ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document for the Rocky Flats Plant – Occupational Internal Dose	Document Number: ORAUT-TKBS-0011-5 Effective Date: 12/13/2005 Revision No.: 00 PC-1 Controlled Copy No.: _____ Page 1 of 103
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RECORD OF ISSUE/REVISIONS

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01/12/2004	12/13/2005	00 PC-1	Page change initiated to incorporate recent direction from NIOSH to include DOL review comments on page 7 in Section 5.1. Change made to Table 5.3.1.4.2-2 on page 17 in Section 5.3. No sections were deleted. Retraining is not required. Initiated by Robert Meyer. Approval: Signature on File 11/22/2005 Robert Meyer, TBD Team Leader Signature on File 11/22/2005 Judson L. Kenoyer, Task 3 Manager Signature on File 12/07/2005 Kate Kimpan, Project Director Signature on File 12/13/2005 James W. Neton, Associate Director for Science

ACRONYMS AND ABBREVIATIONS

cm	centimeter
cm^2	square centimeter
cpm	counts per minute
CWT	chest wall thickness
dpm	disintegrations per minute
DTPA	diethylenetriaminepentaacetate
EDTA	ethylenediaminetetraacetate
hr	hour
keV	kilovolts-electron, 1,000 electron volts
L X-rays	low-energy x-rays produced during radioactive decay
LLL	Lawrence Livermore laboratory
ml	milliliter
MLT	minutes live time
MPLB	maximum permissible lung burden
nCi	nanocurie
pCi	picocurie
PHA	pulse height analysis
ppm	parts per million
RCG	radioactive concentration guides
RF	Rocky Flats
ROI	region of interest
TBP	tributyl phosphate
TOPO	trioxyl phosphene oxide
TTA	thenoyl trifluro acetone
µCi	microcurie
µg	microgram
ZPPR	zero-power physics reactor

5.1 INTRODUCTION

Technical basis documents and site profile documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the National Institute for Occupational Safety and Health (NIOSH) in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the [probability of causation] guidelines established under subsection (c) …." [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. §Section 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all radiation exposures in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

This section discusses Rocky Flats internal dosimetry data for the dose reconstructor, including guidance for the appropriate use of that information.

Workers at Rocky Flats had the potential to receive intakes of plutonium, americium, enriched uranium, depleted uranium, and tritium, as well as miscellaneous other radionuclides. Section 5.2 describes the available source term information, including isotopic composition, solubility, and particle

size. Site-specific internal dosimetry information for other radionuclides, such as thorium, curium and neptunium, is rare or not available.

The primary modes of intake would have been chronic or acute inhalation or through breaks in the skin (wounds). The primary bioassay data are the urine data, the activity of the radionuclide of interest that is excreted in the urine following an inhalation or wound intake, and the lung count data, the activity of the radionuclide present in the lungs after an inhalation intake. Section 5.3 discusses these two data sets in detail, including the history, sensitivity, and pertinent nuances of the methods and data.

The internal exposure record for a worker consists of records of the bioassay data and reports of involvement in incidents, accidents, or special situations. Section 5.4 describes samples of these records and reports with explanations of the aspects important to dosimetry.

Workers could have received intakes not monitored by bioassay, or the records could be missing or incomplete. Section 5.5 discusses internal dosimetry for those instances.

5.2 SOURCE TERM

5.2.1 Plutonium

5.2.1.1 Isotopic Composition

Three aspects of the isotopic composition of plutonium are important to internal dose reconstruction:

1. The percent by weight of ^{241}Pu, to calculate the ingrowth of ^{241}Am for the lung count data

2. The fraction of the activity for each alpha-emitting plutonium isotope, to account for the dose contributed by unmeasured isotopes

3. The ratio of the activity of ^{241}Pu to the alpha activity of the other plutonium isotopes, to calculate the intake of ^{241}Pu from intakes from bioassay data for ^{239}Pu and ^{240}Pu.

For weapons-grade plutonium, which was present at Rocky Flats throughout most of its 1952 to 1989 production history, the ratio of the activity of ^{241}Pu to the alpha activity of the other plutonium isotopes is 5.1, and the ^{240}Pu content is about 6% by weight. Table 5.2.1.1-1 shows the weight percent and fraction of alpha activity for each isotope.

The ZPPR special project in the mid-1960s involved reactor-grade plutonium. The ratio of the activity of ^{241}Pu to the alpha activity of the other plutonium isotopes is 32. Table 5.2.1.1-2 lists the weight percent and alpha activity fraction for each isotope. Reports of accidents or incidents involving ZPPR plutonium generally note “ZPPR’ or “ZPPR material”, especially on the lung count reports.

The dose reconstruction should account for the activity of ^{241}Am in the plutonium mixture. The concentration of the ^{241}Am is variable depending on the time since the plutonium was purified and whether the mixture involves waste or by-product (separated ^{241}Am) from the purification of aged plutonium. Starting in 1969, ppm ^{241}Am was measured for the plutonium mixture involved in significant possible inhalation incidents and is generally recorded on lung count reports for workers involved in those incidents. A nominal amount, 100 or 1000 parts per million (ppm) by mass, of ^{241}Am should be assumed with the plutonium if no other data are available. If the plutonium intake for weapons grade plutonium is assessed for ^{239,240}Pu , the activity of ^{241}Am in the intake mixture is

calculated by multiplying the ^{239,240}Pu activity by [48.2 x ppm ^{241}Am/ (1x10^{6} - ppm ^{241}Am)]. For ZPPR plutonium, the ^{239,240}Pu activity is multiplied by [44.6 x ppm ^{241}Am/ (1x10^{6} - ppm ^{241}Am)] to obtain the activity of ^{241}Am in the intake mixture.

Table 5.2.1.1-1. Weight percent and fraction of alpha activity for weapons-grade plutonium.[a]

Isotope	Percent by weight	Fraction of alpha activity
^{238}Pu	0.01	0.023
^{239}Pu	93.79	0.80
^{240}Pu	5.80	0.18
^{241}Pu	0.36 [b]	–
^{242}Pu	0.03	Negligible

a. Source: *Final Environmental Impact Statement, Rocky Flats Plant Site* (DOE 1980, Volume 1, Table 2.7.2-2, p. 2-170). Values are the average for Rocky Flats plutonium from July 1976 to July 1, 1978. This isotopic composition is also typical of plutonium metal processed at Rocky Flats through 1990 (James 1990).

b. The percent by weight of ^{241}Pu for the period 1959 through 1977 was 0.49, with a range of 0.35 to 0.65 (RFETS 2002, p. 5.1).

Table 5.2.1.1-2. Weight percent and fraction of alpha activity for ZPPR plutonium.[a]

Isotope	Percent by weight	Fraction of alpha activity
^{239}Pu	87.6	0.70
^{240}Pu	10.0	0.30
^{241}Pu	2.4	–

a. These ZPPR values are based on extracted data in a working file, from an undocumented source.

5.2.1.2 Pu Solubility and Particle Size

Most plutonium in metal-working operations and involved in fires is insoluble (i.e., type S). Exceptions, such as plutonium metal associated with solvents such as carbon tetrachloride, may be assumed to be more soluble (type M) if this is what the data show or it is more claimant favorable.

The plutonium fire on October 15, 1965, in Buildings 776 and 777 is a special case. The plutonium was avidly retained in the lungs of exposed workers with relatively low transfer to the urine, exhibiting highly insoluble (super type S) characteristics.

Plutonium in chemical-processing operations can be either soluble (type M), insoluble (type S), or a mixture of solubilities. A claimant favorable approach is to assume insoluble plutonium if the qualifying cancer is of the respiratory system and to assume soluble plutonium for all other cases. Lung count data in conjunction with urine data may help to determine absorption type.

In general, particle size and distributions are not available for work areas or incidents at Rocky Flats. Therefore, dose reconstructions should use the default value of 5 µm.

One exception is the plutonium fire on October 15, 1965, in Buildings 776 and 777, for which Mann and Kirchner (1967) measured a mass median diameter of 0.3 µm with a geometric deviation of 1.83. A claimant favorable approach is to assume 0.3 µm for all plutonium fires unless the qualifying cancer involves the tissues of the extrathoracic regions.

5.2.2 Americium

5.2.2.1 Isotopic Composition

For the NIOSH dose reconstruction project, the assumption is that measured americium is 100% ^{241}Am.

5.2.2.2 Am Solubility and Particle Size

Americium was present in two forms at Rocky Flats, as a purified by-product of plutonium recovery and as atoms formed by the nuclear transformation of ^{241}Pu and imbedded in the matrix of the plutonium particle. As a purified by-product, ICRP 68 specifies americium inhalation absorption as type M. For imbedded atoms in the matrix of an inhaled plutonium particle, the dose reconstruction should use the solubility classification described for the plutonium particle in Section 5.2.1.2.

The dose reconstruction should assume a 5 um AMAD, except for fires a X.X um AMAD should be assumed for consistency with Section 5.2.1.3 above.

5.2.3 Enriched Uranium

5.2.3.1 Isotopic Composition

Production at Rocky Flats involved enriched uranium from 1952 to 1963. Internal dose reconstructions would comprise mainly the percent of the alpha activity for ^{234}U, but should also account for the dose contributed by unmeasured isotopes. Table 5.2.3.1-1 lists the weight percent and fraction of alpha activity for each isotope.

Table 5.2.3.1-1. Weight percent and fraction of alpha activity for enriched uranium.[a]

Isotope	Percent by weight	Fraction of alpha activity
^{234}U	1.0	0.97
^{235}U	93.	0.031
^{236}U	0.39	0.0039
^{238}U	5.4	0.00028

a. Source: DOE (1980, Volume 1, Table 2.7.2-4, p. 2-172).

5.2.3.2 EU Solubility and Particle Size

Operations for enriched uranium paralleled those for plutonium, including chemical processing and metalworking. Compounds of uranium are generally more soluble than those of plutonium, and solubility classification is uncertain. The International Commission on Radiological Protection assigns compounds UO_3 (yellow cake), UF_4, and UCl_4 to inhalation type M and compounds UO_2 and U_3O_8 to inhalation type S (ICRP66 1994; ICRP30 1979).

In many cases, the compound of uranium involved in an intake is not identified. There are no Rocky Flats site-specific data for enriched uranium. In general, intakes in chemical processing areas occurred as type M or as mixtures of type M and type S. Reconstructions should use the most claimant favorable mixture. For intakes that occur in metal-working areas, the claimant favorable assumption is type S if the qualifying cancer site is in the respiratory system. For other cancer sites, the more claimant favorable assumption is type M. Reconstructions should use the default value of 5 µm.

5.2.4 Depleted Uranium

5.2.4.1 Isotopic Composition

Depleted uranium (DU) was present at Rocky Flats throughout its production history. U-238 will account for the majority of DU internal dose, but the total uranium alpha activity should be included in the dose reconstruction.

Table 5.2.4.1-1. Weight percent and fraction of alpha activity for depleted uranium.[a]

Isotope	Percent by weight	Fraction of alpha activity
^{234}U	0.00058	0.097
^{235}U	0.23	0.013
^{238}U	99.77	0.890

a. These values are derived from data in Table 2.7.2-4, page 2-172 in DOE (1980, Volume 1).

5.2.4.2 DU Solubility and Particle Size

Operations with depleted uranium involved metal working, including casting, forming, and melting. Likely compounds are UO_3 and U_3O_8. The solubility classification is ambiguous, falling somewhere between type S and type M (RFETS 1998a, Section 6.1; HPS 1995; Lawrence 1984). If the qualifying cancer site is in the respiratory system, use the claimant favorable assumption of type S. For other cancer sites, the more claimant favorable assumption is type M.

Site-specific data for particle size of uranium is not available. Reconstructions should use the default value of 5 µm AMAD.

5.3 BIOASSAY DATA

The primary data for intake assessment at Rocky Flats are the urinalysis data and the lung count data. Other bioassay data, such as wound count data, fecal sample data, and nasal smear data, were obtained in special situations but generally were not used to quantify intakes.

5.3.1 Urinalysis Data

Attachment 5A, Minimum Detectable Activity for Urinalysis Methods at Rocky Flats, discusses the history of the methods, reporting and recording levels, and sensitivities of the methods as they evolved and were implemented at Rocky Flats. This section summarizes, supplements, and expands the information in Attachment 5A.

5.3.1.1 Plutonium Urinalysis

5.3.1.1.1 Methods, Units, Isotopes, and Interferences

Through 1989, the units of the results are disintegrations per minute per a 24-hour excretion period (dpm/24-hr). After 1989, the units of the results are disintegrations per minute per sample (dpm/sample), regardless of the sample volume or excretion period. Assume a 24-hour excretion period unless the record indicates that the actual excretion period was different.

Through 1977, samples were counted using an air proportional detector system that did not have sufficient resolution to separate the alpha energies for the plutonium alpha-emitting isotopes. Starting in 1973, an alpha pulse height analysis (PHA) system with surface barrier detectors was phased in and had completely replaced the air proportional detector system by 1978. The plutonium urine results provided by the air proportional detector system include activity from ^{238}Pu, ^{239}Pu, and ^{240}Pu. Plutonium urine results for samples counted by the PHA system include only ^{239}Pu and ^{240}Pu results. Intake assessments are simpler and more claimant favorable if the dose reconstruction assumes ^{239}Pu and ^{240}Pu for all plutonium urine results unless the worker was involved in a special situation involving pure ^{238}Pu. If the intake is assessed using ^{239}Pu and ^{240}Pu data, the ^{238}Pu component of the intake is obtained by multiplying the ^{239}Pu and ^{240}Pu intake by 1.0264.

Interferences were likely in the period 1952 through 1962 because of a lack of specificity of the chemical procedure to isolate only the plutonium in the extract. Plutonium results would likely include some americium and thorium activity. In addition, for gross alpha analyses assigned to plutonium through 1973, the result could include some contribution from uranium. However, it is claimant favorable to disregard such interferences and take the plutonium results at face value unless a value can be determined to be an outlier.

From 1963 to 1977, the ion exchange method significantly reduced interferences from americium, uranium, and thorium. As the PHA system was phased in starting in 1973, the possibility of interferences was further reduced. After 1977, these interferences were not a significant issue for plutonium urine results because all samples were counted on the PHA system.

Another source of interference was contamination of the tracer (^{236}Pu or ^{242}Pu) by the analyte isotopes, ^{239}Pu and ^{240}Pu, an infrequent occurrence.

Chelation (EDTA or DTPA) treatments cause enhanced excretion of plutonium in the urine. Urine data within 90 days of a chelation injection have historically been excluded from calculations of intakes or depositions of plutonium. Information in the medical or dosimetry records should allow the dose reconstructor to discern chelation treatments, which generally followed a significant and documented incident. In the urine data reports for the health sciences data system, urine data affected by chelation were flagged with a code 1. Code 1 was also used to flag urine data that did not pass quality standards. The dose reconstructor should be wary of any urine result flagged with a code 1, and in general should not use these data in dose reconstruction.

5.3.1.1.2 Plutonium Reporting Levels, Minimum Detectable Activities, and Uncertainties

The minimum reporting level for plutonium through 1961 was 0.88 dpm/24-hr sample (this was 10% of the RF tolerance level). For 1962 through April 6, 1970, the minimum reporting level was 0.20 dpm/24-hr sample. Results less than the reporting level were reported as zero or background (or some abbreviation, e.g., BK). For some workers, results initially reported as background were superceded by the report of the actual result, if the actual result was ≥0.00 dpm/24-hr sample. After April 6, 1970, all results ≥0.00 dpm/24-hr sample were reported. Negative results were reported as zero through 1989. After 1989, the actual negative value was reported. Starting in approximately 1990, urine results were not normalized to a 24-hr sample. Instead, the results are dpm/sample, regardless of the sample volume.

The minimum detectable activity (MDA) for plutonium is presented here for the median conditions. By definition of the median value, half of the sample-specific MDAs are lower than the median value, and half are higher. In most cases the dose reconstructor is not likely to have sufficient data to determine the sample-specific MDA, so the median values should be used.

Table 5.3.1.1.2-1 lists the MDA values for plutonium. The values for 1952 through 1977 are based on examination of urinalysis data logs for the period 1952 – 1971 (see Attachment 5A). The MDA value for 1971 was extrapolated through 1977. The MDA value for 1978 through 1989 is based on matrix blank data for the routine plutonium urinalysis program for the period August 1, 1990, through September 27, 1991, using blank values with a sample-specific recovery in the range of 0.10 to 1.10. This range of recoveries mimics the range used from 1978 to 1989 for a valid analysis of routine samples. For 1990 to 1992, the blank values with a sample-specific recovery in the range from 0.35 to 1.10 were used to determine the MDA value. For 1993 to the present, the value of the MDA is equal to the sample-specific MDA of 0.020 dpm/sample contractually required in the Rocky Flats Environmental Technology Site (RFETS) bioassay statement of work (RFETS 1998b) for any laboratory processing the sample, although the required MDA was not consistently achieved by the on-site laboratory. Note that, the value of the sample-specific MDA is included in the urinalysis data reports starting in 1990.

Table 5.3.1.1.2-1. Median MDA values for plutonium .[a,b]

Period	dpm/24-hr sample
1952 – 1953	0.57
1954 – 1962	0.51
1963	0.44
1964 – 1977	0.54
1978 – 1989	0.24
1990 – 1992	0.24
1993 –	0.020

a. Note: The unit of the MDA values starting in 1990 is dpm/sample.
b. Sample-specific MDA values, if found in the record starting 1990, should be used instead of the generic MDA values in this table.

Some urine samples may have been processed by an off-site commercial laboratory before 1993. The reports for those samples may have the sample-specific MDAs. If these are not available, the MDA listed in Table 5.3.1.1.2-1 should be used.

Some periods contain transitions that improved the detection of plutonium. For example, from 1964 to 1977, electrodeposition of the plutonium replaced evaporation of the extract on the planchet. In addition, starting in 1973 with four detectors, plutonium samples were processed with an internal standard and were counted on a PHA system to establish the sample-specific recovery. The count time was also increased to 720 minutes. Because of the difficulty of determining which improvements apply to each sample, the MDAs in Table 5.3.1.1.2-1 do not account for the improvement until the transition was completed for all samples (claimant favorable).

The uncertainty of the result was not quantified and reported in the record until approximately 1980. The reported value was the two-sigma standard error and included only uncertainties of counting statistics, adjusted by the sample-specific recovery. Starting in approximately 1986, contributions from other sources of uncertainty were included, and the reported value was the one-sigma standard error. To estimate the uncertainty for results without a reported uncertainty, a reasonable approach is to divide the median MDA value by 3.3, where 3.3 is the sum of k_α and k_β, and $k_\alpha = k_\beta = 1.645$ (see Attachment 5A).

5.3.1.2 Americium Urinalysis

5.3.1.2.1 Methods, Units, Isotopes, and Interferences

Attachment 5A describes the methods through 1971. After 1971, the method for americium paralleled that for plutonium. The isotope is ^{241}Am.

The units of the results are disintegrations per minute per a 24-hr excretion period (dpm/24-hr sample) through 1989. After 1989, the units of the results are disintegrations per minute per sample (dpm/sample), regardless of the sample volume or excretion period.

The main interference is thorium, specifically ^{228}Th, which has two alphas with energies similar to those of ^{241}Am and has chemical properties similar to americium. If the chemical extraction procedure for americium was not run precisely, thorium would be eluted from the ion exchange column with the americium. When the extract was counted, even for the PHA system, the ^{228}Th could not be distinguished from the ^{241}Am.

The plutonium to americium alpha activity ratio (^{239,240}Pu dpm/24-hr sample divided by ^{241}Am dpm/24-hr sample) for paired plutonium and americium urine results provides a credibility check. An alpha activity ratio less than 2.0 (corresponding to a parts per million (ppm) value for ^{241}Am of 10,000 or greater) is not credible unless the worker was involved with 1) separated ^{241}Am (Line 1 in Building 771, 2) the molten salt process in Building 776, 3) research and development projects involving pure americium), 4) with material from the ZPPR project, or 5) waste identified for those operations.

The dose reconstructor should use the plutonium urine data instead of the ^{241}Am urine data to assess intakes of weapons grade plutonium. The intake of the ^{241}Am is then calculated from the value of the initial parts per million of ^{241}Am measured or assumed for the plutonium mixture involved in the intake.

5.3.1.2.2 Americium Reporting Levels, Minimum Detectable Activities, and Uncertainties

The reporting levels for americium were ≥ 0.24 d/m/24 hours in 1963, ≥ 0.20 d/m/24 hours in 1964 through 1967, and ≥ 0.30 d/m/24 hours in 1968 through 1971. Results less than the reporting level were reported as zero or background (or some abbreviation, e.g., BK). The reporting practice for the period 1972 through 1976 is to be determined. Until it is determined, reconstructions should assume that the reporting level for 1968 to 1971 was continued through 1976. Starting in 1977, all results ≥0.00 dpm/24-hr sample were reported. Negative results were reported as zero through 1989. After 1989, the actual negative value was reported. As for plutonium, urine results were not normalized to a 24-hr sample starting in about 1990. Instead, the results are dpm/sample, regardless of the sample volume.

The MDAs for americium (Table 5.3.1.2.2-1) were determined as described for plutonium (see Section 5.5.1.1.2 and Attachment 5A), with the difference that the americium analyses started in 1963.

The discussions of MDA and uncertainty for plutonium in Section 5.3.1.1.2 apply to americium.

Table 5.3.1.2.2-1. Median MDA values for americium.[a,b]

Period	dpm/24-hr sample
1963	0.44
1964 – 1965	0.55
1965 – 1970	0.46
1971 – 1977	0.76

1978 – 1989	0.31
1990 – 1992	0.30
1993 –	0.020

a. Note: The unit of the MDA values starting in 1990 is dpm/sample.
b. Sample-specific MDA values, if found in the record starting 1990, should be used instead of the generic MDA values in this table.

5.3.1.3 Enriched Uranium Urinalysis

5.3.1.3.1 Methods, Units, Isotopes, and Interferences

The units of the results are disintegrations per minute per a 24-hr excretion period (dpm/24-hr sample) for the entire period.

Since urine samples analyzed for enriched uranium were counted with the air proportional detectors, all of the alpha emitting isotopes of uranium are included in the result.

Site-specific information about possible interferences that may have occurred for the urinalysis methods for enriched uranium is not available.

It is claimant favorable to assume that the result is all enriched uranium.

5.3.1.3.2 EU Reporting Levels, Minimum Detectable Activities, and Uncertainties

Table 5.3.1.3.2 lists the MDAs for enriched uranium. The reporting level for enriched uranium through 1963 was ≥8.8 dpm/24-hr sample (10% of the RF tolerance level). From 1964 to 1971, the minimum reporting level ranged from 20 to 28 dpm/24-hr sample, depending on the volume of the sample, as observed from the urinalysis data logs for that period. Results less than the reporting level were reported as zero or background (or some abbreviation, e.g., BK). When urinalysis for enriched uranium was stopped at Rocky Flats is undetermined, although it likely occurred in the early 1970s.

Table 5.3.1.3.2. Median MDAs for enriched uranium.

Period	dpm/24-hr sample
1952 – 1953	14
1954 – 1959	13
1960 – 1963	9.4
1964 – 1969	31
1970 – 1971	25

The MDAs for enriched uranium were determined as described for plutonium (see Section 5.5.1.1.2 and Attachment 5A).

Uncertainties for the enriched uranium urine results have not been quantified or reported. To estimate the uncertainty for results without a reported uncertainty, a reasonable approach is to divide the median MDA value by 3.3, where 3.3 is the sum of k_α and k_β, and $k_\alpha = k_\beta = 1.645$(see Attachment 5A).

5.3.1.4 Depleted Uranium Urinalysis

5.3.1.4.1 Methods, Units, Isotopes, and Interferences

Attachment 5A describes the uranium urinalysis methods through 1971. In 1972 through 1979, depleted uranium samples were chemically processed with the uranium-specific process, trioxyl phosphene oxide (TOPO) extraction procedure, and the extract (electrodeposited) was counted on the gas flow proportional counter. From 1980 to 1997, depleted uranium samples were processed with a tracer (^{232}U or ^{236}U) by ion exchange and alpha-counted with the alpha spectrometry system with surface barrier detectors in vacuum. The starting year of use of the tracer has not been determined. From 1997 to the present, depleted uranium samples were processed at an off-site, commercial laboratory according to provisions of the bioassay statement of work (RFETS 1998b).

The units for 1952 to April 1964 are micrograms uranium per 24-hr excretion period (µg/24-hr sample). The mass measurement is for all the isotopes of uranium. From May 1964 to 1989, the units are dpm/24-hr sample. After 1989, the units of the results are dpm/sample, regardless of the sample volume or excretion period.

The urine data logs through 1971 do not identify the isotopes involved. However, it is reasonable to assume that all the uranium alpha-emitting isotopes were included in the air proportional detectors measurement. For the 1980s, the logs have not been reviewed sufficiently to determine which isotopes were included in addition to ^{238}U, which contributes 89% of the alpha activity. It is claimant favorable to assume that the reported urine result pertains only to ^{238}U and to determine additional intakes for the other isotopes. In the 1990 reports, the urine data include the results separately for ^{234}U, ^{235}U, and ^{238}U.

The major interference is the contribution from natural uranium, which is ubiquitous, sometimes in concentrated pockets, in the terrain near the Rocky Flats site. No adjustments have been made to the reported depleted uranium urine results for this background, which was highly variable. It is claimant favorable to assume that the depleted uranium urine results are from occupational intakes of depleted uranium unless isotopic data are available that indicate natural uranium (i.e., ^{234}U activity is approximately equal to ^{238}U activity).

5.3.1.4.2 DU Reporting Levels, Minimum Detectable Activities, and Uncertainties

The minimum reporting level for depleted uranium through April 1964 was 5.8 µg/24-hr sample (10% of the tolerance level). After April 1964 through 1971, the minimum reporting level was the same as for enriched uranium, 20 to 28 dpm/24-hr sample, depending on the volume of the sample. The reporting level for 1972 through 1979 (TOPO procedure) is to be determined. A claimant favorable approach is to use the reporting level for 1964 through 1971. In the 1980s, all results ≥0.00 dpm/24-hr sample were reported. Negative values were reported as 0.00 dpm/24-hr sample. In the 1990s and after, all actual results, including negative values, were reported.

The MDAs for depleted uranium for fluorometric measurements were determined as described in Attachment 5A. Median MDAs for depleted uranium from 1952 to April 1964 are shown in Table 5.3.1.4.2-1. For alpha-counting methods, the MDAs in the period 1964 through 1971 are the same as those for enriched uranium in Table 5.3.1.3.2. The MDAs for 1972 through 1979 are to be determined. The MDAs for 1980 to the present were derived in the same manner as described for plutonium but are based on ^{238}U.

Table 5.3.1.4.2-1. Median MDAs for depleted uranium from 1952 to April 1964.

Period	µg/24-hr sample
1952 – 1955	31
1955 – 1959	12
1960 – 1964 (April)	11

Table 5.3.1.4.2-2. Median MDAs for depleted uranium from May 1964 to the present.[a,b]

Period	dpm/24-hr sample
1964 – 1969	31
1970 – 1971	25
1972 – 1979	25c
1980 – 1989	0.56
1990 – 1992	0.40
1993 –	0.10

a. The MDA value unit starting in 1990 is dpm/sample.
b. Sample-specific MDA values, if found for 1990+, should be used instead of generic MDA values.
c. actual practice unknown; assume continuation of earlier practice.

The discussion of the uncertainty for plutonium in Section 5.3.1.1.2 applies to depleted uranium.

5.3.1.5 Gross Alpha Urinalysis

5.3.1.5.1 Methods, Units, Isotopes, and Interferences

Gross alpha measurement is a non-specific analysis used for workers who were potentially exposed to both uranium and plutonium in the same monitoring period. Workers who were potentially exposed to other alpha-emitting radionuclides, such as neptunium and curium, may also have been monitored for gross alpha. Urinalysis methods are discussed in Attachment 5A. The gross alpha method was discontinued in the early 1970s, likely 1973. The results are reported as dpm/24-hr sample of either enriched uranium (the default analyte through 1963) or plutonium (after 1963). Interferences are likely, because the methods were non-specific. Isotopes are all alpha-emitting isotopes of the analyte.

5.3.1.5.2 Reporting Levels, Minimum Detectable Activities, and Uncertainties

The reporting level for gross alpha through 1963 was ≥8.8 dpm/24-hr sample (10% of the RF tolerance level for enriched uranium). After 1963, the reporting level was ≥0.9 dpm/24-hr sample, credited to plutonium. (Gross alpha data are likely coded as G in the urine data reports.)

Samples with results ≥0.9 dpm/24-hr sample typically, but not always, were counted using a PHA system to determine whether to credit the result to enriched uranium or plutonium, or a portion to both. The default condition, through 1963, was to credit the result to enriched uranium unless the PHA count indicated otherwise. After 1963 (and enriched uranium operations were phased out), the default condition was to credit the result to plutonium. In either case, the results should be considered to be upper bounds, because of the non-specificity of the analysis.

The MDA for gross alpha listed in Table 5.3.1.5.2-2 were determined as described in Attachment 5A.

Uncertainties for the gross alpha urine results have not been quantified or reported. To estimate the uncertainty for results without a reported uncertainty, a reasonable approach is to divide the median MDA value by 3.3, where 3.3 is the sum of k_α and k_β and $k_\alpha = k_\beta = 1.645$ (see Attachment 5A). This uncertainty does not include the effect of interferences, which is a major issue for a non-specific analysis like gross alpha measurement.

Table 5.3.1.5.2-2. Median MDAs for gross alpha measurements.[a]

Period	dpm/24-hr sample
1952	1.0
1953	0.88
1954 – 1959	0.79
1960 – 1962	0.55
1963	0.55
1964 – 1971	0.69

5.3.1.6 Tritium

Workers were monitored for possible tritium exposures only for special projects or situations, starting in 1973. The methods have not been reviewed, but likely involved liquid scintillation measurements. The urine results are reported as pCi/liter of urine, and actual results were reported, generally with the standard deviation. It has not been determined whether the reported uncertainty in the 1970s to early 1980s is one or two times the standard deviation. The sensitivity of the method was two to three orders of magnitude better than the significant level of about 1 µCi/liter. Although the actual MDA has not been quantified for the methods in the 1970s and 1980s, it likely is in the range of several hundred to several thousand pCi/liter. The current MDA for tritium is 600 pCi/liter (RFETS 1998c, p. 7-3).

5.3.2 Lung Count Data

In vivo lung counts have been performed at Rocky Flats since 1964 to determine the activity of plutonium in the lungs of workers who were exposed, or had the potential to be exposed, to airborne plutonium. The method of *in vivo* lung counts was to place one or more detectors over the chest of the subject and count the photons emitted from the plutonium mixture, if any, in the chest. Plutonium was not detected directly because of the low abundance of gamma photons and the severe attenuation of the more abundant L X-rays. Instead, the 59.5-keV gamma photon from ^{241}Am was used to detect ^{241}Am, which is present to some extent in all weapons-grade plutonium at Rocky Flats. The activity of plutonium was then calculated from the detected ^{241}Am by measuring, calculating, or assuming the fraction of the ^{241}Am in the plutonium mixture on the date of the lung count. At Rocky Flats, the fraction of the ^{241}Am in the plutonium mixture has historically been characterized in terms of ppm by weight. Direct *in vivo* measurement of plutonium in the lungs, although investigated, was never implemented at Rocky Flats.

The Rocky Flats lung counter also measured ^{234}Th, via the 63-keV gamma (doublet) photon, to determine the activity of ^{238}U in the lungs of workers exposed to depleted uranium. This measurement was made possible by the improved resolution of the germanium detectors (Ge detectors) that allowed baseline separation of the 59.5-keV gamma of ^{241}Am from the 63-keV gamma doublet of ^{234}Th. The activity of ^{238}U was considered to be equal to that of the measured ^{234}Th, assuming equilibrium.

Attachment 5B, Minimum Detectable Activity for Urinalysis Methods at Rocky Flats, contains more detail. Section 5.4 and Attachment 5C discuss of the data and report forms.

5.3.2.1 Americium/Plutonium

5.3.2.1.1 Methods, Units, Isotopes, and Interferences

Before April 1997, lung count data were not converted to a quantified amount or activity unless there was confirmation that the count was from an actual deposition in the lungs.. For unquantified results, the data are generally in units of counts per minute accompanied by a decision noted as normal, background, or some abbreviation of background. For quantified results through about 1968, the unit was micrograms of plutonium. In addition, the result was converted to a fraction of the maximum permissible lung burden (MPLB) using a plutonium specific activity of 0.07 µCi μg^{-1} and the MPLB of 0.016 µCi (16 nCi) for the alpha-emitting isotopes of plutonium. Starting in about 1973, the activities of both plutonium (including all the alpha-emitting isotopes of weapons-grade plutonium) and americium (^{241}Am) were recorded, in nanocuries. In addition, the activity of ^{241}Am was stated as a fraction of the MPLB, using 14.7 nCi for the MPLB for ^{241}Am. After 1989, the results were no longer stated as a fraction of the MPLB.

There are two sources of interferences to consider. The first is the 63-keV gamma doublet of ^{234}Th from depleted uranium operations being mistaken for ^{241}Am for lung counts with the NaI or phoswich detector systems. This interference was most troublesome for workers with residual lung depositions of plutonium and americium who subsequently worked in depleted uranium operations. The second interference is the contribution of count from ^{241}Am not in the lungs, for example, contributions from contamination on the skin, from material being cleared from the upper respiratory system, or from ingested material. A positive detection of ^{241}Am did not necessarily indicate an intake of the plutonium/americium mixture, especially for a lung count in response to an incident.

5.3.2.1.2 Reporting Levels, Minimum Detectable Activities, and Uncertainties

Reporting levels are not easily defined, because quantification was preceded by verification counts and professional judgments. In addition, before 1974, the practice was not to quantify a positive detection of ^{241}Am unless the deposition could be associated with a known incident with a known ppm ^{241}Am. Affected workers were classified as positive unknowns or some variation. Starting in 1974, the practice was changed to quantify the plutonium depositions for positive unknowns by assuming a default value of 1,000 ppm ^{241}Am on the date of the most likely intake or on the date of the first positive lung count. The ppm ^{241}Am was then calculated for the date of the lung count to account for the ingrowth of ^{241}Am from the nuclear transformation of ^{241}Pu and the radioactive decay of the initial ^{241}Am.

In general, this quantification was not applied retroactively to earlier positive lung counts. Once a lung deposition of plutonium had been quantified for a worker, the deposition continued to be quantified for all subsequent lung counts (except screening counts for new intakes), regardless of the result of the subsequent lung count (including negative values), until each of the last three results was less than the decision level for the count and the average of the last three results was within one standard deviation of 0.00 nCi plutonium.

The decision levels varied. From 1965 through 1968, the decision level was two times the uncertainly of the matched subject's net count, when there was a decision level at all. Starting in 1969, for NaI and phoswich detector systems, the decision level was equal to three times the standard deviation of the net count rate for a set of lung counts for unexposed known cold subjects, based on the index

method (see Attachment 5B). Results between two and three sigma were noted but not always investigated. For the Ge detector systems, starting in 1976, the decision level (also called the cutoff) was equal to 1.645 times the standard deviation of the net count rate. The decision level, for 1995 and later, was calculated by the ABACOS-Plus© software for a probability of a Type I (false positive) error of 5%. The decision level was used as a reporting level from 1995 through early 1997.

Table 5.3.2.1.2-1 lists the MDAs for ^{241}Am, which were calculated for the evolution of lung counting systems used at Rocky Flats as described in Attachment 5B.

Table 5.3.2.1.2-1. Summary of MDAs for ^{241}Am.

Period	Detector system	Index	MDA (nCi) for ^{241}Am			
			Minimum system		Standard system	
			Half time	Full time	Half time	Full time
1964–1968	NaI(Tl) 4x4	0.90	1.7	1.5	1.3	1.2
		1.35	2.8	2.5	2.1	1.9
		1.80	4.6	4.1	3.5	3.2
1969 →	NaI(Tl) 4x4	0.90	–	–	0.80	0.76
		1.35	–	–	1.3	1.3
		1.80	–	–	2.2	2.0
1973 →	Phoswich	0.90	–	–	1.2	1.2
		1.35	–	–	2.0	2.0
		1.80	–	–	3.3	3.2
1976 – 1978	Ortec Arrays (High-purity Ge)	0.90	0.26	0.18	0.20	0.14
		1.35	0.48	0.32	0.37	0.25
		1.80	0.86	0.59	0.66	0.45
1979 →	Ortec Arrays (High-purity Ge)	0.90	0.20	0.14	0.16	0.11
		1.35	0.37	0.25	0.28	0.19
		1.80	0.66	0.45	0.51	0.35
1978 →	PGT I Arrays (High-purity Ge)	0.90	0.22	0.15	0.17	0.12
		1.35	0.40	0.27	0.31	0.21
		1.80	0.71	0.49	0.55	0.38
1979 →	PGT I Arrays (High-purity Ge)	0.90	0.17	0.12	0.13	0.09
		1.35	0.31	0.21	0.24	0.16
		1.80	0.55	0.38	0.42	0.29
1979 →	PGT II Arrays (High-purity Ge)	0.90	0.22	0.15	0.17	0.12
		1.35	0.40	0.28	0.31	0.21
		1.80	0.74	0.50	0.57	0.39
1985 →	PGT Organ Pipe Ge Detectors	0.90	–	–	0.15	0.11
		1.35	–	–	0.26	0.18
		1.80	–	–	0.46	0.32
1991 →	EG&G Organ Pipe Ge Detectors	0.90	–	–	0.14	0.10
		1.35	–	–	0.26	0.18
		1.80	–	–	0.48	0.33
1995 →	Ortec 2 Organ Pipe Ge Detectors	0.90	–	–	–	0.14
		1.35	–	–	–	0.3
		1.80	–	–	–	0.6

These values of MDAs are for three indices, representing the median and the approximate 5th- and 95th-percentile body statures of Rocky Flats male workers. To obtain the worker-specific MDA, the dose reconstructor can calculate them using the information in Attachment 5B or interpolate (or extrapolate) from the values in Table 5.3.2.1.2-1. The worker-specific index is generally stated on lung count report forms from 1969 through 1994, and can be derived from the weight and height data on report forms from 1995 and later. (The MDA values are reported on report forms from 1995 and

later, but the values are not worker-specific. The dose reconstructor should disregard these MDA values.) The default MDA would be for an index of 1.35, if height and weight data for the worker are not available.

The MDA for plutonium would be calculated by multiplying the worker-specific value of the MDA for ^{241}Am by the MDA conversion factor (Equation 5B-17 in Attachment 5B), which is based on the value of the ppm ^{241}Am on the date of the lung count. The value of the ppm ^{241}Am on the date of the lung count, accounting for ingrowth of ^{241}Am from the nuclear transformation of ^{241}Pu and the radioactive decay of the initial ^{241}Am, is given by Equation 18 in Attachment 5B. The dose reconstructor needs to establish the date of the intake and the initial ppm ^{241}Am. If that information is not apparent in the available records, a claimant favorable approach is to assume the initial ppm ^{241}Am to be 100.

The assumption of the intake date is not straightforward and should balance maximizing the plutonium lung deposition (intake date is close to the date of the lung count) and maximizing the accrued lung dose (intake date is far from the date of the lung count). In addition, the choice of intake date for the lung count data should be coordinated with that for the associated urine data.

In addition, the dose reconstructor must choose the value of the initial fraction of ^{241}Pu. At the Rocky Flats lung counter, 0.005 was historically used as the initial mass fraction of ^{241}Pu and is a realistic choice for intakes that occurred in the 1950s through June 1976. The fraction 0.0036, based on the isotopic composition for Rocky Flats stream plutonium in the mid 1970s, should be used for intakes that occurred from July 1976 through 1989. For intakes incurred after 1989, the initial fraction of ^{241}Pu should be reduced to account for the aging (radioactive decay) of the ^{241}Pu.

The uncertainties of the results were reported for the net count per minute starting with the Ge detector systems in 1976. The uncertainty was reported at one standard deviation and included only the contribution from counting statistics. Starting in approximately 1981, the counting statistics uncertainty was also applied to the assessed activity and to the value of the fraction of the MPLB. With the advent of the ABACOS-Plus© software in 1995, the percent error at one standard deviation was reported for all identified nuclides. Beginning on October 11, 1999, a 30% systematic uncertainty, which included contributions of uncertainties in the chest wall thickness (CWT), the location of the activity in the lungs, the uncertainty in the ppm ^{241}Am, and the influence of activity deposited in other organs, was included in the total propagated uncertainty (RFETS 2000, p. 3-18).

The major uncertainty for the calculation of the plutonium lung deposition is the ppm ^{241}Am in the plutonium in the lungs at the time of the lung count. Elements contributing to the uncertainty are the intake date, the value of the initial ppm ^{241}Pu, the initial fraction of ^{241}Pu, and the degree of association of the americium with the plutonium while in the lungs. An underlying assumption is that the americium remains associated with the plutonium particles in the lungs until the particles are dissolved or removed from the lungs. The degree of validity of this assumption has not been determined.

5.3.2.2 Thorium/Depleted Uranium

5.3.2.2.1 Methods, Units, Isotopes, and Interferences

The method to detect depleted uranium was to detect the 63-keV gamma (doublet) photon of ^{234}Th and to calculate the activity of ^{238}U, assuming equilibrium. This method was implemented manually for special cases in approximately 1978. Starting in 1983, the count data for the 63-keV doublet photon were routinely processed and reported. However, the activity of the ^{238}U was calculated only for special cases and not routinely. A supplemental method, implemented in about 1989, detected the

93-keV gamma (doublet) photon of ^{234}Th, and the count data were routinely processed and reported. This supplemental method was used mainly to reduce false positive results for the detection of ^{234}Th, because detection of both doublet photons was required before detection of ^{234}Th was considered.

Starting in 1995, the activity of ^{238}U was calculated and reported if the 63-keV peak (or sometimes the 93-keV peak) was detected by the ABACOS-Plus© peak search software. If the peak was not detected, the activity of ^{238}U was reported as less than the decision level (the activity of the decision level was reported). Starting in early 1997, the activity of ^{238}U was reported, including negative results, even if a peak was not detected. In a similar manner, the activity of ^{235}U was reported. Starting in about 1999, the activity of ^{238}U was based solely on the 63-keV peak.

The main part of the data for the 63-keV doublet photon is in units of net counts per minute. To convert to activity (nanocuries) of ^{238}U, the counts per minute is divided by the calibration factor for ^{241}Am (see Attachment 5B), normalized to the ratio of photon abundances [abundance of 59.5-keV gamma, ^{241}Am, is 0.359; abundance of 63-keV doublet gamma, ^{234}Th, is 0.0381 (Lederer and Shirley 1978); ratio (59.5 keV gamma/63 keV doublet gamma) = 9.4]. That is, nCi ^{238}U equals [(^{234}Th 63-keV net cpm) divided by (^{241}Am calibration factor)] multiplied by 9.4. To calculate the activity for depleted uranium, the ^{238}U activity is divided by 0.89 (see Section 5.2.4.1).

The interference is ^{238}U in natural uranium. Unless there is an activity reported for ^{234}U that is approximately equal to that reported for ^{238}U, the dose reconstruction should use the claimant favorable assumption that the ^{238}U activity is all from occupational exposure to depleted uranium.

5.3.2.2.2 Reporting Levels, Minimum Detectable Activities, and Uncertainties

Reporting levels were not generally used for depleted uranium until 1995 with the implementation of the ABACOS-Plus© software (see Section 5.3.2.2.1). Before 1995, the ^{238}U activity was generally quantified only after verification of an intake.

The MDA for ^{238}U has not been determined rigorously. However, the ^{238}U worker-specific MDA can reasonably be expected to be a multiple of the ^{241}Am worker-specific MDA because the detected photons (63 keV and 59.5 keV) are very close in energy. As described in Section 5.3.2.2.1 for using the calibration factor for ^{241}Am to determine the ^{238}U activity, the ^{238}U worker-specific MDA can be obtained by multiplying the ^{241}Am worker-specific MDA by 9.4. That result is divided by 0.89 to obtain the worker-specific MDA for depleted uranium. (As noted in Section 5.3.2.1.2 for americium and plutonium, MDA values are reported on report forms 1995 and later, but are not worker-specific. The dose reconstructor should disregard these MDA values.)

The major uncertainty is the assumption of equilibrium of the ^{234}Th with the ^{238}U before 1990, when depleted uranium was still being processed. Part of the process was to remove decay chain radionuclides, especially thorium, by heating the uranium ingot to drive the smaller atoms of thorium to the surface or top of the ingot, which was then cut off. The result was depleted uranium metal with a deficiency of ^{234}Th for several weeks plus scrap depleted uranium with an excess of ^{234}Th (super-equilibrium). Super-equilibrium is claimant favorable. The effect of a deficiency of ^{234}Th has not been assessed.

The standard deviation of the net count rate is reported through 1995, but includes only the contribution of counting statistics. To estimate the uncertainty of a ^{238}U or depleted uranium activity calculated from the net count rate, the dose reconstructor can divide the worker-specific MDA by 3.3.

5.3.3 Other Bioassay Data

5.3.3.1 Wound Count Data

Wounds are defined as any break in the skin (e.g., cuts, punctures, abrasions, acid burns). Any wound that occurred in a work area involving plutonium was monitored for plutonium contamination, especially after the advent of the wound counter in 1957. Counting a blood sample or directly counting the wound site with an alpha detector were also methods used to monitor wounds to detect possible plutonium contamination. In Rocky Flats terminology in the 1950s and 1960s, wound counts were called gamma specs, and the wound counter was called a gamma spectrometer. Wounds occurring in uranium work areas were monitored selectively. The record could contain an incident report, a wound count data sheet, a medical decontamination report, and a medical treatment report, depending on the era and circumstances.

The process was to attempt to decontaminate the wound in the building of the occurrence by washing and encouraging bleeding to flush any plutonium out of the wound. Then the worker was sent or escorted to the medical facility for a wound count and additional decontamination if the wound count was positive. The sequence of additional decontamination was washing with soap and water, washing with Clorox©, scrubbing with Clorox©, and excision.

Wound count information is largely irrelevant to dose reconstruction. The relevant items are the urinalysis data, the identification of the mode and date of intake, and whether there was residual plutonium at the wound site. If there was residual plutonium at the wound site, the dose reconstructor should consider an acute injection into the blood stream plus a possible long-term chronic injection. The profile of the urine data following the date of the wound provides guidance on the proportion of the acute and chronic components. If there was no detected residual plutonium at the wound site, there would have been an acute injection into the blood stream.

Residually positive uranium contamination in wounds was rare, if at all. It is reasonable and claimant favorable to assess any initially positive uranium wound as an acute injection.

5.3.3.2 Nasal Smears and Fecal Samples

Nasal smear (later called swab) and fecal sample data were occasionally obtained throughout Rocky Flats operations as supplemental data for workers with actual or suspected significant inhalation intakes. Through the 1980s, they were used subjectively to verify that an intake did occur and to estimate the possible magnitude of the intake. The data have also been used to determine or confirm the ppm ^{241}Am in the inhaled plutonium mixture. Some obstacles to using nasal smear or fecal data to quantify an intake are unknown particle size distribution, unknown fraction of the plutonium captured by the nasal smear or fecal sample, inconsistent and largely undocumented sampling technique for nasal smears (which sometimes were called nose blows), and unknown counting efficiency (e.g., sample geometry and alpha absorption, especially in the 1950s and 1960s). Through 1989, the requested fecal sample was the second voiding following the incident. In some cases, the second, third, and fourth voidings were requested.

Starting in the 1990s, the nasal or mouth smears were used as a workplace indicator to identify potential intakes, and fecal sampling was used to confirm and evaluate suspected intakes (RFETS 1998d, p. 2-2).

The reported MDAs (RFETS 1998d, pp. 2-7, 2-8) are:

- 20 dpm/sample, for (gross alpha, liquid scintillation) routine nasal samples
- 0.20 dpm/sample, for fecal samples with a 21-day reporting time (plutonium alpha isotopic)
- 1.30 dpm/sample, for fecal samples with a 14-day reporting time (plutonium alpha isotopic)
- 2.6 dpm/sample, for fecal samples with a 7-day reporting time (plutonium alpha isotopic)
- 100 dpm/sample, for fecal samples with a 2-day reporting time (nonisotopic, rapid analysis)

These MDA values apply to samples starting approximately in 1993. MDA values for earlier years are not available.

5.4 RECORDS AND REPORTS

This section discusses the interpretation of the data and information on records and reports of bioassay data. Attachment 5C, Examples of Records and Reports Used at Rocky Flats, contains the figures described below.

5.4.1 Urinalysis Records and Reports

Figures 5C-1 through 5C-3 are examples of the Urinalysis Record Card and the Health Sciences Data System – Urinalysis Detail report. The Urinalysis Record Card was the recording medium for the urinalysis data from 1952 through 1969 and is the primary record for urine data in this period. The urine data were manually entered on this card through 1969. These data were also entered into a database starting in about 1961. In about 1970, the Health Sciences Data System was implemented to record, process, and report urinalysis data and the derived fraction of the maximum permissible systemic burden. Examples of reports from this system are included in Figures 5C-1 through 5C-3 for instructional purposes.

Interpretation of the Urinalysis Record Card
Urine results are presented in columns under the month for a given year (in the row). The top number is the day of the month (assumed to be the excretion day). The middle number is the sample result, either a number or BK (see Section 5.3.1.1.2). The bottom number is the technique code and refers to the codes in the header (see Attachment 5A, page 3).

The unit of the result is given in the header. Sometimes the unit is written with the result (e.g., µg in Figure 5C-1). Be careful not to interpret µg as the number 49.

The corresponding data on the Health Sciences Data System – Urinalysis Detail report should be the same as that on the Urinalysis Record Card. If not, the data on the Urinalysis Record Card should be taken as the correct data, with the exception noted in Section 5.3.1.1.2 (i.e., some plutonium results reported as BK on the card were re-reported with the actual result). On some cards, the dose reconstructor may observe the initially reported result crossed out and replaced by a lower value. The technical basis for that change has not been determined. In addition, that change generally was not applied to the data in the Health Sciences Data System. It is reasonable and claimant favorable to disregard the modified result.

The analyte code for depleted uranium was sometimes transcribed incorrectly from the card to the urinalysis detail report as U (see Figure 5C-1) instead of D (see Figures 5C-2 and 5C-3) with the unit of dpm/24-hr sample instead of µg/24-hr sample.

Figures 5C-4 and 5C-5 are two versions of urinalysis reports from the Health Sciences Data System. Both versions report the data in the same way but with differences in the headers. A third version, Figure 5C-5 (the newer version), adds a column (the uncertainty of the result).

Interpretation of the Health Sciences Data System – Urinalysis Detail Report
The Activity Date is taken to be the date that the sample was excreted. However, the recorded date frequently was the date that the sample was received at the laboratory, especially for routine samples. (This applies also to the dates on the Urinalysis Record Card.)

ANAL is the code for the analyte:

P = plutonium
A = americium
U = enriched uranium (pre-1970, approximately)
U = depleted uranium (1970–1989, approximately)
D = depleted uranium (1952–1969, approximately)
G = gross alpha

NO CAL is a code used to flag the logic of the software.

0 = use normally in the calculation
1 = do not use in the calculation
2 = date of a new intake

Code 1 was used primarily for two situations to exclude a sample result from the systemic burden calculation: if the excretion of the analyte was enhanced by a chelation treatment or if the analysis of the sample did not meet quality standards (an invalid analysis or result). Sample results within 90 days of a chelation treatment were generally (or should have been) coded as 1. Using Code 2 to flag the date of a new, significant intake was done inconsistently. In reports generated in the 1980s, an asterisk was used instead of a Code 2 to flag the date of a new intake. The dose reconstructor should disregard the Code 2 or asterisked entries.

- ELAPSED DAYS is the number of days since the hire date. This data field is not likely to be of use.

- The EXPOSURE VALUE or DPM/24HR is the result of the urinalysis for the analyte. In general, the unit was dpm/24-hr sample, except for depleted uranium, from 1952 through April 1964.

- The column in parentheses is the uncertainty, starting in 1980. Any value or symbol in the parentheses before 1980 is only a placeholder and should be disregarded.

- The BODY BURDEN % or SYSTEM BURDEN is the calculated fraction of the maximum permissible systemic burden, calculated from Code 0 results for plutonium and for americium. This data field is not likely to be of use.

Figures 5C-6 and 5C-7 are examples of urinalysis reports from the on-site bioassay laboratory from 1990 to the mid-1990s. Figure 5C-6 is for a special urine sample analyzed for plutonium, and Figure 5C-7 is for a routine urine sample analyzed for plutonium. Both forms have the same format. The first three columns are self-explanatory.

- The Dec Level is the decision level L_c in unit of dpm/sample.

- The Aspec is code for the alpha spectrometry quality. The Aspec codes are defined on the lower-left portion of the report. Aspec code 0 is analogous to the Code 0 previously used for urine data in the Health Sciences Data System. Codes 1, 3, and 4 indicate a failed analysis and disqualify the result.

- The DQO is the code for status of the data quality objectives for the results of the batch blank and control samples. The DQO codes are defined on the lower center portion of the report. DQOs, in theory, were assessed for the blank, accuracy, and precision. In practice, the DQO was usually assessed only for the blank. Hence, the notation ANN means that the blank was acceptable, the accuracy was not assessed, and the precision was not assessed. An F would indicate that the batch failed a data quality objective, and, if the batched failed, every sample in the batch was conditionally failed, pending further evaluation.

- The Batch Val is the overall validation of the result. V means valid, and I means invalid. Do not use a result that has an I validation code.

- The Analyte is self-explanatory.

- The Recovery is the fraction of the tracer recovered by the analysis.

- The Result (DPM) is the result of the sample in units of dpm/sample. The dose reconstructor should assume a 24-hr urine sample unless there is information that indicates otherwise.

- The Error is the uncertainty at one standard deviation.

Figure 5C-8 is an example of the urinalysis data report by Quanterra, a commercial off-site laboratory, starting in 1993. The form header information, except for the collection date and the matrix, is not useful. The collection date, if not the sample excretion date, should be replaced by the sample date written on the form. The result header is largely self-explanatory.

- The Report Unit is the primary information is the result and its total error (at one standard deviation) in units of dpm/sample.

- The decision level (L_c) and the sample-specific MDA are also stated.

- The YIELD is the percent recovery of the tracer.

- The RST/MDA is the ratio of the result and the sample-specific MDA.

- The RST/CNTERR is the ratio of the result and the counting error.

- The ANALYSIS DATE is the date the sample was analyzed, not the excretion date.

- The ALIQUOT SIZE is the volume of the sample, in milliliters (ALQ UNIT).

- The DETECTOR ID is self-explanatory.

- The METHOD NUMBER references the document number of Quanterra's analytical procedure used to process the sample.

Figures 5C-9 and 5C-10 are examples of the analytical report of the on-site bioassay in the mid-1990s. Most of the information is self-explanatory. Some points:

- The date sampled is the excretion date.
- The data can only be used if the Alpha Spec Condition Code is 0 and if the Data Validation Code is V.
- The ^{234}U activity is approximately equal to ^{238}U activity in Figure 5C-9, and both results are greater than the decision level. As stated in Section 5.3.1.4.1, this is the classic pattern indicating natural uranium, and not an occupational intake of depleted uranium.

Figure 5C-11 is an updated version of urinalysis data report of Quanterra. The significant improvement is the validation of each result (QUAL = V). Use only results with a QUAL = V.

Figure 5C-12 is the urinalysis data report for General Engineering Laboratories, Inc. (GEL). The header information is largely self-explanatory.

- The Date Collected is the sample excretion date. The time (0600 military time) is also noted. 0600 is used as a default end time of the 24-hr excretion period if the actual end time is not documented.
- The VF is the volume fraction, the fraction of the sample that was analyzed. VF = 1 indicates that the entire sample was analyzed.
- Use only data that has a Data Validation Code = V.

Figure 5C-13 is an example of data card used in the 1970s and 1980s to record data manually for tritium urine samples and for other samples such as fecal samples and nose smears. The unit of the tritium results is pCi/liter. The unit of the fecal sample and nasal smear results is dpm/sample.

There may be other versions of *in vitro* bioassay reports. In all cases, the important data are the excretion date, the analyte, the result in the proper units, and whether the result was valid.

5.4.2 Lung Count Records and Reports

Figure 5C-14 is an example of an early lung count report. The aftermath of the October 15, 1965, plutonium fire in Buildings 76 and 77 was the first extensive use of the lung counter to detect americium and plutonium depositions for Rocky Flats workers.

- The *in vivo* lung counting system was called the Body Counter. In Rocky Flats terminology, the lung count was called a body count through 1989. Most claimants will likely use the term body count instead of lung count. The dose reconstructor should not mistake the Rocky Flats body count for a whole body count, which was widely used at other facilities to detect intakes of fission products.
- The Time field was used either for the time of the day at the start of the count or for the length of the count. In this case, the length of the count was noted 40 MLT means 40 minutes live time).

- The Minus Bkg + match notation indicates that the result is the net count rate after the room background count rate and the net count rate of a matched person was subtracted.

- The 1.4 LB notation is the calculated plutonium deposition in terms of the multiple of the MPLB of plutonium (1 MPLB = 16 nCi Pu alpha emitters).

- The Body Location is the position of the detector. In this case, the detectors were positioned over the right and left portions of the chest. In many early counts, one of the detectors was positioned over liver, gut, or below sternum instead of over one side of the chest. That data has little dosimetric use.

Figure 5C-15 is the August 1967 revision to the Health Physics Body Counter Information form. The change was to present the results after subtraction of the room background, Net (1) cpm, and after subtraction of matched subject net cpm, Net (2) cpm. In addition, the plutonium deposition was stated in terms of micrograms of plutonium.

Figure 5C-16 is the August 1968 revision to the Health Physics Body Counter Information form.

- The Net cpm is the subject's total count rate minus the room background count rate.

- The Predicted cpm replaced the net count rate of the matched subject.

- The Result is the final net cpm.

- In this example, there is no measurement for the right chest. The dose reconstructor should estimate the contribution for the right chest before using data from this count, because the lung data set generally includes contributions from both right and left lungs.

Figure 5C-17 is an example of a lung count with no result tabulated. This is an example of a positive, unknown case (see Section 5.3.2.1.2). In addition, note the tabulation of the index, which was used later to estimate the chest thickness. Sufficient information is presented here and in Attachment 5B to allow the dose reconstructor to calculate the plutonium and americium activities for this lung count, for any assumed or actual intake date.

Figure 5C-18 is the December 1973 revision to the previous form, with expanded information.

- The ROOM is the designation of the counting chamber, A, B, or C, used for this count.

- The RATIO field documented the ratio of the ^{241}Am photopeak region of interest (ROI) and a background ROI around 100 keV. The ratio was used as a supplemental, subjective tool to improve detection of americium. A ratio of 1.20 or greater indicated likely detection of americium.

- The ppm ^{241}Am was used to record either the ppm ^{241}Am for a new incident or, as in this case, the calculated value of the ppm ^{241}Am (including ingrowth of ^{241}Am) for a prior actual or assumed intake.

The form included fields to record the activity and fraction of the MPLB for both plutonium and americium. (This lung count, now quantified, is for the same positive, unknown case as Figure 5C-17).

Figure 5C-19 is an example of the previous form for a count judged to be background. Data fields were added to capture data for measurements of the L X-ray (17 keV) ROI, especially for the phoswich detector system. Although that information was captured occasionally, the data were not used because of the instability of the predicted background cpm.

The previous lung count reports were for counts using the NaI detector system. Figure 5C-20 is an example of the lung count data for a Ge detector system. The data for the five to eight detectors of the Ge systems were multiplexed into a composite total count tabulated in the row for TOTAL CHEST. The standard deviation of the resultant counts per minute is based on counting statistics only. For workers with confirmed lung depositions, the calibration factors for plutonium and americium were generally written on the form, as in this case.

Figure 5C-21 is an example of the first computer report for the lung count results. The data are labeled appropriately. This report is for a worker with a confirmed deposition. The report for workers without a confirmed deposition does not report the calibration factors, the ppm Am, or the lung burden. Instead, it reports the cutoff, which is the decision level, and Normal if the DIFFERENCE is less than the cutoff.

Figure 5C-22 is an example of a computer report for the phoswich detector system, which was used as a backup screening system in the 1980s. Note the outcome statement, “RESULTS ARE NORMAL.” If the results were not normal, the subject would have been recounted with a Ge detector system. Because the phoswich system could not resolve the 60- and 63-keV photopeaks, they share a common ROI. Another feature is the tabulation of the total count for each pertinent ROI. ROI 3 is the total count for the 60-keV/63-keV ROI, and ROI 4 is the background count for the 60- and 63-keV photopeaks. ROI 4 was also used as the count for the 93-keV photopeak, and ROI 5 was its background. ROI 2 was likely the count in the L X-ray region, but it was not used.

Figures 5C-23 and 5C-24 are examples of the next generation of reports for the Ge detector systems. The innovation is the data capture in ten ROIs. In Figure 5C-24, the ROIs are labeled with the photopeak of interest. Although the data were captured, most of the data were not used, mainly because the relationship between the photopeak and its background was not established or was too variable. ROI 5, labeled BKG in Figure 5C-24, is the common background (divided by a factor) for both the 60- and 63-keV photopeaks.

Figure 5C-25 is an example of a report for a worker with a confirmed deposition. There are no new fields.

Figure 5C-26 is an example of a report for a worker with no detected deposition and illustrates a frequent problem with the L X-ray data, the problem of low-end electronic noise in one or more of the detectors. The dose reconstructor should disregard all L X-ray data (including the 13- and 17-keV ROIs).

Figure 5C-27 is an example of a report where data for the 93-keV photopeak is analyzed and presented.

Figure 5C-28 is an example of the next generation of reports. On this report, the ROI data for each detector is tabulated separately, as well as the sum. ADC #1 stands for analog-to-digital converter for detector #1, which, in this case, is an EG&G detector; and similarly for the other detectors. This report also does not report the results in terms of the fraction of the maximum permissible lung burden, an obsolete concept since 1989.

Figure 5C-29 is an example of the lung count report generated by an early version of the ABACOS-Plus© software, to mid-February 1997. Because this software is based on a peak search method, no ROI data are available. In addition, if a uranium or americium peak was not found, the activity was reported as less than the decision level.

Figure 5C-30 is an example of the lung count report generated by the ABACOS-Plus© software, after mid-February 1997. The activities of ^{235}U, ^{238}U, and ^{241}Am are calculated and reported, even if the peak was not detected or if the result was negative. The MDA values are for the average worker, as stated on the report. The MDA value for ^{238}U is lower than the worker-specific decision level for this case. The worker-specific MDA should be at least twice the worker-specific decision level.

Figure 5C-31 is an example of the lung count report from the ABACOS-Plus© software for a worker with a confirmed deposition. The software calculated the deposition for the plutonium isotopes based on the intake date, noted in the header, and on the calculated ppm ^{241}Am (including in-growth) based on the value of the initial ppm ^{241}Am in the worker's file. The % Error for ^{241}Am is assigned to the plutonium isotopes. The basis of the decision level for the plutonium isotopes is not obvious, but is likely the decision level for detecting the L X-rays. In any case, the decision level value listed here does not apply and should be disregarded for the plutonium isotopes. The value of the ppm ^{241}Am on the date of the count is not reported on lung count reports generated by the ABACOS-Plus© software. This value can be calculated using Equation 5B-18 in Attachment 5B, using the value of the initial ppm ^{241}Am tabulated generally on one of the early lung count reports.

Much of the information from the ABACOS-Plus© software is not useful, including Count Rate, Detector Count Rate, Analysis Limits, and the total activity.

The dose reconstructor should note the intake date. If the intake date is different from the date for Count Started, the intake date is from the file for a worker with a confirmed deposition. Otherwise, the date of the lung count is used as the intake date.

The dose reconstructor should be aware that the lung counter detectors were also used for wound counts. Reports of wound measurements, including the calibration of the detector using americium and plutonium sources, look the same as the lung count reports except for some header information (name, employer, job code, reason, height, or weight).

It is important to note that the activities calculated for plutonium for lung counts are based on a specific, actual, or assumed intake date and initial ppm ^{241}Am. The plutonium values are valid and appropriate only for that intake data. If the dose reconstructor chooses to use another intake date or initial ppm ^{241}Am, the dose reconstructor should recalculate the set of plutonium lung deposition activities based on the recalculated ppm ^{241}Am for ingrowth. This is accomplished by multiplying the original activity of plutonium by the ratio (the original ppm ^{241}Am on the date of the count divided by the new value of the ppm ^{241}Am on the date of the count). The new value of the ppm ^{241}Am on the date of the count can be calculated using Equation 5B-18 in Attachment 5B. The dose reconstructor also should adjust the activities for the discontinuity factors presented in Attachment 5B. Generally, use of the discontinuity factors is claimant favorable.

5.5 INTERNAL DOSIMETRY FOR UNMONITORED WORKERS

This section presents guidance to the dose reconstructor to estimate internal doses to workers who worked in buildings involving plutonium, enriched uranium, or depleted uranium but have no appropriate bioassay data in their record. The dose reconstructor is the judge of the presence of appropriate bioassay data. For example, if a worker was potentially exposed to a radionuclide such

as plutonium, but had bioassay data for a different radionuclide such as enriched uranium, the worker is unmonitored for plutonium but is monitored for enriched uranium, if exposures to the different radionuclides are not linked.

5.5.1 Internal Dosimetry for Workers Not Involved in an Incident

[Please see Note to reviewers preceding the Table of Contents.] This section pertains to workers with no record of involvement in an incident and no citation of an incident in the claimant interview involving a radionuclide associated with the building(s) where they worked. This guidance suggests a reasonable approach, based on the air concentration limits in effect during the period of potential intake by the unmonitored worker.

The air concentration limits, stated in units of µCi/cm^3, were [*To be determined: we need a table of air concentration limits for the history of Rocky Flats, not only the official limits in AEC, ERDA, and DOE orders but also the values actually used. The old, in-house limits were called RCG, which, I believe, stands for radioactivity concentration guides. We need a history of the Rocky Flats RCG values for airborne radioactivity. We know some values. For example, the Rocky Flats limit for plutonium was 8.8 dpm per cubic meter of air, in the 1950s, based on calculations from incident and supplied air involvement reports that listed both the dpm of the plutonium in the air sample and the % of the limit. We also know, from annual reports of the Radiation Safety Section at Rocky Flats (Radiation Safety 1987), that the in-plant guides in the mid-1980s were: 4.4 dpm/m^3 for soluble plutonium, 9.0 dpm/m^3 for insoluble plutonium, and 70.0 dpm/m^3 for uranium. Maybe the Rocky Flats in-plant guides did not change much over the first 38 years.]*

The suggested approach is to estimate the time spent by the worker in a building involved in a radionuclide of interest and credit the worker with a chronic intake at an arbitrary fraction of the in-plant guide (or official limit, whichever is more claimant favorable). In the 1950s, the practice at Rocky Flats was to monitor workers only if they were expected to be exposed to 10% or more of the limit (called tolerance). Later, the goal was to operate at less than 10% of the RCG and to investigate conditions if an air sample exceeded 100% of the RCG. A reasonable, though arbitrary, choice of the default fraction is 10% of the RCG or official limit, unless worker-specific information is available. The default values and assumptions need to be determined.

[To be determined: Table of intake values, based on 100% of the RCG values, once the timeline of RCG values is obtained. We also need a concurrence that a default intake at 10% of the limit is reasonable.]

5.5.2 Internal Dosimetry for Workers Involved in an Incident

Claim files may include event-specific data that should be used to reconstruct internal dose. When such data is not available default assumptions may be made.

[Section 5.5.2 is reserved -- To Be Determined. This issue is worker specific, and likely would need to be researched on a case-by-case basis.]

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GLOSSARY

alpha particles

Positively charged particles of discrete energies emitted by certain radioactive materials; alpha particles usually expend their energy in short distances and will not usually penetrate the outer layer of skin; they are a significant hazard only when taken into the body where their energy is absorbed by tissues.

curie

A special unit of activity. One curie equals 3.7×10^{10} nuclear transitions per second.

detection limit (lower)

The minimum quantifiable exposure or neutron flux that can be detected.

dosimetry

The science of assessing absorbed dose, dose equivalent, effective dose equivalent, etc., from external or internal sources of radiation.

exposure

As used in the technical sense, exposure refers to a measure expressed in roentgens (R) of the ionization produced by photons (i.e., gamma and X-rays) in air. As used in internal dosimetry an encounter with uncontained radioactive material.

extremity

That portion of the arm extending from and including the elbow through the fingertips, and that portion of the leg extending from and including the knee and patella through the tips of the toes.

gamma rays

Electromagnetic radiation (photons) originating in atomic nuclei and accompanying many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Physically, gamma rays are identical to X-rays of high energy, the only essential difference being that X-rays do not originate in the nucleus.

isotope

Elements having the same atomic number but different atomic weights; identical chemically but having different physical and nuclear properties

maximum permissible lung burden (MPLB)

The occupational limit for plutonium expressed in terms of a quantity of plutonium that could be present in the chest at any given time.

minimum detectable activity (MDA)

Limit of radionuclide activity detection for measurements of specific types and energies of radiation

photon

A unit or particle of electromagnetic radiation, photons originating from the nucleus or extra-nuclear material of an atom are called respectively gamma rays or X rays.

radiation

Alpha, beta, neutron, and photon radiation.

radioactivity

The spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

radionuclide

A radioactive isotope of an element, distinguished by atomic number, atomic weight, and energy state

rem

A unit of dose equivalent equal to the product of the number of rad and the quality factor.

whole-body dose

Commonly defined as the absorbed dose at a tissue depth of 1.0 cm (1000 mg/cm^2); however, also used to refer to the recorded dose.

X-ray

Ionizing electromagnetic radiation of external nuclear origin.

ATTACHMENT A
MINIMUM DETECTABLE ACTIVITY FOR URINALYSIS METHODS AT ROCKY FLATS

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A.1 INTRODUCTION

Urinalysis has been used at Rocky Flats since the start of operations in 1952 to detect intakes of radionuclides by workers who were exposed, or had the potential to be exposed, to plutonium, enriched uranium, or depleted uranium. Urinalysis involved the submission of a urine sample by the worker, a chemical processing of the sample to isolate the radionuclide of interest (the analyte), and measurement and calculation of the quantity (or activity) of the analyte in the sample. The request for submission of the urine was either scheduled as part of a routine monitoring program or was specially requested following an actual or suspected intake. Routine urine samples were typically 24-hr excretions, either one continuous 24-hr period (but not taken at the Rocky Flats site) or two 12-hr periods. Special urine samples could be 24-hr samples, overnight samples, or a single voiding. The chemical processing of the sample depended on the analyte and the need for specificity and recovery. Specificity refers to separation of the desired radionuclide from interferences such as other radionuclides. Recovery refers to isolating as much of the analyte in the final medium to be measured (counted) as possible. The measurement of the sample typically involved counting the alpha radiation from the processed aliquant of the sample and determining the activity of the analyte in the original sample. Also involved was the fluorometric measurement of mass of depleted uranium. The assessment of the minimum detectable activity (MDA) involves the determination of the activity of the analyte in the original urine sample that would be expected to be detected by the methods and systems used at Rocky Flats from 1952 to the current time. The analytes of interest are plutonium, americium, enriched uranium, and depleted uranium. Also addressed is a category called gross alpha, which was a nonspecific analysis used for workers from 1952 to 1971 who were potentially exposed to any of the analytes of interest. This attachment focuses on the period from 1952 to 1971, for which many of the urinalysis logs have been located and analyzed to obtain the information needed to assess the MDA. This also is the period when urinalysis procedures were primitive and evolving and numerous dosimetrically interesting events and intakes were occurring at Rocky Flats.

A.2 MDA METHODOLOGY

The general equation for the MDA is Equation 6 in the American National Standard, *Performance Criteria for Radiobioassay* (HPS 1996):

$$MDA = (1 + \Delta_K)\,(2\Delta_B B + 2k s_o + 3) / KT \qquad (5A\text{-}1)$$

where:

B = the total count of the appropriate blank
s_o = the standard deviation in the net count of a sample with no additional analyte;

$$so = \sqrt{[s_{B1}^2 + (1/m^2)\, s_{B0}^2]} \qquad (5A\text{-}2)$$

where:

s_{B1} = the standard deviation of the sample, where the sample contains no actual analyte above that of the appropriate blank
s_{B0} = the standard deviation in the unadjusted count of the appropriate blank
m = the adjustment factor for the appropriate blank

K = calibration factor
Δ_K = the maximum fractional systemic error bound in the calibration factor K
Δ_B = the maximum expected fractional systemic error bound in the appropriate blank

k = the abscissa of the standardized normal distribution corresponding to the 0.05 probability level (for $\alpha = 0.05$ and $\beta = 0.05$, k = 1.645)
T = the standard counting time for the procedure

Applying this equation to urinalysis methods at Rocky Flats involves determining the value of each variable for measurements of the analytes: plutonium, americium, enriched uranium, depleted uranium, and gross alpha, as the methods evolved.

A.3 HISTORY OF METHODS

General Information
In the beginning of operations (1952), the Rocky Flats Plant was divided into four distinct sub-plants, plus a general support area. The sub-plants were named A Plant, B Plant, C Plant, and D Plant. The designations A, B, C, and D are significant because they are also the code names for the materials processed in those plants as well for the urinalysis procedures used to analyze those materials. The records of the 1950s do not contain the words: depleted uranium, enriched uranium, and plutonium. Instead, depleted uranium is A material processed in A Plant (buildings numbered 4##, mainly Building 444); enriched uranium is B material processed in B Plant (buildings numbered 8##, mainly Building 881); and plutonium is C material processed in C Plant (buildings numbered 7##, mainly Building 771). D Plant (buildings numbered 9##, mainly Building 991) handled all materials. A nonspecific gross alpha urinalysis method was used for workers in D Plant. (Note: Building numbers were two digit numbers until 1968, when the numbers were expanded to three digits, e.g., Building 771 was originally Building 71.) From 1962 to 1963, the enriched uranium operations were phased out at Rocky Flats, although urinalysis monitoring for enriched uranium continued through 1971.

The Urinalysis Record Card is an important and significant record for the early (1952 to 1969) urine data and methods that generated that data for a specific worker. A Urinalysis Record Card was established for each monitored worker, on which the result of each urine sample, the date of the sample, and the code of the urinalysis method used to generate that result are recorded. The card is now in the worker's Health Physics file, which is the primary Rocky Flats record of dosimetry information for a worker. The method codes are:

A	Fluorimeter, reported in micrograms/liter (1952-1956); reported in micrograms/24-hr (1957-1964)
B_1	Electroplating, reported in disintegrations per minute per 24-hr (dpm/24-hr). (Note: electroplating, in Rocky Flats records, more properly should be called electrodeposition.)
B_2	Ether extraction, reported in dpm/24-hr
B_3	Tributyl phosphate (TBP) extraction (hand written on some cards)
C_1	Carrier precipitation, reported in dpm/24-hr
C_2	Thenoyl trifluro acetone (TTA) extraction, reported in dpm/24-hr. (Note: On the header of cards for the period 1961-1965, the code C_2 is "Pu by Radio Autography." There is no indication that this method was implemented at Rocky Flats.)
D	TBP extraction

Although there is some correlation of the codes with the sub-plants, there are some exceptions. The following summarizes the correlation of the method code and the analyte.

Analyte	Method code
Depleted uranium	A, B_1 (starting 5/1/64)
Enriched uranium	B_1
Plutonium	C_1, C_2
Gross alpha	B_2, B_3, D

Tolerance levels were used at Rocky Flats in the 1950s and 1960s as an indicator of the maximum permissible amount (activity) of a radionuclide excreted per day in a worker's urine. The technical basis for the values of tolerance levels used at Rocky Flats has not been identified. The significance is that urinalysis results less than 10% of the tolerance level were recorded and reported as background (BK on the Urinalysis Record Card) or zero, regardless of the underlying sensitivity of the method, with some exceptions. The values of the tolerance levels are:

Analyte	Tolerance level	Reporting level
Depleted uranium	58 µg/24-hr	≥ 5.8 µg/24-hr
Enriched uranium	88 dpm/24-hr	≥ 8.8 dpm/24-hr
Plutonium	8.8 dpm/24-hr	≥ 0.88 dpm/24-hr
Gross alpha	88 dpm/24-hr	≥ 8.8 dpm/24-hr

These reporting (and recording) levels continued through April 1964 for both depleted and enriched uranium, through 1961 for plutonium, and through 1963 for gross alpha. After April 1964 through 1971, the reporting level for depleted and enriched uranium was ≥0.20 to 0.28 dpm/24-hr. After 1963 for gross alpha, the reporting level was ≥0.9 dpm/24-hr.

For plutonium, the reporting and recording level was ≥0.20 dpm/24-hr for the period 1962 through April 6, 1970. After that date, all results ≥0.00 dpm/24-hr were recorded and reported. Negative values were recorded and reported as 0.00 dpm/24-hr. A further exception is that, for some workers, the practice implemented on April 7, 1970 was applied retroactively for their plutonium data. The retroactive application was variable with respect to how far back it was applied.

In 1963, an analysis specific for ^{241}Am was implemented. The recording and reporting level for ^{241}Am was ≥0.24 dpm/24-hr in 1963, ≥0.20 dpm/24-hr from 1964 to 1967, and ≥0.30 dpm/24-hr from 1968 to 1971.

The general method for data analysis for alpha counting procedures (1952 to 1971) was:

$$\text{Activity (dpm/24-hr sample)} = (C/T - B_{Det} - B_{Blk}) \times (V/A) / (\varepsilon \times R) \qquad (5A\text{-}3)$$

where:

- C = Total count (c)
- T = Count time (minutes, m)
- B_{Det} = Detector background count rate (cpm)
- B_{Blk} = Reagent blank count rate (cpm)
- V = Sample (or standard) volume (ml)
- A = Volume of the aliquant analyzed (or volume of the sample, if the entire sample was analyzed) (ml)
- ε = Efficiency (geometry) of the detector (cpm per dpm)
- R = Recovery, fraction of the analyte in the aliquant or sample that is transferred to the planchet or disk to be counted

The detector background count rate was generally tabulated in the urinalysis data logs through 1961. After 1961, the value used for the detector background is implicit in the data reduction but is not explicitly recorded. The same detectors were used for alpha counting for all analytes.

Reagent blanks were generally processed with each batch of samples, and the value of the blank count rate used in the data reduction was generally tabulated in the urinalysis data logs.

The ratio (V/A) is a volume adjustment factor used for two purposes. If the entire sample was not analyzed, this ratio normalizes the result from the volume of the aliquant analyzed to the total sample. If the volume of the total sample was less than a minimum specified volume (e.g., 1,000 ml), the sample was considered to be less than a 24-hr sample, and the ratio was used to normalize the sample result to that for a 24-hr sample. The sample volume was recorded in the urinalysis data log for each sample.

The value of ε was the geometry rating of the detector. From 1952 to 1953, ε was 0.45. After that, the detectors were called 50% detectors, and ε was 0.50. In 1964, 40% detectors (ε of 0.40) were added to the system as a supplement to the 50% detectors.

The value of R was generally a standard value. Depending on the process, spiked samples, samples to which a known activity of the analyte was added, were generally processed with each batch of samples. The recovery values calculated from the spiked samples were the ratios of the count rate of spiked sample to the average count rate of four to six samples deposited on the planchet or plate with minimal processing. The recovery values for the spiked samples were not normalized to the activity (dpm) deposited. In addition, the recovery values from the spikes usually were not used to customize the standard value of R for samples in the batch.

The fraction of absorption of the alpha particles in the residue on the planchet or plate was not explicitly incorporated either in the efficiency or recovery.

The term ε x R was frequently combined, especially in the 1950s. In the 1960s, the term 1/(ε x R) was occasionally tabulated in the urinalysis data logs as R.F., presumably for recovery factor, and was used as a multiplier to convert the net count per minute to activity in the sample.

The general method for the mass measurements of uranium using the fluorimeter (1953 to 1964) was:

$$\text{Mass (µg/24-hr sample)} = (S - B_{Blk}) / K \qquad (5A\text{-}4)$$

where:

- S = Signal reading of the sample aliquant
- B_{Blk} = Signal reading of the blank
- K = Constant/V (The constant is custom to each process. V = Volume (ml) of the entire urine sample. If the sample volume ≤ 1,000 ml, V = 1000 ml.)

The history of the methods is largely based on an interview with the lead chemist for the bioassay program from 1961 to 1992 and on a review of the bioassay data logs from 1952 to 1971.

Plutonium
1952–1961
The urine sample was processed using a method called carrier precipitation (also called co-precipitation). The plutonium in the urine sample (plus some americium and thorium) was carried into the precipitate with lanthanum fluoride. The precipitate was dissolved, and the solution was evaporated on a planchet, which was counted with a gas-flow proportional counter. Typical count time was 150 minutes. A spike sample and a reagent blank sample were processed with the workers' samples, sometimes with each batch and sometimes less frequently. The result of the spike sample may or may not have been used to establish the value of the recovery of the analyte for the batch. Similarly, the result of the blank (counts per minute) may or may not have been used to establish the

value of the blank subtracted from the total count rate of the sample. Detector efficiency was stated to be 0.50. A volume adjustment factor (1,200/sample volume) was applied as a multiplier to the result if the sample volume was less than 1,000 ml. The first evidence of the use of this factor is in 1960.

1961–1962
Starting on December 13, 1961, a TTA extraction step was added to the carrier precipitation method to improve the specificity of the process to isolate plutonium. No other changes were made to the previous method.

1963–1978
The ion exchange method replaced the carrier precipitation/TTA extraction method in 1963 and was used, with refinements, thereafter. The method was plutonium specific. In addition, americium could be recovered separately from the plutonium in the same sample. Evaporation of the analyte on a planchet was continued, but that method was gradually phased out and was replaced by electrodeposition on a stainless steel disk. About one third of the samples were electrodeposited in 1964 and one half or more from 1967 through 1971. In 1973, an alpha pulse height analysis counting system with surface barrier detectors was started with four detectors. The practice of using internal tracers (^{236}Pu or ^{242}Pu) for some plutonium samples was begun concurrently. A batch blank continued to be processed, although its use was inconsistent. For example, in 1971, a blank count rate of 0.00 cpm was used even though the median value of the batch blank was 0.06 cpm. In 1964, detectors with an efficiency of 0.40 were used as a supplement to the detectors with 0.50 efficiency

1978–1993
By 1978, all of the counting system had been converted to the PHA system, and all of the plutonium samples were processed with internal tracers. The fraction of the internal tracer recovered for that sample was applied in the analysis of the result for that sample. The acceptable range of the fractional tracer recovery was 0.10 to 1.10. The result of a sample was invalidated if the recovery was outside of the acceptable range. In 1990, the acceptable recovery range was changed to 0.35 to 1.10. The count time of 720 minutes was used for all samples. A batch blank continued to be processed and generally was used in the data analysis unless suspected to have been contaminated excessively (a subjective decision). In 1985, the blank method was modified. The value of the blank used in the analysis of the result for a sample was the average value of the last 20 valid batch blanks. To be valid, a batch blank value was tested using the Dixon outlier test and, if it passed the test, was added to the population of the last twenty blanks. In 1988, the blank process was further modified by use of the Winsorized trimmed mean of the population of 20 blanks instead of the average value. The purpose of these modifications was to minimize the influence of laboratory contamination artifacts, which were considered to be nonrandom events that, if incorporated in the blank, would inappropriately bias the results of the other samples on the low side. In addition, the reagent blank was replaced by a matrix blank, either real or artificial urine. The volume of the sample analyzed (aliquant) was 800 ml if the volume of the sample was greater than 800 ml, or the entire sample if the volume of the sample was less than 800 ml. The result of the aliquant was divided by the volume fraction (800 ml/volume of the sample) if the volume of the sample was ≥800 ml. The efficiency of the detectors was typically in the range 0.25 to 0.35.

1993 →
Upgrades to procedures occurred in 1993 in order to achieve a process MDA less than or equal to 0.020 dpm/sample. Count time was increased to 2,400 minutes. The entire sample was analyzed so that the volume fraction was unity for all samples. In addition, a contract was established with a commercial bioassay laboratory, with a requirement that a MDA ≤0.020 dpm/sample be achieved. In 1997, the on-site bioassay laboratory was shut down.

Americium (1963 →)
Except for the details of the chemistry, the process for americium was similar to that described for plutonium. A solvent extraction process, specific for americium, was first used in 1963. A new process (not defined in the data log) was started in November 1965. At some point, not defined in the examined data logs, the ion exchange method was implemented for americium.

Enriched Uranium (1952 -1971)
Urine samples were analyzed for enriched uranium according to a process called electroplating. A 50-ml aliquant of urine was extracted from the 24-hr sample and was chemically processed to minimize impurities. The resulting solution was poured into an electrodeposition column, and the uranium was deposited on a stainless-steel disk. The disk then was counted for alpha radiation with the gas flow proportional counters, as described for plutonium. Counting times used in this period were 30, 40, 60, 70, 90, 120, and 150 minutes.

From 1952 to 1955, one aliquant per sample was used. In 1960, a second aliquant was processed if the result of the first aliquant was ≥7 dpm/24-hr sample. If the second result was within a specified range of the first result, the average of the two results was recorded and reported. If the second result was out of the specified range, a third aliquant was processed, and the average of the two results that best confirmed each other was used. If that average was less than the reporting level of 8.8 dpm/24-hr, the result was recorded and reported as background. From 1961 to 1971, two aliquants routinely were processed for each urine sample, with a third aliquant (1961 to 1969) processed if the spread of the results of the first set was outside the specified range. The recording and reporting logic was the same as that for 1960. From 1964 to 1971, the recording and reporting limit appears to be ≥20 to 28 dpm/24-hr sample, depending on the volume of the sample.

Blank data were not used to adjust the sample count rate, except sporadically in 1963 and 1964. Detector background usually was subtracted, but not always. Spike samples were processed, although it is not obvious how that data were used, if at all. Instead, a constant value of the product of the detector efficiency (ε) and the recovery (R) was used: 0.40 (1953 to 1955 and 1971), 0.30 (1960 to 1970), and 0.24 (1964 to 1970 for detectors with ε = 0.40).

Enriched uranium operations were phased out at Rocky Flats from 1962 to 1963, although some workers were still monitored for enriched uranium intakes through 1971.

Depleted Uranium (1952–1971)
Two methods were used to analyze urine samples for depleted uranium. From 1952 to April 1964, a fluorimeter was used to measure the mass (micrograms) of uranium in a 100λ (0.1 ml) aliquant of the 24-hr urine sample. The result was extrapolated to the total sample and was reported in the unit of µg/24-hr sample. A volume adjustment was made if the sample volume was less than 1,000 ml. If less than 1,000 ml, the volume was set equal to 1,000 ml.

Screening was done with one aliquant. A second aliquant was processed if the net reading of the first aliquant was greater than or equal to a value in a chart correlated with the volume of the 24-hr urine sample. A third aliquant was processed if the results (net readings) of the first two aliquants varied by 20% or more. The average result of the two aliquants that agreed was converted to µg/24-hr sample and reported only if the result was greater than or equal to the reporting level 5.8 µg/24-hr sample. Otherwise, the result was reported as background.

After April 1964, the urine sample was analyzed using the electroplating procedure described previously for enriched uranium, and the results were reported in the unit of dpm/24-hr sample (or background).

Gross Alpha (1952–1971)
Two methods were used to analyze urine samples for gross alpha counts, from either plutonium or uranium. The ether extraction method was used from 1952 to December 12, 1962, and the TBP extraction method was used from December 12, 1962, to 1964. The TBP method was replaced by the TOPO method. All methods were non-specific in extracting plutonium and uranium, as well as americium and natural thorium.

In all methods, the entire urine sample was processed, and the final extract was evaporated on a planchet and counted on the gas flow proportional counter. Counting time was typically 150 minutes, although from 1952 to 1955 count times of 55, 60, and 75 minutes, and in 1971 count times of 40 and 60 minutes, were also used.

Samples with results ≥0.9 dpm/24-hr sample typically, but not always, were counted using a PHA system to determine whether to credit the result to enriched uranium or plutonium, or a portion to both. The default condition, through 1963, was to credit the result to enriched uranium unless the PHA count indicated otherwise. After 1963 (and enriched uranium operations were phased out), the default condition was to credit the result to plutonium. In either case, the results should be considered to be upper bounds, because of the non-specificity of the analysis.

Assessment of MDA
The MDA is assessed for plutonium, americium, enriched uranium, depleted uranium, and gross alpha, based on equation 5A-1 and the values of parameters for the methods. Some considerations are:

- The probabilities of Type I (false positive) and Type II errors (false negative) are each 5% ($\alpha = \beta = 0.05$).
- The MDA is assessed for the typical, average, or median condition. Where appropriate, the MDA is also assessed for the 5th- or 95th-percentile conditions.
- The MDA is assessed for the methods as they should have been performed, with respect to such factors as alpha transmission factor, blank subtraction, recovery fraction, and volume adjustment.
- For methods with two or more options in the same period (e.g., evaporation vs. electrodeposition, 40% detectors vs. 50% detectors) the option that gives the higher MDA is used.

The value of the MDA for the typical, average, or median condition pertains to the process and indicates the amount or activity in the population of urine samples that would have been detected with a 95% probability, given a properly set decision criterion that allows a 5% probability of a Type I error. In reality, the decision criterion (and method) at Rocky Flats was not based on the probability of a Type I error. Instead, an arbitrary level (10% of the tolerance level or any non-negative value) was used as the decision criterion for recording and reporting detected amounts or activities.

The value of the MDA for the 5th- or 95th- percentile conditions pertains to individual samples for which the conditions of the sample [e.g., low volume, or conditions of the processing (low recovery, high blank, high alpha self-absorption)], were marginal. The conditions of low recovery, low volume, and high alpha self-absorption are associated with the calibration factor K and can be incorporated either in the value of K or in the value of Δ_K.

Sample volumes for routine 24-hr urine samples are:

Median:	1,350 ml
5th percentile:	700 ml
95th percentile:	1,750 ml

The values for the parameter values for the processes were obtained through review of the urine data logs for the periods from 1952 to 1955 and from 1960 to 1971. For some years in this period, logs for only a part of the year were available.

Data for Alpha Counting Systems

The detector background (cpm) for the gas flow proportional counters, based on tabulations in the urine data logs from 1952 to 1955 and from 1960 to 1963, for sample count time of 150 minutes, are:

	Average	5th percentile	Median	95th percentile
1950s	0.060 ± 0.022	0.02	0.06	0.10
1960s	0.054 ± 0.014	0.03	0.05	0.08
Composite	0.056 ± 0.017	0.03	0.05	0.08

No documentation was found concerning the count time used to measure the detector background, but the count time is likely to be 150 minutes or longer. For the purpose of assessing the MDA, the composite average is used for the value of the detector background count rate, B_{Det} = 0.056 cpm, with the standard deviation, s_{Det} = 0.017 cpm, for all alpha counting methods (except for americium) and for all sample count times. For americium, the values for the 1960s are used because the americium process was not implemented in the 1950s.

The blank count rate is method specific, and the application of the blank in the data analysis was variable between methods and within a method over time. The confounder was the intermittent, but persistent, laboratory contamination artifacts introduced into blanks and worker samples. These artifacts caused false positives from a worker exposure viewpoint but real positives from a detection viewpoint. In practice, high blank values (a subjective decision) were generally ignored, and suspect (unexpectedly high) sample results were either confirmed or overruled by recounting, resampling, or analyzing another aliquant.

For the purpose of this MDA analysis, the median value of the blank is used to determine the process MDA and the 95th-percentile (low to high) value is used to determine the MDA for the more extreme conditions. The median and 95th-percentile blank count rates are summarized:

Analyte	Period	Blank cpm	
		Median	95th percentile
Plutonium	1952-1971	0.06	0.28
Enriched uranium	1952-1971	0.05	0.22
Depleted uranium	1964-1971	0.05	0.22
Americium	1963-1971	0.07	0.26
Gross alpha	1952-1971	0.08	0.30

These values are the average of the yearly values extracted from available urine data logs. For each of the analytes, the yearly median and 95th-percentile values did not differ enough over the period to warrant a separate MDA analysis. The blank values for enriched and depleted uranium are based on log entries in 1963 and 1964 for cell blank checks for the electrodeposition process.

The value of the blank count rate, B_{Blk}, is taken from the above table for the given analyte. The standard deviation, s_{Blk}, is taken to be the square root of the blank count for the process divided by the count time of the process:

$$s_{Blk} = (1/T)\sqrt{(B_{Blk} \times T)} \quad (5A\text{-}5)$$

The values for B, s_{B0}, s_{B1}, and s_o in the MDA equation (5A-1) are derived from the detector background and blank values:

$$B = (B_{Det} + B_{Blk}) \times T \quad (5A\text{-}6)$$

$$s_{B0} = T \times \sqrt{(s_{Det}^2 + s_{Blk}^2)} \quad (5A\text{-}7)$$

$$s_{B1} = \sqrt{B} \quad (5A\text{-}8)$$

$$s_o = \sqrt{(s_{B1}^2 + s_{B0}^2)} \quad (5A\text{-}9)$$

For some analytes (enriched uranium, depleted uranium) and periods, the decision with regard to detection was based on the average of two aliquants. In this case, the value of s_o for the average two aliquants is equal to the value of s_o for one aliquant divided by the square root of two.

The value of Δ_B is taken to be zero. This variable may be used to account for high blank values. Instead, the effect of high blank values is determined by using the 95th-percentile value of the blank.

The calibration factor K is a combination of the detector efficiency ε, the recovery R, and the volume adjustment factor (V/A). Also included is a factor that accounts for absorption of alpha particles in the residue of planchets or plates.

Common detectors were used for all alpha-counting methods. The efficiencies of the detectors are:

Period	Detector efficiency
1952-1953	0.45
1954-1963	0.5
1964-1971	0.4 and 0.5

For 1964 to 1971, the value of 0.4 is used as the efficiency for the MDA calculation.

The recoveries used in the MDA assessment are taken to be the median recovery and the 5th-percentile (low to high) value discerned from the spike data for the process:

Analyte	Period	Recovery	
		Median	5th percentile
Plutonium	1952-1962	0.57	0.25
Plutonium	1963-1971	0.67	0.28
Enriched uranium	1952-1971	0.60	0.21
Depleted uranium	1964-1971	0.60	0.21
Americium	1963-1965	0.67	0.29
Americium	1965-1971	0.80	0.26
Gross alpha	1952-1971	0.57	0.24

The recovery values are based on incomplete data sets and involve extrapolations to cover the total period. For plutonium from 1952 to 1962, the values are based on data for 1961 and 1962. For

plutonium from 1963 to 1971, the values are based on data for 1963 to 1965 and 1969 to 1971. For enriched and depleted uranium, recoveries were not calculated for the spiked samples. The median value is based on the value used for most of the period.

The 5th-percentile value is based on the relative standard deviation (0.40) of the average count rate of the spiked samples from 1963 to 1966. For americium from 1963 to 1965, the values are based on a complete set for that period, ending November 1, 1965. For 1965 to 1971, the values are based on data from November 1, 1965, through 1966, and 1968 to 1970. For gross alpha, the values are based on data from 1962 to 1969 for the TBP method. In general, values for all the processes are remarkably similar, except for americium from 1965 to 1971.

The volume adjustment factor (V/A) is incorporated into the calibration factor K as the reciprocal 1/(V/A), so it becomes a multiplier with the efficiency and recovery. For convenience, the reciprocal of the volume adjustment factor is designated V_f.

For plutonium, americium, and gross alpha, the median condition is V = A and V_f = 1. The extreme condition is a low sample volume normalized to 1,200 ml: V = 1,200 ml, A = 700 ml (the 5th-percentile volume), and V_f = 0.58.

For enriched and depleted uranium (for the electrodeposition process), A = 50 ml, the median V = 1,350 ml, and V_f = 0.037. The extreme condition is a high sample volume: V = 1,750 ml (the 95th-percentile volume), A = 50 ml, and V_f = 0.029.

The absorption of the alpha particles in the residue evaporated on the planchets or electrodeposited on the plates should be incorporated into the value of the calibration factor. The factor to incorporate this effect is the fraction of the alphas emitted by the deposited analyte that successfully escape from the residue. Let this factor be designated F_a, where F_a = (1 – fraction of alphas absorbed in the residue), and let the fraction of alphas absorbed in the residue be f_{abs}. The values of f_{abs}, based on judgments of experienced bioassay chemists, for the extreme (95th-percentile) condition, and the corresponding values of F_a are:

Analyte	Period	95th percentile	
		f_{abs}	F_a
Plutonium (evaporated)	1952-1962	0.4	0.6
Plutonium (evaporated)	1963-1971	0.3	0.7
Plutonium (electrodeposited)	1963-1971	0.05	0.95
Enriched uranium (electrodeposited)	1952-1971	0.05	0.95
Depleted uranium (electrodeposited)	1964-1971	0.05	0.95
Americium (evaporated)	1964-1971	0.3	0.7
Americium (electrodeposited)	1964-1971	0.05	0.95
Gross alpha (evaporated)	1952-1962	0.1	0.9
Gross alpha (evaporated)	1962-1971	0.3	0.7

From 1963 to 1971, approximately half of the plutonium and americium samples were electrodeposited. However, the identities of samples that were electrodeposited are not discernable from the databases and reports of urinalysis results that are readily accessible. For the purpose of the MDA assessment, use the value of F_a for the evaporation process.

For the median condition, the value of F_a is taken to be 1, under the assumption that the absorption of alphas for the median condition of the planchet or plate was incorporated in the recovery value used at the time.

The calibration factor K is the product of ε, R, V_f, and F_a:

$$K = \varepsilon R V_f F_a \quad (5A\text{-}10)$$

The values of Δ_B and Δ_K are considered to be zero.

Data for Fluorometric Mass Measurements
Applying the MDA equation (5A-1) for fluorometric mass measurements involves setting the value of T to unity and eliminating the term "3".

The value of s_{B0} is the standard deviation of the blank flux readings that are subtracted for the signal of the aliquant reading. The value of s_{B1} is set equal to s_{B0}, and s_o is equal to the value of s_{B0} multiplied by the square root of 2:

$$s_o = s_{B0} \sqrt{2} \quad (5A\text{-}11)$$

The value of s_{B0} was determined from a review of the urine data logs for 1955 and 1960 to 1962. One discontinuity was noted on September 14, 1955. The value of s_{B0} before the discontinuity was 0.37 and, after the discontinuity, averaged 0.15.

The calibration factor K converts the fluorimeter net reading to the unit of µg uranium/24-hr sample (see equation 5A-4). In 1955, the calibration factor was applied to the uncorrected net reading. In 1960 and following, the calibration factor was applied to the corrected reading, which was the net reading multiplied by the factor 1.15. The factor of 1.15 is incorporated into the value of K starting in 1960. For the 1950s, the calibration factor for 1955 is used:

Period	K
1952-1959	75/V
1960-1964	87/V

For the median condition, the volume V is equal to 1,350 ml. For the extreme condition, the 95th-percentile volume of 1,750 ml is used.

The values of Δ_B and Δ_K are considered to be zero.

MDA Values
The value of the MDA is presented to two significant figures, for information purposes. In most cases, the value of the MDA should be considered only to one significant figure.

Plutonium
The MDA for plutonium is assessed for the median condition and for the extreme (5th- or 95-percentile) condition for the blank, the recovery, the volume factor V_f, and the alpha transmission factor F_a, individually and in combination. A count time of 150 minutes is used for all assessments.

For the median MDA (dpm/24-hr sample):

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1952-1953	5.74	0.45	0.57	1.0	1.0	0.57
1954-1962	5.74	0.50	0.57	1.0	1.0	0.51
1963	5.74	0.50	0.67	1.0	1.0	0.44
1964-1971	5.74	0.40	0.67	1.0	1.0	0.54

The values of the variables for the extreme (5th- or 95-percentile) conditions and the resulting MDA (dpm/24-hr sample) for all of the extreme conditions occurring for the same sample are:

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1952-1953	7.98	0.45	0.25	0.58	0.6	5.0
1954-1962	7.98	0.50	0.25	0.58	0.6	4.5
1963	7.98	0.50	0.28	0.58	0.7	3.4
1964-1971	7.98	0.40	0.28	0.58	0.7	4.3

The value of s_o incorporates the 95th-percentile value of the blank.

It is unlikely that the four extreme conditions (high blank, low recovery, low volume, and cruddy residue on the planchet) all occurred for the same sample. The following tables present the MDA for each of the extreme conditions individually, as well as for combinations of two and three extreme conditions.

MDA (dpm/24-hr sample) for one extreme condition

Period	s_o	R	V_f	F_a
1952-1953	0.76	1.3	0.98	0.95
1954-1962	0.68	1.2	0.88	0.85
1963	0.58	1.0	0.75	0.62
1964-1971	0.73	1.3	0.94	0.78

MDA (dpm/24-hr sample) for two extreme conditions

Period	s_o, R	s_o, V_f	s_o, F_a	R, V_f	R, F_a	V_f, F_a
1952-1953	1.7	1.3	1.3	2.2	2.2	1.6
1954-1962	1.6	1.2	1.1	2.0	2.0	1.5
1963	1.4	1.0	0.97	1.8	1.5	1.1
1964-1971	1.7	1.3	1.2	2.3	1.9	1.3

MDA (dpm/24-hr sample) for three extreme conditions

Period	s_o, R, V_f	s_o, R, F_a	s_o, V_f, F_a	R, V_f, F_a
1952-1953	3.0	2.9	2.2	3.7
1954-1962	2.7	2.6	2.0	3.4
1963	2.4	2.0	1.4	2.6
1964-1971	3.0	2.5	1.8	3.2

Enriched Uranium

The MDA for enriched uranium is assessed for the median condition and for the extreme (5th- or 95th-percentile) condition for the blank, the recovery, the volume factor V_f, and the alpha transmission factor F_a, individually and in combination. A count time of 150 minutes is used for MDA assessments from 1952 to 1963. In the period 1964-1969, the count time of 30 minutes is used, and, for 1970 to 1971, the count time of 40 minutes is used. For 1952 to 1959, the value of s_o is calculated for one aliquant, and, for 1960 to 1971, the value of s_o is calculated based on the average of two aliquants.

For the median MDA (dpm/24-hr sample):

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1952-1953	5.45	0.45	0.60	0.037	1.0	14
1954-1959	5.45	0.50	0.60	0.037	1.0	13
1960-1963	3.85	0.50	0.60	0.037	1.0	9.4
1964-1969	1.57	0.40	0.60	0.037	1.0	31
1970-1971	1.83	0.40	0.60	0.037	1.0	25

The values of the variables for the extreme (5th- or 95th-percentile) conditions and the resulting MDA (dpm/24-hr sample) for all of the extreme conditions occurring for the same sample are:

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1952-1953	6.72	0.45	0.21	0.029	0.95	64
1954-1959	6.72	0.50	0.21	0.029	0.95	58
1960-1963	4.75	0.50	0.21	0.029	0.95	43
1964-1969	2.18	0.40	0.21	0.029	0.95	150
1970-1971	2.48	0.40	0.21	0.029	0.95	120

The value of s_o incorporates the 95th-percentile value of the blank.

It is unlikely that the four extreme conditions (high blank, low recovery, low volume, and cruddy residue on the planchet) all occurred for the same sample. The following tables present the MDA for each of the extreme conditions individually, as well as for combinations of two and three extreme conditions.

MDA (dpm/24-hr sample) for one extreme condition

Period	s_o	R	V_f	F_a
1952-1953	17	40	18	15
1954-1959	15	36	16	13
1960-1963	11	27	12	9.9
1964-1969	38	88	39	32
1970-1971	31	74	32	27

MDA (dpm/24-hr sample) for two extreme conditions

Period	s_o, R	s_o, V_f	s_o, F_a	R, V_f	R, F_a	V_f, F_a
1952-1953	48	21	18	51	42	19
1954-1959	43	19	16	46	38	17
1960-1963	32	14	12	34	28	13
1964-1969	110	49	40	110	92	41
1970-1971	90	40	33	93	76	34

MDA (dpm/24-hr sample) for three extreme conditions

Period	s_o, R, V_f	s_o, R, F_a	s_o, V_f, F_a	R, V_f, F_a
1952-1953	61	50	23	54
1954-1959	55	45	20	48
1960-1963	41	34	15	43
1964-1969	140	120	51	150
1970-1971	120	94	42	120

Depleted Uranium

The MDA for depleted uranium is assessed for two processes: fluorimetric mass measurements from 1952 to April 30, 1964; and electrodeposition/alpha counting measurements from May 1, 1964, to 1971.

For the fluorimetric mass measurements, the MDA is assessed for one aliquant, because the decision for detection was based on one aliquant, even though quantification was based on the average of two aliquants. The MDA at the extreme condition is based on the 95th-percentile volume.

Period	s_{B0}	K		MDA (µg/24-hr sample)	
		Median	Extreme	Median	Extreme
1952-1955	0.37	0.056	0.043	31	40
1955-1959	0.15	0.056	0.043	12	16
1960-1964	0.15	0.064	0.050	11	14

For the electrodeposition/alpha counting measurements, the MDA values tabulated for enriched uranium for 1964 to 1971 apply also to depleted uranium.

Americium

The MDA for americium is assessed for the median condition and for the extreme (5th- or 95th-percentile) condition for the blank, the recovery, the volume factor V_f, and the alpha transmission factor F_a, individually and in combination. A count time of 150 minutes is used for assessments from 1963 to 1970. In 1971, the typical (and minimum) count time is 60 minutes.

Values of the MDA are presented to two significant figures.

For the median MDA (dpm/24-hr sample):

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1963	5.82	0.50	0.67	1.0	1.0	0.44
1964-1965	5.82	0.40	0.67	1.0	1.0	0.55
1965-1970	5.82	0.40	0.80	1.0	1.0	0.46
1971	3.51	0.40	0.80	1.0	1.0	0.76

The values of the variables for the extreme (5th- or 95th-percentile) conditions and the resulting MDA (dpm/24-hr sample) for all of the extreme conditions occurring for the same sample are:

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1963	9.95	0.50	0.26	0.58	0.7	4.3
1964-1965	9.95	0.40	0.26	0.58	0.7	5.4
1965-1970	9.95	0.40	0.26	0.58	0.7	5.4
1971	5.94	0.40	0.26	0.58	0.7	8.9

The value of s_o incorporates the 95th-percentile value of the blank.

It is unlikely that the four extreme conditions (high blank, low recovery, low volume, and cruddy residue on the planchet) all occurred for the same sample. The following tables present the MDA for each of the extreme conditions individually, as well as for combinations of two and three extreme conditions.

MDA (dpm/24-hr sample) for one extreme condition

Period	s_o	R	V_f	F_a
1963	0.68	1.1	0.76	0.63
1964-1965	0.86	1.4	0.95	0.79
1965-1970	0.72	1.4	0.80	0.66
1971	1.2	2.3	1.3	1.1

MDA (dpm/24-hr sample) for two extreme conditions

Period	s_o, R	s_o, V_f	s_o, F_a	R, V_f	R, F_a	V_f, F_a
1963	1.8	1.2	0.98	2.0	1.6	1.1
1964-1965	2.2	1.5	1.2	2.4	2.0	1.4
1965-1970	2.2	1.2	1.0	2.4	2.0	1.1
1971	3.6	2.0	1.7	4.0	3.3	1.9

MDA (dpm/24-hr sample) for three extreme conditions

Period	s_o, R, V_f	s_o, R, F_a	s_o, V_f, F_a	R, V_f, F_a
1963	3.0	2.5	1.7	2.8
1964-1965	3.8	3.2	2.1	3.5
1965-1970	3.8	3.2	1.8	3.5
1971	6.2	5.2	2.9	5.7

Gross Alpha

The MDA for gross alpha measurements is assessed for the median condition and for the extreme (5th- or 95th-percentile) condition for the blank, the recovery, the volume factor V_f, and the alpha transmission factor F_a, individually and in combination. A count time of 55 minutes is used for 1952, 75 minutes for 1953 to 1959, and 150 minutes for 1960 to 1971 for assessments of the MDA for both the median and extreme conditions, except for 1971, when a count time of 40 minutes is also used for the extreme condition.

For the median MDA (dpm/24-hr sample):

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1952	3.26	0.45	0.57	1.0	1.0	1.0
1953	4.23	0.45	0.57	1.0	1.0	0.88
1954-1959	4.23	0.50	0.57	1.0	1.0	0.79
1960-1963	6.23	0.50	0.57	1.0	1.0	0.55
1964-1971	6.23	0.40	0.57	1.0	1.0	0.69

The values of the variables for the extreme (5th- or 95th-percentile) conditions and the resulting MDA (dpm/24-hr sample) for all of the extreme conditions occurring for the same sample are:

Period	Values of the variables					MDA
	s_o	ε	R	V_f	F_a	
1952	6.09	0.45	0.24	0.58	0.9	7.4
1953	7.12	0.45	0.24	0.58	0.9	6.2
1954-1959	7.12	0.50	0.24	0.58	0.9	5.6
1960-1962	10.27	0.50	0.24	0.58	0.9	3.9
1963	10.27	0.50	0.24	0.58	0.7	5.0
1964-1971	10.27	0.40	0.24	0.58	0.7	6.3
1971 (T=40minutes)	5.18	0.40	0.24	0.58	0.7	13

The value of s_o incorporates the 95th-percentile value of the blank.

It is unlikely that the four extreme conditions (high blank, low recovery, low volume, and cruddy residue on the planchet) all occurred for the same sample. The following tables present the MDA for each of the extreme conditions individually, as well as for combinations of two and three extreme conditions.

MDA (dpm/24-hr sample) for one extreme condition

Period	s_o	R	V_f	F_a
1952	1.6	2.5	1.8	1.2
1953	1.4	2.1	1.5	0.98
1954-1959	1.2	1.9	1.4	0.88
1960-1962	0.86	1.3	0.95	0.61
1963	0.86	1.3	0.95	0.79
1964-1971	1.1	1.6	1.2	0.98
1971 (T=40minutes)	2.2	3.4	2.4	2.0

MDA (dpm/24-hr sample) for two extreme conditions

Period	s_o, R	s_o, V_f	s_o, F_a	R, V_f	R, F_a	V_f, F_a
1952	3.9	2.8	1.8	4.3	2.8	2.0
1953	3.3	2.4	1.5	3.6	2.3	1.7
1954-1959	2.9	2.1	1.4	3.2	2.1	1.5
1960-1962	2.0	1.5	0.96	2.3	1.5	1.1
1963	2.0	1.5	1.2	2.3	1.9	1.4
1964-1971	2.6	1.9	1.5	2.8	2.3	1.7
1971 (T=40minutes)	5.2	3.8	3.1	5.8	4.8	3.5

MDA (dpm/24-hr sample) for three extreme conditions

Period	s_o, R, V_f	s_o, R, F_a	s_o, V_f, F_a	R, V_f, F_a
1952	6.7	4.3	3.1	4.7
1953	5.6	3.6	2.6	4.0
1954-1959	5.1	3.3	2.4	3.6
1960-1962	3.5	2.3	1.6	2.5
1963	3.5	2.9	2.1	3.1
1964-1971	4.4	3.6	2.6	4.0
1971 (T=40minutes)	9.0	7.5	5.4	8.3

Discussion

The MDA is an *a priori* concept that may be applied *a posteriori* to a sample under certain circumstances: that the parameter values for the sample (e.g., volume, recovery, detector efficiency, count time) are or can be known prior to the processing of the sample result, and that the information is used, conceptually, to determine the sub-population of conditions of which that sample is a member. Then the *a priori* MDA value for that subpopulation can be assigned to that sample. The sample volume, the characteristics of the detector that is used to count the sample, and the count time are all known before the analysis of the sample measurement. In theory, but generally not in practice, the recovery could also be known before the analysis of the sample measurement.

The MDA values presented in this report represent an overall process MDA for the median and extreme conditions. However, sufficient information is presented to allow the determination of the MDA for a specific sample if the sample-specific parameter values were known. The sample-specific parameter values, except for recovery, are generally recorded in the urine data logs, but not all of the urine data logs have been located and some may not have been archived.

The recoveries for 1952 to 1971 were determined by batch spikes. Not until 1973 were some plutonium samples spiked with an internal tracer (first ^{236}Pu and, later, ^{242}Pu). All plutonium samples were spiked with an internal tracer after 1978. Experience has shown that a significant variability of recovery can exist within a batch of samples. Therefore, the recovery of a batch spike does not necessarily indicate the recovery of each sample in the batch.

Whether to use the median value of the MDA or the extreme value depends on the purpose. By definition, the median value implies that half of the samples will have a sample-specific MDA that is lower, and half higher. If the purpose is to define a sample-specific conservative bound, the MDA for the extreme condition should be considered. In general, the recovery is the variable that had the most influence on the sample-specific MDA.

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REFERENCE

HPS (Health Physics Society), 1996, An American National Standard – Performance Criteria for Radiobioassay, HPS N13.30-1996.

ATTACHMENT B
MINIMUM DETECTABLE ACTIVITY FOR *IN VIVO* LUNG COUNTS AT ROCKY FLATS

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B.1 INTRODUCTION

In vivo lung counts have been performed at Rocky Flats since 1964 to determine the activity of plutonium in the lungs of workers who were exposed, or had the potential to be exposed, to airborne plutonium. The method of *in vivo* lung counts was to place one or more detectors over the chest of the subject and count the photons emitted from the plutonium mixture, if any, in the subject's chest. Plutonium was not detected directly because of the low abundance of gamma photons and because of the severe attenuation of the more abundant L X-rays. Instead, the 59.5-keV gamma photon from ^{241}Am was used to detect ^{241}Am, which is present to some extent in all weapons-grade plutonium at Rocky Flats. The activity of plutonium was then calculated from the detected ^{241}Am by measuring, calculating, or assuming the fraction of the ^{241}Am in the plutonium mixture on the date of the lung count. At Rocky Flats, the fraction of the ^{241}Am in the plutonium mixture has historically been characterized in terms of parts per million by weight. Direct *in vivo* measurement of plutonium in the lungs, although investigated, was never implemented at Rocky Flats. The Rocky Flats lung counter detected ^{241}Am. The assessment of the MDA, therefore, is focused on the MDA for ^{241}Am. The MDA for plutonium can then be derived from the ^{241}Am MDA based on the value of the ppm ^{241}Am for the plutonium mixture.

B.2 MDA METHODOLOGY

The general equation for the MDA is Equation 6 in the American National Standard, *Performance Criteria for Radiobioassay* (HPS 1996):

$$MDA = (1 + \Delta_K)\,(2\Delta_B B + 2k s_o + 3) / KT \qquad (5B\text{-}1)$$

where:

B = the total count of the appropriate blank
s_o = the standard deviation in the net sample count of a subject with no additional analyte

$$s_o = \sqrt{[s_{B1}^2 + (1/m^2)\, s_{B0}^2]} \qquad (5B\text{-}2)$$

where:

s_{B1} = the standard deviation of the subject, where the subject contains no actual analyte above that of the appropriate blank
s_{B0} = the standard deviation in the unadjusted count of the appropriate blank
m = the adjustment factor for the appropriate blank

K = calibration factor
Δ_K = the maximum fractional systemic error bound in the calibration factor K
Δ_B = the maximum expected fractional systemic error bound in the appropriate blank
k = the abscissa of the standardized normal distribution corresponding to the 0.05 probability level (for $\alpha = 0.05$ and $\beta = 0.05$, k = 1.645)
T = the standard subject counting time for the procedure

Applying this equation to *in vivo* lung counting at Rocky Flats involves determining the value of each of these variables for the counting systems and procedures used at Rocky Flats as the systems and procedures evolved. The MDA for *in vivo* measurements is necessarily individually specific because the detectability of ^{241}Am in the chest is a significant function of the chest wall thickness (CWT) of the subject.

The MDA may also be determined empirically from replicate measurements on an appropriate blank. This approach is used for the current system at Rocky Flats.

B.3 HISTORY OF COUNTING SYSTEMS AND PROCEDURES

The *in vivo* lung counting systems at Rocky Flats consisted of photon detectors mounted in a shielded room (6 inches thick low-background steel lined with layers of lead, tin, and zinc) with electronic equipment (amplifiers and multi-channel analyzers) to process and record the data.

There were three counting rooms:

- Room A, built in 1964, operational in 1965
- Room B, built in 1968, operational in 1969
- Room C, built in 1975, operational in 1976

Each room was equipped with a detector system. When a new detector system was implemented, the previous system was usually maintained as a standby, backup system. As a result, end dates for a given detector system are not known. In the era of the Ge detector systems, two or more detector systems could have been operational simultaneously. In that type of situation, the detector system is identified in the record for each lung count.

1964–1968
There was one counting room. The detector system consisted of two NaI(Tl) scintillation detectors (there was a third detector used for cesium and potassium measurements), each detector was round with a diameter of 4 inches and was 4 millimeters thick with a surface area of 80 square centimeters. These detectors were known as the 4x4 detectors. In most situations, the detectors were configured with one detector above the left portion of the upper chest and the second detector was over the liver and gut region. The chest detector was sometimes placed over the right portion of the upper chest instead of the left position. In other cases, both detectors were placed over the chest. The chest detector(s) was placed in a framework called a jig to allow a standard and reproducible position for all subjects. Count time was either 40 minutes live time (MLT) or 20 MLT. Two backgrounds were used: 1) room background and 2) matched subject background. The room background was the count rate in the empty counting room measured at the start of the day. The matched subject background was the count rate of an unexposed subject with matched ^{137}Cs and ^{40}K count rates. Calibration was based on ^{241}Am impregnated epoxy lungs in the chest cavity of a water-filled REMCAL™ phantom, manufactured by Alderson Research Laboratories, Inc. No adjustment was made for CWT.

1969–1976
During this period, two counting rooms were operational with three 4x4 NaI(Tl) scintillation detectors, two over the upper chest (right and left portions) and one over the liver/gut region (the liver/gut detector was eliminated in 1974).

Changes:

1. The ROI of the 59.5-keV photopeak of ^{241}Am was expanded.

2. The use of the jig for positioning the detectors was discontinued. Instead, the detectors were positioned in light contact with the surface of the chest.

3. The standard count time was changed to 2,000 seconds (1,000 seconds for expedited counts).

4. The method of the matched subject background based on ^{137}Cs and ^{40}K was replaced by the index method.

The index method, developed by Robert Bistline, had the following features:

1. Subjects were characterized by an index I equal to the ratio of the subject's weight (W, pounds) divided by twice the subject's height (H, inches).

2. A population of at least 20 known cold (unexposed) subjects of a diversity of indices was counted to generate a data set of net count rate versus index.

3. A curve fit to the data set generated a prediction equation with the index as the variable.

4. The subject's index was used to determine the predicted net count rate for the subject.

This approach was done separately for the right chest, the left chest, and the liver/gut.

In 1973, a phoswich detector system was implemented and used intermittently into the 1980's. The NaI(Tl) layer of the phoswich detectors was dimensionally the same as the 4x4 detectors.

This system lacked the stability of the NaI(Tl) detector system and was used mainly as a backup system. Use of the phoswich system to detect plutonium directly via the L X-rays was not successfully implemented at Rocky Flats.

In about 1972, room background was measured at the start of the day shift, at noon, and at the start of the night shift. The value of the room background used was the five-point moving average of the last five counts.

Starting in 1969, the ppm ^{241}Am was measured from a representative sample of the plutonium mixture associated with incidents with the potential for inhalation exposure of workers. This situation was called a PI (for possible inhalation) and refers both to the incident and to the worker involved in the incident.

In this period, the use of a lithium-drifted Ge detector system was investigated but was never implemented.

1976–1985

This period is the era of the high-purity Ge detector array systems. Three counting rooms were operational. When the Ge systems were implemented, most, if not all, quantitative measures were accomplished with that system. The NaI(Tl) and phoswich systems were used only as screening systems, and later only as backup systems. The Ge systems in this period featured four detectors mounted in an array attached to a single cryostat containing liquid nitrogen. The system had two of these arrays, one positioned over the upper right chest and the other over the upper left chest. A full system consisted of eight detectors. However, occasionally one or more of the detectors failed and were electronically eliminated from the system. A minimum system was five detectors, three in the right array and two in the left array. To maintain a minimum functional system, a hybrid system consisting of two arrays of different characteristics was frequently used.

The Ge system implementation timeline was:

1976 Ortec detectors, 10 cm^2 per detector, two arrays

1977 Princeton Gamma Tech (PGT I) detectors, 15 cm^2 per detector, two arrays
1979 First array, Princeton Gamma Tech (PGT II) detectors, 18 cm^2 per detector
1980 Second array, Princeton Gamma Tech (PGT II) detectors, and 18 cm^2 per detector

Other changes in this period were:

1. The calibration factor for the Ge systems was adjusted for the CWT of the subject. The thickness (cm) was equal to twice the index value minus 0.1 (CWT = 2 I – 0.1).

2. Calibration was accomplished using a masonite phantom from 1976 to 1978.

3. Calibration was accomplished using the Lawrence Livermore Laboratory (LLL) phantom from 1979 to present.

4. The method of determining the background changed for the Ge systems. Room and subject background were determined, as a unit, from the subject's own spectrum using a ROI in the range of 65 to 72 keV.

1985–1995
In this period, Ge detectors in the organ pipe configuration were implemented. Instead of clustering four detectors in an array with a common cryostat, each detector was attached to its own cryostat, which was tall and slender. The detectors with the cryostats were then clustered in arrays, two to four detectors per array, over the right and left portions of the upper chest. If a detector malfunctioned, it was physically replaced with a backup, functional detector. A minimum system from 1985 to 1991 was five detectors, three detectors on the right and two on the left. The full system was seven detectors, four detectors on the right and three on the left, although the routine system generally consisted of six detectors, either four on the right and two on the left or three on each side. In 1991, the full system was six detectors with either four detectors on the right and two on the left or three detectors on each side.

The Ge system implementation timeline was:

1985 Princeton Gamma Tech organ pipe detectors, 20 cm^2 per detector
1991 EG&E Ortec organ pipe detectors, 20 cm^2 per detector

No other significant changes were made during this period.

1995–Present
In May 1995 the lung counter hardware, software, and detectors were upgraded. The data acquisition and analysis were accomplished using the Canberra Industries program ABACOS-Plus©. Instead of the ROI approach used historically, this program used a peak-search method to detect activity of a radionuclide. The value of the MDA was established by replicate measurements on an appropriate blank. The Ge detectors were replaced by EG&E Ortec organ pipe detectors with 38 cm^2 per detector. The standard system was four detectors, two on each side. The minimum system was three detectors, two on the right and one on the left.

Another significant change is the equation to determine the CWT. ABACOS-Plus© incorporates the equation developed by Anderson (1983) at Lawrence Livermore National Laboratory:

$$CWT\ (cm) = 1.973\ (W/H) - 2.0038 \qquad (5B\text{-}3)$$

where:

W = subject's weight (pounds), and
H = subject's height (inches).

The effect of this change is an adjustment factor, given by the equation:

$$\text{CWT Adjustment Factor} = 0.5364 \exp(0.635\ I) \quad \text{(5B-4)}$$

This adjustment factor is a multiplier to the activity of ^{241}Am, detected via the 59.5-keV gamma, for all previous detector systems at Rocky Flats. Equation 5B-4 may also be applied as a divisor to historical calibration factors for previous systems at Rocky Flats.

B.4 ASSESSMENT OF MDA

The value of the MDA for ^{241}Am is assessed for each detector system and for each significant change in the procedure. It is assessed not only for the typical Rocky Flats male (I = 1.35, CWT = 3.3 cm) but also for a reasonable range of statures (I = 0.90, CWT = 1.5 cm and I = 1.80, CWT = 5.1 cm). The assessment is also done for the minimally configured system as well as for the standard system and for half of the normal count time (for expedited lung counts) as well as the full count time.

Discontinuities, which were significant changes in methods affecting the interpretation of the raw data (and hence the MDA), were identified and were incorporated into the value of the calibration factor. This process was done starting with the most recent calibration method, assumed to be the most accurate. The factors associated with each discontinuity were then applied, as divisors to the calibration factor, back through the history of the systems. Alternatively, the product of the factors, for the appropriate period, may be used in place of the term $(1 + \Delta_K)$ in Equation 5B-1. The discontinuity factors are:

Year	Discontinuity	Factor
1995	New CWT method	
	Index = 0.90	0.95
	Index = 1.35	1.26
	Index = 1.80	1.68
1979	Calibration using LLL phantom	1.30
1969	Fixed positioning discontinued ROI for 59.5-keV photopeak increased	1.45

The discontinuity factors for the CWT can be calculated by any index I using:

$$\text{CWT Discontinuity Factor} = 0.5364 \exp(0.635\ I) \quad \text{(5B-5)}$$

Values of the Variables, 1964–1968
The minimum system was one NaI(Tl) detector positioned over the left chest.

Count time T = 20 MLT or 40 MLT

The appropriate blank, B, was the net man background (after room background was subtracted) estimated from matched, unexposed subjects based on ^{137}Cs and ^{40}K measurements.

B = 600 for T = 20 MLT
B = 1,200 for T = 40 MLT

Δ_B = 0.2, estimated as the upper bound for this method.

The value of s_o is calculated from counting statistics, including the total subject count, which is taken as the sum of B and the room background R.

R = 500 for T = 20 MLT
R = 1,000 for T = 40 MLT

Because the decision of detection was based on the net subject count rate (after subtraction of room background) compared with the predicted net count rate of the appropriate blank, the calculation of s_{B1} includes an extra component of the room background.

s_{B1}^2 = Total subject count + R = B + 2R
= 1,600 for T = 20 MLT
= 3,200 for T = 40 MLT
s_{B0}^2 = B
= 600 for T = 20 MLT
= 1,200 for T = 40 MLT
m = 1
s_o = 44.9 for T = 20 MLT
= 66.3 for T = 40 MLT

The ^{241}Am calibration factor K for two detectors, normalized to the calibration with the Lawrence LLL phantom and incorporating the discontinuity factors, equation 5B-5, 1.30, and 1.45, is given by:

$$K = 55.13 \exp(-0.2359 (2 I - 0.1))/\exp(0.635 I) \quad (5B\text{-}6)$$

The calibration factor for the system with only one detector over the left portion of the chest is given by Equation 5B-6 multiplied by 0.43. This factor is the fraction of the total activity in the calibration lungs of the Rocky Flats LLL phantom that is in left portion of the lung. The MDA, therefore, pertains to the activity in the total lung based on the detection of activity only in the left portion of the lung.

K = 8.96 for I = 0.90
K = 5.45 for I = 1.35
K = 3.31 for I = 1.80

Because K is normalized to the calibration with the LLL phantom and the discontinuity factors are incorporated into K, the value of Δ_K is taken to be 0. Since the term $(1 + \Delta_K)$ in Equation 5B-1 is a multiplier to the MDA and since the value of Δ_K is estimated based on the professional judgment of the analyst, one can easily adjust the values of the MDA in this paper if another analyst has a different judgment.

For the standard system of two detectors, over both the right and left portions of the lungs, the counts are basically doubled and the values of the variables are:

B = 1,200 for T= 20 MLT
B = 2,400 for T= 40 MLT
Δ_B = 0.2, estimated as the upper bound for this method
R = 1,000 for T= 20 MLT
R = 2,000 for T= 40 MLT
s_{B1}^2 = Total subject count + R = B + 2R

= 3,200 for T = 20 MLT
= 6,400 for T = 40 MLT
s_{B0}^2 = B
= 1,200 for T = 20 MLT
= 2,400 for T = 40 MLT
m = 1
s_o = 69.3 for T = 20 MLT
= 93.8 for T = 40 MLT
K = 20.85 for I = 0.90
= 12.67 for I = 1.35
= 7.70 for I = 1.80

B.5 VALUES OF THE VARIABLES, 1969 → FOR NAI(TL) AND PHOSWICH DETECTOR SYSTEMS

The standard system was two detectors positioned over the left and right portions of the chest. This is also the minimum system.

Count time T = 1,000 seconds or 2,000 seconds

The appropriate blank was the net man background (after room background was subtracted) estimated from matched, unexposed subjects based on the subject's index:

B = 1,100 for T = 1,000 seconds
B = 2,200 for T = 2,000 seconds
Δ_B = 0 for the NaI(Tl) detector system
Δ_B = 0.1, estimated for the phoswich detector system, because the system was less stable than the NaI(Tl) detector system.

The value of s_o is calculated from counting statistics, including the total subject count, which is taken as the sum of B and the room background R. The value of s_{B0} is taken to be 10% of the value B, based on the typical relative standard deviation of the predicted subject net count rate.

R = 833 for T = 1,000 seconds
R = 1,667 for T = 2,000 seconds
s_{B1}^2 = Total subject count + R = B + 2R
= 2,767 for T = 1,000 seconds
= 5,533 for T = 2,000 seconds
s_{B0}^2 = $(0.1B)^2$
= 12,100 for T = 1,000 seconds
= 48,400 for T = 2,000 seconds
m = 1
s_o = 121.9 for T = 1,000 seconds
= 232.2 for T = 2,000 seconds

The ^{241}Am calibration factor K for two detectors, normalized to the calibration with the LLL phantom and incorporating the discontinuity factors, Equation 5B-5 and 1.30, is given by:

$$K = 79.94 \exp(-0.2359 (2 I - 0.1))/\exp(0.635 I) \quad (5B\text{-}7)$$

K = 30.23 for I = 0.90

= 18.37 for I = 1.35
= 11.16 for I = 1.80

B.6 VALUES OF THE VARIABLES, 1976 → FOR ORTEC GERMANIUM DETECTOR SYSTEMS

The standard system was two arrays, each array with four detectors, positioned over the left and right portions of the chest. The minimum system was two arrays with a total of eight detectors.

Count time T = 1,000 seconds or 2,000 seconds

The appropriate blank was the count in the subject's spectrum (composite for all detectors) in the range of 65 keV to 72 keV, divided by eight. The subject, in essence, was his own blank with essentially no bias. Room background was no longer assessed separately for Ge systems.

$\Delta_B = 0$
m = 8

For eight detectors:

B = 341 for T = 1,000 seconds (unadjusted by m = 8)
B = 682 for T = 2,000 seconds (unadjusted by m = 8)

For five detectors:

B = 213 for T = 1,000 seconds (unadjusted by m = 8)
B = 427 for T = 2,000 seconds (unadjusted by m = 8)

For the calculation of s_{B1}, the subject background is B/8.

For eight detectors:

T = 1,000 seconds:
s_{B1} = 6.53 s_{B0} = 18.5 s_0 = 6.93
T = 2,000 seconds:
s_{B1} = 9.23 s_{B0} = 26.1 s_0 = 9.79

For five detectors:

T = 1,000 seconds:
s_{B1} = 5.17 s_{B0} = 14.6 s_0 = 5.48
T = 2,000 seconds:
s_{B1} = 7.30 s_{B0} = 20.7 s_0 = 7.75

The ^{241}Am calibration factor K for two arrays with a total of eight detectors, based on the calibration with the LLL phantom and incorporating the discontinuity factors, Equation 5B-5 and 1.30 (for pre-1979 systems), is given by:

$$K = 24.12 \exp(-0.3398 (2 I - 0.1))/\exp(0.635 I) \quad (5B\text{-}8)$$

and, for Ortec systems 1979 and following:

$$K = 31.36 \exp(-0.3398 (2 I - 0.1))/\exp(0.635 I) \quad (5B\text{-}9)$$

For the minimum system of five detectors, adjust the calibration factor by multiplying by (5/8).

Index	Eight-detector calibration factor (K)	
	Pre-1979	1979 →
0.90	7.64	9.94
1.35	4.23	5.50
1.80	2.34	3.04

B.7 VALUES OF THE VARIABLES, 1978 → FOR PGT I GERMANIUM DETECTOR SYSTEMS

The PGT I Ge system is basically the same as the Ortec Ge system. The main difference is that the PGT I detectors had a larger surface area but a poorer resolution.

$\Delta_B = 0$
m = 4

For eight detectors:

B = 240 for T = 1,000 seconds (unadjusted by m = 4)
B = 480 for T = 2,000 seconds (unadjusted by m = 4)

For five detectors:

B = 150 for T = 1,000 seconds (unadjusted by m = 4)
B = 300 for T = 2,000 seconds (unadjusted by m = 4)

For the calculation of s_{B1}, the subject background is B/4.

For eight detectors:

T = 1,000 seconds:
$s_{B1} = 7.75$ $s_{B0} = 15.5$ $s_0 = 8.67$
T = 2,000 seconds:
$s_{B1} = 10.95$ $s_{B0} = 21.9$ $s_0 = 12.2$

For five detectors:

T = 1,000 seconds:
$s_{B1} = 6.12$ $s_{B0} = 12.2$ $s_0 = 6.84$
T = 2,000 seconds:
$s_{B1} = 8.66$ $s_{B0} = 17.3$ $s_0 = 9.68$

The ^{241}Am calibration factor K for two arrays with a total of eight detectors, based on the calibration with the LLL phantom and incorporating the discontinuity factors, Equation 5B-5 and 1.30 (for pre-1979 systems), is given by:

$$K = 34.09 \exp(-0.3292 (2 I - 0.1))/\exp(0.635 I) \quad (5B\text{-}10)$$

and, for PGT I systems 1979 and following:

$$K = 44.318 \exp(-0.3292 (2 I - 0.1))/\exp(0.635 I) \quad (5B\text{-}11)$$

For the minimum system of five detectors, adjust the calibration factor by multiplying by (5/8).

Index	Eight-detector calibration factor (K)	
	Pre-1979	1979 →
0.90	11.00	14.30
1.35	6.15	7.99
1.80	3.43	4.46

B.8 VALUES OF THE VARIABLES, 1979 → FOR PGT II GERMANIUM DETECTOR SYSTEMS

The PGT II Ge system is basically the same as the Ortec and PGT I systems. The main difference is that the PGT II detectors, again, had a larger surface area but a poorer resolution.

$\Delta_B = 0$
m = 4

For eight detectors:

B = 273 for T = 1,000 seconds (unadjusted by m = 4)
B = 546 for T = 2,000 seconds (unadjusted by m = 4)

For five detectors:

B = 170 for T = 1,000 seconds (unadjusted by m = 4)
B = 341 for T = 2,000 seconds (unadjusted by m = 4)

For the calculation of s_{B1}, the subject background is B/4.

For eight detectors:

T = 1,000 seconds:
$s_{B1} = 8.26$ $s_{B0} = 16.5$ $s_0 = 9.23$
T = 2,000 seconds:
$s_{B1} = 11.7$ $s_{B0} = 23.4$ $s_0 = 13.1$

For five detectors:

T = 1,000 seconds:
$s_{B1} = 6.53$ $s_{B0} = 13.1$ $s_0 = 7.31$
T = 2,000 seconds:
$s_{B1} = 9.23$ $s_{B0} = 18.5$ $s_0 = 10.3$

The ^{241}Am calibration factor K for two arrays with a total of eight detectors, incorporating Equation 5B-5, is given by:

$$K = 38.65 \exp(-0.3579 (2 I - 0.1))/\exp(0.635 I) \quad (5B\text{-}12)$$

For the minimum system of five detectors, adjust the calibration factor by multiplying by (5/8).

Index	Eight-detector calibration factor (K)
0.90	11.88
1.35	6.47
1.80	3.52

B.9 VALUES OF THE VARIABLES, 1985 → FOR PGT ORGAN PIPE GERMANIUM DETECTOR SYSTEMS

The PGT organ pipe Ge system is basically the same as the previous Ge array systems. The main difference is the ability to maintain a stable, standard configuration with six detectors.

$\Delta_B = 0$
m = 4

	T = 1,000 seconds	T = 2,000 seconds
B:	215	429
s_{B1}:	7.33	10.4
s_{B0}:	14.7	20.7
s_0:	8.20	11.6

The ^{241}Am calibration factor K for two arrays with a total of six detectors, incorporating equation 5B-5, is given by:

$$K = 34.32 \exp(-0.2946 (2 I – 0.1)) / \exp(0.635 I) \quad (5B\text{-}13)$$

Index	Six-detector calibration factor (K)
0.90	11.74
1.35	6.77
1.80	3.90

B.10 VALUES OF THE VARIABLES, 1985 → FOR EG&G ORGAN PIPE GERMANIUM DETECTOR SYSTEMS

The EG&G organ pipe Ge system is basically the same as the previous PGT organ pipe Ge array system.

$\Delta_B = 0$
m = 4

	T = 1,000 seconds	T = 2,000 seconds
B:	204	408
s_{B1}:	7.14	10.1
s_{B0}:	14.3	20.2
s_0:	7.98	11.3

The ^{241}Am calibration factor K for two arrays with a total of six detectors, incorporating equation 5B-5, is given by:

$$K = 42.36 \exp(-0.3708 (2 I – 0.1)) / \exp(0.635 I) \quad (5B\text{-}14)$$

Index	Six-detector calibration factor (K)
0.90	12.73
1.35	6.85
1.80	3.69

Values of the Variables, 1995 →
The MDA for the current system at Rocky Flats was not determined analytically using equation 5B-1. Instead, the MDA was determined empirically from replicate measurements on an appropriate blank simulating the counts of the average Rocky Flats worker (CWT = 3.36 cm). Therefore, there are no values of the variables to be listed here. The value of the MDA for the average Rocky Flats worker (CWT = 3.36 cm, I = 1.35) is 0.3 nCi ^{241}Am.

To extrapolate this value to the range of workers (CWT = 1.15 cm, I = 0.90 to CWT = 5.10 cm, I = 1.80), the following approach was used to establish the calibration factor equation as a function of CWT:

The efficiency equation is:

$$\varepsilon = a_1 \exp(a_2 \, CWT) \qquad (5B\text{-}15)$$

where

ε = count per minute per gamma from ^{241}Am
a_1 = 0.045 (factor determined from calibration)
a_2 = -0.41 (factor determined from calibration)

The efficiency equation converts to the style of historical calibration equations, using the conversion factors of 0.359 gamma photons (59.5 keV) per ^{241}Am nuclear transformation, and 797 gammas per minute per nCi ^{241}Am. The derived calibration equation is:

$$K = 35.9 \exp(-0.41 \, CWT) \qquad (5B\text{-}16)$$

The MDA for any value of CWT is then obtained from the product of 0.3 nCi (the MDA for the average Rocky Flats worker) and the ratio (9.05/K for the value of the CWT).

B.11 MDA FOR ROCKY FLATS PLUTONIUM

The MDA for Rocky Flats plutonium is derived from the MDA of ^{241}Am, based on the value of the ppm ^{241}Am in the plutonium mixture at the time of the lung count. To convert the MDA for ^{241}Am to the MDA for plutonium (^{239}Pu and ^{240}Pu), the MDA for ^{241}Am is multiplied by the factor:

$$\text{MDA Conversion Factor} = (1 \times 10^6 - \text{ppm } ^{241}\text{Am})/(48.2 \text{ ppm } ^{241}\text{Am}) \qquad (5B\text{-}17)$$

The MDA conversion factors for some typical values of ppm ^{241}Am are:

ppm ^{241}Am	MDA conversion factors
100	207
1,000	20.7
10,000	2.05

The task is to determine the value of the ppm ^{241}Am at the time of the lung count. The practice at Rocky Flats was to measure the ppm ^{241}Am in a representative sample of material involved in a possible inhalation incident. If a representative sample was not obtained or the origin of the intake was not known, a default value of 1,000 ppm ^{241}Am was used and was assigned to the date of the intake or to the date of the first positive lung count, if the date of the intake was not known. For subsequent lung counts, the value of the ppm ^{241}Am was updated to account for the ingrowth of the ^{241}Am from the nuclear transformation of ^{241}Pu and for the radioactive decay of the ^{241}Am. The rate of ingrowth of ^{241}Am in the plutonium mixture depends on the fraction by weight of the ^{241}Pu in the mixture. The initial weight fraction of ^{241}Pu in Rocky Flats plutonium is taken to be 0.0050 in the 1950s and 1960s and 0.0036 in the 1970s and later. The following table presents values of the ppm ^{241}Am at times (years) after the intake for initial values of ppm ^{241}Am of 100, 1,000, and 10,000. The value of 100 ppm ^{241}Am may be taken as the lower bound and represents freshly purified plutonium.

	^{241}Am ppm at Time (years) after Intake					
	Initial fraction ^{241}Pu = 0.0036			**Initial fraction ^{241}Pu = 0.0050**		
Years	**100**	**1,000**	**10,000**	**100**	**1,000**	**10,000**
1	270	1,200	10,200	340	1,200	10,200
2	430	1,300	10,300	560	1,500	10,400
4	730	1,600	10,600	980	1,900	10,800
6	1,000	1,900	10,800	1,400	2,200	11,100
10	1,500	2,400	11,200	2,000	2,900	11,700
20	2,300	3,200	11,900	3,100	4,000	12,700
30	2,800	3,600	12,200	3,800	4,700	13,200
40	3,000	3,900	12,300	4,200	5,000	13,500
50	3,200	4,000	12,300	4,400	5,200	13,500

The appropriate value of the ppm ^{241}Am should be applied for lung counts that occurred following a known or assumed intake.

The equation to calculate the ppm ^{241}Am for any time (years) after the intake is:

$$A = L_1 P_0 [\exp(-\lambda_{Pu\,241} T) - \exp(-\lambda_{Am241} T)] + 10^6 A_0 L_2 / [A_0 L_2 + \exp(-\lambda_{Pu239} T)] \qquad (5B\text{-}18)$$

where

A = ppm ^{241}Am at time T (years)
L_1 = $\lambda_{Pu241} / (\lambda_{Am241} - \lambda_{Pu241})$
λ_{Pu241} = decay constant for ^{241}Pu (half-life = 14.4 years) = 0.0481
λ_{Am241} = decay constant for ^{241}Am (half-life = 433 years) = 0.00160
A_0 = initial ppm ^{241}Am
P_0 = initial ^{241}Pu ppm = (Initial ^{241}Pu fraction by weight) × $(10^6 - A_0)$
L_2 = $\exp(-\lambda_{Am241} T) / (10^6 - A_0)$
λ_{Pu239} = decay constant for ^{239}Pu (half-life = 24,100 years) = 0.0000288

Half-times are from *Table of Isotopes, Seventh Edition* (Lederer and Shirley 1978).

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SUMMARY OF MDA FOR *IN VIVO* LUNG COUNTS AT ROCKY FLATS

Period	Detector system	Index	MDA (nCi) for ^{241}Am				Comments
			Minimum system		Standard system		
			Half time	Full time	Half time	Full time	
1964 - 1968	NaI(Tl) 4x4	0.90	1.7	1.5	1.3	1.2	Full time = 40 minutes live time (MLT). Minimum system is one detector over the left chest. Standard system is two detectors, over right and left chests.
		1.35	2.8	2.5	2.1	1.9	
		1.80	4.6	4.1	3.5	3.2	
1969 -	NaI(Tl) 4x4	0.90			0.80	0.76	Full time = 2000 seconds. Standard system is two detectors, over right and left chests.
		1.35			1.3	1.3	
		1.80			2.2	2.0	
1973 -	Phoswich	0.90			1.2	1.2	Full time = 2000 seconds. Standard system is two detectors, over right and left chests. NaI sensitive layer is the same as the NaI 4x4.
		1.35			2.0	2.0	
		1.80			3.3	3.2	
1976 - 1978	Ortec Arrays (High-purity Ge)	0.90	0.26	0.18	0.20	0.14	Full time = 2000 seconds. Standard system is 8 detectors in 2 arrays. Minimum system is 5 detectors in 2 arrays.
		1.35	0.48	0.32	0.37	0.25	
		1.80	0.86	0.59	0.66	0.45	
1979 -	Ortec Arrays (High-purity Ge)	0.90	0.20	0.14	0.16	0.11	Same as previous Ge system.
		1.35	0.37	0.25	0.28	0.19	
		1.80	0.66	0.45	0.51	0.35	
1978 -	PGT I Arrays (High-purity Ge)	0.90	0.22	0.15	0.17	0.12	Same as previous Ge systems.
		1.35	0.40	0.27	0.31	0.21	
		1.80	0.71	0.49	0.55	0.38	
1979 -	PGT I Arrays (High-purity Ge)	0.90	0.17	0.12	0.13	0.09	Same as previous Ge systems.
		1.35	0.31	0.21	0.24	0.16	
		1.80	0.55	0.38	0.42	0.29	
1979 -	PGT II Arrays (High-purity Ge)	0.90	0.22	0.15	0.17	0.12	Same as previous Ge systems.
		1.35	0.40	0.28	0.31	0.21	
		1.80	0.74	0.50	0.57	0.39	
1985 -	PGT Organ Pipe (OP) Ge Detectors	0.90			0.15	0.11	Standard system = 6 detectors. Standard count time = 2000 seconds. Occasionally, 5 or 7 detectors were used.
		1.35			0.26	0.18	
		1.80			0.46	0.32	
1991 -	EG&G Organ Pipe Ge Detectors	0.90			0.14	0.10	Standard system = 6 detectors. Standard count time = 2000 seconds.
		1.35			0.26	0.18	
		1.80			0.48	0.33	
1995 -	Ortec 2 Organ Pipe Ge Detectors	0.90				0.14	Standard system = 4 detectors. Standard count time = 2000 seconds.
		1.35				0.3	
		1.80				0.6	

Note: Starting in 1978, hybrid Ge systems were used that combined two differing Ge arrays or detector types. For hybrid systems, use the higher of the MDA values for the detector types involved.

The index is the ratio of the weight (pounds) of the subject divided by twice the height (inches) and is correlated with the CWT. The index of 1.35 represents the typical Rocky Flats male subject, with a reasonable range of 0.90 (CWT = 1.5 cm) to 1.80 (CWT = 5.1 cm).

To convert the MDA for ^{241}Am to the MDA for Pu-239,240, multiply the MDA for ^{241}Am by [(1x10^{6} – ppm ^{241}Am)/(48.2 x ppm ^{241}Am)], where ppm ^{241}Am is the parts per million by weight of the ^{241}Am in the plutonium mixture at the time of the lung count.

SUMMARY OF MDA FOR *IN VIVO* LUNG COUNTS AT ROCKY FLATS (Cont'd.)

^{241}Am grows into the plutonium mixture from the nuclear transformation of Pu-^{241}. The initial weight fraction of Pu-^{241} in Rocky Flats plutonium is 0.0050 in the 1950's and 1960's and 0.0036 in the 1970's and 1980's. For freshly purified plutonium, with a residual of approximately 100 ppm 241Am, the ppm ^{241}Am would be 270 to 340 after the first year, 430 to 560 after the second year, 730 to 980 after the 4th year, 1000 to 1400 after the 6th year, 1500 to 2000 after the 10th year, 2300 to 3100 after the 20th year, 2800 to 3800 after the 30th year, 3000 to 4200 after the 40th year, and 3200 to 4400 after the 50th year.

Half time was usually used for non-scheduled counts or when a large number of subjects needed to be counted expeditiously.

THE ATTACHMENT C
EXAMPLES OF BIOASSAY DATA RECORDS AND REPORTS

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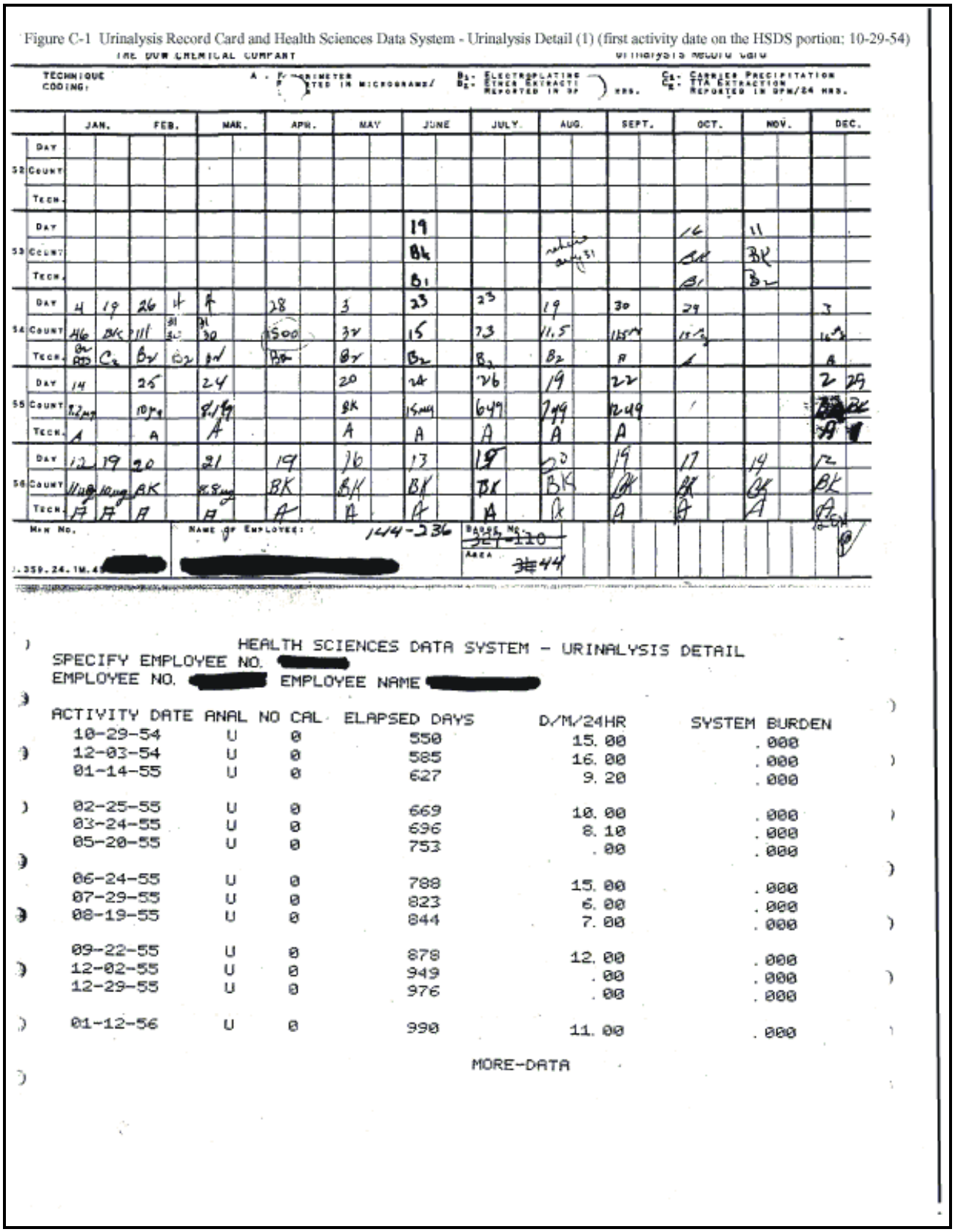


Figure C-1 Urinalysis Record Card and Health Sciences Data System - Urinalysis Detail (1) (first activity date on the HSDS portion: 10-29-54)

THE DOW CHEMICAL COMPANY — Urinalysis Record Card

TECHNIQUE CODING: A - Fluorimeter Reported in micrograms/ ; B1 - Electroplating; B2 - Ether Extraction Reported in gp) hrs.; C1 - Carrier Precipitation; C2 - TTA Extraction Reported in gpm/24 hrs.

		JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
52	Day												
	Count												
	Tech.												
53	Day						19				16	11	
	Count						BK		[illegible]		BK	BK	
	Tech.						B1				B1	B2	
54	Day	4 19	26 4	4	28	3	23	23	19	30	29		3
	Count	46 BK	111 31 30	31 30	1500	32	15	73	11.5	115	15		16
	Tech.	B2 AD C2	B2 B2	B2	B2	B2	B2	B2	B2	A	A		A
55	Day	14	25	24		20	24	26	19	22			2 29
	Count	8.2 µg	10 µg	8.1 µg		BK	15 µg	649	749	1249			BK
	Tech.	A	A	A		A	A	A	A	A			A
56	Day	12 19	20	21	19	16	13	19	20	19	17	14	12
	Count	11 µg 10 µg	BK	8.8 µg	BK	BK	BK	BK	BK	BK	BK	BK	BK
	Tech.	A A	A	A	A	A	A	A	A	A	A	A	A

MAN NO. [redacted] NAME OF EMPLOYEE: [redacted] 144-236 BADGE NO. ~~327-110~~ AREA ~~3E~~44

HEALTH SCIENCES DATA SYSTEM - URINALYSIS DETAIL

SPECIFY EMPLOYEE NO. [redacted]

EMPLOYEE NO. [redacted] EMPLOYEE NAME [redacted]

ACTIVITY DATE	ANAL	NO CAL	ELAPSED DAYS	D/M/24HR	SYSTEM BURDEN
10-29-54	U	0	550	15.00	.000
12-03-54	U	0	585	16.00	.000
01-14-55	U	0	627	9.20	.000
02-25-55	U	0	669	10.00	.000
03-24-55	U	0	696	8.10	.000
05-20-55	U	0	753	.00	.000
06-24-55	U	0	788	15.00	.000
07-29-55	U	0	823	6.00	.000
08-19-55	U	0	844	7.00	.000
09-22-55	U	0	878	12.00	.000
12-02-55	U	0	949	.00	.000
12-29-55	U	0	976	.00	.000
01-12-56	U	0	990	11.00	.000

MORE-DATA

Figure C-1. Urinalysis Record Card and Health Sciences Data System – Urinalysis Detail (1) (first activity date on the HSDS portion: 10-29-54).

Figure C-2 Urinalysis Record Card and Health Sciences Data System - Urinalysis Detail (2) (first activity date on the HSDS portion 8-19-53)

CODING: Reported in micrograms/liter B_E^- - Ether Extraction Reported in DPM/24 HRS. C_E^- - TTA Extraction Reported in DPM/24 HRS.

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY.	AUG.	SEPT.	OCT.	NOV.	DEC.
12 Day												
12 Count												
12 Tech.												
13 Day								19		16	6	24
13 Count								BK		BK	BK	BK
13 Tech.								B_2		B_2	B_2	B_2
14 Day	27	24	19	28	20	18	23	16	30	27		1 17
14 Count	3H	BK	10	BK	BK	35	12	9.3				
14 Tech.	BV RES	BV	BV	BV	B_2	B_2	B_2	B_2	B	B		A A
15 Day	26	24	23	22	20	19	22	18	21	19	17	21
15 Count	36mg	BK	8.7mg	8.5	BK	1mg	749	BK	BK	749	BK	969
15 Tech.	A	A-	A-	A-	A-	A-	A-	A-	A-	A-	A-	A-
16 Day		2 17	21	18	7 4	15	19	16	19	17	14	12
16 Count		BK BK	BK	BK	12K 8.7	6K	BK	BK	BK	BK	BK	BK
16 Tech.		A- A-	A-	A-	A	A-	A-	A-	A-	A-	A-	A-

MAN NO. [redacted] NAME OF EMPLOYEE: [redacted] BADGE NO. 144-200 AREA 44

SPECIFY EMPLOYEE NO. [redacted]

EMPLOYEE NO. [redacted] EMPLOYEE NAME [redacted]

ACTIVITY DATE	ANAL	NO CAL	ELAPSED DAYS	D/M/24HR	SYSTEM	BURDEN
08-19-53	G	0	44	.00	(00000)	.000
10-16-53	G	0	102	.00	(00000)	.000
11-06-53	G	0	123	.00	(00000)	.000
12-24-53	G	0	171	.00	(00000)	.000
01-27-54	G	0	205	34.00	(00000)	.000
02-24-54	G	0	233	.00	(00000)	.000
03-19-54	G	0	256	10.00	(00000)	.000
04-28-54	G	0	296	.00	(00000)	.000
05-20-54	G	0	318	.00	(00000)	.000
06-18-54	G	0	347	35.00	(00000)	.000
07-23-54	G	0	382	12.00	(00000)	.000
08-16-54	G	0	406	9.30	(00000)	.000
09-30-54	D	0	451	.00	(00000)	.000

( )

MORE-DATA

Figure C-2. Urinalysis Record Card and Health Sciences Data System – Urinalysis Detail (2) (first activity date on the HSDS portion 8-19-53).

Figure C-3 Urinalysis Record Card and Health Sciences Data System - Urinalysis Detail (3) (first activity date on the HSDS portion: 1-6-58)

TECHNIQUE CODING: A-Fluorimeter Reported in micrograms/24-hrs. B_1- Electroplating B_2- Ether Extraction Reported in d/m/24 hrs. C_1- Carrier Precipitation, d/m/24-hrs.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
56	Day												
	Count												
	Tech												
57	Day	16	14	14	17	15	27	18	15	13	11	14	11
	Count	BK	BK	BK	BK	BK	BK	BK	BK	BK	BK	BK	BK
	Tech	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+
58	Day	4	6	26	24						10		
	Count	BK	BK	BK	BK						BK		
	Tech	A+	B+	C+	C+						A+		
59	Day		24								9		
	Count		BK								BK		
	Tech		A+								A+		
60	Day	13			8			12			12		14
	Count	BK			BK			BK			BK		BK
	Tech	A+			A+			A+			A+		A+

Man No. [redacted] Name of Employee: [redacted] Badge No. [redacted] Area [redacted]

HEALTH SCIENCES DATA SYSTEM - URINALYSIS DETAIL

SPECIFY EMPLOYEE NO. [redacted]

EMPLOYEE NO. [redacted] EMPLOYEE NAME [redacted]

ACTIVITY DATE	ANAL	NO CAL	ELAPSED DAYS	D/M/24HR	SYSTEM BURDEN
01-06-58	D	0	1,644	.00 (00000)	.000
02-06-58	U	0	1,675	.00 (00000)	.000
03-26-58	P	0	1,723	.00 (00000)	.000
04-24-58	P	0	1,752	.00 (00000)	.000
10-10-58	D	0	1,921	.00 (00000)	.000
02-24-59	D	0	2,058	.00 (00000)	.000
10-09-59	D	0	2,285	.00 (00000)	.000
01-13-60	D	0	2,381	.00 (00000)	.000
04-08-60	D	0	2,467	.00 (00000)	.000
07-12-60	D	0	2,562	.00 (00000)	.000
10-12-60	D	0	2,654	.00 (00000)	.000
12-14-60	D	0	2,717	.00 (00000)	.000
01-13-61	D	0	2,746	.00 (00000)	.000

MORE-DATA

Figure C-3. Urinalysis Record Card and Health Sciences Data System – Urinalysis Detail (3) (first activity date on the HSDS portion: 1-6-58).

Figure C-4 Health Sciences Data System - Urinalysis Detail (1) (first activity date 9-17-58)

HEALTH SCIENCES DATA SYSTEM - URINALYSIS DETAIL

SPECIFY EMPLOYEE NO. [redacted]
EMPLOYEE NO. [redacted] EMPLOYEE NAME [redacted]

ACTIVITY DATE	ANAL	NO	CAL	ELAPSED DAYS	EXPOSURE VALUE	BODY BURDEN %
09-17-58	P	0		1,968	.00	.000
12-12-58	P	0		2,054	.00	.000
03-13-59	P	0		2,145	.00	.000
04-17-59	P	0		2,180	6.00	.258
04-20-59	P	0		2,183	.40	.139
04-21-59	P	0		2,184	1.94	.135
04-29-59	P	0		2,192	.18	.112
05-08-59	P	0		2,201	.12	.096
06-05-59	P	0		2,229	.07	.075
09-18-59	P	0		2,334	.24	.074
12-11-59	P	0		2,418	.22	.075
03-18-60	P	0		2,516	.16	.075
05-16-60	P	0		2,575	.07	.073

MORE-DATA

Figure C-4. Health Sciences Data System – Urinalysis Detail (1) (first activity date 9-17-58).

Figure C-5 Health Sciences Data System - Urinalysis Detail (2) (first activity date: 3-19-73)

HEALTH SCIENCES DATA SYSTEM - URINALYSIS DETAIL

SPECIFY EMPLOYEE NO. [redacted]

EMPLOYEE NO. [redacted] EMPLOYEE NAME [redacted]

ACTIVITY DATE	ANAL	NO CAL	ELAPSED DAYS	D/M/24HR	SYSTEM BURDEN
03-19-73	P	0	860	.09 (708)	.000
03-14-75	P	0	1,585	.00 (708)	.000
09-04-75	P	0	1,759	.00 (708)	.000
09-04-75	A	0	1,759	.00 (708)	.000
04-26-78	P	0	2,723	.08 (00000)	.005
01-30-79	P	0	3,002	.03 (00000)	.004
03-23-79	P	0	3,054	.14 (00000)	.012
03-23-79	A	0	3,054	.17 (00000)	.006
05-20-80	A	0	3,478	.03 (.109)	.003
05-20-80	P	0	3,478	.09 (.0752)	.010
03-24-81	A	0	3,785	.00 (0.62)	.002
03-24-81	P	0	3,785	.05 (0.03)	.009
05-01-81	P	0	3,823	.00 (.1060)	.008
				( )	

END-OF-DATA

Figure C-5. Health Sciences Data System – Urinalysis Detail (2) (first activity date 3-19-73).

Figure C-6 Analytical Report - Bioassay Analysis Data 3-15-93

Employee Name : [redacted]
Employee Number: [redacted]
Worksheet ID : 123PU242_594

ANALYTICAL REPORT
Bioassay Analysis Data

Date: 15-MAR-1993

Analysis Type	Sample Date	Laboratory Sample Number	Det Level	Aspec	DQO	BATCH Val	Analyte	Recovery	Result (DPM)	Error
Special Urine	24-JAN-1993 13:33	14630/1	0.048	0	ANN	V	PU239	0.865	0.030	0.030
			0.053				PU238		-0.035	0.014

ASPECT CODES

0 = OK
1 = Analytical Failure
3 = Low recovery
4 = Poor Planchet

DQO'S - BLANK, ACCURACY, PRECISION

A = Acceptable
C = Conditional
F = Failed
U = Unassessed
N = Not assessed

Jo Ann Read, QA
3-17-93

Figure C-6. Analytical Report – Bioassay Analysis Data 3-15-93.

Figure C-7 Analytical Report - Bioassay Analysis Data 10-28-93

Employee Name : [redacted]
Employee Number: [redacted]
Worksheet ID : 123PU242_002

ANALYTICAL REPORT
Bioassay Analysis Data

Date: 28-OCT-1993

Analysis Type	Sample Date	Laboratory Sample Number	Dec Level	Aspec	DQO	Batch Val	Analyte	Recovery	Result (DPM)	Error
Routine Urine	8-SEP-1993 09:24	25747/1	0.016	0	ANN	V	PU239	0.896	0.002	0.006

ASPEC CODES

0 = OK
1 = Analytical Failure
3 = Low recovery
4 = Poor Planchet

DQO'S - BLANK,ACCURACY,PRECISION

A = Acceptable
C = Conditional
F = Failed
U = Unassessed
N = Not assessed

Jo Ann Read, QA
DATE OCT 29 1993

Figure C-7. Analytical Report – Bioassay Analysis Data 10-28-93.

Figure C-8 Form 1 - Sample Results 1-29-96

FORM I

SAMPLE RESULTS

Date: 1/29/96

LAB NAME: - QUANTERRA, Richland SDG: 5915 COLLECTION DATE: 11/21/95

LAB SAMPLE ID: 51128827 REPORT NBR: 955 RECEIVED DATE: 11/22/95 10:30:00 AM

CLIENT ID: [redacted] ORDER NBR: MATRIX: URINE

ISOTOPE	RESULT	COUNTING ERROR (1s)	TOTAL ERROR (1s)	Lc	MDA	REPORT UNIT	YIELD	RST/MDA	RST/CNTERR	ANALYSIS DATE	ALIQUOT SIZE	ALQ UNIT	DETECTOR ID	METHOD NUMBER
PU239/40	9.69E-03	3.25E-03	3.32E-03	4.44E-03	1.21E-02	dpm/sa	94.90%	0.8	(U)	12/28/95	1039.3	ML	ALPHA-SPEC	RICHRC5010

Number of Results: 1

[redacted]

Sample Date: 10-16-95

Comments:

Figure C-8. Form 1 – Sample Results 1-29-96.

Figure C-9 Rocky Flats Environmental Technology Site (1) 8-27-96 (analytes: U238, U235, U234)

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
ANALYTICAL LABORATORIES--BIOASSAY 123/ENVIRONMENTAL 123

ANALYTICAL REPORT Date: 27-AUG-1996

Customer: DOSIMETRY
Sample Type: Routine Urine

Employee Number: [redacted]
Employee Name: [redacted]

Lab Sample #: 117598/1
Worksheet ID: 123U232_1483

Date Sampled: 3-JUL-1996 16:32:10.02
Date Received: 23-JUL-1996

Sample Size: 1200.000 ML
Aliquot Frac: 1200.000/ 1200.000

QA Data:

Alpha Spec Condition Code: 0
Chemical Recovery: 0.730
Data Qual Objective Codes: AAN

Analyte Results:

Analyte	RESULT (DPM)	ERROR (DPM)	DECISION LEVEL(DPM)	MDA (DPM)
U238	0.0282 >DL	0.0149	0.0281	0.0630
U235	0.0025	0.0078	0.0128	0.0324
U234	0.0295 >DL	0.0142	0.0225	0.0519

Comments: In March of 1995, the statistical method used for computing bioassay results was evaluated and EG&G Rocky Flats Internal Dosimetry initiated the use of a more appropriate statistical method for calculating the blank population variance. This report uses the new methodology for calculating the Decision Level, MDA, and the Results.

ASPEC CODES

0 = OK
1 = Analytical Failure
3 = Low recovery
4 = Poor Planchet
5 = High Recovery

DQO'S - BLANK, ACCURACY, PRECISION

A = Acceptable
C = Conditional
F = Failed
U = Unassessed
N = Not assessed

Michael M. Salmans
Michael M. Salmans AUG 29 1996
QA Officer

Data Validation Code: V Reviewed by [illegible] Date: 8-28-96

Figure C-9. Rocky Flats Environmental Technology Site (1) 8-27-96 (analytes: U238, U235, U234).

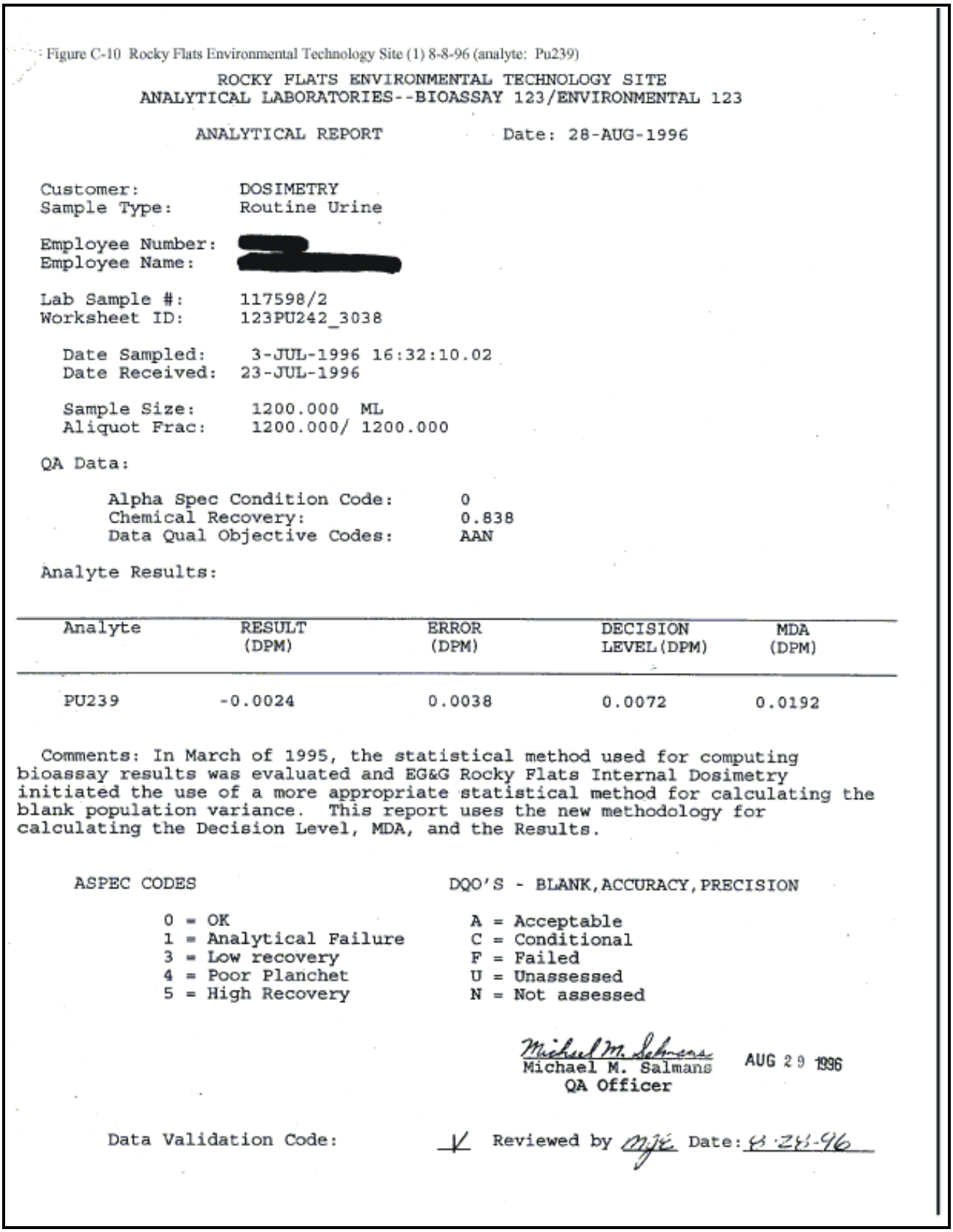


Figure C-10 Rocky Flats Environmental Technology Site (1) 8-8-96 (analyte: Pu239)

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
ANALYTICAL LABORATORIES--BIOASSAY 123/ENVIRONMENTAL 123

ANALYTICAL REPORT Date: 28-AUG-1996

Customer: DOSIMETRY
Sample Type: Routine Urine

Employee Number: [redacted]
Employee Name:

Lab Sample #: 117598/2
Worksheet ID: 123PU242_3038

Date Sampled: 3-JUL-1996 16:32:10.02
Date Received: 23-JUL-1996

Sample Size: 1200.000 ML
Aliquot Frac: 1200.000/ 1200.000

QA Data:

Alpha Spec Condition Code: 0
Chemical Recovery: 0.838
Data Qual Objective Codes: AAN

Analyte Results:

Analyte	RESULT (DPM)	ERROR (DPM)	DECISION LEVEL(DPM)	MDA (DPM)
PU239	-0.0024	0.0038	0.0072	0.0192

Comments: In March of 1995, the statistical method used for computing bioassay results was evaluated and EG&G Rocky Flats Internal Dosimetry initiated the use of a more appropriate statistical method for calculating the blank population variance. This report uses the new methodology for calculating the Decision Level, MDA, and the Results.

ASPEC CODES

0 = OK
1 = Analytical Failure
3 = Low recovery
4 = Poor Planchet
5 = High Recovery

DQO'S - BLANK, ACCURACY, PRECISION

A = Acceptable
C = Conditional
F = Failed
U = Unassessed
N = Not assessed

Michael M. Salmans AUG 29 1996
Michael M. Salmans
QA Officer

Data Validation Code: V Reviewed by MJE Date: 8-28-96

Figure C-10. Rocky Flats Environmental Technology Site (1) 8-8-96 (analyte: Pu239).

FORM I

SAMPLE RESULTS

QUANTERRA, Richland

Date: 7/31/98

LAB SAMPLE ID: 80709501 SDG: 10398 COLLECTION DATE: 7/2/98 7:00:00 AM

CLIENT ID: 98M5156-001.001 REPORT NBR: 5725 RECEIVED DATE: 7/7/98 10:30:00 AM

EMPLOYEE NBR [redacted] RIN NBR: 98M5156 MATRIX: URINE

EMPLOYEE: [redacted]

ISOTOPE	RESULT	COUNTING ERROR (1 s)	TOTAL ERROR (1 s)	Lc	MDA	QUAL*	REPORT UNIT	YIELD	ANALYSIS DATE	TOTAL SA SIZE	ALIQUOT SIZE	UNIT	DETECTOR ID	METHOD NUMBER
U-234	5.75E-02	1.45E-02	1.51E-02	1.60E-02	4.10E-02	V	dpm/samp	62.80%	7/25/98	1594.7	1594.7	ML	ALPHA-SPEC	RICHRC5030
U-235	1.45E-03	4.90E-03	4.94E-03	6.34E-03	2.17E-02	V	dpm/samp	62.80%	7/25/98	1594.7	1594.7	ML	ALPHA-SPEC	RICHRC5030
U-238	2.54E-02	1.12E-02	1.15E-02	1.53E-02	3.95E-02	V	dpm/samp	62.80%	7/25/98	1594.7	1594.7	ML	ALPHA-SPEC	RICHRC5030
PU239/40	-2.91E-03	1.65E-03	1.80E-03	7.23E-03	1.94E-02	V	dpm/samp	75.20%	7/24/98	1594.7	1594.7	ML	ALPHA-SPEC	RICHRC5010

Number of Results: 4

* (V=Valid; I=Invalid)

Comments:

(Validated by)

Date 8/3/98

0013

Figure C-11 Form 1 - Sample Results - Quanterra, Richland 7-31-98

Figure C-11. Form 1 – Sample Results – Quanterra, Richland 7-31-98.

Figure C-12 General Engineering Laboratories, Inc. 6-28-99

General Engineering Laboratories, Inc.

Employee Name:

Employee Number: [redacted]

Lab ID: 9906900-06

RIN #: 99M8334

Sample #: 99M8334-006.001

Date Received: 28-JUN-99

Date Collected: 6/24/99 0600

Date Reported: 7/21/99

Sample Type: Urine

Parameter	Result	Uncertainty (1-Sigma)	Lc	MDA	Units	VF	Yield	Run Date	Sample Volume mL	Batch	Data Validation Code
Uranium-238	0.0244	0.0137	0.0258	0.0663	DPM/S	1.00	48.31	11-JUL-99	1802	152239	V [illegible] 7/22/99
Uranium-235	0.0018	0.0092	0.0257	0.0662	DPM/S	1.00	48.31	11-JUL-99	1802	152239	V [illegible] 7/22/99
Uranium-233/234	-0.0054	0.0110	0.0315	0.0776	DPM/S	1.00	48.31	11-JUL-99	1802	152239	V [illegible] 7/22/99
Plutonium-239/240	-0.0008	0.0030	0.0060	0.0157	DPM/S	1.00	94.69	11-JUL-99	1802	152239	V [illegible] 7/22/99

Comments:

This data report has been prepared and reviewed in accordance with General Engineering Laboratories, Inc. standard operating procedures.

Validated By: [signature]

Page 1 of 1

019

Figure C-12. General Engineering Laboratories, Inc. 6-28-99.

Figure C-13 Health Sciences Uranalysis Record (with tritium, fecal and nasal smear results)

HEALTH SCIENCES Urinalysis Record

PD = URINE DISTILLED
PR = URINE RAW
H_3 & GR

NAME [redacted]
MAN NO. [redacted] Status:

DATE	Element	Type Sample	Type Anal	RESULTS	DATE	Element	Type Sample	Type Anal	RESULTS
1-18-74	H_3	PD	6	7990 ± 486					
2-5-74	"	"	150	21603 ± 5801					
8-25-76	"	"		1253 ± 426					
10-5-76	"	"	37	1320 ± 498					
4-11-78	PU	FECAL	52	32.3 ± 1.8					
〃	AM	〃	〃	0.15 ± 0.13					
〃		〃	〃	PPM AM 100					
5-17-78	PU	NOSE	93	1.0 ± 0.28					
〃	AM	〃	〃	0.43 ± 0.20					
〃		〃	〃	PPM AM 9.200					

Figure C-13. Health Sciences Urinalysis Record (with tritium, fecal and nasal smear results).

Figure C-14 Health Physics - Body Counter Information 12-8-65

Circulate:
~~[illegible]~~
~~CWP~~
~~EAP~~
CRL
~~SEH~~
~~JRM~~
Pers. File

HEALTH PHYSICS

BODY COUNTER INFORMATION

Name [redacted] Man No. [redacted] Date 12-8-65 Time 40 MLT

Reason for Counting: 76 Fire exposure
minus Bkg + match

Detectors	Body Location	Isotope	Results
# 1 : 4"x4mm NaI Crystal	R Chest	Am	33.8 C/m
# 2 : 4"x4mm NaI Crystal	L Chest	Am	31.2 C/m
# 3 : 9"x4" NaI Crystal			
			1.4 LB

☐ Collect all urine until further notice. Each void should be put in a separate jar. Mark the covers with the date and time of day.

☐ Collect all urine until further notice. All jars used in a 24-hour sampling period (midnite to midnite) should be marked with the date.

☐ Collect all fecal samples until further notice and mark date on the box.

☐ Collect fecal samples occasionally as per instructions and mark each box with the date.

Pennock
Operator

White copy: Circulate
Pink copy: To H. P. area office

RF-27740

Figure C-14. Health Physics – Body Counter Information 12-8-65.

Figure C-15 Health Physics - Body Counter Information 5-16-68

Circulate:
~~[redacted]~~
~~CMD~~
~~[redacted]~~
~~CBL~~
~~[redacted]~~
~~JHM~~
Pers. File

HEALTH PHYSICS

BODY COUNTER INFORMATION

Name [redacted] Man No. [redacted] Date 5-16-68 Time 1000

Reason for Counting: 76 Fire

Detector	Body Location	Isotope	Kev	Net (1) c/m	Mean	Net (2) c/m	μ g
#1 : 4"x4mm NaI Crystal	R chest	Am	60	52.2	34.9	17.3	0.065
#2 : 4"x4mm NaI Crystal	L chest	Am	60	46.6	34.9	11.7	0.044
							0.4
#3 : 9"x4" NaI Crystal				___ nci Cs^{137} ; ___ g K			

(1) Gross c/m — Background

(2) Gross c/m — Bkgd. — Match subject

Tally
Operator

White copy: Circulate
Blue copy: To H. P. area office

RF-22740 (Rev. 3-67) Prev. Issue May Be Used

Figure C-15. Health Physics – Body Counter Information 5-16-68.

Figure C-16 Health Physics - Body Counter Information 8-26-68

HEALTH PHYSICS BODY COUNTER INFORMATION

CIRCULATE:
~~C.W.P.~~
~~E.A.P.~~
~~C.R.L.~~
~~S.E.R.~~
~~J.R.M.~~
PERS. FILE

NAME: [redacted] MAN NO. [redacted] DATE: 8-26-68 TIME: 1030

REASON FOR COUNTING:

BODY LOCATION	NET C/M	PREDICTED C/M	RESULT	INTERPRETATION OF DATA
LEFT CHEST	48.6	24.4	24.2	0.092 mg.
RIGHT CHEST				
LIVER	34.1	28.9	5.2	0.015 mg.
				X

REMARKS:

ECAL SAMPLING:
☐ NON REQUESTED ☐ NEXT SAMPLE ☐ CONTINUOUSLY

DISTRIBUTION:
WHITE- CIRCULATE
BLUE- TO H.P. AREA OFFICE

OPERATOR: Tally

AEC 27740 (Rev. 7-68) PREVIOUS ISSUE MAY BE USED

Figure C-16. Health Physics – Body Counter Information 8-26-68.

Figure C-17 Health Physics - Body Counter Information 9-16-70

HEALTH PHYSICS BODY COUNTER INFORMATION

CIRCULATE:
C.W.P.
E.A.P.
C.R.L.
S.F.H.
J.R.M.
PERS. FILE

NAME: [redacted] MAN NO. [redacted] DATE: 9-16-70 TIME: 1100

REASON FOR COUNTING:
Routine

BODY LOCATION	NET C/M	PREDICTED C/M	RESULT	INTERPRETATION OF DATA
LEFT CHEST	41.3	36.2		
RIGHT CHEST	46.8	"		
LIVER	42.8	48.0		

REMARKS:
Gr def 1.40

FECAL SAMPLING:
☐ NON REQUESTED ☐ NEXT SAMPLE ☐ CONTINUOUSLY

DISTRIBUTION:
WHITE-CIRCULATE
BLUE-TO H.P. AREA OFFICE

OPERATOR: Tolly

Figure C-17. Health Physics – Body Counter Information 9-16-70.

Figure C-18 Radiation Dosimetry - Body Count Results 10-3-74

PERSONAL & CONFIDENTIAL

RADIATION DOSIMETRY

BODY COUNT RESULTS

NAME: [redacted] MAN NO.: [redacted] DATE: 10-3-74 TIME: 0930

INDEX NUMBER: 165 ROOM: A (B) C

REASON FOR COUNTING: ☐ NEW Quarterly ☒ RECOUNT ☐ ROUTINE ☐ TERMINATION

☐ POSSIBLE INHALATION ☐ REQUEST BY: _____

BUILDING: ROOM: LINE OR OPERATION:

BODY LOCATION	NET C/M	PREDICTED C/M	RESULT C/M	nCi Pu	MPLB Pu	nCi Am	MPLB Am	RATIO		
RIGHT CHEST	45.2	34.3	10.9	3.42				1.361		
LEFT CHEST	42.2	33.5	8.7	2.73				1.218		
GUT										
TOTAL CHEST			19.6	6.15	0.38	0.66	0.04			

REMARKS:

INCIDENT SAMPLE: ppm ^{241}Am 2041 (calc). Chemical Form _____. Solubility _____.

URINE SAMPLING: ☐ NONE REQUESTED ☐ OVERNIGHT SAMPLE ☐ CONTINUOUSLY

FECAL SAMPLING: ☐ NONE REQUESTED ☐ NEXT SAMPLE ☐ CONTINUOUSLY

TECHNICIAN: RGF R.V. Perchuk SUPERVISOR:

PERSONAL & CONFIDENTIAL

Figure C-18. Radiation Dosimetry – Body Count Results 10-3-74.

Figure C-19 Radiation Dosimetry = Body County Results 5-30-75

RADIATION DOSIMETRY
BODY COUNT RESULTS

NAME: [redacted]	MAN NO.: [redacted]	DATE: 5-30-75	TIME: 1000
INDEX NUMBER: 1,55	ROOM: (A) B C		

REASON FOR COUNTING: ☐ NEW ☐ RECOUNT ☑ ROUTINE ☐ TERMINATION

☐ POSSIBLE INHALATION ☐ REQUEST BY: _____

BUILDING: ROOM: LINE OR OPERATION:

BODY LOCATION	NET C/M	PREDICTED C/M	RESULT C/M	nCi Pu	MPLB Pu	nCi Am	MPLB Am	RATIO		
60 KEV RIGHT CHEST	36.9	33.2	Bkgd					1.13		
60 KEV LEFT CHEST	36.2	32.6	Bkgd					1.10		
17 KEV RIGHT CHEST										
17 KEV LEFT CHEST										
TOTAL CHEST										

REMARKS:

INCIDENT SAMPLE: ppm ^{241}Am _____. Chemical Form _____. Solubility _____.

URINE SAMPLING: ☐ NONE REQUESTED ☐ OVERNIGHT SAMPLE ☐ CONTINUOUSLY

FECAL SAMPLING: ☐ NONE REQUESTED ☐ NEXT SAMPLE ☐ CONTINUOUSLY

TECHNICIAN: RGF	SUPERVISOR:

PERSONAL & CONFIDENTIAL

RFT-285 (12-73)

Figure C-19. Radiation Dosimetry – Body Count Results 5-30-75.

Figure C-20 Radiation Dosimetry - Body Count Results 1-9-78

PERSONAL - PRIVILEGED
INFORMATION

RADIATION DOSIMETRY
BODY COUNT RESULTS

NAME: [redacted]	MAN NO: [redacted]	DATE: 1-9-78	TIME: 0843
INDEX NUMBER: 1,80	ROOM: A B C		
REASON FOR COUNTING:	☐ NEW Quarterly ☑ RECOUNT	☐ ROUTINE	☐ TERMINATION
	☐ POSSIBLE INHALATION	☐ REQUEST BY:	
BUILDING:	ROOM:	LINE OR OPERATION:	

BODY LOCATION	NET C/M	PREDICTED C/M	RESULT C/M	nCi Pu	MPLB Pu	nCi Am	MPLB Am	RATIO		
60 KEV RIGHT CHEST										
60 KEV LEFT CHEST										
17 KEV RIGHT CHEST										
17 KEV LEFT CHEST										
TOTAL CHEST	8.19	3.11	5.08 ± 0.50	6.4	0.40	0.81	0.055			

REMARKS:

Ge Array Hybrid

Calibration Factor Pu: 4.90 c/m per 16 nCi Pu @ 1000 ppm Am; 12.67 @ 2585 ppm Am

Am: 6.25 c/m per nCi Am

INCIDENT SAMPLE: ppm ^{241}Am 2585 (cnc). Chemical Form _____. Solubility _____.

URINE SAMPLING: ☐ NONE REQUESTED ☐ OVERNIGHT SAMPLE ☐ CONTINUOUSLY

FECAL SAMPLING: ☐ NONE REQUESTED ☐ NEXT SAMPLE ☐ CONTINUOUSLY

TECHNICIAN: RBF [signature] SUPERVISOR:

RFT-285 (12-73)

PERSONAL - PRIVILEGED

Figure C-20. Radiation Dosimetry – Body Count Results 1-9-78.

Figure C-21 Body Counter Results 12-8-81

BODY COUNTER RESULTS

[redacted] MAN# [redacted] 12 / 8 / 1981 FILE

DETECTOR RIGHT PGT II INDEX 1.9
LEFT PGT II COUNTING TIME 2000 SE

COUNT RATE IN THE AMERICIUM REGION OF THE SPECTRUM IS + 8.49 C/M
COUNT RATE IN THE BACKGROUND REGION OF THE SPECTRUM IS + 4.07 C/M
DIFFERENCE + 4.42 C/M
STANDARD DEVIATION 0.51 C/M

CALIBRATION FACTORS
+ 3.55 C/M PER 16 NANOCURIES PU AT 1000 PPM AMERICIUM
+ 4.562 C/M PER NANOCURIE AM

PARTS PER MILLION AM FOR THIS COUNT- 3142 PPM

LUNG BURDEN CALCULATED FOR THIS COUNT

	NANOCURIES	FRACTION OF A LUNG BURDEN
PLUTONIUM+	6.34 + OR - 0.74	+ 0.40 + OR - 0.05
AMERICIUM+	0.968 + OR - 0.112	+ 0.066 + OR - 0.008

BODY COUNTER TECHNICIAN:

APPROVED BY: Roy B. Falk

Figure C-21. Body Counter Results 12-8-81.

Figure C-22 Radiation Dose Assessment - Body Count Results 7-22-83

PERSONAL-PRIVILEGED INFORMATION

RADIATION DOSE ASSESSMENT
BODY COUNT RESULTS

NAME: [redacted] EMPLOYEE #: [redacted]
DATE: 7/22/83 12:45 PM ROOM # B
COUNT TIME 2000 SEC INDEX #: 1.2318
BLDG #: 334 ROOM#: OPERATION:

REASON FOR COUNT: -- NEW -X- ROUTINE -- TERMINATION
DETECTORS: RIGHT: -- PHOSWICH -X- LEFT: -- PHOSWICH

60 & 63 KEV

GROSS CT/MIN =	33.78
BKG CT/MIN =	33.66
NET CT/MIN =	0.12
STD DEV =	1.42
CUTOFF =	2.34

93 KEV

GROSS CT/MIN =	33.66
BKG CT/MIN =	32.46
NET CT/MIN =	1.20
STD DEV =	1.41
CUTOFF =	2.32

ROI 2	ROI 3	ROI 4	ROI 5
SUM 593	1126	1122	1082

RESULTS ARE NORMAL
URINE SAMPLING: -- X NONE -- OVERNIGHT
-- 24 HOUR -- THREE 24 HOUR
FECAL SAMPLING: -X- NONE -- ONE SAMPLE
-- 3 SAMPLES

BODY COUNTER TECHNICIAN: [signature]

APPROVED BY: Roger B. Fuller

Figure C-22. Radiation Dose Assessment – Body Count Results 7-22-83.

Figure C-23 Radiation Dose Assessment - Body Count Results 5-13-83

PERSONAL-PRIVILEGED INFORMATION

RADIATION DOSE ASSESSMENT
BODY COUNT RESULTS

NAME: [redacted] EMPLOYEE #: [redacted]
DATE: 5/13/83 10:38 AM ROOM # A
COUNT TIME 2000 SEC INDEX #: 1.4758
BLDG #: 778 ROOM#: OPERATION:

REASON FOR COUNT: -- NEW -- RECOUNT X ROUTINE -- TERMINATION
-- POSSIBLE INHALATION (-------- PPM)
-- OTHER ----------

DETECTORS: RIGHT: PGT-1 LEFT: PGT-1

AM-241/PLUTONIUM TH-234/U-238

GROSS CT/MIN =	4.98	GROSS CT/MIN =	5.16
BKG CT/MIN =	4.39	BKG CT/MIN =	4.99
NET CT/MIN =	0.59	NET CT/MIN =	0.17
STD DEV =	0.43	STD DEV =	0.43
CUTOFF =	0.70	CUTOFF =	0.71

	ROI 2	ROI 3	ROI 4	ROI 5	ROI 6	ROI 7	ROI 8	ROI 9	ROI10	ROI11
SUM	870	166	172	585	543	407	129	221	68	94

RESULTS ARE NORMAL

URINE SAMPLING: X NONE -- OVERNIGHT
-- 24 HOUR -- THREE 24 HOUR

FECAL SAMPLING: X NONE -- ONE SAMPLE
-- 3 SAMPLES

BODY COUNTER TECHNICIAN: [signature]

APPROVED BY: [signature]

Figure C-23. Radiation Dose Assessment – Body Count Results 5-18-83.

Figure C-24 Radiation Dose Assessment - Body Count Results 2-21-84

PERSONAL-PRIVILEGED INFORMATION

RADIATION DOSE ASSESSMENT
BODY COUNT RESULTS

NAME: [redacted] EMPLOYEE #: [redacted]
DATE: 2/21/84 1:27 PM ROOM # A
COUNT TIME 2000 SEC INDEX #: 1.2291
BUILD #: 444 ROOM#: OPERATION:
REASON FOR COUNT: __ NEW __ RECOUNT __ ROUTINE ___ TERMINATION
__ POSSIBLE INHALATION (_____ PPM)
OTHER _____
DETECTORS: RIGHT: PGT-1 LEFT: PGT-1

	AM-241/PLUTONIUM		TH-234/U-238	
GROSS CT/MIN	=	4.56	GROSS CT/MIN	= 5.07
BKG CT/MIN	=	3.98	BKG CT/MIN	= 4.51
NET CT/MIN	=	0.58	NET CT/MIN	= 0.56
STD DEV	=	0.41	STD DEV	= 0.43
CUTOFF	=	0.67	CUTOFF	= 0.70

RESULTS ARE NORMAL

	L-XRAY	60KEV	63KEV	BKG	13KEV	17KEV	93KEV	93BKG	185KEV	185BKG
SUM	739	152	169	530	682	290	188	119	89	151

URINE SAMPLING: ✓ NONE __ OVERNIGHT __ 24 HOUR __ THREE 24 HOUR
FECAL SAMPLING: ✓ NONE __ ONE SAMPLE __ 3 SAMPLES

BODY COUNTER TECHNICIAN: W. Jacobs
APPROVED BY: Roger B. Falk

Figure C-24. Radiation Dose Assessment – Body Count Results 2-21-84.

Figure C-25 Radiation Dose Assessment - Body Count Results 3-22-84

PERSONAL-PRIVILEGED INFORMATION

RADIATION DOSE ASSESSMENT
BODY COUNT RESULTS

NAME: [redacted] EMPLOYEE #: [redacted]
DATE: 3/22/84 2:55 PM ROOM # A
COUNT TIME 2000 SEC INDEX #: 1.8115
BUILD #: 881 ROOM#: OPERATION:
REASON FOR COUNT: __ NEW __ RECOUNT (X) ROUTINE ___ TERMINATION
__ POSSIBLE INHALATION (_____ PPM)
OTHER _____
DETECTORS: RIGHT: PGT-1 LEFT: PGT-1

	AM-241/PLUTONIUM		TH-234/U-238	
GROSS CT/MIN	=	9.12	=	4.26
BKG CT/MIN	=	4.25	=	4.78
NET CT/MIN	=	4.87	=	-0.52
STD DEV	=	0.55	=	0.40

	L-XRAY	60KEV	63KEV	BKG	13KEV	17KEV	93KEV	93BKG	185KEV	185BKG
SUM	794	304	142	567	715	306	196	129	74	128

CALIBRATION FACTORS

CT/MIN PER 16 NANOCURIE PU @ 1000 PPM AM-241 = 4.19
CT/MIN PER NANOCURIE AM-241 = 5.392
PPM TODAY AM-241 = 3420 PPM

LUNG BURDEN CALCULATED FOR THIS COUNT

	NANOCURIES			FRACTION OF LUNG BURDEN		
PU-239 =	5.43	+-	0.62	0.34	+-	0.04
AM-241 =	0.903	+-	0.103	0.061	+-	0.007

URINE SAMPLING: (X) NONE __ OVERNIGHT __ 24 HOUR __ THREE 24 HOUR
FECAL SAMPLING: (X) NONE __ ONE SAMPLE __ 3 SAMPLES

BODY COUNTER TECHNICIAN: [signature]
APPROVED BY: [signature]

Figure C-25. Radiation Dose Assessment – Body Count Results 3-22-84.

Figure C-26 Radiation Dose Assessment - Body Count Results 10-10-85

PERSONAL-PRIVILEGED INFORMATION

RADIATION DOSE ASSESSMENT
BODY COUNT RESULTS

NAME: [redacted] EMPLOYEE #: [redacted]
DATE: 10/10/85 9:51 AM ROOM # C
COUNT TIME 2000 SEC INDEX #: 1.2238
BUILD #: 778 ROOM#: OPERATION:
REASON FOR COUNT: __ NEW __ RECOUNT _✓_ ROUTINE ___ TERMINATION
__ POSSIBLE INHALATION (_____ PPM)
OTHER _____
DETECTORS: RIGHT: PBT-2 LEFT: PBT-2

	AM-241/PLUTONIUM		TH-234/U-238
GROSS CT/MIN	= 3.84	GROSS CT/MIN	= 4.71
BKG CT/MIN	= 4.51	BKG CT/MIN	= 4.76
NET CT/MIN	= -0.67	NET CT/MIN	= -0.05
STD DEV	= 0.39	STD DEV	= 0.42
CUTOFF	= 0.63	CUTOFF	= 0.69

RESULTS ARE NORMAL

	L-XRAY	60KEV	63KEV	BKG	13KEV	17KEV	93KEV	93BKG	185KEV	185BKG
SUM	119407	128	157	601	90860	88124	144	187	56	78

URINE SAMPLING: _✓_ NONE __ OVERNIGHT __ 24 HOUR __ THREE 24 HOUR
FECAL SAMPLING: __ NONE __ ONE SAMPLE __ 3 SAMPLES

BODY COUNTER TECHNICIAN: C Barnett

APPROVED BY: Roger B. Falk

Figure C-26. Radiation Dose Assessment – Body Count Results 10-10-85.

Figure C-27 Radiation Dose Assessment - Body Count Results 3-6-89

SUM 638 1619 16 , 1595

PERSONAL-PRIVILEGED INFOR
MATION

RADIATION DOSE ASSESSMENT
BODY COUNT RESULTS

NAME: [redacted] EMPLOYEE #: [redacted]
DATE: 2/09/87 11:09 AM ROOM # B
COUNT TIME 2000 SEC INDEX #: 1.2910
BLDG #: 778 ROOM#: OPERATION:

REASON FOR COUNT: __ NEW __ ROUTINE ___ TERMINATION
DETECTORS: RIGHT: PHOSWICH LEFT: PHOSWICH

60 & 63 KEV		93 KEV	
GROSS CT/MIN =	47.57	GROSS CT/MIN =	49.71
BKG CT/MIN =	49.71	BKG CT/MIN =	47.85
NET CT/MIN =	-2.14	NET CT/MIN =	1.86
STD DEV =	1.72	STD DEV =	1.71
CUTOFF =	2.82	CUTOFF =	2.81

	ROI 2	ROI 3	ROI 4	ROI 5
SUM	638	1619	1657	1595

RESULTS ARE NORMAL

URINE SAMPLING: __ NONE __ OVERNIGHT
__ 24 HOUR __ THREE 24 HOUR
FECAL SAMPLING: __ NONE __ ONE SAMPLE
__ 3 SAMPLES

BODY COUNTER TECHNICIAN: _____

APPROVED BY: B.C. Baker

Figure C-27. Radiation Dose Assessment – Body Count Results 3-6-89.

Figure C-28 Internal Dosimetry - Lung Count Results 11-23-93

EG&G ROCKY FLATS

RADIOLOGICAL HEALTH

ANALYTICAL REPORT

PERSONAL-PRIVILEGED INFORMATION

INTERNAL DOSIMETRY
LUNG COUNT RESULTS

NAME: [redacted] EMPLOYEE #: [redacted]
DATE: 11/23/93 11:08 AM ROOM # B
COUNT TIME 2000 SEC INDEX #: 1.3615
BUILD #: [redacted] ROOM#: OPERATION:
REASON FOR COUNT: __ NEW __ RECOUNT __ ROUTINE ___ SEPARATION
__ POSSIBLE INHALATION (_____ PPM)
OTHER Recount
DETECTORS: RIGHT: EG&G 1, PGT OP 2,3,4 LEFT: EG&G 5, PGT OP 6

	AM-241/PLUTONIUM		TH-234/U-238	63KEV	93 KEV
GROSS CT/MIN	=	12.69	GROSS CT/MIN =	4.38	3.78
BKG CT/MIN	=	3.82	BKG CT/MIN =	4.12	3.41
NET CT/MIN	=	8.87	NET CT/MIN =	0.26	0.37
STD DEV	=	0.64	STD DEV =	0.40	0.40

	L-XRAY	60KEV	63KEV	BKG	13KEV	17KEV	93KEV	93BKG	185KEV	185BKG
ADC #1	91	60	21	86	30	39	19	29	18	24
ADC #2	126	94	19	73	49	60	17	42	15	26
ADC #3	194	53	29	92	529	106	22	32	8	22
ADC #4	121	40	23	102	49	52	25	40	16	29
ADC #5	83	113	17	78	27	43	18	34	18	35
ADC #6	119	43	37	82	52	66	25	38	17	26
ADC #7	0	0	0	0	0	0	0	0	0	0
ADC #8	0	0	0	0	0	0	0	0	0	0
SUM	734	423	146	513	736	366	126	215	92	162

CALIBRATION FACTORS

CT/MIN PER 16 NANOCURIE PU @ 1000 PPM AM-241 = 6.44
CT/MIN PER NANOCURIE AM-241 = 8.283
PPM TODAY AM-241 = 4339 PPM

ACTIVITY CALCULATED FOR THIS COUNT
NANOCURIES
PU-239 = 5.08 +- 0.37
AM-241 = 1.071 +- 0.077

DID EMPLOYEE SHOWER BEFORE COUNT? YES__ NO✓

LUNG COUNTER TECHNICIAN: [redacted]

APPROVED BY:_____

Figure C-28. Internal Dosimetry – Lung Count Results 11-23-93.

Figure C-29 ABACOS-Plus 3-6-96

ABACOS-Plus | Printed:6-MAR-1996 15:37:14. | Page: 1

Subject name: [redacted]
Employer: [redacted]
Job Code: [redacted]
Reason: Routine
Count type: Individual
Height: 77.000
Sex: Male
CWT: 3.4540
Comment:

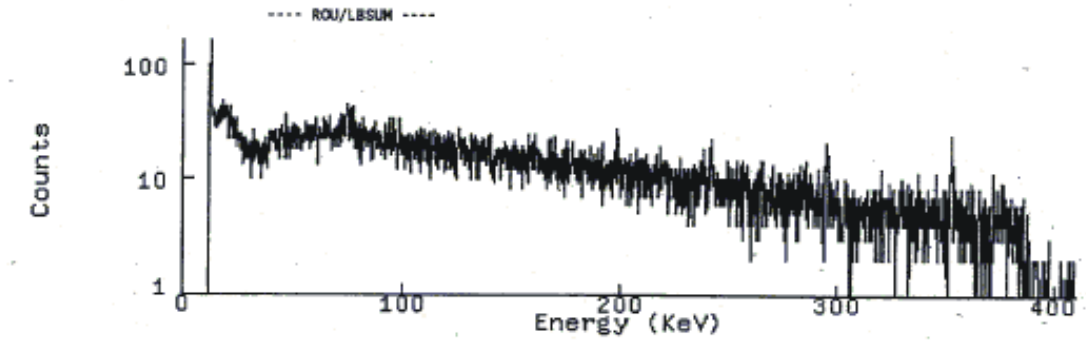
Identification #: [redacted]
Count Started: 6-MAR-1996 15:06:55.
Intake Date: 6-MAR-1996 15:06:55.
Frequency:
Operator: K.J. Nannie / K.J. Moul
Weight: 213.00
Date of Birth: [redacted]

Counter: Room B4 Sum
Arrangement/Geometry: ROU/LBSUM
Detector: LUNGS
Analysis limits: 200 to 1900

Facility: Rocky Flats ETS
Elapsed Live Time: 0 00:30:00.00
Elapsed Real Time: 0 00:30:00.35
Count Rate: 2.942 3.152 2.994 3.145 0.00 0.00 0.00 0.00

Nuclide Results for ROU/LBSUM

Nuclide	Activity (nCi)	%Error (2 SD)	Comments
U-235	<7.245E-02		Decision level reported
U-238	< 1.00		Decision level reported
AM-241	<0.117		Decision level reported
			----- No Nuclides Identified -----
totals:	0.000E+00		



Energy Calibration Performed: 14-FEB-1996 11:03:20 ROU/LBSUM Efficiency Calibration Performed: 12-FEB-1996 19:42:30
Libraries Used: ND_WBC_LIB:PU_OPTION.WLB,ND_WBC_LIB:PU_OPTION.WLB,ND_WBC_LIB:PU_OPTION.WLB
Analyses By: GAMMAN V1.2,PEAKEFF V2.2,NID V3.1,WTMEAN V1.8,NINACT V2.5

Reviewed by: Dennis Brown Date: March 7, 1996

Figure C-29. ABACOS-Plus 3-6-96.

Figure C-30 ABACOS-Plus 11-15-01

ABACUS-Plus | Printed:15-NOV-2001 08:31 | Page: 1

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE IN-VIVO COUNTER

SENSITIVE - UNCLASSIFIED INFORMATION

Subject name: [redacted]
Employer: [redacted]
Job Code: [redacted]
Sex: Male
Height: 68.000
CWT: 3.6251
Reason: OTHER
Comment: MED RECALL

Identification #: [redacted]
Count Started: 15-NOV-2001 08:00:11
Intake Date: 15-NOV-2001 08:00:11
Date of Birth: [redacted]
Weight: 194.00

Operator: KJN Initials: KJN

Counter: Room A Lung
Analysis Limits (channels): 100 to 2000
Detector Count Rate (gross cps): 3.778 3.548 3.580 3.359
Analysis Energies (keV) Am-241: 59.54 U-235: 143, 185, and 204 U-238: 63 and 93

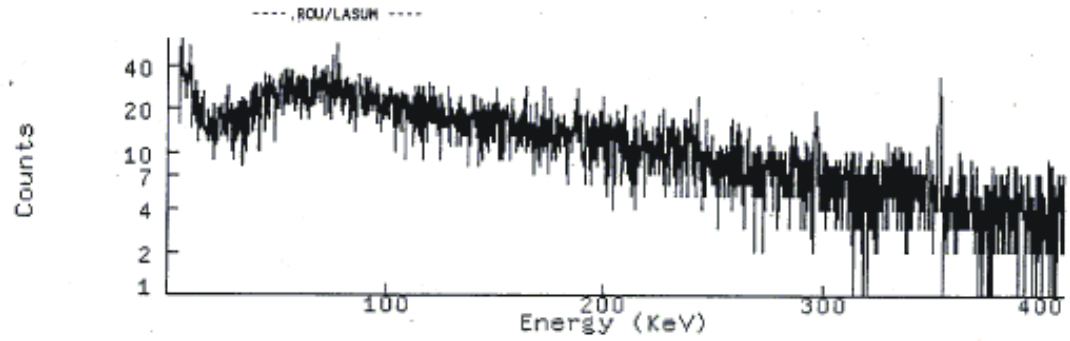
Arrangement/Geometry: RDU/LASUM
Elapsed Live Time: 0 00:30:00.00

MDA values are for an average RFETS worker. Results for an individual count may be greater than the stated MDA.

Nuclide Results for RDU/LASUM

Nuclide	Activity (nCi)	DL (nCi)	MDA (nCi)	%Error (1SD)	> DL	> MDA	Comments
U-235	-3.915E-02	0.654	0.790	-787.			
U-238	-1.38	2.12	2.10	-81.0			
AM-241	-0.119	0.230	0.290	-98.5			
----- No Nuclides Identified -----							
totals:	-1.53						

Flags: "+" = nuclide identified



Energy Calibration Performed: 1-OCT-2001 08:17:16. RDU/LASUM Efficiency Calibration Performed: 9-AUG-2001 13:10:09.
Libraries Used: ND_WBC_LIB:PU_OPTION_A.WLB,ND_WBC_LIB:PU_OPTION_A.WLB,ND_WBC_LIB:PU_OPTION_A.WLB
Analyses By: PEAK V16.9,PEAKEFF V2.2,MID V3.3,WTMEAN V1.8,MINACT V2.8

Reviewed by: Fred Duran Date: 11-15-01

Figure C-30. ABACOS-Plus 11-15-01.

Figure C-31 ABACOS-Plus 6-14-01

ABACOS-Plus | Printed:14-JUN-2001 11:36 | Page: 1

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE IN-VIVO COUNTER

SENSITIVE - UNCLASSIFIED INFORMATION

Subject name: [redacted]
Employer: [redacted]
Job Code: [redacted]
Sex: Male
Height: 68.000
CWT: 3.0738
Reason: OTHER
Comment: MEDICAL RECALL

Identification #: [redacted]
Count Started: 14-JUN-2001 11:05:57
Intake Date: 15-OCT-1965 00:00:00
Date of Birth: [redacted]
Weight: 175.00

Operator: JSN Initials: [redacted]

Counter: Room A Lung
Analysis Limits (channels): 100 to 2000
Detector Count Rate (gross cps): 4.062 3.619 3.782 3.563
Analysis Energies (keV) Am-241: 59.54 U-235: 143, 185, and 204 U-238: 63 and 93

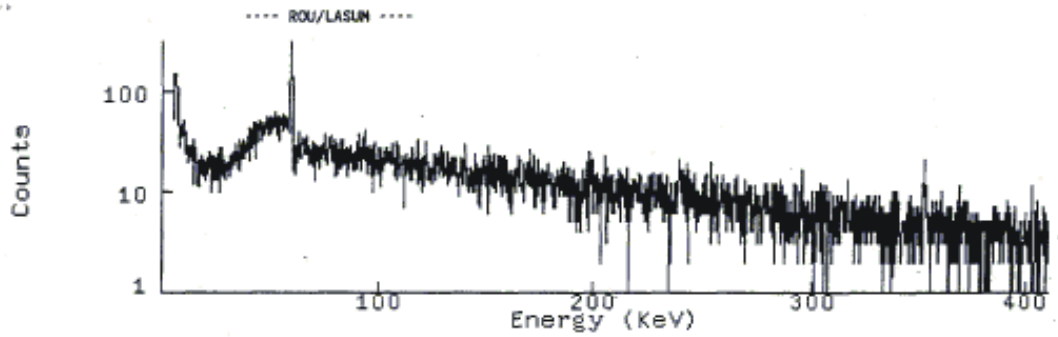
Arrangement/Geometry: ROU/LASUM
Elapsed Live Time: 0 00:30:00.00

MDA values are for an average RFETS worker. Results for an individual count may be greater than the stated MDA.

Nuclide Results for ROU/LASUM

Nuclide	Activity (nCi)	DL (nCi)	MDA (nCi)	%Error (1SD)	> DL	> MDA	Comments
U-235	0.397	0.561	1.10	70.6			
+PU-238	0.204	40.1	0.000E+00	30.5		>	
U-238	-0.327	1.66	2.90	-241.			
+PU-239	9.21	45.6	0.000E+00	30.5		>	
+PU-240	2.07	42.3	0.000E+00	30.5		>	
+AM-241	3.15	0.214	0.270	30.5	>	>	
+PU-241	13.7	71.2	0.000E+00	30.5		>	
+PU-242	1.865E-04	51.1	0.000E+00	30.5		>	
totals:	28.4						

Flags: "+" = nuclide identified



Energy Calibration Performed: 7-JUN-2001 06:43:59. ROU/LASUM Efficiency Calibration Performed: 15-FEB-2001 13:26:36
Libraries Used: ND_WBC_LIB:PU_OPTION_A.WLB,ND_WBC_LIB:PU_OPTION_A.WLB,ND_WBC_LIB:PU_OPTION_A.WLB
Analyses By: PEAK V16.9,PEAKEFF V2.2,NID V3.3,WTMEAN V1.8,MINACT V2.8

Reviewed by: [redacted] Date: 6/15/01

Figure C-31. ABACOS-Plus 6-14-01.