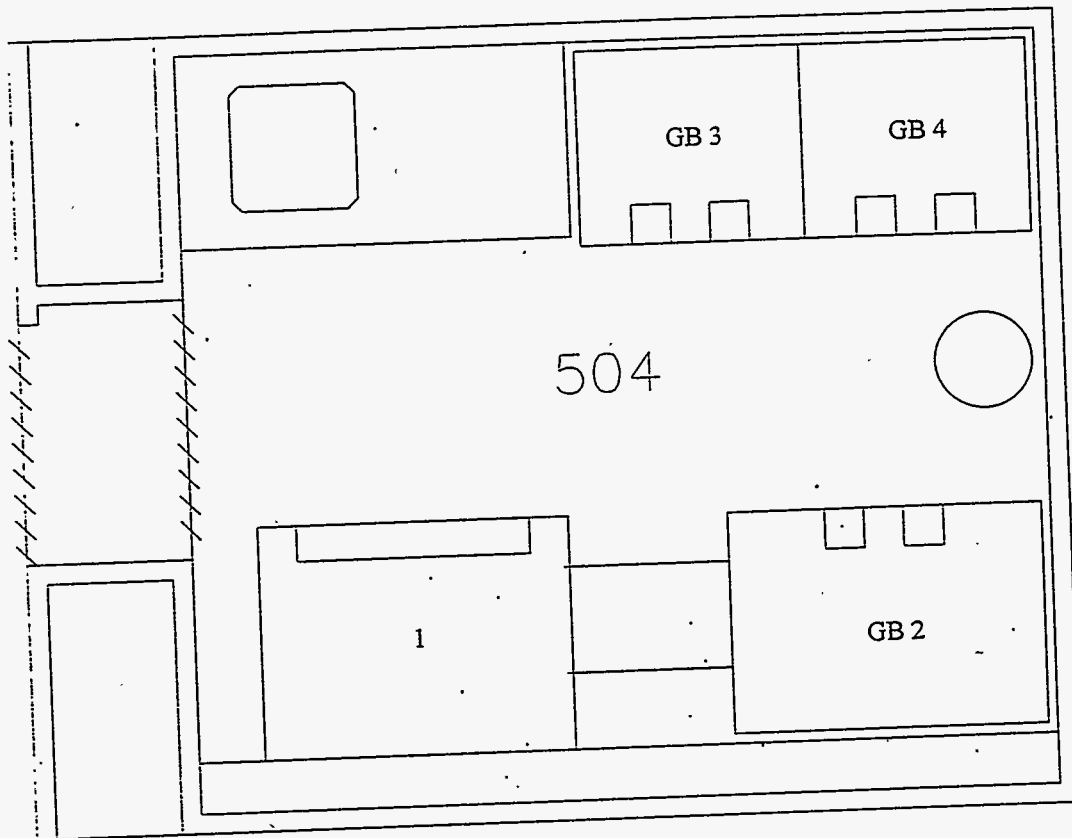


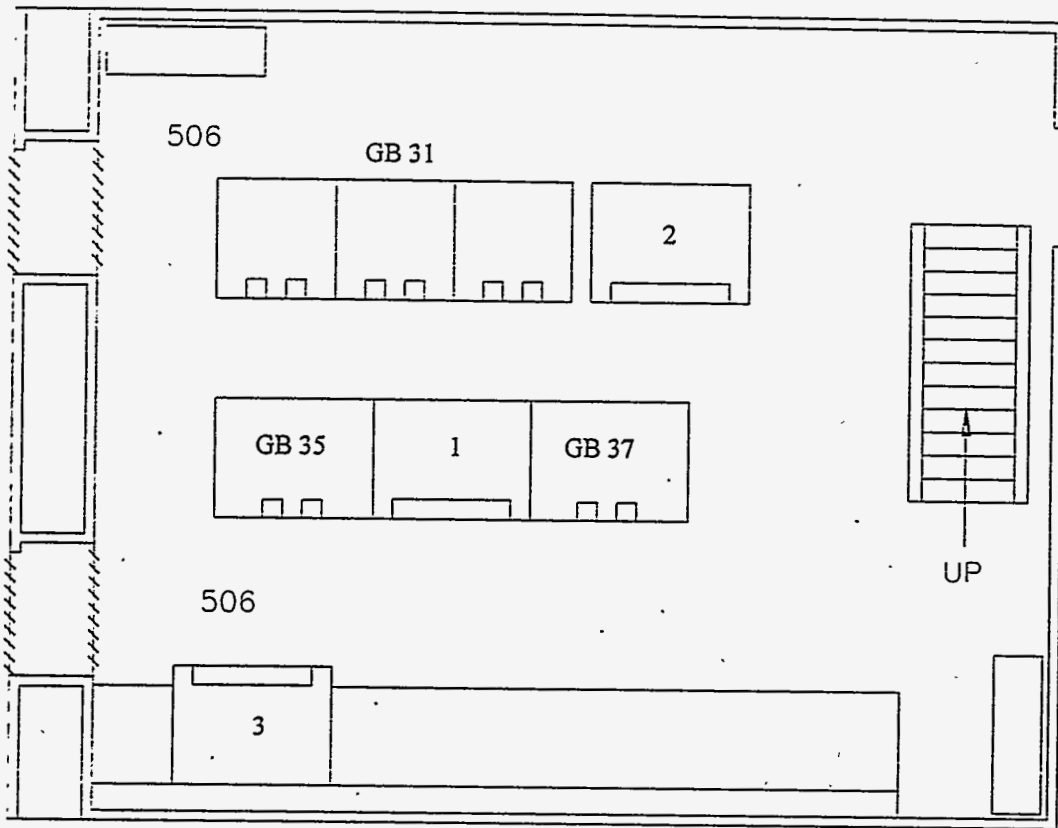


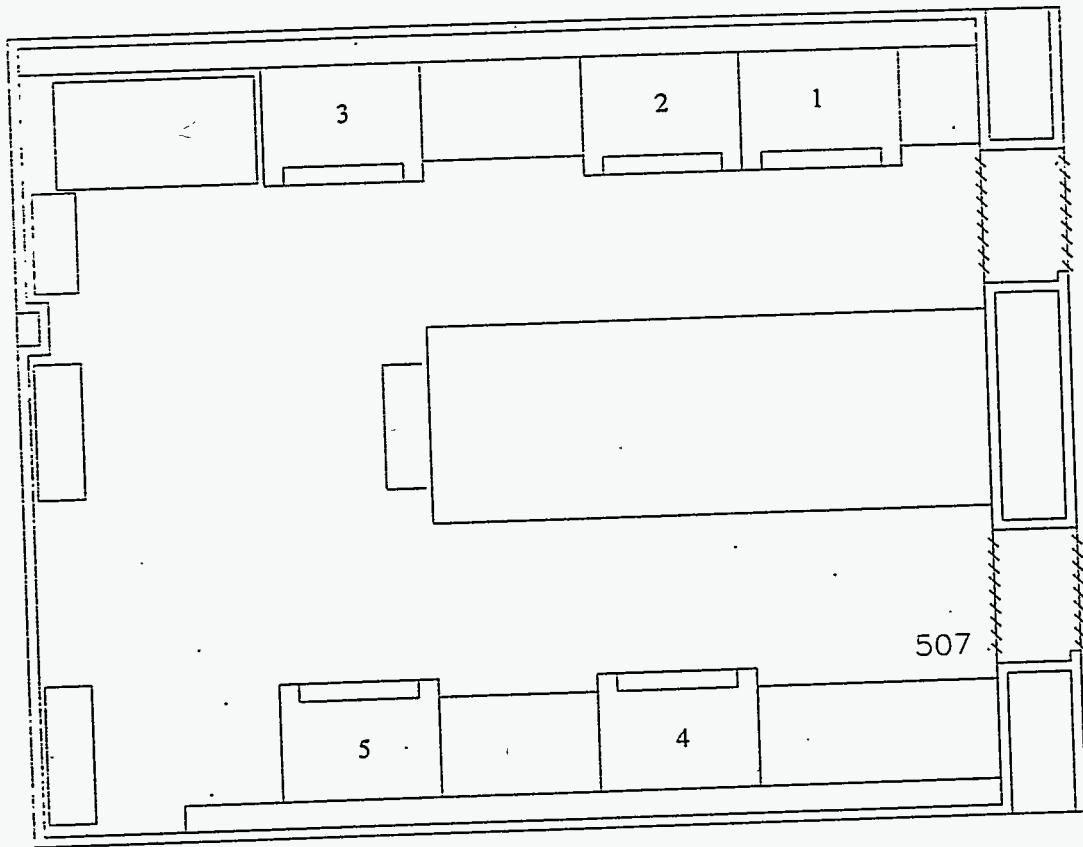












PNL Analytical Chemistry Laboratory 10/11/95
Radiochemistry Group, 325 Bldg.

Client: P. Gaither K41812 Analyst : _____

Reviewer: _____

Sample: Lab Vac Slab Tank ALO# 96-00128

Small aliquots of the as received sample were mounted for total alpha, alpha energy analysis, total beta, and gamma energy analysis. Results appear to be reasonably consistent with previous analyses on this tank performed in March 1995. The alpha energy analysis (AEA) clearly indicates the presence of ²³⁹Pu, although this technique cannot discriminate between ²⁴¹Am and ²³⁸Pu. However, the gamma energy analysis (GEA) confirms that the majority of the alpha activity is due to ²⁴¹Am.

— Activity (μCi/ml) — Reference Date: 10/11/95

Total Alpha: 5.58E-2 ± 4%

AEA: ²⁴¹Am/²³⁸Pu 5.16E-2 ± 6% Note: GEA indicates mostly ²⁴¹Am

²³⁹Pu 4.24E-3 ± 8%

Total Beta : 1.13E-1 ± 4%

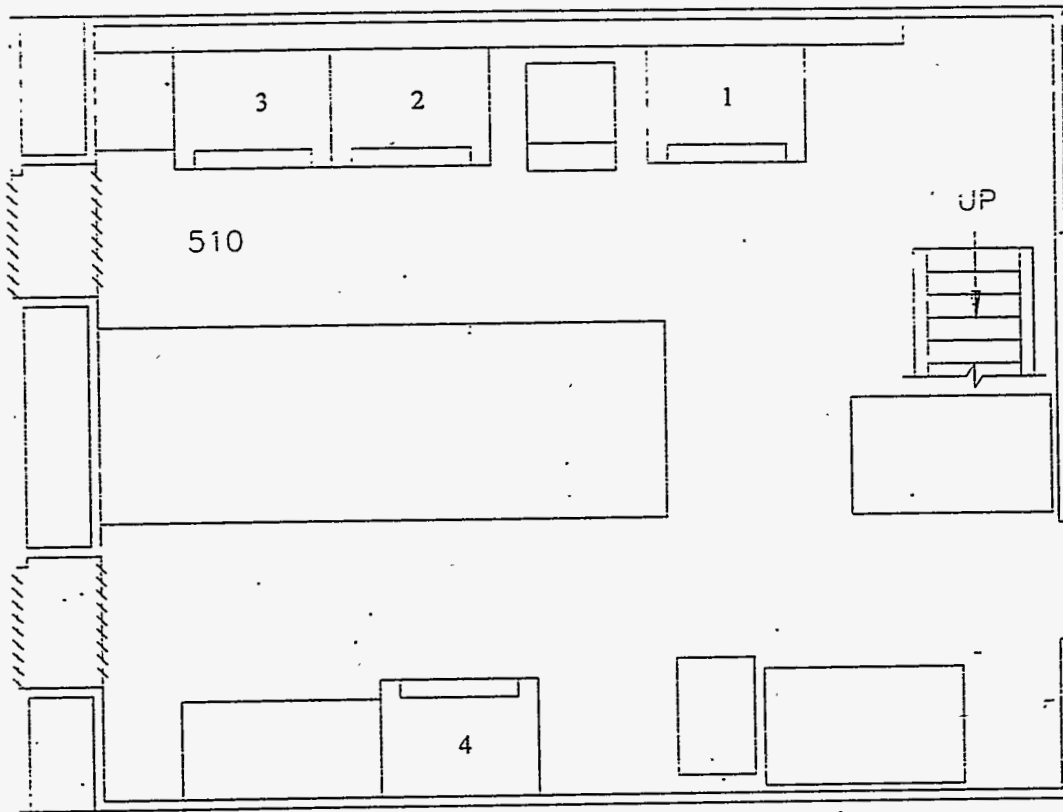
GEA: ²⁴¹Am 4.52E-2 ± 3%

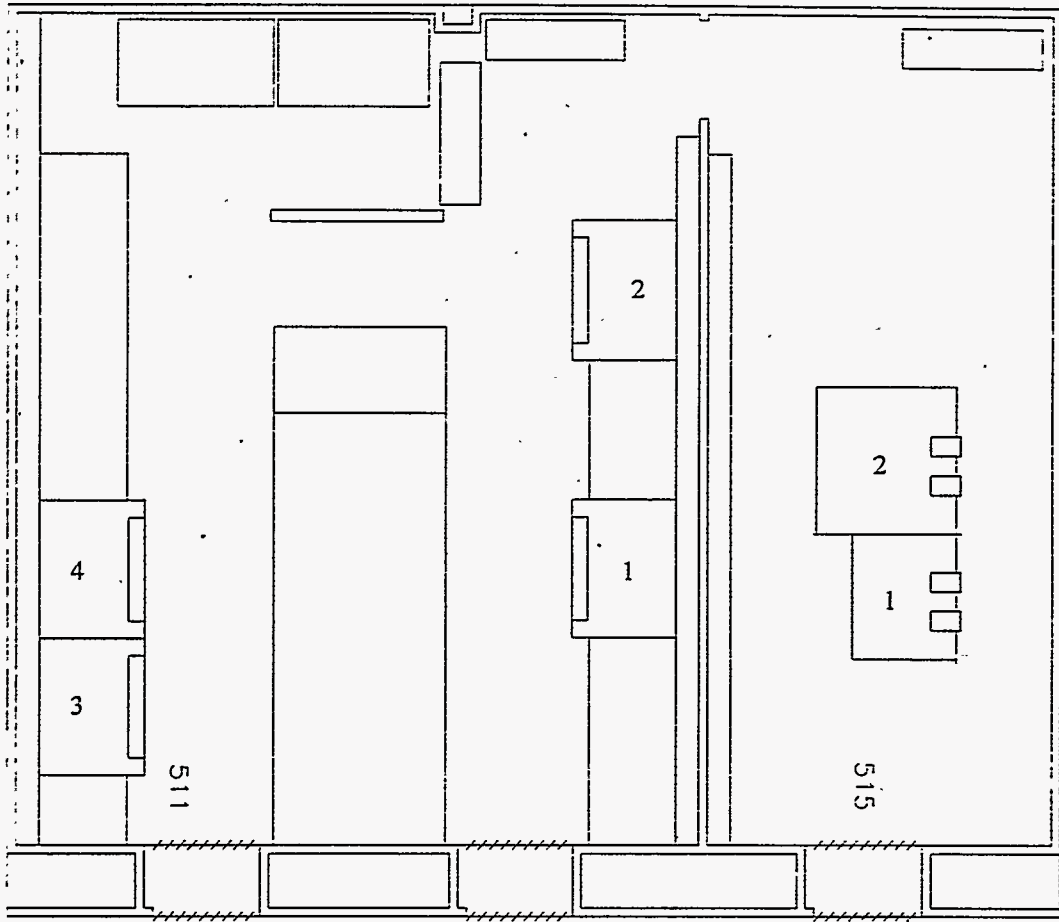
¹³⁷Cs 5.17E-3 ± 3%

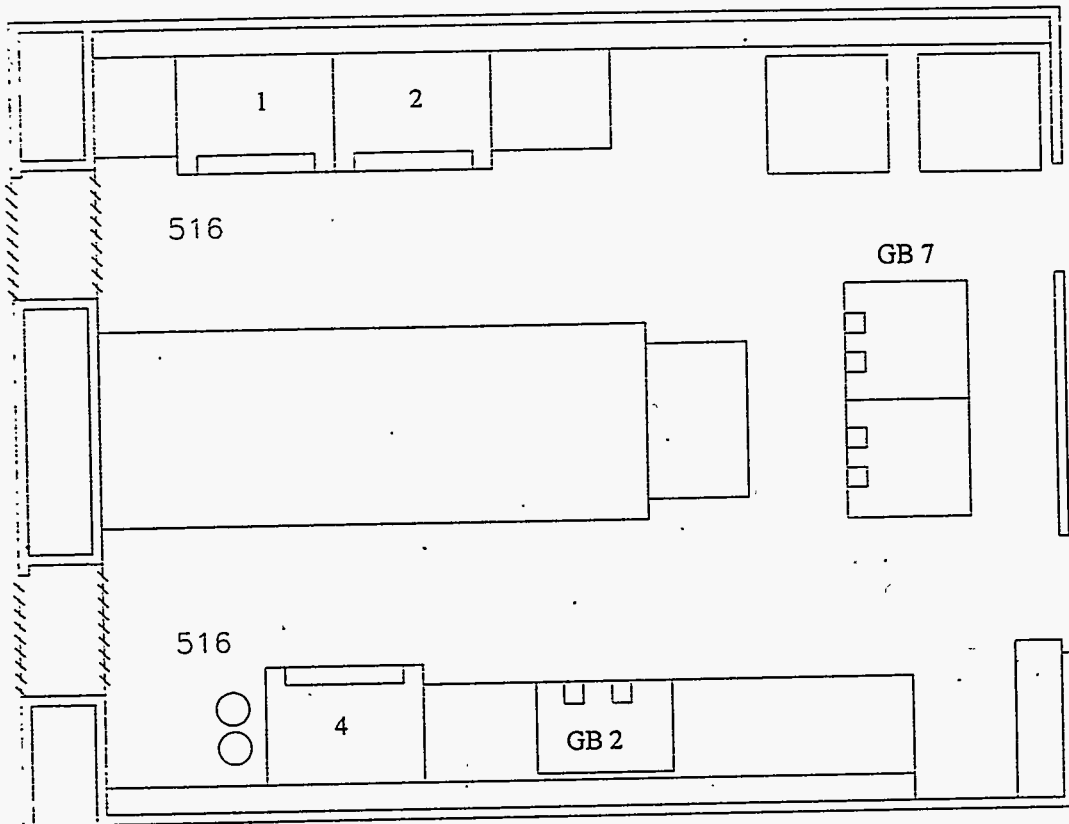
¹⁵⁴Eu 1.07E-3 ± 4%

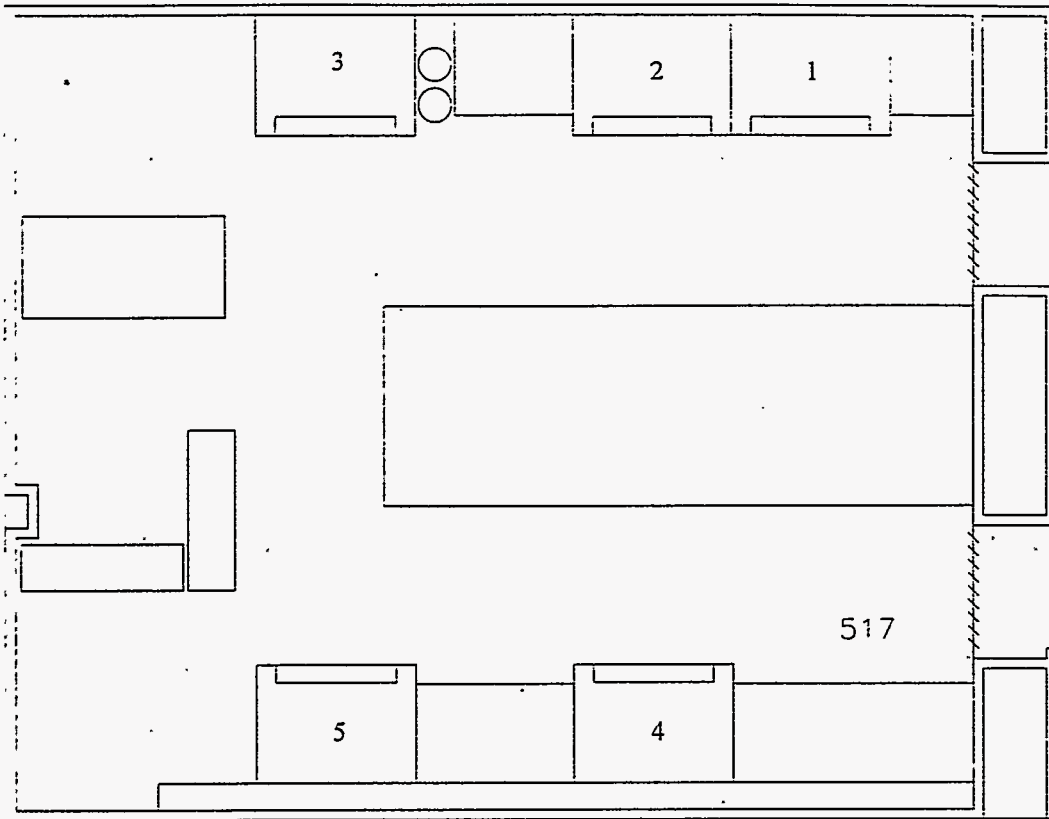
¹⁵⁵Eu 3.57E-4 ± 12%

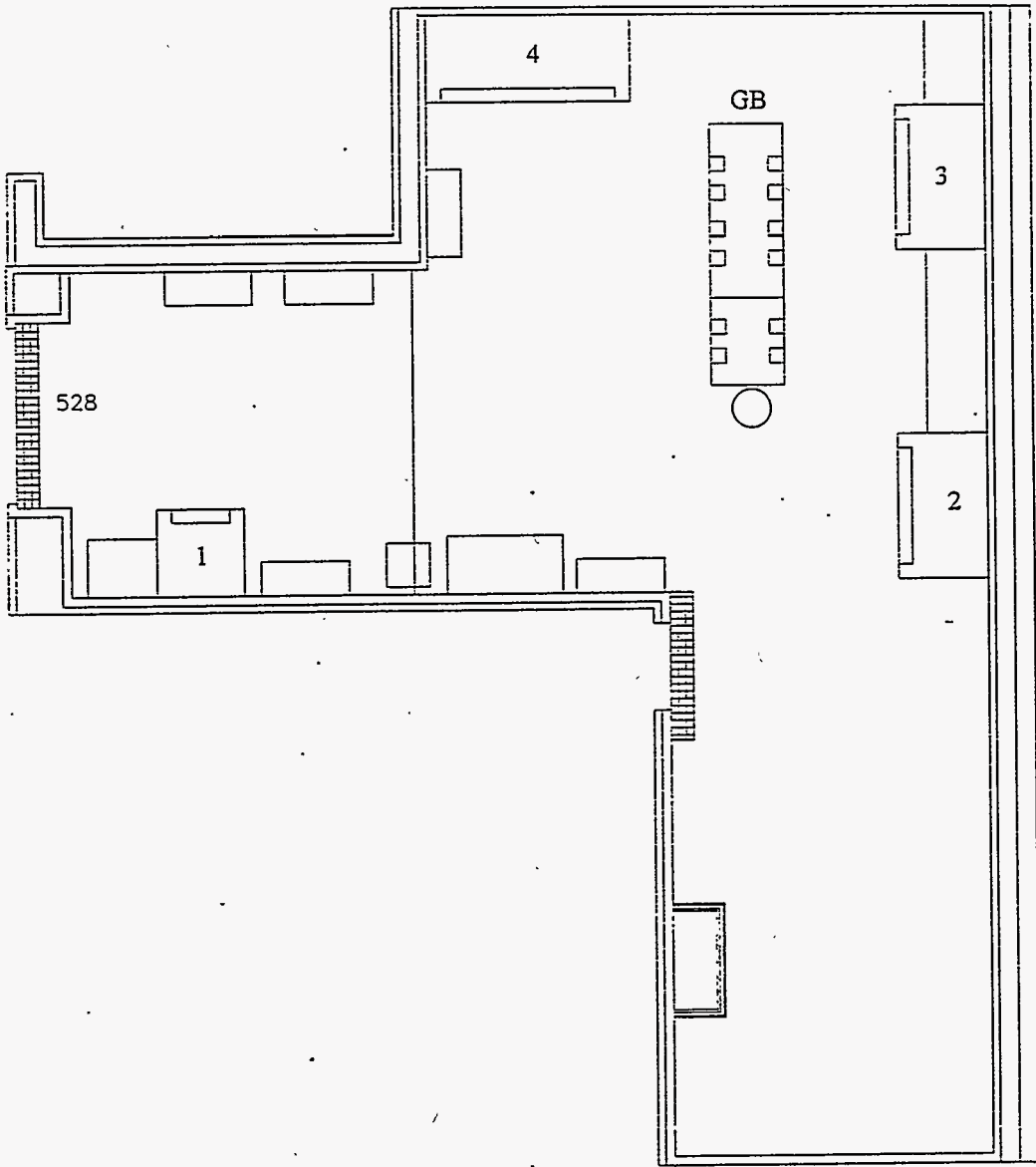
¹⁵²Eu 5.35E-4 ± 8%

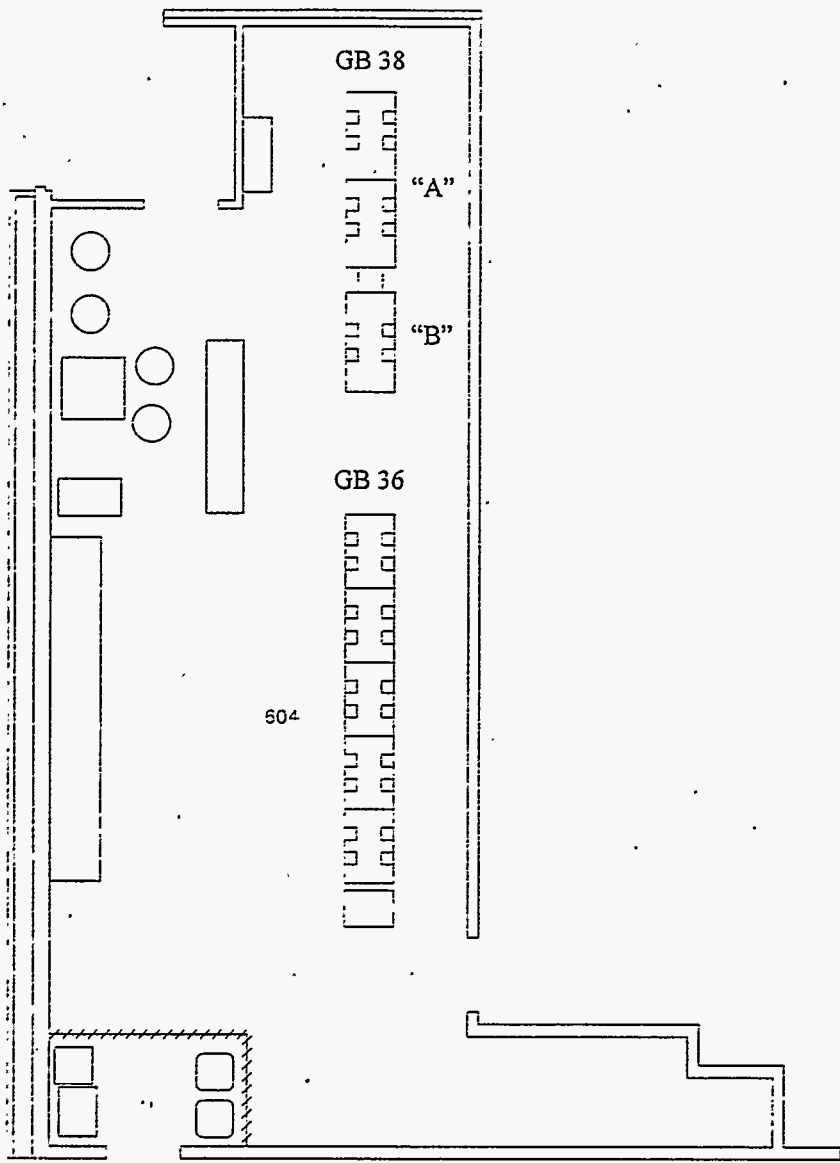


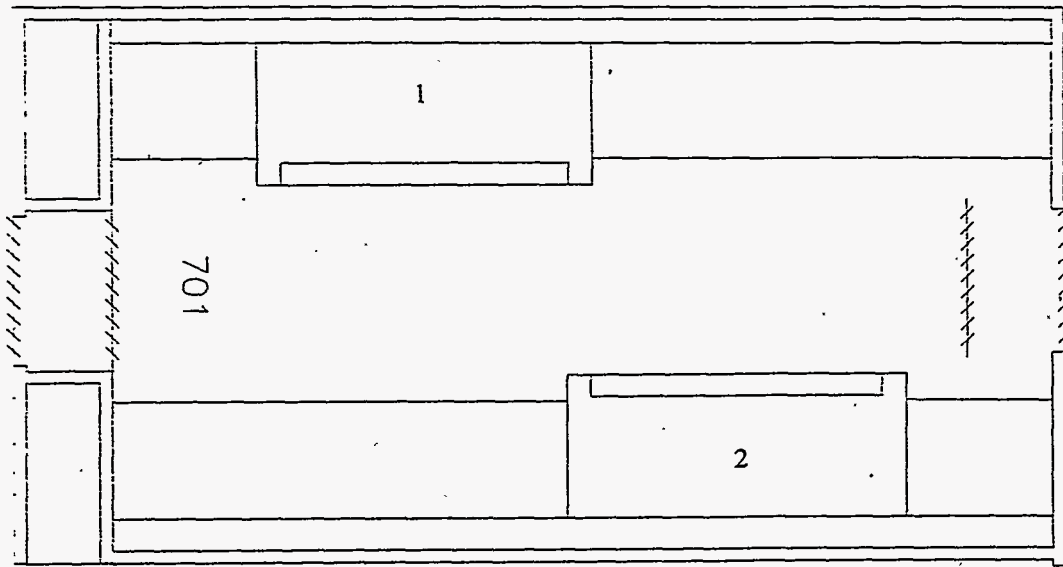












Appendix C

Neutron Measurement Results

Appendix C

Neutron Measurement Results

This appendix contains the spreadsheet analysis of the neutron counting data using the methods outlined in Section 3.5. Basically, the count rate is determined, then corrected for neutron background using the method explained in Section 3.5.2. Then, a correction is made to compensate for room scatter and distance from the source, using Equation 4.6. Finally, the background-corrected count rate is divided by the counts/second/gram of plutonium to derive the mass of plutonium. (based on weapons grade isotopics).

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source Distance	ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/away	grams of Pu	Filename
2/2/96												
s	rm 43 dr	16.5"	12	87	2046	33,478	300	111.59				
s	"	16.5	12	87	2046	32,148	300	107.16				
s	"	16.5	12	87	2046	33,091	300	110.30				
s	"	16.5	12	87	2046	33,431	300	111.44				
s	"	16.5	12	87	2046	33,235	300	110.78				
b	rm 43	16.5	24	87	2046	8,602,566	100,000	86.03				long_ct
2/8/96												
s	rm 42 dr	16.5	12	87	2046	740,409	300	2468.03				
s	rm 42 dr	16.5	12	87	2046	741,461	300	2471.54				
s	rm 42 dr	16.5	12	87	2046	717,369	300	2391.23				
2/8/96												
t	45-	67	24	87	2046	18,836	300	62.79	61.77	25.92	4.03	h506h3t
a	45-	67	24	87	2046	25,705	300	85.68	84.67			h506h3a
a	45-	67	24	87	2046	29,876	300	99.59	98.57			h506h1a
t	45-	67	24	87	2046	21,322	300	71.07	70.06	27.70	4.31	h506h1t
a	45-	67	24	87	2046	34,116	300	113.72	112.70			h504gb1a
t	45-	67	24	87	2046	25,515	300	85.05	84.03	36.91	5.74	h504gb1t
a	45-	67	24	87	2046	32,975	300	109.92	108.90			h506gb1a
t	45-	67	24	87	2046	24,206	300	80.69	79.67	33.63	5.23	h506gb1t
2/9/96												
s	rm 43	18.5	12	87	2046	32,405	300	108.02	107.00			
t	45-	64.5	24	87	2046	29,638	300	98.79	97.78	72.63	11.29	h4basext
a	45-	64.5	24	87	2046	26,287	300	87.62	86.61			h4basexa
t	45-	64.5	24	87	2046	22,701	300	75.67	74.65	56.09	8.72	h511h3t
a	45-	64.5	24	87	2046	19,855	300	66.18	65.17			h511h3a
t	45-	64.5	24	87	2046	17,098	300	56.99	55.98	41.64	6.47	h511h4t
a	45-	64.5	24	87	2046	15,152	300	50.51	49.49			h511h4a
2/14/96												
s	rm 42	18.5	12	87	2046	525,332	300	1751.11	1750.33			

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325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector		ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgnd Corrected	towards/ away	grams of Pu	Filename
		Detector Height, in	to Source Distance									
t	rlws-4	71	12	87	2046	302	300	1.01	0.23	0.15	0.01	325rlw04
t	rlws-5	62.5	18	87	2046	303	300	1.01	0.24	0.23	0.02	325rlw05
t	rlsw-6	62.5	12	87	2046	290	300	0.97	0.19	0.18	0.01	325rlw06
t	rlws-7	77	24	87	2046	303	300	1.01	0.24	0.32	0.05	325rlw07
t	rlws-8	62.5	20	87	2046	327	300	1.09	0.32	0.25	0.03	325rlw08
t	rlws-9	71	12	87	2046	330	300	1.10	0.33	0.41	0.02	325rlw09
t	rlws-10	65.5	18	87	2046	311	300	1.04	0.26	0.32	0.03	325rlw10
a	rlws-7	77	18	87	2046	232	300	0.77	0.00			325rlw7a
b	rm 97 dr	18.5	bkgd	87	2046	3,658	3600	1.02	0.24			rm97bkgd
t	rlws-11	86.5	12	87	2046	296	300	0.99	0.21	0.00	0.00	325rlw11
t	rlws-12	86.5	16	87	2046	340	300	1.13	0.36	0.20	0.01	325rlw12
a	rlws-12	86.5	16	87	2046	358	300	1.19	0.42			325rl12a
a	rlws-5,6	62.5	18	87	2046	269	300	0.90	0.12			325rlw5a
a	rlws-4	62.5	12	87	2046	305	300	1.02	0.24			325rlw4a
a	rlws-10	65.5	18	87	2046	245	300	0.82	0.04			325rl10a
t	rlws-13	70	18	87	2046	335	300	1.12	0.34	0.41	0.04	325rlw13
a	rlws-13	70	18	87	2046	254	300	0.85	0.07			325rl13a
t	rlws-14	88	22	87	2046	372	300	1.24	0.47	0.38	0.05	325rlw14
a	rlws-14	88	22	87	2046	340	300	1.13	0.36			325rl14a
t	rlws-15	88	22	87	2046	484	300	1.61	0.84	0.61	0.08	325rlw15
a	rlws-15	88	22	87	2046	460	300	1.53	0.76			325rl15a
t	rlws-16	72	18	87	2046	656	300	2.19	1.41	1.22	0.11	325rlw16
t	rlws-17	81	35	87	2046	686	300	2.29	1.51	1.35	0.41	325rlw17
a	rlws-16	72	18	87	2046	532	300	1.77	1.00			325rl16a
2/15/96												
s	rm 42	18.5	12	87	2046	583,923	300	1946.41	1945.64			
t	rlws-23	113	24	87	2046	17,662	300	58.87	57.86	34.12	5.31	325rlw23
t	rlws-24	121	24	87	2046	4,486	300	14.95	13.94	7.68	1.19	325rlw24
t	rlws-25	100.5	37	87	2046	2,651	300	8.84	7.82	9.48	3.16	325rlw25
t	rlws-26	123.5	24	87	2046	1,014	300	3.38	2.36	2.20	0.34	325rlw26

C.3

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source Distance	ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/away	grams of Pu	Filename
t	rlws-27	123	24	87	2046	830	300	2.77	1.75	1.38	0.22	325rlw27
t	rlws-28	124	24	87	2046	743	300	2.48	1.46	1.00	0.16	325rlw28
a	rlws-28	124	24	87	2046	732	300	2.44	1.42			325rl28a
a	rlws-24	121	24	87	2046	5,213	300	17.38	16.36			325rl24a
a	rlws-23	113	24	87	2046	19,663	300	65.54	64.53			325rl23a
2/20/96												
s	rm 42	18.5	12	87	2046	581,992	300	1939.97	1938.96			
t	rlws-31	74.5	32	87	2046	713	300	2.38	1.36	0.98	0.26	325rlw31
a	rlws-31	74.5	32	87	2046	678	300	2.26	1.24			325rl31a
2/23/96												
s	rm 42	18.5	12	87	2046	784,143	300	2613.81	2612.79			
t	45-1	76.5	24	87	2046	1,454	300	4.85	3.83	3.20	0.50	h309h8t
a	45-1	76.5	24	87	2046	1,164	300	3.88	2.86			h309h8a
t	45-2	76.5	24	87	2046	803	300	2.68	1.66	0.66	0.10	h309h4t
a	45-2	76.5	24	87	2046	1,004	300	3.35	2.33			h309h4a
t	45-3	76.5	24	87	2046	884	300	2.95	1.93	1.72	0.27	h313h4t
a	45-3	76.5	24	87	2046	689	300	2.30	1.28			h313h4a
t	45-4	72	24	87	2046	906	300	3.02	2.00	1.51	0.23	d45me4t
a	45-4	72	24	87	2046	829	300	2.76	1.75			d45me4a
t	45-5	81	24	87	2046	759	300	2.53	1.51			d45me5a
a	45-5	81	24	87	2046	856	300	2.85	1.84	1.44	0.22	d45me5t
t	45-7	75	24	87	2046	3,791	300	12.64	11.62	2.24	0.35	h416h3t
a	45-7	75	24	87	2046	6,268	300	20.89	19.88			h416h3a
t	45-8	75.5	24	87	2046	11,679	300	38.93	37.91	33.92	5.27	h517h4t
a	45-8	75.5	24	87	2046	7,790	300	25.97	24.95			h517h4a
a	45-8	75.5	24	87	2046	13,495	300	44.98	43.97			h517h4a2
2/27/96												
s	rm 42	18.5	12	87	2046	555,975	300	1853.25	1852.23			
t	45-6	67	24	87	2046	474	300	1.58	0.56	0.55	0.09	d45me6t
a	45-6	67	24	87	2046	397	300	1.32	0.31			d45me6a

C4

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector		ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgnd Corrected	towards/ away	grams of Pu	Filename
		Detector Height, in	to Source Distance									
t	45-11	74	24	87	2046	290	300	0.97	-0.05	0.01	0.00	h427bht
a	45-11	74	24	87	2046	271	300	0.90	-0.11			h427bha
t	45-22	74.5	24	87	2046	2,285	300	7.62	6.60	5.80	0.15	f5lvst
a	45-22	74.5	24	87	2046	1,657	300	5.52	4.51			f5lvsa
t	45-22	74.5	34	87	2046	2,267	300	7.56	6.54	1.56	0.08	f5lvs2t
a	45-22	74.5	34	87	2046	3,525	300	11.75	10.73			f5lvs2a
2/28/96												
t	45-9	72	24	87	2046	3,455	300	11.52	10.50	8.84	0.24	h9lvs9t
a	45-9	72	24	87	2046	2,625	300	8.75	7.73			h9lvs9a
t	45-10	66.5	26	87	2046	814	300	2.71	1.70	1.48	0.27	d45me10t
a	45-10	66.5	26	87	2046	657	300	2.19	1.17			d45me10a
a	30a-1	92.25	24	87	2046	369	300	1.23	0.21			d30a1a
t	30a-1	92.25	24	87	2046	404	300	1.35	0.33	0.30	0.05	d30a1t
t	45-12	86	24	87	2046	737	300	2.46	1.44	0.55	0.01	e9lvs12t
a	45-12	86	24	87	2046	921	300	3.07	2.05			e9lvs12a
2/29/96												
t	31-2	12	12	87	2046	455	300	1.52	0.50	0.50	0.02	rlws30t
a	31-2	12	13	87	2046	378	300	1.26	0.24			rlws30a
t	31-1	86.5	24	87	2046	574	300	1.91	0.90	0.98	0.15	d31me1t
a	31-1	86.5	24	87	2046	400	300	1.33	0.32			d31me1a
t	62-2	72	24	87	2046	409	300	1.36	0.35	0.29	0.05	h320h2t
a	62-2	72	24	87	2046	381	300	1.27	0.25			h320h2a
t	62-1	70	24	87	2046	405	300	1.35	0.33	0.40	0.06	h320h1t
a	62-1	70	24	87	2046	323	300	1.08	0.06			h320h1a
t	62-3	92	48	87	2046	358	300	1.19	0.18	0.22	0.11	h320d1t
a	62-3	92	48	87	2046	311	300	1.04	0.02			h320d1a
t	33-1	12	24	87	2046	468	300	1.56	0.54	0.21	0.03	rlw33t1t
a	33-1	12	24	87	2046	537	300	1.79	0.77			rlw33t1a
t	45-13	18	24	87	2046	28,121	300	93.74	92.72	20.37	3.17	45smp13t
a	45-13	18	24	87	2046	46,771	300	155.90	154.89			45smp13a

C5

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source		Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename	
			Distance	ROI Start								ROI Stop
3/4/96												
t	45-14	25	24	87	2046	462	300	1.54	0.52	0.11	0.00	45lvs14t
a	45-14	25	24	87	2046	571	300	1.90	0.89			45lvs14a
t	45-15	90	24	87	2046	14,303	300	47.68	46.66	37.56	1.00	45lvs15t
t	45-15	96	18	87	2046	14,608	300	48.69	47.68	39.08	0.61	45lvs15u
t	45-16	80	32	87	2046	28,729	300	95.76	94.75	59.16	2.64	45lvs16t
t	45-17	85	24	87	2046	27,594	300	91.98	90.96	57.46	1.53	45lvs17t
t	45-18	84	25	87	2046	5,954	300	19.85	18.83	14.96	0.43	45lvs18t
a	45-18	82	27	87	2046	4,871	300	16.24	15.22			45lvs18a
a	45-17	85	24	87	2046	29,027	300	96.76	95.74			45lvs17a
a	45-16	78	26	87	2046	30,533	300	101.78	100.76			45lvs16a
a	45-15	90	24	87	2046	11,397	300	37.99	36.97			45lvs15a
a	45-15	96	18	87	2048	11,323	300	37.74	36.73			45lvs15b
3/6/96												
s	rm 42	18.5	12	87	2046	673,912	300	2246.37	2245.36			
t	45-19	85	24	87	2046	2,114	300	7.05	6.03	4.67	0.12	45lvs19t
a	45-19	85	24	87	2046	1,821	300	6.07	5.05			45lvs19a
a	45-20	93	40	87	2046	603	300	2.01	0.99			45lvs20a
t	45-20	93	40	87	2046	764	300	2.55	1.53	1.38	0.09	45lvs20t
t	45-21	93	40	87	2046	659	300	2.20	1.18	1.12	0.07	45lvs21t
a	45-21	93	40	87	2046	509	300	1.70	0.68			45lvs21t
a	45-23	86	27	87	2046	718	300	2.39	1.38			45lvs23a
t	45-23	86	27	87	2046	697	300	2.32	1.31	0.82	0.03	45lvs23t
3/7/96												
s	rm 42	18.5	12	87	2046	745,346	300	2484.49	2483.47			
t	lab 313	38.5	30	87	2046	640	300	2.13	0.74	0.03	0.01	313h1t
a	lab 313	50.5	30	87	2046	848	300	2.83	1.44			313h1a
t	lab 313	50.5	30	87	2046	686	300	2.29	0.90	-0.05	-0.01	313h2t
a	lab 313	50.5	30	87	2046	977	300	3.26	1.87			313h2a
t	lab 313	50.5	30	87	2046	1,142	300	3.81	2.42	2.25	0.52	313h3t

C.6

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source		Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename
			Distance	ROI Start ROI Stop							
a	lab 313	50.5	30	87 2046	854	300	2.85	1.46			313h3a
t	lab 313	50.5	30	87 2046	1,267	300	4.22	2.83	2.58	0.60	313h4t
a	lab 313	50.5	30	87 2046	956	300	3.19	1.80			313h4a
t	lab 309	50.5	30	87 2046	1,279	300	4.26	2.87	0.90	0.21	309h1t
a	lab 309	50.5	30	87 2046	1,736	300	5.79	4.40			309h1a
t	lab 309	50.5	30	87 2046	1,395	300	4.65	3.26	0.78	0.18	309h2t
a	lab 309	50.5	30	87 2046	2,021	300	6.74	5.35			309h2a
t	lab 309	50.5	30	87 2046	1,910	300	6.37	4.98	1.38	0.32	309h3t
a	lab 309	50.5	30	87 2046	2,784	300	9.28	7.89			309h3a
t	lab 309	50.5	30	87 2046	2,158	300	7.19	5.80	1.92	0.45	309h4t
a	lab 309	50.5	30	87 2046	3,033	300	10.11	8.72			309h4a
t	lab 309	50.5	30	87 2046	3,601	300	12.00	10.61	10.18	2.37	309h5t
a	lab 309	50.5	30	87 2046	2,204	300	7.35	5.96			309h5a
t	lab 309	50.5	30	87 2046	5,775	300	19.25	17.86	17.90	4.16	309h6t
a	lab 309	50.5	30	87 2046	3,076	300	10.25	8.86			309h6a
t	lab 309	50.5	30	87 2046	6,691	300	22.30	20.91	21.06	4.90	309h7t
a	lab 309	50.5	30	87 2046	3,489	300	11.63	10.24			309h7a
t	lab 309	50.5	34	87 2046	4,625	300	15.42	14.03	12.88	3.72	309h8t
a	lab 309	50.5	34	87 2046	3,037	300	10.12	8.73			309h8a
3/8/96											
t	lab 303	50.5	30	87 2046	1,292	300	4.31	2.92	0.04	0.01	303h4t
a	lab 303	50.5	30	87 2046	2,151	300	7.17	5.78			303h4a
t	lab 303	50.5	29.5	87 2046	1,303	300	4.34	2.95	0.13	0.03	303r3t
a	lab 303	50.5	29.5	87 2046	2,132	300	7.11	5.72			303r3a
3/11/96											
t	lab 303	50.5	30	87 2046	1,100	300	3.67	2.28	-0.24	-0.06	303h1t
a	lab 303	50.5	30	87 2046	1,890	300	6.30	4.91			303h1a
t	lab 312	50.5	30	87 2046	677	300	2.26	0.87	0.72	0.17	312h1t
a	lab 312	50.5	30	87 2046	615	300	2.05	0.66			312h1a
t	lab 312	50.5	30	87 2046	633	300	2.11	0.72	0.50	0.12	312h2t

C.7

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source		Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename	
			Distance	ROI Start ROI Stop								
a	lab 312	50.5	30	87	2046	626	300	2.09	0.70		312h2a	
t	lab 312	50.5	30	87	2046	626	300	2.09	0.70	0.40	0.09	312gb1t
a	lab 312	50.5	30	87	2046	657	300	2.19	0.80			312gb1a
t	lab 312	50.5	30	87	2046	591	300	1.97	0.58	0.41	0.10	312gb2t
a	lab 312	50.5	30	87	2046	579	300	1.93	0.54			312gb2a
t	lab 312	50.5	30	87	2046	629	300	2.10	0.71	0.46	0.11	312h3t
a	lab 312	50.5	30	87	2046	633	300	2.11	0.72			312h3a
t	lab 312	50.5	30	87	2046	562	300	1.87	0.48	0.28	0.07	312gbpt
a	lab 312	50.5	30	87	2046	581	300	1.94	0.55			312gbpa
b	lab 313	50.5	30	87	2046	8,421	3600	2.34	0.95			3131hrb
t	lab 305	50.5	30	87	2046	2,892	300	9.64	8.25	0.84	0.20	305h1t
a	lab 305	50.5	30	87	2046	4,989	300	16.63	15.24			305h1a
t	lab 305	50.5	30	87	2046	3,514	300	11.71	10.32	0.69	0.16	305h2t
a	lab 305	50.5	30	87	2046	6,301	300	21.00	19.61			305h2a
t	lab 305	50.5	26	87	2046	8,394	300	27.98	26.59	27.12	3.27	305gb1t
a	lab 305	50.5	26	87	2046	4,168	300	13.89	12.50			305gb1a
t	lab 305	50.5	26	87	2046	8,484	300	28.28	26.89	27.55	3.33	305gb2t
a	lab 305	50.5	26	87	2046	4,155	300	13.85	12.46			305gb2a
t	lab 305	50.5	28	87	2046	19,953	300	66.51	65.12	61.75	8.52	305gb3t
a	lab 305	50.5	28	87	2046	11,702	300	39.01	37.62			305gb3a
t	lab 305	50.5	28	87	2046	54,572	300	181.91	180.52	186.63	25.75	305gb4t
a	lab 305	50.5	28	87	2046	24,743	300	82.48	81.09			305gb4a
t	lab 305	50.5	28	87	2046	35,843	300	119.48	118.09	120.78	16.67	305gb5t
a	lab 305	50.5	28	87	2046	16,917	300	56.39	55.00			305gb5a
t	lab 305	50.5	35	87	2046	13,011	300	43.37	41.98	-8.91	-1.81	305gbb2t
a	lab 305	50.5	35	87	2046	29,615	300	98.72	97.33			305gbb2a
t	lab 305	50.5	35	87	2046	19,670	300	65.57	64.18	-5.15	-1.05	305gbb1t
a	lab 305	50.5	35	87	2046	41,242	300	137.47	136.08			305gbb1a
t	lab 305	50.5	32	87	2046	17,128	300	57.09	55.70	55.31	9.66	305gb6t
a	lab 305	50.5	32	87	2046	8,949	300	29.83	28.44			305gb6a

C.8

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector		ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename
		Detector Height, in	to Source Distance									
t	lab 305	50.5	32	87	2046	8,382	300	27.94	26.55	25.16	0.26	305gb7t
a	lab 305	50.5	32	87	2046	5,025	300	16.75	15.36			305gb7a
3/12/96												
t	lab 317	50.5	28	87	2046	521	300	1.74	0.35	-0.21	-0.04	317h1t
a	lab 317	50.5	28	87	2046	719	300	2.40	1.01			317h1a
t	lab 317	50.5	28	87	2046	584	300	1.95	0.56	0.18	0.04	317h2t
a	lab 317	50.5	35	87	2046	669	300	2.23	0.84			317h2a
t	lab 410	50.5	35	87	2046	1,935	300	6.45	4.75	2.31	0.70	410h1t
a	lab 410	50.5	35	87	2046	2,319	300	7.73	6.03			410h1a
t	lab 410	50.5	35	87	2046	1,562	300	5.21	3.50	1.88	0.57	410h2t
a	lab 410	50.5	32	87	2046	1,767	300	5.89	4.19			410h2a
t	lab 410	50.5	32	87	2046	1,385	300	4.62	2.91	1.73	0.45	410h3t
a	lab 410	50.5	32	87	2046	1,479	300	4.93	3.23			410h3a
t	lab 410	50.5	32	87	2046	1,674	300	5.58	3.88	2.92	0.76	410h4t
a	lab 410	50.5	32	87	2046	1,523	300	5.08	3.37			410h4a
t	lab 410	50.5	31	87	2046	1,857	300	6.19	4.49	3.36	0.83	410h5t
a	lab 410	50.5	31	87	2046	1,691	300	5.64	3.93			410h5a
t	lab 410	50.5	31	87	2046	3,408	300	11.36	9.66	8.55	2.11	410h6t
a	lab 410	50.5	31	87	2046	2,456	300	8.19	6.48			410h6a
t	lab 401	50.5	31	87	2046	628	300	2.09	0.39	0.17	0.04	401h1t
a	lab 401	50.5	31	87	2046	667	300	2.22	0.52			401h1a
t	lab 401	50.5	24	87	2046	722	300	2.41	0.70	0.59	0.09	401h2t
a	lab 401	50.5	24	87	2046	667	300	2.22	0.52			401h2a
3/13/96												
t	lab 406	50.5	31	87	2046	2,152	300	7.17	5.47	3.04	0.75	406h1t
a	lab 406	50.5	31	87	2046	2,424	300	8.08	6.38			406h1a
t	lab 406	50.5	31	87	2046	1,785	300	5.95	4.25	2.51	0.62	406h2t
a	lab 406	50.5	31	87	2046	1,929	300	6.43	4.73			406h2a
t	lab 406	50.5	31	87	2046	2,040	300	6.80	5.10	3.07	0.76	406h4t
a	lab 406	50.5	31	87	2046	2,188	300	7.29	5.59			406h4a

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325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source		Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename	
			Distance	ROI Start ROI Stop								
t	lab 406	50.5	28	87	2046	9,684	300	32.28	30.58	29.81	6.13	406gb1t
a	lab 406	50.5	28	87	2046	5,444	300	18.15	16.44			406gb1a
t	lab 406	50.5	28	87	2046	11,578	300	38.59	36.89	36.43	7.50	406gb2t
a	lab 406	50.5	28	87	2046	6,250	300	20.83	19.13			406gb2a
t	lab 406	50.5	28	87	2046	7,405	300	24.68	22.98	22.26	4.58	406gb3t
a	lab 406	50.5	28	87	2046	4,283	300	14.28	12.57			406gb3a
t	lab 406	50.5	28	87	2046	5,694	300	18.98	17.28	16.01	3.29	406gb4t
a	lab 406	50.5	28	87	2046	3,673	300	12.24	10.54			406gb4a
t	lab 406	50.5	28	87	2046	6,047	300	20.16	18.45	17.20	3.54	406gb5t
a	lab 406	50.5	28	87	2046	3,844	300	12.81	11.11			406gb5a
t	lab 406	50.5	28	87	2046	6,359	300	21.20	19.49	18.67	3.84	406gb6t
a	lab 406	50.5	28	87	2046	3,806	300	12.69	10.98			406gb6a
t	lab 406	48	31	87	2046	8876	300	29.59	27.88	20.09	4.95	406gbb2t
a	lab 406	48	31	87	2046	8200	300	27.33	25.63			406gbb2a
t	lab 419	50.5	31	87	2046	572	300	1.91	0.20	0.20	0.05	419h1t
a	lab 419	50.5	31	87	2046	545	300	1.82	0.11			419h1a
t	lab 419	50.5	31	87	2046	569	300	1.90	0.19	0.30	0.07	419h2t
a	lab 419	50.5	31	87	2046	494	300	1.65	-0.06			419h2a
t	lab 419	50.5	31	87	2046	556	300	1.85	0.15	0.24	0.06	419h3t
a	lab 419	50.5	31	87	2046	493	300	1.64	-0.06			419h3a
t	lab 419	50.5	31	87	2046	523	300	1.74	0.04	-0.06	-0.02	419h4t
a	lab 419	50.5	31	87	2046	563	300	1.88	0.17			419h4a
t	lab 419	50.5	31	87	2046	479	300	1.60	-0.11	-0.18	-0.05	419h5t
a	lab 419	50.5	31	87	2046	530	300	1.77	0.06			419h5a
b	lab 419	50.5	North	87	2046	61,289	36,000	1.70	0.00			background
3/14/96												
t	lab 500	50.5	31	87	2046	10,408	300	34.69	32.99	27.81	6.85	500h1t
a	lab 500	50.5	31	87	2046	7,789	300	25.96	24.26			500h1a
t	lab 500	50.5	31	87	2046	30,304	300	101.01	99.31	96.67	23.82	500h2t
a	lab 500	50.5	31	87	2046	16,596	300	55.32	53.62			500h2a

C.10

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source Distance	ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename	
t		lab 500	50.5	31	87	2046	5,922	300	19.74	18.04	2.71	0.67	500h3t
a		lab 500	50.5	31	87	2046	10,112	300	33.71	32.00			500h3a
t		lab 500	50.5	32	87	2046	5,462	300	18.21	16.50	3.03	0.79	500h4t
a		lab 500	50.5	32	87	2046	9,051	300	30.17	28.47			500h4a
t		lab 500	50.5	24	87	2046	85,772	300	285.91	284.20	295.10	45.88	500cabt
a		lab 500	50.5	24	87	2046	38,237	300	127.46	125.75			500cba
t		lab 504	50.5	30	87	2046	263,819	300	879.40	877.69	892.75	12.19	504h1t
a		lab 504	50.5	30	87	2046	125,391	300	417.97	416.27			504h1a
t		lab 504	50.5	28	87	2046	24,429	300	81.43	79.73	54.90	11.30	504gb2t
a		lab 504	50.5	28	87	2046	23,644	300	78.81	77.11			504gb2a
t		lab 504	50.5	36	87	2046	43,022	300	143.41	141.70	67.87	21.61	504gb3t
a		lab 504	50.5	28	87	2046	54,990	300	183.30	181.60			504gb3a
t		lab 504	50.5	28	87	2046	21,608	300	72.03	70.32	41.63	8.57	504gb4t
a		lab 504	50.5	28	87	2046	23,970	300	79.90	78.20			504gb4a
t		lab 507	50.5	31	87	2046	8,277	300	27.59	25.89	16.19	3.99	507h1t
a		lab 507	50.5	31	87	2046	8,760	300	29.20	27.50			507h1a
t		lab 507	50.5	31	87	2046	6,246	300	20.82	19.12	11.47	2.83	507h2t
a		lab 507	50.5	31	87	2046	6,818	300	22.73	21.02			507h2a
t		lab 507	50.5	31	87	2046	5,073	300	16.91	15.21	6.59	1.62	507h3t
a		lab 507	50.5	31	87	2046	6,671	300	22.24	20.53			507h3a
t		lab 507	50.5	30	87	2046	8,338	300	27.79	26.09	19.61	4.56	507h4t
a		lab 507	50.5	30	87	2046	7,341	300	24.47	22.77			507h4a
t		lab 507	50.5	30	87	2046	29,725	300	99.08	97.38	95.07	22.11	507h5t
a		lab 507	50.5	30	87	2046	16,158	300	53.86	52.16			507h5a
	3/15/96												
t		lab 510	50.5	33	87	2046	10,143	300	33.81	32.11	16.37	4.50	510h1t
a		lab 510	50.5	33	87	2046	12,410	300	41.37	39.66			510h1a
t		lab 510	50.5	31	87	2046	10,880	300	36.27	34.56	18.25	4.50	510h2t
a		lab 510	50.5	31	87	2046	13,038	300	43.46	41.76			510h2a
t		lab 510	50.5	31	87	2046	10,961	300	36.54	34.83	17.73	4.37	510h3t

C.11

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source Distance	ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename
a	lab 510	50.5	31	87	2046	13,435	300	44.78	43.08			510h3a
t	lab 510	50.5	31	87	2046	21,411	300	71.37	69.67	55.01	13.55	510h4t
a	lab 510	50.5	31	87	2046	17,558	300	58.53	56.82			510h4a
b	lab 510	50.5	bkgd	87	2046	7,129	300	23.76				510bkea
b	lab 510	50.5	bkgd	87	2046	10,138	300	33.79				510bkno
b	lab 510	50.5	bkgd	87	2046	11,877	300	39.59				510bkwe
b	lab 510	50.5	bkgd	87	2046	10,670	300	35.57				510bkso
b	lab 510	50.5	bkgd 2	87	2046	19,070	300	63.57				510bk2so
b	lab 510	50.5	bkgd 2	87	2046	16,288	300	54.29				510bk2no
t	lab 511	50.5	31	87	2046	5,143	300	17.14	15.44	9.72	2.39	511h1t
a	lab 511	50.5	31	87	2046	5,403	300	18.01	16.31			511h1a
t	lab 511	50.5	30	87	2046	3,598	300	11.99	10.29	5.90	1.37	511h2t
a	lab 511	50.5	30	87	2046	4,032	300	13.44	11.74			511h2a
t	lab 511	50.5	30	87	2046	7,849	300	26.16	24.46	18.60	4.33	511h3t
a	lab 511	50.5	30	87	2046	6,818	300	22.73	21.02			511h3a
t	lab 511	50.5	30	87	2046	6,511	300	21.70	20.00	15.35	3.57	511h4t
a	lab 511	50.5	30	87	2046	5,606	300	18.69	16.98			511h4a
t	lab 515	50.5	30	87	2046	7,483	300	24.94	23.24	20.48	4.76	515gb1t
a	lab 515	50.5	30	87	2046	5,241	300	17.47	15.77			515b1a
t	lab 515	50.5	36	87	2046	5,426	300	18.09	16.38	13.30	4.23	515gb2t
a	lab 515	50.5	36	87	2046	4,357	300	14.52	12.82			515gb2a
t	lab 515	50.5	36	87	2046	6,476	300	21.59	19.88	14.94	4.76	515gbb2t
a	lab 515	50.5	36	87	2046	5,718	300	19.06	17.36			515gbb2a
t	lab 515	50.5	35	87	2046	7,959	300	26.53	24.83	19.55	5.94	515gbb1t
a	lab 515	50.5	35	87	2046	6,608	300	22.03	20.32			515gbb1a
t	lab 517	50.5	30	87	2046	2,433	300	8.11	6.41	3.54	0.82	517h1t
a	lab 517	50.5	30	87	2046	2,764	300	9.21	7.51			517h1a
t	lab 517	50.5	30	87	2046	1,952	300	6.51	4.80	2.24	0.52	517h2t
a	lab 517	50.5	30	87	2046	2,387	300	7.96	6.25			517h2a

C.12

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector		ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename
		Detector Height, in	to Source Distance									
t	lab 517	50.5	30	87	2046	1,598	300	5.33	3.62	1.61	0.38	517h3t
a	lab 517	50.5	30	87	2046	1,959	300	6.53	4.83			517h3a
t	lab 517	50.5	30	87	2046	3,635	300	12.12	10.41	8.93	2.08	517h4t
a	lab 517	50.5	30	87	2046	2,742	300	9.14	7.44			517h4a
t	lab 517	50.5	30	87	2046	2,734	300	9.11	7.41	6.10	1.42	517h5t
a	lab 517	50.5	30	87	2046	2,211	300	7.37	5.67			517h5a
3/18/96												
t	lab 528	53	35.5	87	2046	29,294	300	97.65	95.94	76.04	23.65	528gb1t
a	lab 528	53	35.5	87	2046	23,860	300	79.53	77.83			528gb1a
t	lab 528	53	35.5	87	2046	27,080	300	90.27	88.56	70.85	22.04	528gb2t
a	lab 528	53	35.5	87	2046	21,769	300	72.56	70.86			528gb2a
t	lab 528	53	35.5	87	2046	24,743	300	82.48	80.77	64.89	20.18	528gb3t
a	lab 528	53	35.5	87	2046	19,776	300	65.92	64.22			528gb3a
t	lab 528	53	35.5	87	2046	39,808	300	132.69	130.99	54.27	16.88	528gbb1t
a	lab 528	53	35.5	87	2046	54,684	300	182.28	180.58			528gbb1a
t	lab 528	53	35.5	87	2046	39,620	300	132.07	130.36	47.25	14.70	528gbb2t
a	lab 528	53	35.5	87	2046	57,466	300	191.55	189.85			528gbb2a
t	lab 528	53	35.5	87	2046	33,325	300	111.08	109.38	48.49	15.08	528gbb3t
a	lab 528	53	35.5	87	2046	44,317	300	147.72	146.02			528gbb3a
t	lab 528	51	31	87	2046	16,254	300	54.18	52.48	22.63	5.58	528h4t
a	lab 528	51	31	87	2046	21,815	300	72.72	71.01			528h4a
t	lab 528	18.5	24	87	2046	15,984	300	53.28	51.58	23.10	3.59	528rlwst
a	lab 528	18.5	24	87	2046	21,063	300	70.21	68.51			528rlwsa
t	lab 516	51	31	87	2046	3,803	300	12.68	10.97	6.73	1.66	516h1t
a	lab 516	51	31	87	2046	4,066	300	13.55	11.85			516h1a
t	lab 516	51	31	87	2046	3,890	300	12.97	11.26	7.07	1.74	516h2t
a	lab 516	51	31	87	2046	4,087	300	13.62	11.92			516h2a
t	lab 516	51	31	87	2046	5,949	300	19.83	18.13	14.20	3.50	516h4t
a	lab 516	51	31	87	2046	4,998	300	16.66	14.96			516h4a
t	lab 516	60	31.5	87	2046	6,028	300	20.09	18.39	14.18	3.59	516gb2t

C.13

325 NEUTRON MEASUREMENTS

	NDA Log Number	Location	Detector Height, in	Detector to Source		Integral Counts	Count Time	Count Rate	Bkgnd Corrected	towards/ away	grams of Pu	Filename
				Distance	ROI Start ROI Stop							
a		lab 516	60	31.5	87	2046	5,166	300	17.22	15.52		516gb2a
t		lab 701	51	30	87	2046	407	300	1.36	-0.35	-0.31	701h2st
a		lab 701	51	30	87	2046	442	300	1.47	-0.23		701h2sa
t		lab 701	51	30	87	2046	433	300	1.44	-0.26	-0.08	701h2nt
a		lab 701	51	30	87	2046	392	300	1.31	-0.40		701h2na
	3/19/96											
t		lab 330	51	27	87	2046	389	300	1.30	-0.09	-0.17	330h1t
a		lab 330	51	27	87	2046	438	300	1.46	0.07		330h1a
t		lab 330	51	27	87	2046	383	300	1.28	-0.11	-0.09	330h2t
a		lab 330	51	27	87	2046	390	300	1.30	-0.09		330h2a
t		lab 330	51	27	87	2046	425	300	1.42	0.03	-0.02	330h3t
a		lab 330	51	27	87	2046	444	300	1.48	0.09		330h3a
t		lab 330	51	27	87	2046	439	300	1.46	0.07	0.02	330h4t
a		lab 330	51	27	87	2046	453	300	1.51	0.12		330h4a
t		lab 320	51	31	87	2046	411	300	1.37	-0.02	0.00	320h1t
a		lab 320	51	31	87	2046	407	300	1.36	-0.03		320h1a
t		lab 320	51	33	87	2046	458	300	1.53	0.14	0.16	320h2t
a		lab 320	51	33	87	2046	425	300	1.42	0.03		320h2a
b		300 N. hall	51	na	87	2046	5,003	3600	1.39	0.00		300nbkgd
t		lab 516	51	28	87	2046	5,366	300	17.89	16.18	11.76	516gb7nt
a		lab 516	51	28	87	2046	4,930	300	16.43	14.73		516gb7na
t		lab 516	51	28	87	2046	6,280	300	20.93	19.23	14.14	516gb7st
a		lab 516	51	28	87	2046	5,688	300	18.96	17.26		516gb7sa
t		lab 516	51	28	87	2046	5,485	300	18.28	16.58	10.73	516bg7nt
a		lab 516	51	28	87	2046	5,632	300	18.77	17.07		516bg7na
t		lab 516	51	28	87	2046	6,538	300	21.79	20.09	13.40	516bg7st
a		lab 516	51	28	87	2046	6,535	300	21.78	20.08		516bg7sa
	3/20/96											
t		lab 506	51	31	87	2046	25,431	300	84.77	83.07	71.02	506h3t
a		lab 506	51	31	87	2046	18,391	300	61.30	59.60		506h3a

C.14

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector		ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/ away	grams of Pu	Filename
		Detector Height, in	to Source Distance									
b	lab 506	51	n/a	87	2046	13,923	300	46.41	44.71			506hall
t	lab 506	51	36	87	2046	19,365	300	64.55	62.85	44.78	8.93	506gb1t
a	lab 506	51	36	87	2046	18,070	300	60.23	58.53			506gb1a
t	lab 506	51	36	87	2046	22,352	300	74.51	72.80	55.36	11.04	506gb2t
a	lab 506	51	36	87	2046	19,281	300	64.27	62.57			506gb2a
t	lab 506	51	36	87	2046	26,773	300	89.24	87.54	73.13	14.59	506gb3t
a	lab 506	51	36	87	2046	20,125	300	67.08	65.38			506gb3a
t	lab 506	46	31	87	2046	33,805	300	112.68	110.98	99.86	9.89	506h2t
a	lab 506	46	31	87	2046	22,162	300	73.87	72.17			506h2a
t	lab 506	55	36	87	2046	19,453	300	64.84	63.14	33.76	10.75	506h1t
a	lab 506	55	36	87	2046	23,203	300	77.34	75.64			506h1a
t	lab 506	55	33	87	2046	14,522	300	48.41	46.70	35.87	9.85	506gb5t
a	lab 506	55	33	87	2046	12,392	300	41.31	39.60			506gb5a
t	lab 506	55	33	87	2046	19,256	300	64.19	62.48	29.13	8.00	506gbb5t
a	lab 506	55	33	87	2046	24,894	300	82.98	81.28			506gbb5a
t	lab 506	51	36	87	2046	22,514	300	75.05	73.34	49.01	9.77	506gbb1t
a	lab 506	51	36	87	2046	22,465	300	74.88	73.18			506gbb1a
t	lab 506	51	36	87	2046	24,963	300	83.21	81.51	59.75	11.92	506gbb2t
a	lab 506	51	36	87	2046	22,530	300	75.10	73.40			506gbb2a
t	lab 506	51	36	87	2046	30,222	300	100.74	99.04	80.96	16.15	506gbb3t
a	lab 506	51	36	87	2046	23,502	300	78.34	76.64			506gbb3a
t	lab 506	55	33	87	2046	17,907	300	59.69	57.99	34.56	9.49	506gbb4t
a	lab 506	55	33	87	2046	19,750	300	65.83	64.13			506gbb4a
3/1/96												
t	lab 604	20	36.5	87	2046	7,965	300	26.55	24.85	21.37	6.96	604gb1t
a	lab 604	20	36.5	87	2046	5,803	300	19.34	17.64			604gb1a
t	lab 604	20	36.5	87	2046	13,793	300	45.98	44.27	41.91	13.66	604gb2t
a	lab 604	20	36.5	87	2046	8,216	300	27.39	25.68			604gb2a
t	lab 604	20	36.5	87	2046	16,920	300	56.40	54.70	51.70	16.85	604gb3t
a	lab 604	20	36.5	87	2046	10,063	300	33.54	31.84			604gb3a

C.15

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector		ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgnd Corrected	towards/ away	grams of Pu	Filename
		Detector Height, in	to Source Distance									
t	lab 604	20	36.5	87	2046	15,220	300	50.73	49.03	45.77	14.92	604gb4t
a	lab 604	20	36.5	87	2046	9,333	300	31.11	29.41			604gb4a2
t	lab 604	20	36.5	87	2046	14,965	300	49.88	48.18	44.64	14.55	604gb5t
a	lab 604	20	36.5	87	2046	9,333	300	31.11	29.41			604gb5a
t	lab 604	50	35.5	87	2046	21,744	300	72.48	70.78	61.38	19.09	604gb6t
a	lab 604	50	35.5	87	2046	15,358	300	51.19	49.49			604gb6a
t	lab 604	50	35.5	87	2046	23,835	300	79.45	77.75	70.26	21.85	604gb7t
a	lab 604	50	35.5	87	2046	15,541	300	51.80	50.10			604gb7a
t	lab 604	50	35.5	87	2046	23,325	300	77.75	76.05	72.79	22.64	604gb8t
a	lab 604	50	35.5	87	2046	13,382	300	44.61	42.90			604gb8a
3/22/96												
t	lab 416	51	31	87	2046	875	300	2.92	1.21	0.64	0.16	416h1t
a	lab 416	51	31	87	2046	952	300	3.17	1.47			416h1a
t	lab 416	51	31	87	2046	850	300	2.83	1.13	0.58	0.14	416h2t
a	lab 416	51	31	87	2046	928	300	3.09	1.39			416h2a
t	lab 416	51	31	87	2046	1,406	300	4.69	2.98	2.47	0.61	416h3t
a	lab 416	51	31	87	2046	1,190	300	3.97	2.26			416h3a
t	lab 416	51	31	87	2046	1,211	300	4.04	2.33	2.06	0.51	416h4t
a	lab 416	51	31	87	2046	986	300	3.29	1.58			416h4a
3/26/96												
t	45-15	96	24	87	2046	8,335	300	27.78	26.77	25.55	0.68	45lvs15v
a	45-15	96	24	87	2046	4,867	300	16.22	15.21			45lvs15c
t	45-16	80	32	87	2046	3,048	300	10.16	9.14	7.11	0.32	45lvs16v
a	45-16	78	34	87	2046	2,593	300	8.64	7.63			45lvs16c
t	45-17	85	24	87	2046	2,267	300	7.56	6.54	5.26	0.14	45lvs17v
a	45-17	85	24	87	2046	1,864	300	6.21	5.20			45lvs17c
t	45-9	72.5	24	87	2046	1,692	300	5.64	4.62	3.91	0.10	45lvs9v
a	45-9	72.5	24	87	2046	1,320	300	4.40	3.38			45lvs9c
t	45-19	84	24	87	2046	1,007	300	3.36	2.34	1.92	0.05	45lvs19v
a	45-19	84	24	87	2046	846	300	2.82	1.80			45lvs19c

C.16

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source Distance	ROI Start	ROI Stop	Integral Counts	Count Time	Count Rate	Bkgrnd Corrected	towards/away	grams of Pu	Filename
t	rm 58	54.5	27	87	2046	877	300	2.92	1.91	1.47	0.28	58h1t
a	rm 58	54.5	27	87	2046	786	300	2.62	1.60			58h1a
3/28/96												
t	32-1	45	28	87	2046	12,697	300	42.32	41.31	40.64	8.36	32hep1t
a	32-1	45	28	87	2046	6,802	300	22.67	21.66			32hep1a
t	32-2	45	28	87	2046	1,484	300	4.95	3.93	2.92	0.60	32hep2t
a	32-2	45	28	87	2046	1,348	300	4.49	3.48			32hep2a
t	32-3	45	28	87	2046	1,946	300	6.49	5.47	3.01	0.62	32hep3t
a	32-3	45	28	87	2046	2,231	300	7.44	6.42			32hep3a
t	32-4	45	28	87	2046	8,393	300	27.98	26.96	23.58	4.85	32hep4t
a	32-4	45	28	87	2046	5,870	300	19.57	18.55			32hep4a
t	32-5	81.5	34.5	87	2046	1,106	300	3.69	2.67	2.13	0.63	32rlw1t
a	32-5	81.5	34.5	87	2046	949	300	3.16	2.15			32rlw1a
t	32-6	90	24	87	2046	684	300	2.28	1.26	-0.02	0.00	32rlw2t
a	32-6	90	24	87	2046	1,074	300	3.58	2.56			32rlw2a
t	32-7	18.5	22	87	2046	7,633	300	25.44	24.43	20.51	2.71	32hot1t
a	32-7	18.5	22	87	2046	5,732	300	19.11	18.09			32hot1a
t	32-8	78	24	87	2046	12,039	300	40.13	39.11	40.85	6.35	32hot2t
a	32-8	78	24	87	2046	5,391	300	17.97	16.95			32hot2a
8/7/96												
s	rm 42	18.5	12	94	2046	150,372	100	1503.72	1501.56			mc080796
t	45-24	65.5	23	94	2046	471	100	4.71	2.55	1.13	0.16	h305gbt
a	45-24	65.5	23	94	2046	557	100	5.57	3.41			h305gba
t	lab 309	51.5	33.5	94	2046	4,817	300	16.06	13.90	12.75	3.59	309h8t
a	lab 309	51.5	33.5	94	2046	3,250	300	10.83	8.68			309h8a
t	lab 309	51.5	30.5	94	2046	3,409	300	11.36	9.21			309h7a
a	lab 309	51.5	30.5	94	2046	6,399	300	21.33	19.17	19.43	4.65	309h7t
t	lab 305	61.5	32	94	2046	59,273	300	197.58	195.42	204.12	35.65	305gb9bt
a	lab 305	61.5	32	94	2046	26,043	300	86.81	84.65			305gb9ba
a	lab 305	61.5	32	94	2046	16,867	300	56.22	54.07			305gb9da

C.17

325 NEUTRON MEASUREMENTS

NDA Log Number	Location	Detector Height, in	Detector to Source		Integral Counts	Count Time	Count Rate	Bkgnd Corrected	towards/ away	grams of Pu	Filename	
			Distance	ROI Start								ROI Stop
t	lab 305	61.5	32	94	2046	35,800	300	119.33	117.18	120.19	20.99	305gb9dt
a	lab 305	61.5	32	94	2046	23,033	300	76.78	74.62			305gb9aa
t	lab 305	61.5	32	94	2046	51,628	300	172.09	169.94	176.83	30.89	305gb9at
t	lab 305	61.5	32	94	2046	32,920	300	109.73	107.58	109.11	19.06	305gb9ct
a	lab 305	61.5	32	94	2046	16,094	300	53.65	51.49			305gb9ca
b	lab 317	46.5	NA	94	2046	15,538	7200	2.16	0.00			bkgd0807

Distribution

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