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Nevada Test Site – Occupational Environmental Dose

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FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
04/20/2004	00	New technical basis document for the Nevada Test Site–Occupational Environmental Dose. First approved issue. Initiated by Eugene M. Rollins.
12/08/2006	00 PC-1	Approved page change revision as a result of biennial review. Adds acronyms and abbreviations on pages 4 and 5. Updates required language on page 6 in the Introduction. Adds Purpose and Scope sections on page 7. Added instructions to dose reconstructors on pages 44 and 45 in Section 4.5. As a result of formal internal review, deletes Section 4.5.2 from page 45. Completes references on page 47. This revision results in no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Eugene M. Rollins. Approval: Signature on File 12/05/2006 Eugene M. Rollins, Document Owner Signature on File 10/24/2006 John M. Byrne, Task 3 Manager Signature on File 10/24/2006 Edward F. Maher, Task 5 Manager Signature on File 11/15/2006 Kate Kimpan, Project Director Brant A. Ulsh Signature on File for 12/08/2006 James W. Neton, Associate Director for Science
05/27/2008	01	Approved revision initiated to apply only to post 1962 employment periods and all covered employees including those identified by job classification as a drillback operator prior to 1965. Also applies to covered employees involved with any of the 10 underground tests that resulted in unexpected release of radioactive materials. Revised Table 4.2.1.2.2.-2 (new Table 4-3) to reflect 2,000 hr/yr and 2400 m^3/yr breathing rate. Deleted Tables 4.2.1.2.2-3 and 4.2.1.2.2-4. Deleted Sections 4.2.1.2.3 and 4.2.1.2.4. Added Sections 4.2.1.2.3 and 4.1.2.4 to introduce revised method for assigning environmental ambient inhalation intakes. Replaced Section 4.2.2 with ambient ingestion intake section. Revised Section 4.4 to include dose from radon and other alpha and beta emitting radionuclides and to include discussion of radon exposure in gravel gerties. Added Section 4.4.3. Revised Section 4.4.4, Table 4.21 to increase radon WLM for G-Tunnel prior to 1984 and to maximize radon exposures for unidentified work locations. Added discussion of radon in gravel gerties. Added Section 4.4.5 to provide method for assigning inhalation and ingestion intakes for underground workers. Added Section 4.5.2 to provide instructions to dose reconstructors for assigning inhalation and ingestion ambient environmental intakes for all workers at the NTS. Occupational environmental dose will increase for all claims not previously worked using ORAUT-OTIB-0018 or ORAUT-OTIB-0002. Also, cases of lung, ET1, and ET2 will need to be re-evaluated for increased radon exposures. Attachments A and B (formerly Rollins 2007, SRDB Ref ID: 37805)

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
05/27/2008 (continued)	01 (continued)	were added to support the changes discussed in Section A.6.0 which included enriching the near-field environment with refractory elements. The 01-C version only added refractory elements back to the depleted refractory near-field environment given by the Hicks data (i.e., multiplied the Hicks refractory values by 2). The 01-D version enriched the near-field refractory environment by multiplying the Hicks refractory values by 4. Assumption of the enriched refractory near-field environment resulted in larger fission and activation product inhalation and ingestion correction factors (Tables 4-8 and 4-12) and increased number of affected organs and the resultant doses (Tables 4-9 and 4-14). Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Task Manager. Initiated by Eugene M. Rollins.
04/15/2010	02	Revision initiated to incorporate definitions and directions for dose reconstruction for nonpresumptive cancers that are excluded from the 1963 through 1992 Special Exposure Cohort. Added Section 4.1.2. Added years 2002 through 2008 ambient external doses to Tables 4-15 and 4-16. Incorporates formal internal and NIOSH review comments. Updated ORAUT references. Training required: As determined by the Objective Manager. Initiated by Eugene M. Rollins.
08/24/2012	03	Revision extended measured ambient radiation doses in Tables 4-15 and 4-16 to 2010 in Section 4.3.1. Also in Section 4.3.1, clarification was added to ensure that ambient dose was not to be assigned for years when no data was available; in particular, prior to 1958. Instructions clarified that for unmonitored workers likely to be exposed prior to 1958, the 50% coworker dose in Table 6-11 of ORAUT-TKBS-0008-6 (the NTS External TBD) should be assigned. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Eugene M. Rollins.
02/19/2020	04	Clarified in Section 4.3.1 that site maximum values would be entered into IREP as constants. Clarified in Section 4.4.4 that ^{220}Rn should be assumed to be present at twice the concentrations of ^{222}Rn in Table 4-20. Added discussion in Sections 4.3.1 to provide maximum and best-estimate methods, respectively, for estimating onsite ambient external doses. In Section 4.5.2, clarified that the intake values in Tables 4-7 and 4-11 are to be considered bounding and should be applied in IREP as constants. Also for a best estimate, 10% of the intakes in Tables 4-7 and 4-11 should be assigned. The best-estimate intakes should be applied in IREP as a lognormal distribution with a GSD of 3.0. Added to Section 4.4.4 that doses for all organs should be adjusted in accordance with DCAS-TIB-011 for radon (DCAS 2018). Added instructions in Section 4.4.4 for the application of underground occupancy factors for work in the gravel gerties and tunnels. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Eugene M. Rollins.

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ACRONYMS AND ABBREVIATIONS

AWE	Atomic Weapons Employer
Bq	becquerel
CFR	Code of Federal Regulations
Ci	curie
cm	centimeter
d	day
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EPA	U.S. Environmental Protection Agency
ET	extrathoracic
ET1	extrathoracic region 1
ET2	extrathoracic region 2 (posterior nasal passage, larynx, pharynx, and mouth)
ft	foot
g	gram
GSD	geometric standard deviation
hr	hour
HT	elemental tritium (tritiated gas)
HTO	tritiated water vapor
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
in.	inch
IREP	Interactive RadioEpidemiological Program
JASPER	Joint Actinide Shock Physics Experimental Research
keV	kiloelectron-volt, 1,000 electron-volts
kg	kilogram
L	liter
lb	pound
LLI	lower large intestine
LLNL	Lawrence Livermore National Laboratory
LN	lymph nodes
LN(ET)	extrathoracic lymph nodes
LN(TH)	thoracic lymph nodes (trachea, bronchi, bronchioles, alveolar ducts, and sacs)
m	meter
MeV	megaelectron-volt, 1 million electron-volts
mg	milligram
mi	mile
min	minute

mL	milliliter
mR	milliroentgen
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NNSS	Nevada National Security Site
NTS	Nevada Test Site
ORAU	Oak Ridge Associated Universities
pCi	picocurie
PER	program evaluation report
PERM	passive environmental radon monitor
RBM	red bone marrow
RDC	radon daughter concentration
REECo	Reynolds Electrical & Engineering Company
RPISU	radon progeny integrating sampling unit
s	second
SEC	Special Exposure Cohort
SI	small intestine
SRDB Ref ID	Site Research Database Reference Identification (number)
Sv	sievert
TBD	technical basis document
TLD	thermoluminescent dosimeter
TRU	transuranic
TTR	Tonopah Test Range
ULI	upper large intestine
U.S.C.	United States Code
wk	week
WL	working level
WLM	working level month
yr	year
µCi	microcurie
µm	micrometer

4.1 INTRODUCTION

Technical basis documents (TBDs) and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular U.S. Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies), such as changing scientific understanding of operations, processes, or procedures involving radioactive materials. These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of individual dose reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA).

In this document the word “facility” is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean nor should it be equated to an “AWE facility” or a “DOE facility.” The term “AWE facility” is defined in EEOICPA to mean “a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling” [42 *United States Code* (USC) 7384l(5)]. On the other hand, a DOE facility is defined as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located—(A) in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program); and (B) with regard to which the [DOE] has or had—(i) a proprietary interest; or (ii) entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services” [42 USC 7384l(12)]. The DOE determines whether a site meets the statutory definition of an AWE facility and the U.S. Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Under EEOICPA, a Part B cancer claim for benefits must be based on an energy employee’s eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility’s designated time period and location (i.e., a “covered employee with cancer”). After DOL determines that a claim meets the eligibility requirements under Part B of EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility [42 USC 7384l(11)]. Also under EEOICPA, the types of exposure to be included in dose reconstructions for DOE employees are those radiation exposures incurred in the performance of duty. As such, NIOSH includes all radiation exposures received as a condition of employment at DOE facilities in its dose reconstructions for covered employees, which may include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. This is because NIOSH does not determine the fraction of total measured radiation exposure at a DOE facility that is contributed by the Naval Nuclear Propulsion Program at the DOE facility during a specified period of time for inclusion in dose reconstruction.

NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment at a DOE facility. Therefore these exposures are not included in dose reconstructions for covered employees [NIOSH 2010]:

- Background radiation, including radiation from naturally occurring radon present in conventional structures, and
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons.

4.1.1 Purpose

This technical basis document (TBD) discusses occupational environmental dose. Occupational environmental dose is the dose individuals received at the Nevada Test Site (NTS), now known as the Nevada National Security Site (NNSS), while outside operational facilities but on the site during work activities. These doses can be internal or external depending on the characteristics of the individual radionuclides. While inhalation of most radionuclides would cause a dose to various organs in the body, noble gases would primarily cause only an external dose because these inert radionuclides are not readily absorbed by the body. However, inhalation of radon will result in dose to the lungs and respiratory airways due to the subsequent deposition and decay of daughter products. Occupational environmental dose would be received by workers in the aboveground and underground working environments.

With the cessation of atmospheric testing at NTS in 1962, the greatest potential for environmental intakes of radioactive material in the aboveground environment results from the inhalation of radioactive particles that were resuspended from NTS soils into the atmosphere and from ingestion of soils that were previously contaminated by atmospheric nuclear weapons tests, reactor tests, and safety tests. The potential inhalation intakes can be estimated from air sampling data in the NTS annual environmental reports (see the Environmental Reports list in the References section) coupled with extensive soil contamination data gathered between 1983 and 1991 (McArthur and Kordas 1983, 1985; McArthur and Mead 1987, 1988, 1989; McArthur 1991). Because the air monitoring data were limited to gross alpha and beta measurements, tritium, and isotopes of plutonium (e.g., ^{238}Pu, ^{239}Pu, ^{240}Pu), inhalation intakes of other relatively long-lived radionuclides that have been identified in NTS soils (e.g., ^{241}Am, ^{60}Co, ^{137}Cs, ^{90}Sr, ^{152}Eu, ^{154}Eu, ^{155}Eu) are scaled to those of plutonium based on their relative abundance in NTS soils. Ingestion intakes can be estimated by assuming consumption of contaminated NTS soils. To ensure that inhalation and ingestion intakes are not underestimated, the relative abundances of the long-lived radionuclides in NTS soils determined from the 1991 soil contamination data (McArthur 1991) were decay-corrected back to 1963. In addition, to ensure that intakes and resultant doses were not underestimated, correction factors were developed to account for potential exposures to short-lived fission and activation products based on test-specific data provided by Hicks (1981a, 1981b, 1981c, 1981d). In addition, a correction factor was developed for inhalation intakes that accounts for the phenomenon of early resuspension (Anspaugh et al. 2002).

4.1.2 Scope

Section 4.2 discusses internal doses to aboveground workers from onsite releases to the air and resuspension of radioactive materials in soil, as well as from ingestion of contaminated soils. Section 4.3 describes external doses to workers from ambient radiation and releases of radioactive noble gases to air. Section 4.4 discusses internal dose to underground workers from inhalation of ambient concentrations of radioactive materials in the air, ingestion of contaminated materials, and exposure to radon. Section 4.5 provides instructions to dose reconstructors for assignment of environmental intakes. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 4.6.

4.1.3 Special Exposure Cohort

January 27, 1951 through December 31, 1962
The Secretary of the U.S. Department of Health and Human Services has added the following class to the SEC (Leavitt 2006):

> *Department of Energy (DOE) employees or DOE contractor or subcontractor employees who worked at the Nevada Test Site from January 27, 1951 through December 31, 1962*

> *for a number of work days aggregating at least 250 work days, either solely under this employment or in combination with work days within the parameters (excluding aggregate work day requirements) established for other classes of employees included in the SEC, and who were monitored or should have been monitored.*

NIOSH has determined that, in the absence of bioassay results for the worker, internal doses cannot be reconstructed from January 27, 1951 through December 31, 1962. Based on the SEC petition evaluation, internal dose is not to be reconstructed for work before 1963 unless a worker has specific bioassay results that can be directly related to an event or incident (NIOSH 2006).

Any bioassay results in the DOE files for NTS workers before 1963 should be assumed to be valid because they were determined using HASL-300 (Harley 1976) procedures in the early bioassay program; therefore, these results can be used to evaluate internal dose. Much of the internal monitoring for individuals during the SEC period was event related. However, certain job classifications required routine monitoring. These included radiation safety personnel, industrial hygienist, and security personnel.

January 1, 1963 through December 31, 1992
The Secretary has added the following class to the SEC (Sebelius 2010):

> *All employees of the Department of Energy, its predecessor agencies, and its contractors and subcontractors who worked at the Nevada Test Site from January 1, 1963 through December 31, 1992 for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees in the SEC.*

NIOSH has determined that it lacks sufficient information that would allow it to adequately estimate internal exposures during the period from January 1, 1963, through December 31, 1992 (NIOSH 2010b).

NIOSH believes that the cessation of nuclear testing, coupled with the implementation of the 1993 NTS internal dose TBD that demonstrates NTS compliance with 10 CFR Part 835, supports NIOSH's ability to bound internal dose for the evaluated class starting in 1993.

Dose reconstruction guidance in this TBD for periods before January 1, 1993, is presented to provide a technical basis for partial dose reconstructions for nonpresumptive cancers not covered in the SEC classes through December 31, 1992. Although NIOSH found that it is not possible to bound total internal dose for the classes, it intends to use internal and external monitoring data that might become available for an individual claim (and that can be interpreted using its existing dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals who were employed at NTS during this period, but who do not qualify for inclusion in the SEC, can be performed using these data as appropriate.

4.2 INTERNAL INHALATION AND INGESTION DOSE TO ABOVEGROUND WORKERS

Section 4.2.1 discusses the internal dose for workers outside the facilities as determined from air concentrations resulting from ground-level releases. Section 4.2.2 discusses the internal dose from resuspension of radioactive materials in the soil.

4.2.1 Onsite Releases to Air

4.2.1.1 Source Description

4.2.1.1.1 Weapons Testing

NTS has been the primary location for the testing of nuclear explosives in the continental United States since 1951. Test programs have included atmospheric testing in the 1950s and early 1960s, earth-cratering experiments, and open-air nuclear reactor and rocket engine testing. Since the mid-1960s, testing of nuclear devices has occurred underground in drilled vertical holes or in mined tunnels. No nuclear tests have been conducted since September 1992 (Black 1995).

In all, more than 900 nuclear tests have taken place at the Test Site as part of these programs. One result of these tests is that the surface soils in many parts of NTS contain measurable amounts of several long-lived radionuclides. Almost all of the more than 100 aboveground tests contaminated the soil near ground zero. In addition, several underground tests were cratering experiments that threw radioactive rock and soil hundreds of feet, and some deeper underground tests vented radioactive material to the surface. A few safety tests, in which a nuclear device was destroyed by conventional explosives, scattered plutonium (and in some cases uranium) over the nearby ground. Further, there was fallout of radioactive debris from many tests over the northern and eastern parts of the Test Site (McArthur 1991).

Radiation levels at NTS have been monitored regularly, and safety officials have identified and fenced off areas where the soil is heavily contaminated. In many other areas, radionuclide levels are not high enough to warrant closing the area, but they are still above background.

Atmospheric weapon and safety tests from 1951 and 1963 resulted in the release of about 1.2×10^{10} Ci to the atmosphere (DOE 1996). Much of this activity was from relatively short-lived radionuclides that decayed in a matter of days or weeks. The volatile radionuclides (such as radioiodines, noble gases, and tritium) were diluted in the atmosphere and transported off site. However, much of the nonvolatile, long-lived radionuclides settled in the soils at various locations (see Table 4-10 in Section 4.2.2). These contaminated soils continue to represent a potential inhalation pathway to workers from resuspension of soils by wind and such mechanical activities as cleanup and remediation (McArthur 1991).

In 1963, nuclear weapons testing was moved underground to prevent the release of radionuclides to the atmosphere and achieve containment. Releases of radioactive material after an underground test are generally categorized with terms that describe the volume of material released and the conditions of the release (DOE 1996a):

- Containment Failures. Containment failures are unintentional releases of radioactive matter to the atmosphere due to failure of the containment system. A prompt massive release, or one that occurs soon after a test, is a venting.

- Late-Time Seeps. Late-time seeps are small releases that occur days or weeks after a test when gases diffuse through pore spaces in the overlying rock and are drawn to the surface by decreases in atmospheric pressure.

- Controlled Tunnel Purging. A controlled tunnel purge is an intentional release to enable either recovery of experimental data and equipment or reuse of part of the tunnel system.

- Operational Release. Operational releases are small consequential releases that occur when core or gas samples are collected or when a drillback hole is sealed.

Handling of radioactive materials includes the transport and storage of nuclear explosive devices and the operation of a radioactive waste management site for low-level radioactive and mixed wastes. Monitoring and evaluation of the activities indicate that the potential sources of onsite radiation exposure are releases from the following sources (Black 1995):

- Tritiated water vapor (HTO) from drainage containment ponds for E Tunnel in Area 12,
- Onsite radioanalytical laboratories,
- Area 3 and 5 waste facilities, and
- Other diffuse sources.

The following sections describe effluent sources at NTS from information in Black (1995) and Hardesty (2018).

4.2.1.1.2 Ground Seepage of Noble Gases

Ground seepage can be enhanced when changes in ambient pressure pump small amounts of noble gases up through the overburden and into the atmosphere from the cavity created by a nuclear test. This process, sometimes referred to as *atmospheric pumping*, creates a diffuse source of radiological effluents. These area sources are rare and therefore not routinely monitored. The phenomenon is usually restricted to tests in the Pahute Mesa region of NTS. These seepages are from nuclear tests before 1993.

4.2.1.1.3 Tunnel Operations

Nuclear tests occurred in mined tunnel complexes in the Rainier Mesa region. Because some tunnels were sealed in the mid-1990s, small amounts of contaminated water continue to drain from only one tunnel.

4.2.1.1.4 Containment Ponds

Water contaminated with radionuclides seeps from the tunnels in Area 12 and collects in containment ponds where some evaporates and some seeps into the soil. The only radiological contaminant that produces a measurable air emission from evaporation of the water is tritium (^{3}H) in the form of HTO.

4.2.1.1.5 Drillbacks

After underground nuclear tests, core samples have been taken from the cavity that was formed by the detonation for analysis and diagnosis. This core sampling is accomplished by drilling into the area of interest and recovering samples using special equipment. Radioactive material can escape to the atmosphere during these operations.

4.2.1.1.6 Laboratories

Reynolds Electrical & Engineering Company (REECo) conducted radiological analyses in Building 650, and Los Alamos National Laboratory conducted similar analyses in Building 701 at Mercury, Nevada. Because these facilities have processed primarily environmental samples, very little radioactivity has passed through them. However, there was a potential for radionuclides to be discharged to the atmosphere through the hood ventilation system during sample processing, particularly from spiked samples or from loss of radioactive standards that contained heavy water, radioiodines, or noble gases.

Continuous stack monitoring has been conducted in the past at one facility on the NNSS, the Joint Actinide Shock Physics Experimental Research (JASPER) facility in Area 27 (Hardesty 2018). In

2013, the potential air emissions from the facility were re-evaluated and determined to result in a potential dose that is much less than the 0.1 mrem/yr threshold at which stack monitoring is required under NESHAP. Therefore, only periodic sampling is recommended to verify low emissions. In 2017, one sample was taken from January 18 to January 25 for this purpose. No manmade radionuclides were detected in the sample, which confirms continued low emissions.

4.2.1.1.7 Radioactive Waste Management Sites

Areas 3 and 5 contain sites for the disposal of low-level radioactive waste. Area 5 contains sites for storage of transuranic (TRU) and mixed TRU wastes as well as the Greater Confinement Disposal Test Unit and 12 accompanying boreholes, of which only a few contain waste. Disposal occurs in pits and trenches; concrete pads provide temporary storage of certain wastes. Area 5 is for packaged waste disposal only. The Waste Examination Facility houses a glovebox with high-efficiency particulate air filtration that is used to examine and repack TRU waste drums. No contamination has been released from glovebox operations to the environment. The drums, which have been sent to NTS from Lawrence Livermore National Laboratory (LLNL) in past years, are stored in the TRU Pad Cover Building. Repacked drums will be sent to the Waste Isolation Pilot Plant. The facility is a diffuse source of radiological effluents. The only radioactive effluent that has been detected by the various samplers around the site is HTO in atmospheric moisture. The Area 3 low-level waste site is in a location where surface soil has been contaminated by deposited plutonium, and resuspension of this soil by wind and vehicular activity has resulted in detection of above-background levels of plutonium in nearby air samples.

4.2.1.2 Atmospheric Radionuclide Concentrations

In 1964, REECo established an environmental surveillance program at NTS to measure radiological conditions throughout the site without regard to nuclear tests (Glora and Brown 1964a). That is, the collected data were not meant to relate to specific tests but to general conditions of radiation. The short-term objective of the program was to minimize casual personnel exposure to radiation by locating and identifying localized radiological environmental conditions by type and quantity of contamination. The long-range objective of the program was to establish baseline environmental data that could provide a reference for comparison with subsequent test activities and radiation measurements (Glora and Brown 1964a).

The initial surveillance program included, over time, 12 permanent air-sampling stations in the most populated areas at NTS. The air samplers were low-volume Filter Queen samplers with 8- by 10-in. (Gelman Type E) glass-fiber filter papers. Operating times were determined by integrated electric timers with flow rates from calibrated rotometers. Typical flow rates varied from 3 to 6 ft^3/min; samples were collected weekly (Glora and Brown 1964b).

After the first reporting period (June 1964), positive-displacement Gast pumps, which were equipped with in-line total volume gas meters, replaced the Filter Queen samplers. In May and June 1965, the 8- by 10-in. Gelman filters were replaced with a new sampler that used 4-in. diameter Whatman 41 filter paper (Lewis, Glora, and Aoki 1965). The sampling rate of these samplers was about 3 ft^3/min. Therefore, the total volume of sampled air in a 7-day period was about 1×10^3 m^3. During this period, the number of sampling stations increased to 13, and caustic scrubbers were added for the detection of radioiodines.

Early particulate samples were typically analyzed only for gross alpha and gross beta. However, if gross beta concentrations exceeded 1×10^{-5} µCi/m^3, researchers conducted an analysis for ^{227}Ac (the most hazardous beta emitter present). Because no historical evidence exists that ^{227}Ac has been detected in air or soil samples, the assumption that unidentified beta emitters were ^{227}Ac would be unreasonable and inappropriate. Therefore, for dose reconstruction, ^{90}Sr is assumed to be the

unidentified beta-emitting radionuclide with the highest internal dose impact (see Section 4.2.1.2.4 for details).

Environmental samples were analyzed for gross alpha and beta radioactivity by gas proportional counting. Air samples were analyzed with a Nuclear Chicago ULTRASCALER system with a 9- by 10-in. detection chamber to accommodate the 8- by 10-in. filters. All other samples were analyzed with a Beckman WIDEBETA system equipped with an automatic sample changer. This counting equipment and protocol allowed lower detection limits of about 2.9×10^{-9} and 1.6×10^{-8} µCi/m^3 for gross alpha and gross beta, respectively (Lewis, Glora, and Aoki 1965). By 1978, the lower detection limit for gross beta counting had been reduced to 1×10^{-10} µCi/m^3 (Lewis, Glora, and Aoki 1965).

Gross gamma screening was typically performed on samples that were prepared for gross beta counting. The screening was performed using a 5- by 5-in. NaI(Tl) detector that was coupled to a single-channel analyzer. Any samples that showed elevated gamma readings were sent to a multichannel analyzer for radionuclide identification (Lewis, Glora, and Aoki 1965). In the early 1970s, gamma spectroscopy was performed using germanium-lithium [Ge(Li)] detectors and 2,000-channel analyzers with a lower detection limit of 5×10^{-9} µCi/m^3 (Lantz 1978a). After cessation of atmospheric testing at NTS in 1963, fission products were frequently measured in the atmosphere but were typically correlated with foreign atmospheric weapons testing (see Section 4.2.1.2.4).

In 1971, weekly air samples from a given station were batched on a monthly basis and subjected to radiochemical analysis for ^{239}Pu. The procedure included acid dissolution with ion exchange recovery and electroplating onto stainless-steel discs, which was followed by alpha spectroscopy using solid-state surface barrier detectors (Lantz 1978a). This analysis provided a nominal minimum detection limit of 3×10^{-7} µCi/m^3 (Lantz 1978a). Routine analysis for ^{238}Pu started in 1989 (Wruble and McDowell 1990a).

In 1977, a separate sampler was designed for the collection of airborne elemental tritium (HT) and HTO. The sampler was portable and capable of unattended operation for as long as 2 weeks in desert areas. A small electronic pump drew air into the sampler at about 0.5 L/min, and the HTO was removed from the air stream by a silica gel drying column. The dry air then passed through a catalytic converter with platinum to generate HTO from HT. Another drying column collected the vapor, in which a small volume of distilled water served as a trap for the HTO. Appropriate aliquots of condensed moisture were obtained by heating the silica gel. Counting via liquid scintillation techniques enabled the determination of HT and HTO activities. The typical minimum detection limit for this analysis was 3×10^{-7} µCi/m^3 (Lantz 1978a).

The number of air sampling stations increased over the years to a peak of 52 in 1989 (Wruble and McDowell 1990a). This number remained fairly constant until a gradual reduction began in 1995 (Black and Townsend 1996). This reduction occurred primarily because of a gradual strategy shift from environmental monitoring to demonstration of compliance with National Emission Standards for Hazardous Air Pollutants as approved by the U.S. Environmental Protection Agency (EPA; i.e., 40 CFR Part 61) (Black and Townsend 1997). Figure 4-1 shows the locations of the 48 sampling stations in 1997 (Black and Townsend 1998).

Since the late 1980s the environmental surveillance program has routinely monitored atmospheric concentrations of tritium, ^{238}Pu, ^{239}Pu, and ^{240}Pu. These radionuclides were considered the most important to dose for workers and members of the public (Wruble and McDowell 1990a). In addition, since the mid-1960s, measurements have been reported for gross alpha and gross beta concentrations (Glora and Brown 1964b). The following sections discuss the history of these measurements in the NTS annual environmental reports (see References section) and their importance to dose reconstruction for unmonitored employees.

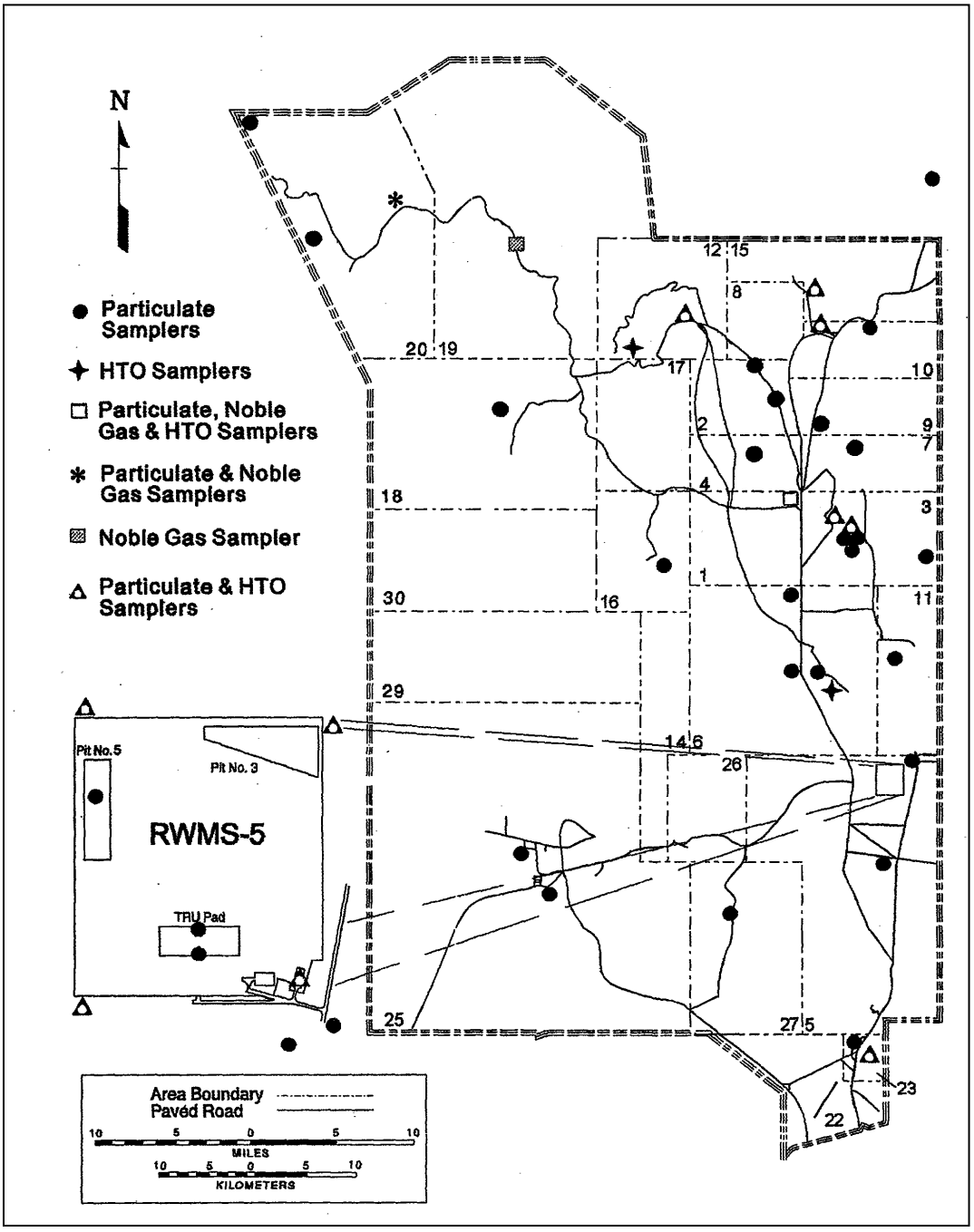

Figure 4-1. Air sampling stations in 1997 (Black and Townsend 1998).

4.2.1.2.1 Annual Inhalation Intakes of Tritium

Atmospheric measurements at NTS began in 1977 with samplers in Areas 5, 10, and 23 (Lantz 1978a). The sampler near Building 650 (Mercury) was the control station. During that year, the samples in Area 10 (near the Sedan Crater) demonstrated the highest HTO concentrations with a high of 1.11×10^{-11} Bq/m^3 (Lantz 1978a). The number of sampling locations increased over the following years to include all the areas in Table 4-1. These locations provided representative samples from the most populated areas on the site (Black and Townsend 1998).

The tritium concentrations in Table 4-1 are typically the average of the maximum concentrations for a given area in a given year, unless these values were determined to be adversely affected by nearby

Table 4-1. HTO atmospheric concentrations by year and area with estimated maximum and average annual organ dose.[a,b]

Year	Area 1	Area 3	Area 5	Area 6	Area 10	Area 12	Area 15	Area 16	Area 18	Area 20	Area 23	Area 25	Site average (Bq/m^3)	Site maximum (Bq/m^3)	Site maximum annual dose (rem)	Site average annual dose (rem)
1977	ND	ND	ND	ND	1.11E+01	ND	ND	ND	ND	ND	4.44E-02	ND	5.55E+00	1.11E+01	6.90E-05	3.50E-05
1978	ND	ND	1.07E+02	ND	4.81E+00	7.03E-01	7.03E-01	ND	ND	ND	1.11E+00	ND	2.29E+01	1.07E+02	6.70E-04	1.40E-04
1979	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.29E+01[c]	1.07E+02[c]	6.70E-04[c]	1.40E-04[c]
1980	ND	ND	9.62E+00	ND	ND	ND	ND	ND	ND	ND	2.63E+00	ND	6.29E+00	9.62E+00	6.00E-05	3.80E-05
1981	ND	ND	1.33E+02	ND	ND	ND	ND	ND	ND	ND	3.63E+01	ND	8.51E+01	1.33E+02	8.30E-04	5.30E-04
1982	2.78E+01	ND	8.51E+01	ND	ND	1.63E+02	2.81E+01	ND	ND	ND	1.85E+02	ND	9.62E+01	1.85E+02	1.20E-03	6.10E-04
1983	3.03E+00	ND	4.07E+00	ND	ND	3.29E+00	1.44E+02	ND	ND	ND	2.41E+01	ND	3.55E+01	1.44E+02	8.90E-04	2.20E-04
1984	6.29E+00	ND	1.96E+01	ND	ND	1.22E+00	1.30E+00	ND	ND	ND	1.85E+02	ND	4.44E+01	1.85E+02	1.20E-03	2.70E-04
1985	5.18E+00	ND	3.18E+00	ND	ND	1.74E+02	1.30E+00	ND	ND	ND	1.74E+01	ND	4.07E+01	1.74E+02	1.10E-03	2.50E-04
1986	4.44E+00	ND	2.07E+00	ND	ND	2.44E+00	2.22E+00	ND	ND	ND	3.11E+01	ND	8.51E+00	3.11E+01	1.90E-04	5.30E-05
1987	1.67E+00	ND	6.29E+00	ND	ND	2.33E+00	1.70E+01	ND	ND	ND	9.62E+00	ND	7.40E+00	1.70E+01	1.00E-04	4.60E-05
1988	1.63E+00	ND	1.44E+00	ND	ND	7.40E-01	1.92E+01	ND	ND	ND	1.18E+00	ND	4.81E+00	1.92E+01	1.20E-04	3.00E-05
1989	6.29E+00	ND	1.15E+00	ND	4.81E-01	7.03E-01	3.03E+00	ND	ND	ND	1.70E-01	ND	1.96E+00	6.29E+00	3.90E-05	1.20E-05
1990	2.74E-01	ND	8.14E-01	ND	4.81E-01	1.48E-01	8.51E-01	ND	ND	ND	2.78E+00	7.77E-01	8.88E-01	2.78E+00	1.70E-05	5.50E-06
1991	3.37E-01	ND	1.04E+00	ND	2.33E-01	3.11E-01	6.29E-01	ND	ND	ND	1.59E-01	7.77E-02	4.07E-01	1.04E+00	6.50E-06	2.50E-06
1992	3.70E-01	ND	1.30E+00	ND	1.22E-01	2.29E+00	2.29E+00	ND	ND	ND	2.26E-01	3.26E+00	1.41E+00	3.26E+00	2.00E-05	8.80E-06
1993	3.22E-01	ND	1.04E+00	ND	2.92E-01	1.37E-01	7.40E-01	ND	ND	ND	1.48E-01	7.03E-02	4.07E-01	1.04E+00	6.50E-06	2.40E-06
1994	1.48E-01	ND	1.74E+00	1.89E-01	8.14E-02	9.62E-02	1.37E+00	ND	ND	ND	1.52E-01	1.07E-01	3.92E-01	1.74E+00	6.74E-06	2.55E-06
1995	1.37E-01	5.18E-02	7.77E-01	3.52E-02	2.59E-01	1.59E-01	3.70E-01	ND	ND	ND	9.62E-02	5.18E-02	2.15E-01	7.77E-01	4.90E-06	1.30E-06
1996	1.15E-01	1.52E-01	5.92E-01	2.07E+00	9.62E-01	7.40E-01	5.18E-01	ND	ND	ND	4.07E-02	4.07E-02	5.92E-01	2.07E+00	1.30E-05	3.60E-06
1997	8.14E-02	1.41E-01	2.78E-01	2.07E+00	1.07E+00	8.51E-01	7.40E-01	ND	ND	ND	4.81E-02	4.81E-02	5.92E-01	2.07E+00	1.30E-05	3.70E-06
1998	1.26E-01	ND	6.29E-01	6.66E+00	1.07E+00	2.04E+00	5.18E-01	ND	ND	1.70E+01	ND	ND	4.07E+00	1.70E+01	1.10E-04	2.50E-05
1999	7.40E-01	ND	6.66E-01	1.55E-01	1.52E+00	1.04E+00	9.99E-01	ND	ND	2.78E+01	ND	ND	4.81E+00	2.78E+01	1.70E-04	2.90E-05
2000	1.52E-01	ND	5.55E-01	ND	1.89E+00	2.00E+00	7.03E-01	ND	ND	3.59E+01	ND	ND	7.03E+00	3.59E+01	2.20E-04	4.30E-05
2001	1.55E-01	ND	1.33E-01	2.29E-01	1.55E+00	9.25E-01	1.41E-01	8.51E-02	4.81E-02	4.07E+01	2.63E-02	2.26E-01	4.07E+00	4.07E+01	2.50E-04	2.50E-05

a. Sources: Environmental Reports listed in the References section.
b. ND = no data.
c. Value not provided in annual reports; assumed same as that for 1978.

point-source releases (e.g., Building 790 in 1983; Scoggins 1983, p. 29). If maximum values were not provided, the average concentrations were reported.

In addition to the annual area tritium concentrations, Table 4-1 lists NTS site average and maximum concentrations, which represent the arithmetic averages of the concentrations of all the areas and the maximum of all the areas, respectively. For dose reconstruction, these average and maximum site concentrations have been converted to annual organ dose using the dose conversion factor (DCF) for inhalation of 1.80×10^{-9} rem/Bq (ICRP 1997) and by assuming submersion in the respective concentrations for 2,000 hr/yr and an inhalation rate of 2,400 m^3/yr.

In addition to the inhalation dose, a factor of 1.5 was included in the organ dose calculation to account for absorption through the skin.

The uncertainty that is associated with the values in Table 4-1 was not provided in the annual environmental reports until 2001. Based on the values for that year, the standard deviation would be typically less than 10% of the measured values. Because sampling methods changed over time and uncertainty estimates for previous years were unavailable, the assumption that Table 4-1 lists the 50th-percentile expected intakes and that the 95th-percentile values are twice the Table 4-1 values is favorable to claimants.

For dose reconstruction, the geometric standard deviation (GSD) of the values in Table 4-1 would be estimated by using the following expression for a lognormal distribution (Till 2002):

$$GSD = \left(\frac{95th\ percentile}{50th\ percentile}\right)^{\left(\frac{1}{1.645}\right)} \quad (4\text{-}1)$$

If the assumption is made that the 95th-percentile values are twice the Table 4-1 values, the GSD can be shown using Equation 4-1 to be 1.52.

If the assumption that is favorable to claimants is used to estimate the 95th-percentile dose (i.e., add 100%) from the maximum annual doses in Table 4-1, the resultant annual organ doses would be less than 2 mrem/yr.

For purposes of dose reconstruction, these small doses would be inconsequential to estimates of causation and should not be included in the IREP evaluations.

4.2.1.2.2 Annual Intakes of Plutonium

Routine isotopic atmospheric measurements of plutonium at NTS began in 1971 with samplers in 15 locations across the site (Lantz 1978a). Six additional sampling stations were added in 1978 (Lantz 1979). Equipment at fixed locations continuously sampled the ambient air to monitor for radioactive materials. These locations were chosen to provide representative samples from populated areas on the site and to monitor resuspension of low-fired plutonium spread by safety experiments before 1960 in Areas 2, 3, 4, 7, 9, and 10. Access, worker population, geographical coverage, presence of radioactivity, and availability of electric power were considerations in the site selection for air samplers (Black and Townsend 1997).

In 1988, efforts to monitor radioactive air emissions at NTS increased as a result of the requirements of DOE Order 5400.1 (DOE 1990). Known and potential effluent sources throughout NTS were assessed for their potential to contribute to public dose (Black and Townsend 1997).

The ^{239}Pu concentrations in Table 4-2 for 1989 through 2001 represent the average of the maximum concentrations for a given area in a given year. For cases in which maximum values were not provided (i.e., 1971 through 1988), the average of the average concentrations was listed. In addition to annual area concentrations, Table 4-2 lists NTS site average and maximum concentrations, which represent the arithmetic averages of the concentration of all the areas and the maximum of the area maximum or area averages of all the areas, respectively. Potential intakes associated with these concentrations can be calculated under the assumption that an unmonitored worker was occupationally exposed for 2,000 hours per year and had a breathing rate of 2,400 m^3/yr. Table 4-3 lists these calculated intakes.

Some covered employees remained on the site continuously for weeks at a time. However, because most nonworking hours were spent indoors where ambient air particulate loadings would be much less than outdoor loadings and because of the conservative assumptions that were used to estimate the values in Table 4-3, adjustment of the tabular data is not required to ensure intakes are not underestimated for these individuals. In addition, employees who lived on the site during their workweek would have been housed in Area 12 or Area 23 (Mercury). For most years, the values in Table 4-2 for these locations are less than the site average values. For dose reconstruction, the inhalation intake values in Table 4-3 can be assumed to be bounding; therefore, the organ dose from these intakes should be applied in the IREP evaluation with a constant distribution.

It is assumed that plutonium could be any of absorption types S, Super S, or M depending on which type delivers the maximum organ dose. Because these doses are based on air monitoring results, evaluation for type Super S (ORAUT 2010) is required for lung and thoracic cancers if there were no bioassay results for the employee.

4.2.1.2.3 Annual Intakes of Other Radionuclides

Extensive studies were performed in the 1980s to quantify residual contamination at NTS (McArthur and Kordas 1983, 1985; McArthur and Mead 1987, 1988, 1989; McArthur 1991). Table 4-4 lists the results of these studies (McArthur 1991). Table 4-5 lists the total areal depositions based on the inventory values in Table 4-4 divided by the areal size. The results in Table 4-5 are representative of areas of NTS that contain measurable levels of contamination. These areas actually represent only about one-third of the total area within the boundaries of NTS.

In addition, because the data in Table 4-4 are representative of soil contamination in 1991, the values in Table 4-5 were decay-corrected to the beginning of 1963, the first year after the cessation of atmospheric testing.

4.2.1.2.4 Scaling Factors for Inhalation Intakes

Because the air sampling program did not provide isotopic analyses for all the radionuclides identified in NTS soils, scaling factors were developed to estimate potential intakes for these radionuclides based on their relative abundances in comparison with ^{239}Pu when the soil contamination data (McArthur 1991) have been decay-corrected to 1963. These area-specific ratios are listed in Table 4-6.

The scaling factors in Table 4-6 are used in conjunction with the ^{239}Pu intakes in Table 4-3 to determine potential environmental intakes of all the radionuclides important to dose (in Table 4-6) that have been identified as persistent in NTS soils. For dose reconstruction, maximum intakes of these radionuclides are calculated by selecting the maximum annual intake of plutonium (e.g., 0.381 Bq/yr derived for Area 9 in 1972) and multiplying this value by the maximum scaling factor for each of the radionuclides in Table 4-6.

Table 4-2. Atmospheric concentrations of ^{239}Pu for sampled areas (Bq/m^3).[a,b]

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 9	Area 10	Area 11	Area 12
1971	1.37E-05	2.45E-05	6.11E-06	ND	4.37E-06	6.36E-06	ND	2.67E-05	7.70E-06	3.37E-06	6.03E-06
1972	5.48E-06	8.29E-06	1.36E-05	ND	5.18E-06	4.96E-05	ND	1.59E-04	1.07E-05	8.99E-06	2.91E-05
1973	3.22E-06	8.25E-06	7.62E-06	ND	3.23E-06	4.44E-06	ND	3.18E-05	1.63E-06	8.99E-06	1.59E-06
1974	2.96E-06	2.52E-06	4.66E-06	ND	1.85E-06	2.93E-06	ND	7.81E-06	2.11E-06	2.96E-06	2.15E-06
1975	1.07E-06	1.41E-06	5.40E-06	ND	1.59E-06	2.32E-06	ND	6.22E-06	2.11E-06	1.81E-06	1.22E-06
1976	1.06E-05	6.36E-06	3.85E-05	ND	5.55E-06	1.64E-05	ND	1.18E-04	7.88E-06	8.73E-06	1.03E-05
1977	9.99E-07	2.41E-06	9.44E-06	ND	1.24E-06	2.05E-06	ND	9.36E-06	1.70E-06	4.48E-06	7.77E-07
1978	1.74E-06	4.92E-06	1.04E-05	ND	2.26E-06	3.66E-06	ND	2.01E-05	1.07E-05	3.96E-06	2.29E-06
1979	2.74E-06	1.72E-05	6.11E-08	ND	7.59E-07	1.46E-06	1.81E-06	1.94E-05	1.07E-05	1.37E-06	8.88E-07
1980	8.51E-07	9.58E-06	4.14E-08	ND	1.08E-06	1.78E-06	1.67E-06	1.67E-05	ND	1.63E-06	7.03E-07
1981	9.62E-07	2.35E-06	5.18E-06	ND	9.18E-07	1.07E-06	1.22E-06	1.19E-05	ND	1.70E-06	7.40E-07
1982	2.26E-06	1.48E-06	2.31E-06	ND	7.36E-07	1.30E-06	2.74E-06	7.96E-06	ND	1.96E-06	9.99E-07
1983	1.15E-06	2.39E-06	3.42E-06	ND	8.40E-07	1.20E-06	1.22E-06	7.92E-06	ND	6.73E-06	8.51E-07
1984	7.03E-07	3.68E-06	8.44E-06	ND	1.40E-06	7.40E-07	1.41E-06	3.77E-05	ND	2.07E-06	6.29E-07
1985	5.55E-07	2.13E-06	7.88E-06	ND	1.13E-06	9.99E-07	9.99E-07	4.92E-05	ND	1.92E-06	8.51E-07
1986	5.48E-06	2.29E-06	2.02E-05	ND	1.02E-06	6.88E-06	1.78E-06	1.04E-05	ND	9.25E-07	1.18E-06
1987	2.02E-06	8.51E-07	1.04E-04	ND	6.11E-07	9.36E-07	5.92E-07	4.07E-06	ND	1.18E-06	5.92E-07
1988	3.40E-06	1.04E-06	7.92E-06	ND	1.02E-06	8.14E-07	5.55E-07	1.89E-06	ND	4.44E-07	5.92E-07
1989	3.16E-05	2.15E-06	1.99E-05	ND	1.86E-06	2.96E-06	9.99E-06	1.30E-05	ND	2.00E-05	2.52E-05
1990	3.66E-06	1.20E-06	1.28E-05	ND	1.14E-06	1.37E-06	1.50E-06	1.84E-05	1.57E-06	3.96E-06	3.85E-07
1991	1.15E-04	7.59E-07	1.42E-05	ND	1.30E-06	2.68E-06	1.20E-06	1.30E-05	1.99E-08	8.29E-06	5.29E-07
1992	5.55E-06	4.07E-06	8.36E-05	ND	2.97E-06	2.69E-06	1.44E-05	3.26E-05	8.88E-06	3.26E-06	1.41E-06
1993	7.51E-06	1.81E-06	1.47E-05	ND	2.96E-06	3.31E-06	2.89E-06	9.99E-05	6.29E-06	1.55E-05	3.11E-05
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	1.50E-06	4.07E-07	8.99E-06	ND	5.66E-07	1.86E-06	4.44E-07	1.44E-05	1.39E-06	1.48E-06	4.07E-07
1996	2.78E-05	ND	1.12E-05	ND	6.07E-07	1.70E-06	1.67E-05	2.26E-05	2.13E-06	7.03E-07	1.37E-07
1997	ND	3.96E-07	ND	ND	ND	ND	ND	ND	9.73E-07	4.07E-07	5.55E-08
1998	1.74E-05	ND	2.49E-06	ND	3.52E-06	4.07E-07	1.01E-06	2.72E-05	ND	3.50E-07	ND
1999	ND	ND	ND	2.18E-06	ND	ND	ND	ND	ND	ND	ND
2000	3.14E-06	ND	9.95E-06	2.18E-06	7.59E-07	1.52E-05	1.26E-06	1.05E-04	ND	ND	ND
2001	1.68E-05	4.62E-07	4.29E-06	6.92E-06	2.53E-06	3.57E-06	6.28E-07	1.86E-05	3.13E-07	ND	ND

Year	Area 15	Area 16	Area 18	Area 19	Area 20	Area 23	Area 25	Area 27	Area 28	Site average	Site maximum
1971	ND	7.14E-06	2.96E-06	8.36E-06	ND	3.46E-06	ND	3.11E-06	1.44E-06	8.35E-06	2.67E-05
1972	ND	6.25E-06	5.37E-06	1.01E-04	ND	1.29E-05	ND	6.14E-06	1.89E-06	2.82E-05	1.59E-04
1973	ND	1.63E-06	1.41E-06	2.65E-06	ND	2.07E-06	ND	1.37E-06	1.22E-06	5.41E-06	3.18E-05
1974	ND	2.22E-06	ND	2.44E-06	ND	3.15E-06	3.18E-06	2.66E-06	4.33E-06	3.20E-06	7.81E-06
1975	ND	1.59E-06	ND	1.24E-06	ND	1.63E-06	2.11E-06	2.52E-06	2.59E-06	2.32E-06	6.22E-06
1976	ND	5.77E-06	ND	3.66E-06	ND	2.10E-05	7.44E-06	5.07E-06	2.33E-06	1.78E-05	1.18E-04
1977	ND	9.62E-07	ND	8.51E-07	ND	9.99E-07	1.22E-06	1.15E-06	8.51E-07	2.56E-06	9.44E-06
1978	ND	1.89E-06	ND	2.28E-06	ND	2.15E-06	2.58E-06	3.48E-06	1.44E-06	4.92E-06	2.01E-05
1979	1.92E-06	7.77E-07	ND	7.22E-07	ND	8.25E-07	6.66E-07	5.92E-07	8.51E-07	3.69E-06	1.94E-05
1980	2.36E-06	ND	ND	3.53E-06	ND	1.31E-06	1.13E-06	7.77E-07	5.92E-07	2.73E-06	1.67E-05
1981	3.44E-06	9.62E-07	ND	8.51E-07	ND	1.06E-06	8.99E-07	9.25E-07	5.92E-07	2.17E-06	1.19E-05
1982	1.55E-06	6.29E-07	ND	8.03E-07	ND	7.77E-07	6.29E-07	ND	ND	1.87E-06	7.96E-06
1983	8.25E-07	5.55E-07	ND	1.09E-06	ND	1.04E-06	1.11E-06	ND	ND	2.17E-06	7.92E-06
1984	1.18E-06	1.04E-06	ND	9.25E-07	ND	1.06E-06	1.18E-06	1.78E-06	ND	4.26E-06	3.77E-05
1985	1.48E-06	7.77E-07	ND	1.30E-06	ND	8.14E-07	9.73E-07	1.15E-06	ND	4.81E-06	4.92E-05
1986	1.44E-06	1.04E-06	ND	8.14E-07	ND	2.42E-06	7.59E-07	8.51E-07	ND	3.83E-06	2.02E-05
1987	6.66E-07	5.18E-07	ND	6.29E-07	ND	5.92E-07	8.51E-07	ND	ND	8.43E-06	1.04E-04
1988	8.99E-07	ND	ND	5.00E-07	ND	1.30E-06	5.55E-07	5.55E-07	ND	1.53E-06	7.92E-06
1989	8.62E-07	4.07E-07	ND	3.33E-07	ND	4.33E-06	3.50E-07	1.78E-07	ND	8.87E-06	3.16E-05
1990	3.03E-06	2.16E-07	ND	1.45E-07	ND	3.13E-06	4.18E-07	1.30E-06	ND	3.39E-06	1.84E-05
1991	4.55E-06	1.07E-06	ND	3.26E-07	ND	4.92E-07	9.51E-07	2.86E-07	ND	1.03E-05	1.15E-04
1992	4.07E-05	7.03E-07	ND	3.29E-07	ND	4.70E-07	6.70E-07	5.92E-06	ND	1.30E-05	8.36E-05
1993	1.22E-05	4.81E-07	ND	2.85E-07	ND	2.31E-07	1.26E-07	4.07E-07	ND	1.25E-05	9.99E-05
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	5.92E-06	5.18E-07	ND	3.70E-08	ND	2.75E-07	1.67E-07	ND	ND	2.56E-06	1.44E-05
1996	8.88E-06	6.66E-08	1.30E-07	ND	1.67E-07	2.31E-07	1.55E-07	9.62E-08	ND	5.82E-06	2.78E-05
1997	1.07E-06	7.03E-09	7.40E-07	ND	7.40E-07	2.22E-08	3.74E-08	5.92E-08	ND	4.11E-07	1.07E-06
1998	2.35E-06	ND	1.14E-06	ND	1.21E-06	4.29E-07	2.32E-07	ND	ND	4.81E-06	2.72E-05
1999	4.07E-07	ND	4.07E-07	ND	7.40E-07	ND	2.29E-07	ND	ND	7.93E-07	2.18E-06
2000	9.56E-06	ND	3.78E-07	ND	2.43E-07	ND	4.25E-07	ND	ND	1.34E-05	1.05E-04
2001	5.18E-07	3.53E-07	6.37E-07	ND	2.80E-07	7.51E-08	1.63E-07	ND	ND	3.75E-06	1.86E-05

a. Sources: Environmental Reports listed in the References section.
b. ND = no data.

Table 4-3. Annual inhalation intakes from ^{239}Pu for sampled areas (Bq) (from Attachment A).[a]

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 9	Area 10	Area 11	Area 12
1971	0.0329	0.0587	0.0147	ND	0.0105	0.0153	ND	0.0640	0.0185	0.0081	0.0145
1972	0.0131	0.0199	0.0327	ND	0.0124	0.1190	ND	0.3810	0.0258	0.0216	0.0698
1973	0.0077	0.0198	0.0183	ND	0.0078	0.0107	ND	0.0763	0.0039	0.0216	0.0038
1974	0.0071	0.0060	0.0112	ND	0.0044	0.0070	ND	0.0187	0.0051	0.0071	0.0052
1975	0.0026	0.0034	0.0130	ND	0.0038	0.0056	ND	0.0149	0.0051	0.0044	0.0029
1976	0.0255	0.0153	0.0924	ND	0.0133	0.0392	ND	0.2824	0.0189	0.0210	0.0248
1977	0.0024	0.0058	0.0226	ND	0.0030	0.0049	ND	0.0225	0.0041	0.0107	0.0019
1978	0.0042	0.0118	0.0250	ND	0.0054	0.0088	ND	0.0481	0.0258	0.0095	0.0055
1979	0.0066	0.0413	0.0001	ND	0.0018	0.0035	0.0044	0.0465	0.0258	0.0033	0.0021
1980	0.0020	0.0230	0.0001	ND	0.0026	0.0043	0.0040	0.0401	ND	0.0039	0.0017
1981	0.0023	0.0056	0.0124	ND	0.0022	0.0026	0.0029	0.0286	ND	0.0041	0.0018
1982	0.0054	0.0036	0.0055	ND	0.0018	0.0031	0.0066	0.0191	ND	0.0047	0.0024
1983	0.0028	0.0057	0.0082	ND	0.0020	0.0029	0.0029	0.0190	ND	0.0162	0.0020
1984	0.0017	0.0088	0.0202	ND	0.0034	0.0018	0.0034	0.0906	ND	0.0050	0.0015
1985	0.0013	0.0051	0.0189	ND	0.0027	0.0024	0.0024	0.1181	ND	0.0046	0.0020
1986	0.0131	0.0055	0.0484	ND	0.0025	0.0165	0.0043	0.0249	ND	0.0022	0.0028
1987	0.0048	0.0020	0.2495	ND	0.0015	0.0022	0.0014	0.0098	ND	0.0028	0.0014
1988	0.0082	0.0025	0.0190	ND	0.0025	0.0020	0.0013	0.0045	ND	0.0011	0.0014
1989	0.0759	0.0052	0.0478	ND	0.0045	0.0071	0.0240	0.0311	ND	0.0480	0.0604
1990	0.0088	0.0029	0.0308	ND	0.0027	0.0033	0.0036	0.0442	0.0038	0.0095	0.0009
1991	0.2753	0.0018	0.0340	ND	0.0031	0.0064	0.0029	0.0311	0.0000	0.0199	0.0013
1992	0.0133	0.0098	0.2007	ND	0.0071	0.0065	0.0346	0.0781	0.0213	0.0078	0.0034
1993	0.0180	0.0044	0.0352	ND	0.0071	0.0079	0.0069	0.2398	0.0151	0.0373	0.0746
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	0.0036	0.0010	0.0216	ND	0.0014	0.0045	0.0011	0.0346	0.0033	0.0036	0.0010
1996	0.0666	0.0000	0.0268	ND	0.0015	0.0041	0.0400	0.0542	0.0051	0.0017	0.0003
1997	ND	0.0010	ND	ND	ND	ND	ND	ND	0.0023	0.0010	0.0001
1998	0.0416	ND	0.0060	ND	0.0084	0.0010	0.0024	0.0653	ND	0.0008	ND
1999	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2000	0.0075	ND	0.0239	0.0052	0.0018	0.0366	0.0030	0.2509	ND	ND	ND
2001	0.0404	0.0011	0.0103	0.0166	0.0061	0.0086	0.0015	0.0447	0.0008	ND	ND

Year	Area 15	Area 16	Area 18	Area 19	Area 20	Area 23	Area 25	Area 27	Area 28	Site average	Site maximum
1971	ND	0.0171	0.0071	0.0201	ND	0.0083	ND	0.0075	0.0035	0.0200	0.0640
1972	ND	0.0150	0.0129	0.2424	ND	0.0309	ND	0.0147	0.0045	0.0677	0.3810
1973	ND	0.0039	0.0034	0.0063	ND	0.0050	ND	0.0033	0.0029	0.0130	0.0763
1974	ND	0.0053	ND	0.0059	ND	0.0075	0.0076	0.0064	0.0104	0.0077	0.0187
1975	ND	0.0038	ND	0.0030	ND	0.0039	0.0051	0.0060	0.0062	0.0056	0.0149
1976	ND	0.0139	ND	0.0088	ND	0.0504	0.0178	0.0122	0.0056	0.0428	0.2824
1977	ND	0.0023	ND	0.0020	ND	0.0024	0.0029	0.0028	0.0020	0.0062	0.0226
1978	ND	0.0045	ND	0.0055	ND	0.0052	0.0062	0.0083	0.0035	0.0118	0.0481
1979	0.0046	0.0019	ND	0.0017	ND	0.0020	0.0016	0.0014	0.0020	0.0089	0.0465
1980	0.0057	ND	ND	0.0085	ND	0.0031	0.0027	0.0019	0.0014	0.0070	0.0401
1981	0.0083	0.0023	ND	0.0020	ND	0.0025	0.0022	0.0022	0.0014	0.0052	0.0286
1982	0.0037	0.0015	ND	0.0019	ND	0.0019	0.0015	ND	ND	0.0045	0.0191
1983	0.0020	0.0013	ND	0.0026	ND	0.0025	0.0027	ND	ND	0.0052	0.0190
1984	0.0028	0.0025	ND	0.0022	ND	0.0025	0.0028	0.0043	ND	0.0102	0.0906
1985	0.0036	0.0019	ND	0.0031	ND	0.0020	0.0023	0.0028	ND	0.0115	0.1181
1986	0.0035	0.0025	ND	0.0020	ND	0.0058	0.0018	0.0020	ND	0.0092	0.0484
1987	0.0016	0.0012	ND	0.0015	ND	0.0014	0.0020	0.0000	ND	0.0189	0.2495
1988	0.0022	ND	ND	0.0012	ND	0.0031	0.0013	0.0013	ND	0.0037	0.0190
1989	0.0021	0.0010	ND	0.0008	ND	0.0104	0.0008	0.0004	ND	0.0213	0.0759
1990	0.0073	0.0005	ND	0.0003	ND	0.0075	0.0010	0.0031	ND	0.0081	0.0442
1991	0.0109	0.0026	ND	0.0008	ND	0.0012	0.0023	0.0007	ND	0.0246	0.2753
1992	0.0977	0.0017	ND	0.0008	ND	0.0011	0.0016	0.0142	ND	0.0312	0.2007
1993	0.0293	0.0012	ND	0.0007	ND	0.0006	0.0003	0.0010	ND	0.0300	0.2398
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	0.0142	0.0012	ND	0.0001	ND	0.0007	0.0004	ND	ND	0.0061	0.0346
1996	0.0213	0.0002	0.0003	0.0000	0.0004	0.0006	0.0004	0.0002	ND	0.0124	0.0666
1997	0.0026	0.0000	0.0018	ND	0.0018	0.0001	0.0001	0.0001	ND	0.0010	0.0026
1998	0.0056	ND	0.0027	ND	0.0029	0.0010	0.0006	ND	ND	0.0115	0.0653
1999	0.0010	ND	0.0010	ND	0.0018	ND	0.0006	ND	ND	0.0011	0.0018
2000	0.0229	ND	0.0009	ND	0.0006	ND	0.0010	ND	ND	0.0322	0.2509
2001	0.0012	0.0008	0.0015	ND	0.0007	0.0002	0.0004	ND	ND	0.0090	0.0447

a. ND = no data.

Table 4-4. Inventory of contaminated soil (Bq).[a,b]

Area	Area (m^2)	Am-241	Pu-238	Pu-239,240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	6.86E+07	1.554E+11	2.41E+11	8.88E+11	4.07E+10	3.26E+11	5.55E+11	5.55E+11	3.7E+09	1.85E+10
2	5.10E+07	1.073E+11	3.18E+11	8.14E+11	4.44E+10	8.88E+11	1.7E+12	5.18E+11	ND	1.48E+10
3	8.37E+07	1.702E+11	1.15E+11	1.37E+12	3.7E+10	4.44E+11	1.22E+12	6.66E+11	3.7E+09	1.85E+10
4	4.14E+07	2.442E+11	4.81E+11	1.48E+12	5.92E+10	4.44E+11	4.81E+11	3.37E+11	ND	7.4E+09
5	7.51E+06	2.22E+10	3.7E+09	1.78E+11	2.22E+10	1.48E+10	3.33E+10	3.7E+11	7.4E+09	ND
6	8.37E+07	6.29E+10	1.22E+11	3.11E+11	7.4E+09	1.04E+11	1.3E+11	ND	ND	ND
7	5.00E+07	8.14E+10	2.22E+10	5.92E+11	3.7E+10	1.92E+11	3.4E+11	8.14E+11	7.4E+09	1.11E+10
8	3.60E+07	6.29E+11	2.96E+11	4.07E+12	2.11E+11	1.55E+12	9.25E+11	1.63E+11	ND	2.22E+10
9	5.18E+07	1.554E+11	8.14E+10	3.29E+12	2.59E+10	3.22E+11	4.81E+11	8.51E+11	7.4E+09	1.11E+10
10	5.18E+07	7.03E+11	7.03E+11	4.07E+12	3.59E+11	3.11E+12	2.04E+12	8.14E+10	1.11E+10	1.85E+11
11	1.04E+07	1.221E+11	1.85E+10	1.07E+12	ND	1.85E+10	1.11E+10	ND	ND	ND
12	1.03E+08	2.109E+11	3.15E+11	1.44E+12	4.44E+10	7.4E+11	6.29E+11	ND	ND	ND
15	9.14E+07	2.96E+11	2.89E+11	2.33E+12	1.11E+10	7.03E+11	8.14E+11	ND	ND	ND
16	3.70E+07	2.59E+10	5.55E+10	1.37E+11	3.7E+09	1.07E+11	1.37E+11	ND	ND	ND
17	8.13E+07	1.036E+11	1.67E+11	6.66E+11	3.7E+10	5.55E+11	7.03E+11	ND	ND	ND
18	7.07E+07	7.03E+11	2.07E+11	3.7E+12	2.59E+10	3.7E+11	6.29E+11	4.07E+10	3.7E+09	2.96E+10
19	3.84E+08	7.77E+11	1.18E+12	5.18E+12	4.07E+10	1.33E+12	1.15E+12	ND	ND	ND
20	1.61E+07	8.51E+11	1.11E+12	1.52E+12	2.92E+11	2.04E+11	1.59E+11	4.81E+11	5.92E+10	1.78E+11
25	2.33E+06	ND	ND	ND	ND	7.4E+09	3.7E+09	1.48E+10	ND	ND
26	5.18E+05	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	7.77E+04	1.184E+11	1.67E+11	5.18E+11	2.96E+10	5.55E+10	4.81E+10	2.59E+10	3.7E+09	7.4E+09

a. Source: McArthur (1991).
b. ND = no data.

Table 4-5. Radionuclide areal soil deposition decay, corrected to 1963 (Bq/m^2).[a]

Area	Am-241	Pu-238	Pu-239,240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	2.37E+03	4.37E+03	1.29E+04	2.35E+04	9.06E+03	1.57E+04	3.47E+04	4.89E+02	1.35E+04
2	2.20E+03	7.78E+03	1.60E+04	3.45E+04	3.32E+04	6.49E+04	4.35E+04	ND	1.45E+04
3	2.13E+03	1.71E+03	1.64E+04	1.76E+04	1.01E+04	2.84E+04	3.41E+04	4.01E+02	1.11E+04
4	6.16E+03	1.45E+04	3.57E+04	5.67E+04	2.05E+04	2.26E+04	3.48E+04	ND	8.93E+03
5	3.09E+03	6.15E+02	2.37E+04	1.17E+05	3.76E+03	8.63E+03	2.11E+05	8.94E+03	ND
6	7.86E+02	1.82E+03	3.72E+03	3.51E+03	2.36E+03	3.01E+03	ND	ND	ND
7	1.70E+03	5.54E+02	1.19E+04	2.94E+04	7.35E+03	1.33E+04	6.98E+04	1.34E+03	1.11E+04
8	1.83E+04	1.03E+04	1.13E+05	2.33E+05	8.24E+04	5.00E+04	1.94E+04	ND	3.08E+04
9	3.14E+03	1.96E+03	6.36E+04	1.98E+04	1.19E+04	1.81E+04	7.04E+04	1.30E+03	1.07E+04
10	1.42E+04	1.69E+04	7.86E+04	2.75E+05	1.15E+05	7.65E+04	6.74E+03	1.94E+03	1.79E+05
11	1.23E+04	2.23E+03	1.04E+05	ND	3.41E+03	2.09E+03	ND	ND	ND
12	2.15E+03	3.83E+03	1.41E+04	1.72E+04	1.38E+04	1.19E+04	ND	ND	ND
15	3.39E+03	3.94E+03	2.55E+04	4.82E+03	1.47E+04	1.73E+04	ND	ND	ND
16	7.31E+02	1.87E+03	3.70E+03	3.97E+03	5.53E+03	7.20E+03	ND	ND	ND
17	1.33E+03	2.55E+03	8.20E+03	1.81E+04	1.30E+04	1.68E+04	ND	ND	ND
18	1.04E+04	3.66E+03	5.24E+04	1.45E+04	9.99E+03	1.73E+04	2.47E+03	4.75E+02	2.09E+04
19	2.12E+03	3.85E+03	1.35E+04	4.21E+03	6.62E+03	5.81E+03	ND	ND	ND
20	5.54E+04	8.62E+04	9.45E+04	7.23E+05	2.42E+04	1.93E+04	1.28E+05	3.34E+04	5.53E+05
25	ND	ND	ND	ND	6.06E+03	3.09E+03	2.72E+04	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	1.59E+05	2.67E+05	6.67E+05	1.51E+06	1.36E+05	1.21E+05	1.43E+05	4.32E+04	4.76E+05

a. ND = no data.

Table 4-6. Abundance of radionuclides in NTS soils in relation to ^{239}Pu decay, corrected to 1963.

Area	Am-241	Pu-238	Pu-239,240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	0.183	0.338	1.000	1.818	0.700	1.216	2.677	0.038	1.041
2	0.138	0.487	1.000	2.164	2.081	4.067	2.726	ND[a]	0.908
3	0.130	0.104	1.000	1.072	0.619	1.735	2.084	0.024	0.675
4	0.172	0.405	1.000	1.587	0.572	0.632	0.975	ND	0.250
5	0.131	0.026	1.000	4.958	0.159	0.365	8.925	0.378	ND
6	0.212	0.490	1.000	0.944	0.636	0.810	ND	ND	ND
7	0.144	0.047	1.000	2.479	0.620	1.118	5.890	0.113	0.937
8	0.162	0.091	1.000	2.055	0.728	0.442	0.171	ND	0.273
9	0.049	0.031	1.000	0.312	0.187	0.284	1.107	0.020	0.168
10	0.181	0.215	1.000	3.498	1.457	0.973	0.086	0.025	2.271
11	0.119	0.021	1.000	ND	0.033	0.020	ND	ND	ND
12	0.153	0.272	1.000	1.220	0.978	0.848	ND	ND	ND
15	0.133	0.154	1.000	0.189	0.575	0.679	ND	ND	ND
16	0.198	0.505	1.000	1.072	1.495	1.945	ND	ND	ND
17	0.163	0.312	1.000	2.204	1.590	2.053	ND	ND	ND
18	0.199	0.070	1.000	0.278	0.191	0.331	0.047	0.009	0.400
19	0.157	0.285	1.000	0.312	0.491	0.431	ND	ND	ND
20	0.586	0.912	1.000	7.643	0.256	0.204	1.358	0.354	5.849
25	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	0.229	0.321	1.000	0.057	0.107	0.093	0.050	0.007	0.014
Maximum scaling factor	**0.586**	**0.912**	**1.000**	**7.64**	**2.08**	**4.07**	**8.93**	**0.378**	**5.85**
Scaled maximum intake (Bq/yr)	**0.223**	**0.347**	**0.381**	**2.91**	**0.792**	**1.55**	**3.40**	**0.144**	**2.23**

a. ND = no data.

4.2.1.2.5 Correction for Resuspension for Early Times after Atmospheric Tests

Anspaugh et al. (2002) stated that, based on empirical observations, concentrations of resuspended radionuclides in air have been noted to display a strong time dependence early after deposition and that this pathway could be important for reoccupation of contaminated property. Anspaugh et al. also stated that there had not been universal agreement that resuspension is an important pathway but that it is now generally accepted that there are a few instances in which the pathway could be the dominant one. Many observations have shown that the rate of resuspension decreases rapidly with time and, for accident situations, resuspension is only of importance (in comparison with the inhalation exposure from the initial cloud passage) over short periods. For this reason, Anspaugh et al. stated that the resuspension factor model has been widely used to predict the concentration of resuspended radionuclides early after initial deposition while the mass loading model (which uses measurements of dust loading in air and soil contamination data to predict air concentration of radionuclides) has generally been preferred for times long after deposition. However, Anspaugh et al. also stated that it is always preferable to rely on actual measurements that are performed over long periods (such as those in Section 4.2.1.2.2).

Anspaugh et al. (2002) presented several resuspension models that have been proposed but concluded that they can be over- or under-predictive at various times after deposition in comparison with empirical observations. However, with expanded data sets from the work of Hicks (1981e) and others in the 1980s, Anspaugh et al. proposed a resuspension model that more accurately describes the observed results over the entire timespan of the expanded data set for NTS:

$$S_f = \left[(1\times10^{-5})\,e^{-0.07t} + (6\times10^{-9})\,e^{-0.003t} + (1\times10^{-9}) \right] \times (1\times10^{\pm1})\ m^{-1} \qquad (4\text{-}2)$$

A graphical depiction of Equation 4-2 is in Figure 4-2 from time *t* equal zero to 1,000 days after detonation. As shown in Figure 4-2, the resuspension factor S_f ranges from about 10^{-5} at times early after deposition, falls rapidly during the first 100 or so days to a value of about 10^{-8}, and then approaches a value of 10^{-9} after a few years. The factor of 10 at the end of the equation is a statement of uncertainty in the model.

If it is true that the mass loading approach is more predictive at times long after initial deposition and that the resuspension proposed by Anspaugh et al. is predictive of the observed results over the expanded dataset (including those developed in the 1980s), the factor of 10^{-9} could be taken to be the resuspension factor that would be predictive of the mass loading process that is thought to be more important during the times when air monitoring data are available (i.e., 1971 through 2001, see Section 4.2.1.2.2).

When Anspaugh et al.'s proposed resuspension model (Equation 4-2) is integrated over 180 to 545 days and compared with the result of the integral of the constant 10^{-9} over the same period, a factor is developed that can be used to correct the intakes derived from air sampling data (i.e., times long after initial deposition) for the early resuspension phenomenon that has been observed at NTS.

The period of integration was selected to begin at day 180 because the last atmospheric tests at NTS were in July 1962 and, therefore, about 180 days had passed before the beginning of 1963.

For the Anspaugh et al. (2002) model, the early resuspension correction factor has been determined to be 3.12. In a similar manner, correction factors for 1964 and 1965 were determined to be 1.72 and 1.24, respectively. Thus, for dose reconstruction, the scaled maximum inhalation intakes in Table 4-6 should be multiplied by these factors to account for early resuspension from 1963 through 1965. If necessary, these intakes can be prorated for time less than a year for a best estimate if the worker was on the site for only a fraction of the year.

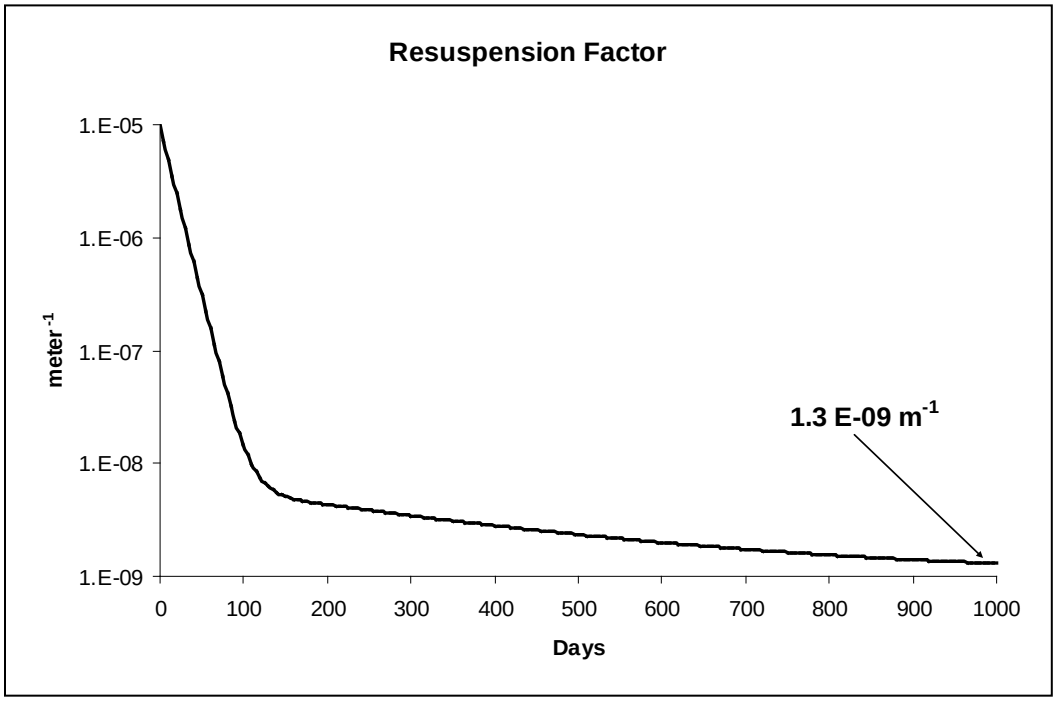

Figure 4-2. Resuspension factor as a function of time after initial deposition (from Attachment A).

4.2.1.2.6 Correction for Inhalation Dose from Short-Lived Fission and Activation Products

Correction factors were developed to account for inhalation intakes of short-lived fission and activation products based on organ-specific dose from the ^{90}Sr intakes in Table 4-7 (from Attachment A). These corrections are listed in Table 4-8.

The Integrated Modules for Bioassay Analysis (IMBA) computer program was used to determine the organ doses resulting from the scaled intakes of ^{90}Sr in Table 4-7 for a period of 10 years (i.e., 4.84 Bq for 1963, 2.65 Bq for 1964, 1.92 for 1965, and 1.55 for all subsequent years through 1972). These doses were then multiplied by the correction factors in Table 4-8 to determine the additional dose that should be added to account for potential dose from inhalation of short-lived fission and activation products. The organ-specific fission and activation product doses greater than 0.001 rem are listed in Table 4-9. Other organs are not listed in Table 4-9 because all were less than 0.001 rem. These doses should be added to the input for the Interactive RadioEpidemiological Program (IREP) as a constant as 100% 30-to-250-keV photons. These doses are input as constants because they are based on bounding intakes (i.e., maximum) and they are entered as 30-to-250-keV photons as an assumption favorable to claimants.

4.2.2 Annual Intakes from Ingestion

To account for potential intakes from inadvertent ingestion of contaminated soil, the area-specific radionuclide soil deposition data in Table 4-5 were converted to volumetric data (i.e., Bq/g) by assuming the radionuclides are deposited within the top 2.3 cm of soil and a soil density of 1.5 g/cm^3 (DOE 2003). The area-specific radionuclide soil concentrations are listed in Table 4-10.

Table 4-7. Scaled inhalation intakes corrected for early resuspension (Bq/yr).

Year of intake	Am-241	Pu-238	Pu-239, 240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1963	0.70	1.08	1.19	9.08	2.47	4.84	10.61	0.45	6.96
1964	0.38	0.59	0.65	4.98	1.35	2.65	5.81	0.25	3.81
1965	0.28	0.43	0.47	3.61	0.98	1.92	4.22	0.18	2.77
All subsequent years	0.223	0.347	0.381	2.91	0.792	1.55	3.40	0.144	2.23

Table 4-8. Organ-specific inhalation dose fission and activation product correction factors.

Organ(s)	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Skin, adrenals, thymus, SI, spleen, skin, muscle, uterus, pancreas, kidneys, breast, testes, esophagus, ovaries, brain, stomach, thyroid, gall bladder	730	364	242	182	145	121	104	90.7	80.6	72.5
ULI	458	179	99.2	64.0	45.0	33.4	25.9	20.6	16.8	14.0
Urinary bladder	335	149	91.3	63.6	47.5	37.2	30.1	24.9	21.0	18.0
Lungs	34,900	14,200	7,960	5,150	3,630	2,700	2,100	1,660	1,360	1,130
ET, ET1, ET2, LN(TH), LN(ET)	1,570	827	598	492	438	412	412	412	412	412
LLI	420	142	70.8	42.4	28.2	20.1	15.1	11.7	9.4	7.6
Colon	390	148	79.4	50.0	34.5	25.2	19.3	15.2	12.3	10.2
Liver	9,260	4,620	1,540	1,190	988	858	769	706	661	629
RBM	37.9	18.2	12.8	10.4	10.4	10.4	10.4	10.4	10.4	10.4
Bone surfaces	78.5	40.1	28.1	22.4	22.4	22.4	22.4	22.4	22.4	22.4

Table 4-9. Inhalation dose from short-lived fission and activation products (rem).

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Liver	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bone surface	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
LLI	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ET	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lung	0.008	0.003	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ET1	1.635	0.474	0.248	0.164	0.146	0.138	0.138	0.138	0.138	0.138

If the assumption is made that the workers ingested 100 mg of soil each day [EPA (1989) recommends a value of 50 mg/d] and that full-time employment was 250 d/yr, annual ingestion can be calculated in a manner favorable to claimants. The area-specific annual ingestion rates are in Table 4-11.

For most radionuclides, Area 30 provided the highest areal deposition and resultant intakes. Area 30 is relatively small (150 km^2) and inaccessible, and is on the western edge of NTS. It has rugged terrain and includes the northern reaches of Fortymile Canyon. In 1968, it was the site of Project BUGGY, the first nuclear row-charge experiment in the PLOWSHARE Program. As a result of the test, a trench 255 m long, 77 m wide, and 206 m deep was created. The test resulted in large quantities of vitrified glass. Because of the bias that is introduced when Area 30 is included, the maximum annual intakes in Table 4-11 have been provided without the Area 30 areal concentrations.

Table 4-10. Radionuclide soil concentration by area (Bq/g).[a]

Area	Am-241	Pu-238	Pu-239, 240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	0.069	0.127	0.375	0.682	0.263	0.456	1.005	0.014	0.391
2	0.064	0.226	0.463	1.001	0.963	1.882	1.262	ND	0.420
3	0.062	0.050	0.475	0.509	0.294	0.824	0.989	0.012	0.321
4	0.179	0.420	1.036	1.644	0.593	0.655	1.010	ND	0.259
5	0.090	0.018	0.686	3.401	0.109	0.250	6.122	0.259	ND
6	0.023	0.053	0.108	0.102	0.069	0.087	ND	ND	ND
7	0.049	0.016	0.344	0.852	0.213	0.384	2.024	0.039	0.322
8	0.530	0.297	3.280	6.741	2.389	1.450	0.562	ND	0.894
9	0.091	0.057	1.844	0.575	0.344	0.524	2.042	0.038	0.311
10	0.411	0.491	2.279	7.973	3.321	2.217	0.195	0.056	5.177
11	0.357	0.065	3.005	ND	0.099	0.060	ND	ND	ND
12	0.062	0.111	0.408	0.498	0.399	0.346	ND	ND	ND
15	0.098	0.114	0.740	0.140	0.426	0.502	ND	ND	ND
16	0.021	0.054	0.107	0.115	0.160	0.209	ND	ND	ND
17	0.039	0.074	0.238	0.524	0.378	0.488	ND	ND	ND
18	0.301	0.106	1.518	0.421	0.290	0.502	0.072	0.014	0.607
19	0.061	0.111	0.391	0.122	0.192	0.169	ND	ND	ND
20	1.607	2.500	2.741	20.946	0.701	0.559	3.723	0.969	16.031
25	ND	ND	ND	ND	0.176	0.090	0.789	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	4.620	7.749	19.340	43.835	3.953	3.493	4.143	1.252	13.804

a. ND = no data.

Table 4-11. Area-specific and maximum annual ingestion rates (Bq/yr).[a]

Area	Am-241	Pu-238	Pu-239, 240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	1.72	3.17	9.38	17.06	6.56	11.41	25.12	0.35	9.77
2	1.59	5.64	11.57	25.03	24.08	47.06	31.54	ND	10.51
3	1.54	1.24	11.87	12.72	7.34	20.59	24.73	0.29	8.01
4	4.47	10.49	25.90	41.10	14.83	16.37	25.24	ND	6.47
5	2.24	0.45	17.15	85.03	2.73	6.25	153.05	6.48	ND
6	0.57	1.32	2.69	2.54	1.71	2.18	ND	ND	ND
7	1.23	0.40	8.59	21.29	5.33	9.61	50.59	0.97	8.05
8	13.24	7.43	81.99	168.52	59.73	36.25	14.05	ND	22.34
9	2.27	1.42	46.11	14.38	8.60	13.10	51.04	0.94	7.76
10	10.29	12.27	56.98	199.31	83.02	55.42	4.88	1.41	129.41
11	8.93	1.61	75.12	ND	2.47	1.51	ND	ND	ND
12	1.56	2.77	10.20	12.45	9.98	8.65	ND	ND	ND
15	2.45	2.85	18.49	3.49	10.64	12.56	ND	ND	ND
16	0.53	1.35	2.68	2.87	4.01	5.21	ND	ND	ND
17	0.97	1.85	5.94	13.09	9.44	12.19	ND	ND	ND
18	7.54	2.65	37.95	10.54	7.24	12.55	1.79	0.34	15.17
19	1.53	2.79	9.78	3.05	4.80	4.21	ND	ND	ND
20	40.17	62.49	68.51	523.64	17.54	13.98	93.06	24.23	400.77
25	ND	ND	ND	ND	4.39	2.24	19.73	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	115.50	193.72	483.50	1,095.89	98.83	87.33	103.56	31.30	345.10
Maximum[b]	**40.17**	**62.49**	**81.99**	**523.64**	**83.02**	**55.42**	**153.05**	**24.23**	**400.77**

a. ND = no data.
b. Maximum value with Area 30 excluded.

As with inhalation intakes, a method was developed to adjust ingestion doses for potential dose from short-lived fission and activation products that are no longer persistent in NTS soils in measurable amounts. The organ-specific fission and activation product correction factors were developed based

on the relative contribution of ^{90}Sr to the total ingestion dose. These correction factors are listed in Table 4-12.

Table 4-12. Organ-specific ingestion fission and activation product correction factors (from Attachment A).

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Adrenals, breast, brain, skin, bladder, stomach, kidneys, muscle, pancreas, brain, esophagus, SI, liver, ovaries, ET, ET1, ET2, LM(ET), LN(TH), lungs, skin, spleen, testes, thymus, thyroid, uterus, gall bladder	416	219	155	123	106	95.0	88.1	84.0	82.0	81.8
ULI	514	184	95.2	58.2	39.3	18.6	16.3	14.6	13.4	12.4
Bone surface, RBM	3.8	3.1	2.7	2.5	2.3	2.3	2.3	2.3	2.3	2.3
LLI, colon	417	208	138	25.6	20.4	17.4	14.6	12.8	11.3	10.2

To simplify the application of organ-specific ingestion dose from short-lived fission and activation products, the IMBA computer program was used to determine organ-specific annual doses for the ^{90}Sr intake of 55.42 Bq/yr for 1963 through 1972. These doses are listed in Table 4-13. The doses in Table 4-13 are multiplied by the Table 4-12 organ-specific correction factors to provide the annual doses resulting from ingestion of short-lived fission and activation products. The annual organ-specific doses that were greater than or equal to 0.001 rem are listed in Table 4-14.

Table 4-13. Organ-specific annual ingestion doses (rem) for the ^{90}Sr intake of 55.42 Bq/yr.

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Adrenals	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Urinary bladder	5.68E-06	6.42E-06	6.67E-06	6.87E-06	7.04E-06	7.18E-06	7.31E-06	7.41E-06	7.50E-06	7.58E-06
Bone surface	1.58E-04	3.74E-04	5.47E-04	6.98E-04	8.32E-04	9.50E-04	1.06E-03	1.15E-03	1.23E-03	1.31E-03
Brain	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Breast	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Esophagus	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Stomach	3.42E-06	3.78E-06	3.95E-06	4.09E-06	4.21E-06	4.31E-06	4.40E-06	4.47E-06	4.54E-06	4.59E-06
Small intestine	4.71E-06	5.07E-06	5.24E-06	5.38E-06	5.50E-06	5.60E-06	5.69E-06	5.76E-06	5.83E-06	5.88E-06
Upper large intestine	3.42E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05
Lower large intestine	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04
Colon	4.36E-03	2.26E-03	1.51E-03	1.14E-03	9.16E-04	7.71E-04	6.61E-04	5.84E-04	5.21E-04	4.71E-04
Kidneys	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Liver	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Muscle	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Ovaries	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Pancreas	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Red bone marrow	1.08E-04	2.66E-04	3.87E-04	4.86E-04	5.69E-04	6.37E-04	6.94E-04	7.42E-04	7.81E-04	8.14E-04
Extrathoracic airways	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Lungs	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Skin	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Spleen	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Testes	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Thymus	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Thyroid	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Uterus	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06

Table 4-14. Organ-specific doses (rem) from ingestion of fission and activation products.

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Bladder	0.002	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bone surface	<0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003
Stomach	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SI	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ULI	0.015	0.006	0.003	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LLI	0.048	0.025	0.017	0.003	0.003	0.002	0.002	0.002	0.001	0.001
Colon	0.028	0.015	0.010	0.002	0.002	0.001	0.001	0.001	<0.001	<0.001

4.3 OCCUPATIONAL EXTERNAL DOSE

Workers incur external doses from ambient radiation levels and noble gases. Ambient radiation measurements were reported in NTS annual environmental reports (see References section) starting in 1967; no ambient radiation data were provided in the reports for 1968 to 1976.

4.3.1 Ambient Radiation

Before 1967, ambient radiation levels that were unaffected by weapons testing were not reported in the annual environmental reports. Although there were many radiation measurements between 1951 and 1967, most of these were to characterize the effects of weapons tests and, therefore, were not appropriate for use in estimating external environmental dose for unmonitored employees.

In 1967, ambient radiation levels were measured using Victoreen Model 239 indirect reading ionization chambers with effective ranges of 0 to 10 mR/hr. Five of these chambers were in small semiprotective enclosures in NTS living areas (REECo 1968). As a backup for the ionization chambers, standard NTS film dosimeters were included at each sample location. However, all results from these dosimeters for 1967 were either zero or lost due to light or heat damage. Results from environmental NTS film dosimeters were subsequently discarded because of the likelihood of heat damage.

The ionization chambers were collected on a weekly basis and read on a Victoreen Minometer II reader. Corrections were made for background and for nonradiation-induced drift. Two sets of chambers were used, one at the sample locations for measurements and another stored fully charged in the laboratory. Each week these sets were exchanged, the fresh set was recharged and a record was kept of the amount of drift that occurred while one was stored in the laboratory. A specially designed shockproof box for transportation minimized accidental discharge from mechanical shock.

Readings from the five chambers in each location were averaged to obtain a mean value for each location each week. Readings significantly higher than others at a particular location were not used in compiling the data because the abnormal readings were most likely to be the result of shock or other malfunction and were not representative measurements. Because of the method of background subtraction discussed above, the data in the 1967 annual report were assumed to be due to manmade radiation in excess of natural background.

No results were reported between 1968 and 1976 in the NTS annual environmental reports; ambient radiation reporting was reestablished in 1977 using thermoluminescent dosimeters (TLDs) (Lantz 1978a). The dosimeters were CaF_2:Dy (TLD-200) 0.25- by 0.25- by 0.035-in. chips from Harshaw Chemical Company. A badge that consisted of at least two chips shielded by 0.047 in. of cadmium (1,030 mg/cm^2) inside a 0.050-in. black plastic (140 mg/cm^2) holder was placed about 1 m above the ground at each of 10 locations that coincided with air sampling stations. These sites were selected because of their proximity to workers. During that year, the natural background ambient radiation level was established at 0.26 mrem/d or about 95 mrem/yr.

In 1987, the Harshaw dosimeters were replaced with Panasonic Model UD-814 TLDs (Gonzalez 1988). These specifically designed environmental dosimeters contain three identical $CaSO_4$:Tm elements and one $Li_2B_4O_7$:Cu element. The lithium element is shielded with 14 mg/cm^2 of material to monitor beta particles in the environment. The three calcium elements are encapsulated in 1,000 mg/cm^2 of plastic and lead to monitor ambient gamma levels. The UD-814 TLDs have remained in use to the present time.

In subsequent years, the number of sampling locations increased to more than 150 and eventually covered all populated areas at NTS. For dose reconstruction, because the values in Table 4-15 represent continuous exposure for an entire year, these values should be adjusted for occupational exposure (i.e., for a maximizing and best estimate value, assume 2,600 hr/yr and 2,500 hr/yr, respectively) and added to the dose of record for unmonitored employees after 1992 (see below). If the area in which the employee worked is known, the average value for that area should be used. If the area is not known, the site maximum value should be used to be favorable to claimants.

Some covered employees remained on site continuously for weeks at a time. However, because most of the nonworking hours were spent indoors where elevated ambient radiation would be reduced by shielding from the building and because of the conservative assumptions used to estimate the values in Table 4-15, adjustment of the tabular data is not required to ensure ambient exposures are not underestimated for these individuals.

Although not explicitly stated in the NTS annual environmental reports, the overall uncertainty of measurements from modern TLDs (e.g., Panasonic UD-814) has been determined to be less than 20% (ORAUT 2012). However, for earlier measurement methods, the overall uncertainty could have been greater. Therefore, for dose reconstructions that are favorable to claimants, the assumption is made that the 95th-percentile values of the expected values (50th percentile) in Table 4-15 are enveloped by a factor of ±2 of the overall error of 50% (i.e., ±100%). Equation 4-1 (Section 4.2.1.2.1) would then estimate the GSD for the expected values at 1.52. Site maximum values would be entered into IREP as constants.

Assignment of dosimeters to all persons at NTS began in April 1957 and ended in December 1992 (ORAUT 2012). During this time, readings from control badges at Mercury were used to subtract ambient background dose from the personnel dosimeters (ORAUT 2012). For this reason, from April 1957 to December 1992, ambient background external radiation dose should not be included in dose reconstructions. Because no documentation is available before 1967 (see Table 4-15), ambient external doses should not be assigned under any circumstances from 1951 through 1956. After 1992, ambient background external dose should be assigned to all unmonitored workers in accordance with the guidelines for Table 4-15. For years after 2010, assume 2010 exposure values.

4.3.2 Releases of Noble Gases

Ground seepage can increase when changes in ambient pressure pump small amounts of noble gases (primarily ^{85}Kr and ^{133}Xe) up through the overburden and into the atmosphere from the cavity created by a nuclear test. This process, sometimes referred to as “atmospheric pumping,” creates a diffuse source of radiological effluents.

In 1982, REECo assumed responsibility for six noble gas sampling stations EPA previously ran and replaced them with new samplers. These sampling units were housed in a metal toolbox with three metal air bottles attached with quick disconnect hoses. A vacuum was maintained on the first bottle, which caused a steady flow of air to be collected in the other two bottles. The flow rate was

Table 4-15. Ambient radiation by area (rem/yr).[a,b]

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9	Area 10	Area 11	Area 12	Area 13	Area 14
1967	ND	ND	0.318	ND	ND	0.194	ND	ND	ND	ND	ND	0.205	ND	ND
1968	ND	ND	0.285	ND	0.183	0.175	ND	ND	ND	ND	ND	0.190	ND	ND
1969	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1970	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1971	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1972	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1973	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1975	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1976	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1977	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1978	0.130	0.167	0.200	ND	0.138	0.110	0.110	0.120	0.150	0.320	0.140	0.150	ND	ND
1979	0.119	0.147	0.190	0.140	0.133	0.104	0.125	0.115	0.140	0.168	0.155	0.191	ND	ND
1980	0.123	0.156	0.199	0.155	0.133	0.106	0.130	0.135	0.145	0.192	0.165	0.196	ND	ND
1981	0.120	0.155	0.218	0.150	0.166	0.113	ND	0.125	0.15	0.180	0.160	0.187	ND	ND
1982	0.126	0.149	0.188	0.145	0.141	0.108	ND	0.125	0.14	0.209	0.140	0.189	ND	ND
1983	0.115	0.141	0.181	0.143	0.144	0.103	ND	0.095	0.135	0.201	0.140	0.174	ND	ND
1984	0.097	0.149	0.162	0.116	0.111	0.086	0.327	0.125	0.102	0.166	0.112	0.155	ND	ND
1985	ND	0.141	0.078	0.101	ND	0.107	0.347	0.094	0.114	0.225	ND	0.180	ND	ND
1986	0.093	0.126	0.150	0.092	0.092	0.077	0.318	0.094	0.096	0.12	0.107	0.106	ND	ND
1987	0.146	0.189	0.184	0.164	0.191	0.126	ND	0.12	0.149	0.181	0.133	0.168	ND	ND
1988	0.155	0.209	0.207	0.164	0.177	0.134	ND	0.15	0.179	0.203	0.158	0.194	ND	ND
1989	0.140	0.217	0.205	0.132	0.141	0.106	ND	0.126	0.151	0.179	0.153	0.139	ND	ND
1990	0.134	0.167	0.187	0.142	0.142	0.109	ND	0.122	0.148	0.170	0.132	0.140	ND	ND
1991	0.128	0.168	0.194	0.146	0.165	0.116	0.132	0.124	0.132	0.15	0.13	0.190	ND	ND
1992	0.123	0.167	0.173	0.141	0.150	0.104	0.145	0.128	0.136	0.157	0.158	0.170	ND	ND
1993	0.147	0.178	0.200	0.158	0.198	0.134	0.165	0.153	0.156	0.172	0.184	0.201	ND	ND
1994	ND	0.062	0.062	ND	0.089	0.084	ND	ND	ND	0.070	0.102	0.097	ND	ND
1995	0.102	0.136	0.150	0.121	0.212	0.087	0.176	0.102	0.104	0.179	0.124	0.130	ND	ND
1996	0.102	0.131	0.151	0.110	0.225	0.105	0.164	0.098	0.099	0.176	0.124	0.135	ND	ND
1997	ND	ND	0.131	ND	0.086	0.088	ND	ND	0.081	ND	ND	ND	ND	ND
1998	0.106	0.132	0.137	0.110	0.134	0.100	0.201	0.127	0.101	0.168	0.121	0.148	ND	ND
1999	0.108	0.133	0.135	0.122	0.110	0.105	0.191	0.129	0.099	0.160	0.122	0.152	ND	ND
2000	0.127	0.155	0.161	0.129	0.134	0.122	0.217	0.147	0.190	0.187	0.144	0.176	ND	ND
2001	0.121	0.299	0.151	0.120	0.136	0.107	0.214	0.143	0.115	0.180	0.14	0.163	ND	ND
2002	0.113	0.272	0.168	0.341	0.122	0.098	0.174	0.135	0.106	0.167	0.131	0.162	ND	ND
2003	0.18	0.26	0.257	0.334	0.145	0.104	0.159	0.209	0.189	0.188	0.133	0.169	ND	ND
2004	0.162	0.251	0.239	0.323	0.148	0.106	0.157	0.204	0.190	0.185	0.130	0.166	ND	ND
2005	0.159	0.246	0.236	0.320	0.148	0.108	0.159	0.205	0.191	0.182	0.132	0.166	ND	ND
2006	0.154	0.243	0.228	0.309	0.144	0.108	0.156	0.202	0.186	0.182	0.133	0.167	ND	ND
2007	0.155	0.242	0.228	0.306	0.147	0.112	0.158	0.199	0.190	0.184	0.138	0.171	ND	ND
2008	0.148	0.227	0.219	0.298	0.138	0.107	0.15	0.189	0.179	0.174	0.129	0.159	ND	ND
2009	0.151	0.229	0.218	0.283	0.140	0.109	0.152	0.191	0.180	0.175	0.134	0.164	ND	ND
2010	0.146	0.216	0.250	0.269	0.144	0.098	0.149	0.184	0.173	0.170	0.132	0.156	ND	ND

Year	Area 15	Area 16	Area 17	Area 18	Area 19	Area 20	Area 21	Area 22	Area 23	Area 24	Area 25	Area 26	Area 27	Area 28	Area 29	Area 30	Average	Maximum
1967	ND	ND	ND	ND	ND	ND	ND	ND	0.142	ND	ND	ND	0.175	ND	ND	ND	0.207	0.318
1968	ND	ND	ND	0.186	ND	ND	ND	ND	0.131	ND	ND	ND	0.172	ND	ND	ND	0.189	0.285
1969	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1970	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1971	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1972	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1973	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1975	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1976	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1977	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.155[c]	0.320[c]
1978	0.129	ND	ND	0.173	0.185	ND	ND	ND	0.150	ND	0.162	ND	0.140	0.120	ND	ND	0.155	0.320
1979	0.121	ND	0.150	0.145	0.155	0.160	ND	0.115	0.117	ND	0.152	ND	0.130	0.120	ND	0.125	0.140	0.191
1980	0.134	ND	0.165	0.163	0.185	0.207	ND	0.070	0.098	ND	0.163	ND	0.135	0.130	ND	0.205	0.152	0.207
1981	0.138	ND	0.155	0.168	0.174	0.163	ND	0.075	0.126	ND	0.175	ND	0.150	ND	ND	0.140	0.152	0.218
1982	0.134	ND	0.150	0.173	0.176	0.200	ND	0.075	0.095	ND	0.150	ND	0.135	0.135	ND	0.140	0.147	0.209
1983	0.124	ND	0.135	0.151	0.158	0.206	ND	0.125	0.163	ND	0.149	ND	0.140	ND	ND	0.185	0.148	0.206
1984	0.108	ND	0.129	0.124	0.132	0.157	ND	0.058	0.154	ND	0.129	ND	ND	ND	ND	0.173	0.137	0.327
1985	ND	ND	0.115	0.123	0.131	0.127	ND	ND	ND	ND	0.103	ND	ND	ND	ND	0.153	0.143	0.347
1986	0.081	ND	ND	0.124	0.134	0.160	ND	0.055	0.071	ND	0.106	ND	0.089	ND	ND	0.135	0.116	0.318
1987	0.135	ND	0.151	0.174	0.246	0.204	ND	0.068	0.096	ND	0.129	ND	0.139	ND	ND	ND	0.155	0.246
1988	0.155	ND	0.172	0.212	0.223	0.211	ND	0.084	0.123	ND	0.163	ND	ND	ND	ND	ND	0.172	0.223
1989	0.162	ND	0.160	0.168	0.178	0.189	ND	0.078	0.116	ND	0.146	ND	0.118	ND	ND	ND	0.150	0.217
1990	0.124	ND	0.164	0.174	0.178	0.192	ND	0.083	0.177	ND	0.139	ND	0.146	ND	ND	ND	0.149	0.192
1991	0.122	ND	0.165	0.175	0.173	0.189	ND	0.081	0.079	ND	0.143	ND	0.154	0.110	ND	0.155	0.144	0.194
1992	0.134	ND	0.152	0.168	0.189	0.185	ND	0.079	0.075	ND	0.132	ND	0.143	ND	ND	0.179	0.145	0.189
1993	0.145	ND	0.177	0.195	0.192	0.213	ND	0.091	0.096	ND	0.158	ND	0.169	ND	ND	0.195	0.167	0.213
1994	0.143	ND	ND	ND	0.141	0.131	ND	0.058	0.061	ND	0.115	ND	0.121	ND	ND	0.104	0.098	0.143
1995	0.109	ND	0.129	0.137	0.149	0.153	ND	0.058	0.070	ND	0.117	ND	0.121	ND	ND	ND	0.127	0.212
1996	0.103	ND	0.137	0.144	0.153	0.150	ND	0.055	0.056	ND	0.114	ND	0.124	ND	ND	0.165	0.128	0.225
1997	0.102	ND	ND	ND	0.150	0.153	ND	0.083	0.063	ND	0.127	ND	0.135	ND	ND	0.170	0.114	0.170
1998	0.099	ND	ND	0.135	0.151	0.156	ND	0.076	0.058	ND	0.113	ND	0.123	ND	ND	0.165	0.127	0.201
1999	0.108	ND	ND	0.137	0.153	0.151	ND	0.075	0.057	ND	0.111	ND	0.126	ND	ND	0.170	0.126	0.191
2000	0.117	ND	ND	0.16	0.185	0.182	ND	0.092	0.081	ND	0.139	ND	0.158	ND	ND	0.205	0.153	0.217
2001	0.112	ND	ND	0.167	0.159	0.131	ND	0.090	0.074	ND	0.135	ND	0.145	ND	ND	0.193	0.147	0.299
2002	0.103	ND	ND	0.144	0.172	0.157	ND	0.081	0.068	ND	0.122	ND	0.128	ND	ND	ND	0.148	0.341
2003	0.116	0.133	ND	0.146	0.165	0.334	ND	ND	0.065	ND	0.127	ND	0.113	ND	ND	ND	0.176	0.334
2004	0.111	0.137	ND	0.145	0.158	0.309	ND	ND	0.093	ND	0.123	ND	0.112	ND	ND	ND	0.172	0.323
2005	0.114	0.144	ND	0.146	0.164	0.305	ND	ND	0.116	ND	0.125	ND	0.115	ND	ND	ND	0.174	0.320
2006	0.117	0.143	ND	0.149	0.161	0.290	ND	ND	0.076	ND	0.125	ND	0.115	ND	ND	ND	0.169	0.309
2007	0.116	0.145	ND	0.151	0.165	0.287	ND	ND	0.098	ND	0.128	ND	0.117	ND	ND	ND	0.172	0.306
2008	0.111	0.137	ND	0.144	0.161	0.272	ND	ND	0.068	ND	0.124	ND	0.114	ND	ND	ND	0.162	0.298
2009	0.115	0.133	ND	0.148	0.160	0.255	ND	ND	0.063	ND	0.117	ND	0.116	ND	ND	ND	0.162	0.283
2010	0.111	0.140	ND	0.142	0.157	0.247	ND	ND	0.068	ND	0.116	ND	0.114	ND	ND	ND	0.159	0.269

a. Sources: Environmental Reports list in the References section.
b. ND = no data.
c. Ambient radiation not provided for these years; assumed equal to value for 1978.

Table 4-16. ^{85}Kr average background and the Area 20 net concentrations and annual organ doses from 1983 through 1993.[a]

Year	NTS background (Bq/m^3)	Area 20 camp (Bq/m^3)	Net elevated (Bq/m^3)	Source[b] elevated concentration (Bq/m^3)	Other organ[c] dose[d] at source[b] (rem/yr)	Skin dose[e] at source[b] (rem/yr)
1983	0.93	0.85	0.00	0.00	0.00E+00	0.00E+00
1984	1.04	1.15	0.11	3.00	4.67E-07	3.00E-05
1985	1.22	1.70	0.48	12.99	2.02E-06	1.30E-04
1986	1.30	2.15	0.85	22.98	3.58E-06	2.30E-04
1987	1.04	1.44	0.41	10.99	1.71E-06	1.10E-04
1988	0.93	1.07	0.15	4.00	6.23E-07	4.00E-05
1989	0.85	1.00	0.15	4.00	6.23E-07	4.00E-05
1990	1.18	1.37	0.19	5.00	7.79E-07	5.00E-05
1991	0.93	1.18	0.26	6.99	1.09E-06	6.99E-05
1992	0.96	1.11	0.15	4.00	6.23E-07	4.00E-05
1993	1.00	1.04	0.04	1.00	1.56E-07	9.99E-06

a. Sources: Environmental reports in the References section.
b. Source receptor location assumed to be 500 m from U-20a emplacement hole.
c. Includes gonads, breast, lung, red bone marrow, bone surfaces, thyroid, remainder, and effective whole body.
d. Assumes 2,000 hr/yr exposure and DCF of 2.2×10^{-16} Sv/Bq/s/m^3 (Eckerman and Ryman 1993).
e. Assumes 2,000 hr/yr exposure and DCF of 1.32×10^{-14} Sv/Bq/s/m^3 (Eckerman and Ryman 1993).

approximately 0.5 cm^3/min. The two collection bottles were exchanged weekly and yielded a sample volume of about 3×10^5 cm^3 (Scoggins 1983).

The noble gases were separated and collected from the atmospheric sample by a series of cryogenic gas chromatographic techniques. Water and carbon dioxide were removed at room temperature and krypton and xenon were collected on charcoal at liquid nitrogen temperatures. These gases were transferred to a molecular sieve where they were separated from remaining gases and each other. The krypton and xenon were transferred to separate scintillation vials and counted on a liquid scintillation counter. The lower limits of detection for krypton and xenon are 4×10^{-6} and 10×10^{-6} pCi/m^3, respectively (Scoggins 1983).

Krypton-85

The original six samplers were in Areas 1, 5, 12, 15, 23, and 25. These samplers showed no statistical difference in atmospheric concentrations of ^{85}Kr during 1983 and 1984. The average concentration of all stations for these years was 0.93 Bq/m^3 and 1.04 Bq/m^3, respectively, which was established as NTS background. This background measurement shows good agreement with the global background of 1.0 Bq/m^3 (WMO 2002).

In 1984, REECo measured a statistically significant elevation in ^{85}Kr concentrations in Area 20 of 0.11 Bq/m^3 above background, which was subsequently related to seeps from nuclear cavities on Pahute Mesa (Scoggins 1984). These elevated concentrations continued until after the cessation of nuclear testing in 1992. Table 4-16 lists the average background and the Area 20 elevated concentrations from 1983 through 1993.

The source of the elevated ^{85}Kr concentrations was attributed to the emplacement hole nearest the Area 20 sampler (U-20a), which is about 3,660 m (12,000 ft) to the south. To determine if these elevated concentrations could be of any consequence for unmonitored workers, upper bound concentrations of ^{85}Kr within 500 m of U-20a were estimated using Area 20 meteorological data station files and the CAP88-PC (ORAUT 2003) computer program. The program was used to develop atmospheric dispersion factors (X/Q) for various distances from the source of emissions. The ratio of the X/Q value at 500 m to that at 3,660 m was determined to be about 27, which means that the ^{85}Kr concentration 500 m from the source could, on average, be 27 times greater than that measured at

the sampler location. The potential dose resulting from submersion in the plume of this noble gas is entirely external because the gas is not readily assimilated by the body. Therefore, these source concentrations were converted to potential organ doses using submersion DCFs from Federal Guidance Report No. 12 (Eckerman and Ryman 1993).

As Table 4-16 indicates, the upper bound annual organ doses for all years are less than 1 mrem. For reconstructing environmental doses for unmonitored employees, these doses are inconsequential for determination of probability of causation and, therefore, should be ignored. In addition, if a monitored employee was exposed to the calculated upper bound ^{85}Kr concentrations or significantly higher concentrations during work activities, these exposures would have been monitored by personal dosimeters and would, therefore, already be in the individual dosimetry record.

Uncertainty estimates for a number of ^{85}Kr measurements indicate, generally, a standard deviation of less than 20% of the measured value. Even at the 2-sigma level of ±40 percent, the annual organ doses in Table 4-16 are less than 1 mrem and, therefore, inconsequential for employee dose reconstruction.

Xenon-133
Although the vast majority of the ^{133}Xe measurements were below the lower limit of detection (i.e., 3.7×10^{-7} Bq/m^3), elevated atmospheric concentrations of ^{133}Xe were occasionally measured in Area 20. As with ^{85}Kr, these elevated concentrations were attributed to seepage from underground test cavities at the Pahute and Rainier Mesa tests (Fauver 1985). However, ^{133}Xe has a short half-life (5.25 days versus 10.7 years for ^{85}Kr). Therefore, these elevated concentrations were short-lived. In addition, these elevated ^{133}Xe concentrations were always less than the derived air concentrations (typically less than 3%) and would result in annual organ doses of less than 1 mrem. Therefore, potential doses to unmonitored employees from elevated concentrations of ^{133}Xe are inconsequential for dose reconstruction.

4.4 INTERNAL INHALATION AND INGESTION DOSE TO UNDERGROUND WORKERS

In the early 1980s, the Environmental Sciences Department of REECo recognized that the buildup of radon and radon daughter concentrations (RDCs) could pose a potential health problem in tunnels on Rainer Mesa and at other NTS locations. In 1984, to determine the concentrations of the RDCs and the effect of environmental conditions on the buildup of these concentrations, REECo conducted radon measurement surveys in G-, T-, and N-Tunnels (Fauver 1987). This section discusses the results of these surveys and those in 1991 and 1992 (Lyons 1992a, 1992b).

4.4.1 Underground Activities

Area 12, which is in the Nuclear or High Explosive Test Zone, occupies 104 km^2 (40 mi^2) at the northern boundary of NTS, known as Rainier Mesa. No atmospheric nuclear tests have occurred at this location; however, Area 12 was the site of the U.S. Atomic Energy Commission's first fully contained underground nuclear detonation, the RAINIER test, on September 19, 1957, in a horizontal tunnel about 487 m (1,600 ft) into the mesa and 274 m (900 ft) beneath the top of the mesa (ORAUT 2008). In the past several decades, a number of tunnels have been mined into Rainier Mesa, in which most of the U.S. Department of Defense horizontal line-of-sight exposure experiments have occurred. The N-, P-, and T-Tunnel complexes, in particular, were developed extensively during the 1970s and 1980s. The tunnel experiments usually involved complex construction of large-diameter [up to 9 m (27 ft)], line-of-sight pipes and special closure mechanisms, blast and gas seal doors, stemming plugs, and the like. The G-Tunnel complex was originally established for nuclear testing but, since 1971, has been used only as an underground research facility (ORAUT 2008).

In addition to its use for nuclear testing purposes, N-Tunnel was the location of a nonproliferation experiment involving 1.3 million kg (2.9 million lb) of conventional explosives on September 22, 1993. At present, the U.S. Department of Defense operates a high-explosives research and development tunnel in Area 12. This reusable test bed supports programs involving the detonation of conventional or prototype high explosives and munitions (ORAUT 2008).

The U1a Complex in Area 1 is an underground laboratory of horizontal tunnels about 0.5 mi long at the base of a vertical shaft about 960 ft beneath the surface. The vertical shaft is equipped with a mechanical hoist for personnel and equipment access. Another vertical shaft about 1,000 ft away provides cross ventilation, instrumentation, utility access, and emergency egress. The shaft was excavated in the 1960s, and a nuclear test was conducted in a horizontal tunnel mined from its base in 1990 (ORAUT 2008).

4.4.2 Radon Measurements

Radon-222, with a radioactive half-life of 3.8 days, occurs in the ^{238}U decay chain; ^{220}Rn, with a radioactive half-life of 54.5 seconds, occurs in the ^{232}Th chain. The decay daughters associated with ^{222}Rn include ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po, and those associated with ^{220}Rn include ^{216}Po, ^{212}Pb, ^{212}Bi, and ^{208}Tl. Because radon is a noble gas and thus chemically inert, it migrates easily from the tunnel rock and soil, which contains naturally occurring trace quantities of uranium and thorium.

Radon progeny measurements in N- and T-tunnels were made in drifts mined in a rock formation known as Tunnel Bed Non-Welded Ash Fall Tuff. This rock is unconsolidated and only slightly fractured. The drift that was sampled in the inclined G-tunnel was mined in Grouse Canyon Welded Ash Fall Tuff, which is extremely fractured. Factors that affect concentrations of radon and radon progeny in air are ventilation rates, barometric pressure, relative humidity, temperature inversions, the degree of fracturing in the rock, and the amount of smoke and dust in the air. Factors such as barometric pressure and fractures affect the rate at which radon emanates from the rock, while others such as dust and ventilation rates affect the accumulation rate of progeny in the air. Concentrations fluctuate with changing seasons, weather conditions, and activities in the area being monitored (Fauver 1987).

The concentration of radon progeny (the major dose contributors) in air is measured in working levels (WL). This is the common unit for expressing radon progeny exposure rates. The WL was developed for use in uranium mines but is now used for environmental exposures. Numerically, the WL is any combination of short-lived decay products in 1 L of air that results in the emission of 1.3×10^5 MeV of potential alpha energy. When radon is in complete equilibrium with its short-lived decay products, 1 WL equals 100 pCi/L (i.e., 100 pCi/L each of ^{222}Rn and short-lived decay products ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) (NCRP 1988, p. 17). For ^{220}Rn and its decay products (^{216}Po, ^{212}Pb, ^{212}Bi, and ^{208}Tl), 1 WL is equal to 7.47 pCi/L. The advantage of the WL unit is that it enables comparison of different equilibrium levels and different concentrations of radon decay products. The degree of equilibrium is a critical factor for estimating inhalation exposure and is of equal importance to the radon concentration itself (NCRP 1988, p. 19). The WL unit considers this factor. However, because the DCFs for ^{220}Rn progeny (^{212}Pb + ^{212}Po) are one-third the values for the ^{222}Rn progeny (ICRP 1981), the dose equivalent WL for ^{220}Rn is only one-third that of a ^{222}Rn WL.

The exposure of tunnel workers can be expressed in units of working level months (WLM), which is an exposure rate of 1 WL for a working month of 170 hours (NCRP 1988, p. 17). For example, an exposure of 1 WLM would result from exposure to a concentration of 1 WL for 1 month or 0.5 WL for 2 months.

4.4.3 Underground Radon Concentrations

Measurements were taken in tunnels N, T, and G. The preliminary measurements indicated N- and T-Tunnel RDCs of about 0.01 WL under normal ventilation conditions. However, the data demonstrated that RDCs could rise to relatively high levels (i.e., 0.24 WL) when ventilation rates were significantly lower (Fauver 1987, Figure 2, p. 7). The RDCs in G-Tunnel were an order of magnitude higher than those in N- and T-Tunnels. The average RDC in the rock mechanics drift (the worst-case location in G-Tunnel) was 0.13 WL (ranging from 0.07 to 0.23 WL). Elevated RDCs in the rock mechanics drift of G-Tunnel seemed to be from a lower ventilation rate in conjunction with the more highly fractured nature of the welded tuff in which the incline drift was mined. By increasing the ventilation rate, a 60% reduction in RDCs from an average of 0.13 WL to an average of 0.05 WL was achieved (Table 4-17).

Table 4-17. Results of experiment to determine the effects of ventilation conditions on RDCs in the G-Tunnel inclined drift.[a]

Location	Ventilation conditions and radon progeny integrated sample average (WL)
Rock mechanics drift at 0+52	Alternating 0.19, Continuous 0.05
Average	Alternating 0.13, Continuous 0.05

a. Source: Fauver (1987, Table 3).

Lyons (1992a, 1992b) reported additional radon measurements from 1991 and 1992. Although the G-Tunnel complex remained inactive in 1992, radon samples were taken to document potential radon WL in a worst-case scenario of complete ventilation failure throughout the complex. The maximum WL for radon daughters was 1.4. No samples were taken in 1992 in T-Tunnel, which was inactive that year.

Tables 4-18 and 4-19 list the results of extensive radon sampling in N- and P-Tunnel complexes in 1992 (from Lyons 1992a, Table 3, p. 8, and Lyons 1992b, Table 1, p. 8, respectively). The average concentrations in N- and P-Tunnels were 0.008 and 0.003 WL, respectively, and the maximum concentrations in N- and P-Tunnels were 0.013 and 0.006 WL, respectively.

Table 4-18. RDCs for N-Tunnel in 1991 and 1992.[a]

	July–December 1991			
N-Tunnel location	Rn-222 average (WL)	Rn-222 maximum (WL)	Rn-220 average (WL)	Rn-220 maximum (WL)
Miner's lunchroom	0.005	0.007	0.011	0.018
Raytheon Alcove	0.009	0.03	0.017	0.06
21 LOS at 2 + 50	0.034	0.059	0.029	0.046
15 Assembly Drift	0.006	0.009	0.015	0.021
Slow Alcove	0.004	0.008	0.01	0.025
23 Fast Alcove	0.009	0.014	0.018	0.03
24 Bypass Drift	0.005	0.007	0.012	0.041
24 LOS Drift	0.005	0.01	0.015	0.036

January–June 1992

N-Tunnel location	Rn-222 average (WL)	Rn-222 maximum (WL)	Rn-220 average (WL)	Rn-220 maximum (WL)
Miner's lunchroom	0.005	0.007	0.01	0.016
Raytheon Alcove	0.003	0.004	0.005	0.008
Slow Alcove	0.005	0.007	0.008	0.009
24 Bypass Drift	0.005	0.006	0.015	0.015
24 LOS Drift at GZ	0.005	0.007	0.012	0.014
22 Bypass	0.006	0.007	0.013	0.015
Average	**0.008**	**0.013**	**0.014**	**0.025**

a. GZ = ground zero; .LOS = line of sight.

Table 4-19. RDCs for P-Tunnel in 1991 and 1992.[a]

July–December 1991

P-Tunnel location	Rn-222 average (WL)	Rn-222 maximum (WL)	Rn-220 average (WL)	Rn-220 maximum (WL)
01 Drift at Access Drift	0.003	0.006	0.004	0.007
01 Fast Alcove	0.003	0.005	0.003	0.006
02 Main Drift at 6 + 00	0.01	0.032	0.01	0.046
04 LOS at VP X-Cut	0.008	0.013	0.012	0.015
04 LOS Drift at GZ	0.005	0.006	0.014	0.02
04 LOS Test Ch.	0.003	0.004	0.005	0.006
04 Bypass at RE#1	0.007	0.013	0.008	0.011
IHD Alcove	0.003	0.009	0.004	0.015
LLNL Alcove	0.003	0.006	0.007	0.02
05 Cavity	0.003	0.006	0.006	0.015

January–June 1992

P-Tunnel location	Rn-222 average (WL)	Rn-222 maximum (WL)	Rn-220 average (WL)	Rn-220 maximum (WL)
01 Drift at Access Drift	0.001	0.001	0.002	0.005
01 Fast Alcove	0.001	0.001	0.004	0.006
02 Main Drift at 6 + 00	0.001	0.001	0.002	0.004
04 Reentry	0.001	0.002	0.004	0.005
04 LOS at 12 + 00	0.002	0.002	0.005	0.006
HPD Base Station	0.001	0.001	0.003	0.006
Miner's lunchroom	0.001	0.001	0.003	0.006
05 Cavity	0.001	0.001	0.003	0.004
Average	**0.003**	**0.006**	**0.006**	**0.011**

a. HPD = Health Protection Department; LOS = line of sight.

4.4.4 Underground Worker Exposure to Radon

Although measurements were periodically performed in the tunnel complexes to ensure adequate worker protection, neither DOE nor its predecessor agencies attempted to quantify or record occupational exposures to radon and its daughters. Therefore, in accordance with DCAS-TIB-011, *Dose Conversion Factors for Radon WLM* (NIOSH 2018), dose reconstructors should adjust the dose for all cancer organs of any employee who was a miner or tunnel worker to account for radon exposure while working in the tunnel complexes. To quantify the exposure, Table 4-20 lists airborne ^{222}Rn RDCs based on measurement results that are favorable to claimants. The values in Table 4-20 pertain only to ^{222}Rn and its daughter products. Based on measurement results shown in Tables 4-18 and 4-19, ^{220}Rn WL concentrations are assumed to be present at twice the ^{222}Rn WL concentrations and should be evaluated in addition to the ^{222}Rn exposures.

Table 4-20. Average annual ^{222}Rn exposures and uncertainties for internal dose reconstruction for miners and tunnel workers (Fauver 1987).

Tunnel complex	RDC concentration (WL)	Annual exposure (WLM)[a]	Uncertainty GSD[b]
G (before 1984)	0.13	1.56	1.52
G (1984 and later)	0.05	0.60	1.52
N	0.008	0.096	1.52
P	0.003	0.036	1.52
T	0.01	0.12	1.52
Unidentified[c] (before 1984)	0.13	1.56	1.52
Unidentified[c] (1984 and later)	0.05	0.60	1.52

a. Based on 170 hours of exposure per month for 12 months.
b. Use these values if underground work location is not known.

For G-Tunnel workers, annual exposures (assuming a full year of underground activity) are assumed to be 1.56 WLM before 1984 and 0.60 WLM during and after 1984. This is because REECo did not recognize until 1984 that significant reductions in RDCs could be effected by leaving all ventilation fans running overnight. Until 1984, the practice was to shut down alternating fans each night, which resulted in higher average RDCs.

Because no radon measurement data were readily available for the underground portions of the U1a Complex, the assumption was made that the RDCs in U1a would be similar to those in G-Tunnel (which is mined in highly fractured tuff) [1], which is favorable to claimants. In addition, a reasonable assumption was made that the U1a Complex is well ventilated, similar to G-Tunnel. Dose reconstructors should use these average annual exposure values for miners and tunnel workers without identified tunnel locations.

Based on measurements shown in Table 4-19, for purposes of dose reconstruction, ^{220}Rn should be assumed to be present at twice the concentrations of ^{222}Rn shown in Table 4-20. For dose reconstruction, the GSD of the values in Table 4-20 can be estimated using Equation 4-1 (Section 4.2.1.2.1). Under the assumption that the 50th-percentile expected annual exposures are those in Table 4-20 and that the 95th-percentile values are twice the values in Table 4-20, the GSD for all values in Table 4-20 is 1.52.

Lastly, when a best estimate is required, and occupancy factor may be applied based on tunnel entry logs contained within the dosimetry data provided by the DOE. The derived occupancy factor should assume full occupancy at 2,040 hours per year based on the assumption of 170 hours of exposure per month used to derive the Annual Exposure (WLM) values provided in Table 4-20. The derived occupancy factor would be the ratio of the hours worked in a tunnel to the full occupancy hours (i.e., 2,040 hours). For example, if the logs indicate that the worker was in the tunnel for 1,020 hours in a year, the derived occupancy factor would be 0.50. The Annual Exposure (WLM) from Table 4-20 would then be multiplied by the occupancy factor. In some instances, the derived occupancy factor could be greater than 1.00. In this case, the Annual Exposure (WLM) from Table 4-20 would be increased by multiplication by the derived occupancy factor. In addition, the Unidentified tunnel exposure values from Table 4-20 should not be used since the actual tunnels worked would have been identified in the tunnel entry logs used to derive the occupancy factor.

Similarly, for a bounding overestimate, the assumption is made that the worker spends 2,600 hours per year (50 hours per week for 52 weeks) underground. This would result in a derived occupancy factor of 1.275.

4.4.4.1 Gravel Gerties

As discussed in Part 2, Section 2.2.5 of this site profile (ORAUT 2008), underground bunkers were constructed in Area 5 for testing containment capabilities involving accidental explosion of high-explosive material in the underground bunker. Containment tests were conducted in the gravel gerties in 1957 and again in 1982. These tests resulted in successful designs that were used at the Pantex Plant in Texas and in the Device Assembly Facility in Area 6. Five gravel gerties were constructed in Area 6 from 1988 to 1992. However, with the cessation of testing in 1992, they have not been activated for device assembly.

Because the Area 5 gravel gerties were constructed for testing and the Area 6 gravel gerties were never activated, it is not likely that workers spent significant time inside the structures. However, if it can be determined from the dosimetry records or telephone interviews that a claimant worked in the gravel gerties for a significant time, it should be assumed that they would have been exposed to elevated levels of radon, and this radon exposure should be evaluated and included in the dose reconstruction.

Although radon measurements are not available for inside the NTS gravel gerties, because of the similarities of construction, application of the radon concentrations measured in the Pantex gravel gerties is assumed to be appropriate. Therefore, for a 12-month period for which it can be determined that a claimant worked in the NTS gravel gerties, a radon exposure of 0.072 WLM should be assigned (ORAUT 2015, Section 5.3.3). This exposure can be prorated as appropriate for employment periods of less than a full year. These exposures should be applied as lognormal with a GSD of 3 (ORAUT 2015, Section 5.3.3). In addition, when a best estimate is required, and occupancy factor may be applied based on entry logs contained within the dosimetry data provided by the DOE. This occupancy factor as well as the bounding overestimate occupancy factor should be derived in a similar fashion as described in Section 4.4.4 for tunnel entries.

4.4.4.2 Uncertainty Associated with Radon Measurements

Two methods used to measure the concentration of radon and its progeny were the grab sample technique and the integration technique. Preliminary measurements were made by grab sampling for a general estimate of the concentrations. Lucas cells collected and counted grab samples of radon gas. The cells were evacuated in the laboratory and opened at the sampling location for a single intake of air. The filled cells were counted at the EPA Las Vegas Laboratory within 24 hours to minimize decay. The number of measurements was small due to limited availability of Lucas cells. Grab samples of radon daughters were collected and counted according to a technique described by Rolle (ANSI 1973), which used a single count of an air sample collected on a filter. Samples were collected on a 2-cm Whatman fiberglass filter at a rate of about 5 L/min and counted on an EDA Instruments Incorporated Radon Detector (Model RD200). The Rolle method allowed a choice of several different analysis regimes. The regime chosen for tunnel measurements was a 5-minute sampling time, a 6-minute decay time, and a 5-minute counting time. Using appropriate correction factors, the RDC in WL can be evaluated 11 minutes after sample collection. The values obtained using the Rolle method were periodically checked using the Kusnetz (Fauver 1987, p. 3) method, which also used a single count of an air filter but allowed for a 40-to-90-minute decay time. These measurement techniques have good accuracy and a relative standard deviation of less than 15% (Fauver 1987, p. 3).

Grab sampling is quick and convenient. However, as mentioned above, radon concentrations can fluctuate widely with time and location. To account for this variability, integrating monitoring instruments were used. A passive environmental radon monitor (PERM) was used to measure radon in picocuries per liter. A radon progeny integrating sampling unit (RPISU) measured the RDC in WL.

The PERM is an integrating radon monitor that employs electrostatic collection of radon daughter ions and uses a TLD as the radiation dose integration element. The lower limit of detection at the 95% confidence level is about 0.3 pCi/L for a 1-week sample with a relative standard deviation of 20% (Fauver 1987, p. 4). The RPISU is a low-volume air sampler that draws air through a 0.65-µm-pore-size Millipore membrane filter. A Teflon disc TLD containing dysprosium-activated calcium fluoride (Harshaw TLD200) is positioned close to the collection surface of the filter and serves as the dose integrating element. The lower limit of detection at the 95% confidence level is about 0.0001 WL for a 1-week sampling period with a relative standard deviation of 10% (Fauver 1987, p. 4). The RPISU technique is recommended for the measurement of RDCs by the DOE Technical Measurements Center, Division of Remedial Action Projects (Fauver 1987, p. 4).

4.4.5 Underground Worker Exposure to Other Radionuclides

In addition to exposure to elevated levels of radon, underground workers could have been exposed to other sources of airborne contamination. Because the breathing air in the underground environment was drawn from the outside environment, underground workers would have been exposed to the same inhalation intakes as aboveground workers (see Sections 4.2.1.2.2 through 4.2.1.2.6).

4.5 INSTRUCTION TO DOSE RECONSTRUCTORS FOR ASSIGNMENT OF EXTERNAL AMBIENT DOSES AND ENVIRONMENTAL INTAKES AND RESULTANT DOSES

4.5.1 Assigning External Ambient Dose

Starting in April 1957 and ending in 1992, all personnel entering NTS were monitored for external radiation exposure (ORAUT 2012). Because unexposed control badges were processed with the personnel dosimeters and the readings from the control badges were subtracted from the dosimeter to obtain a net reading for determining exposure, ambient external dose should not be included in dose reconstruction before 1993. Before the institution of universal badging in April 1957 for employees who were not monitored, coworker doses should be assigned based on the values in ORAUT (2012, Table 6-11) and no additional ambient dose should be assigned through 1992. Based on a review of the dosimetry literature of the site, no change in the handling of dosimeters occurred when universal badging was introduced; therefore, ambient dose is appropriately included in the dosimeter doses beginning in April 1957 through December 1992. After 1992, ambient external dose should be added to dose reconstruction for unmonitored workers in accordance with the guidelines for assigning dose provided below.

The assignment of a best estimate must take into account all available records pertinent to determination of work location. For employees who worked in multiple areas of the site, if the employee records and claimant interview do not provide enough information to determine specific work locations, values representing a site average are appropriate as a best estimate. Otherwise, the annual dose should be calculated according to the fraction of time spent in different areas of the site. The assumption should be made that the energy employee worked 50 hr/wk. In addition, 50 wk/yr should be assumed (to reasonably account for holiday and/or vacation time), for a total of 2,500 work hours per year as a best estimate. Partial years of employment should be scaled accordingly. In addition, if the claimant interview or other available information indicates definitively that fewer or more hours were worked than the default assumption, this information should be used accordingly. For example, if it is indicated that the employee spent half of the time at offsite locations where only natural background radiation levels existed, only 25 hours of exposure per week should be assumed. The calculated annual dose should be multiplied by the appropriate exposure (R)-to-organ DCF documented in OCAS-IG-001 for an isotropic exposure geometry. If the supporting documentation for all of the elements necessary for a best-estimate dose reconstruction does not exist, conservative assumptions should be applied in relation to work location and area conditions, erring in favor of the claimant.

External ambient doses for each year are available in Table 4-15 and can be used for workers with continuous employment but nonexistent or incomplete monitoring records. For example, EG&G employees were likely to be stationed in Las Vegas and received dosimeters when they traveled to NTS. A second example includes REECo employees who were processed as new employees through NTS (Mercury) and assigned to work at Tonopah Test Range (TTR). These employees have at least one NTS dosimeter. Often no additional records are provided for these employees by Sandia National Laboratories, the responsible organization for dosimetry at TTR. For REECo employees assigned at TTR, ambient dose (ORAUT 2013) can be assigned as appropriate.

Assignment of dosimeters to all persons at NTS began in April 1957 and ended in December 1992 (ORAUT 2012). During this time, readings from control badges at Mercury were used to subtract ambient background dose from the personnel dosimeters (ORAUT 2012). For this reason, from April 1957 to December 1992, ambient background external radiation dose should not be included in dose reconstructions. Because no documentation is available before 1967 (see Table 4-15), ambient external doses should not be assigned under any circumstances from 1951 through 1956. After 1992, ambient background external dose should be assigned to all unmonitored workers in accordance with the guidelines for Table 4-15.

4.5.2 Assigning Internal Ambient Dose

With the exception of cases that can be worked after 1992 using the bounding assumptions in ORAUT-OTIB-0018 (ORAUT 2005), environmental inhalation and ingestion intakes listed in Tables 4-7 and 4-11, respectively, shall be applied starting in 1963. The intake values in Tables 4-7 and 4-11 are to be considered bounding and should be applied in IREP as constants. For a best estimate, 10% of the intakes provided in Tables 4-7 and 4-11 should be assigned. The best-estimate intakes should be applied in IREP as a lognormal distribution with a GSD of 3.0.

To correct for exposure to short-lived fission and activation products, the dose reconstructor should add annual doses that were greater than 0.001 rem from Tables 4-9 and 4-14 as 30-to-250-keV photons with a constant distribution. These doses shall be entered into the IREP analysis as constants because they can be considered bounding overestimates of the actual doses.

4.6 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section, with information to identify the source and justification for each associated item. Conventional References, which are provided in the next section of this document, link data, quotations, and other information to documents available for review on the Project's Site Research Database (SRDB).

[1] Rollins, Eugene M. Oak Ridge Associated Universities (ORAU) Team. Senior Health Physicist, October 2007.
The highest radon concentrations were measured in the G-Tunnel and occurred in fractured tuff. Therefore, with the lack of measured data in the U1a Complex, an assumption favorable to claimants was made that the radon concentrations in the U1a Complex were the same as the highest measured concentrations in the G-Tunnel complex.

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GLOSSARY

absorption
In external dosimetry, process in which radiation energy is imparted to material. In internal dosimetry, movement of material to blood regardless of mechanism.

absorption type
Categories for materials according to their rates of absorption from the respiratory tract to the blood, which replaced the earlier inhalation clearance classes. Defined by the International Commission on Radiological Protection, the absorption types are F: deposited materials that are readily absorbed into blood from the respiratory tract (fast solubilization), M: deposited materials that have intermediate rates of absorption into blood from the respiratory tract (moderate rate of solubilization), and S: deposited materials that are relatively insoluble in the respiratory tract (slow solubilization).

accuracy
The characteristics of an analysis or determination that ensures that both the bias and precision of the resultant quantity will remain within the specified limits.

ambient gamma radiation
Penetrating gamma radiation in the outside environment. Includes gamma radiation from natural cosmic and terrestrial sources as well as synthetic (manmade) sources.

background radiation
Radiation from cosmic sources, naturally occurring radioactive materials including naturally occurring radon, and global fallout from the testing of nuclear explosives. Background radiation does not include radiation from source, byproduct, or Special Nuclear Materials regulated by the U.S. Nuclear Regulatory Commission. The average individual exposure from background radiation is about 360 millirem per year.

breathing rate
Amount of air a person breathes in a specified time. In relation to health physics for workers, rates typically vary from light (1.2 cubic meters per hour) to heavy (1.7 cubic meters per hour) as defined by the International Commission on Radiological Protection.

buildup
Increase in flux or dose due to scattering in the medium.

confidence level
The interval about an estimate of a stated quantity within which the value of the quantity is expected to be within a specified probability. See *uncertainty*.

contamination
Radioactive material in undesired locations including air, soil, buildings, animals, and persons.

curie (Ci)
Traditional unit of radioactivity equal to 37 billion (3.7×10^{10}) becquerels, which is approximately equal to the activity of 1 gram of pure ^{226}Ra.

dose
In general, the specific amount of energy from ionizing radiation that is absorbed per unit of mass. Effective and equivalent doses are in units of rem or sievert; other types of dose are in units of rad, rep, or grays.

dose conversion factor (DCF)

Multiplier for conversion of potential dose to the personal dose equivalent to the organ of interest (e.g., liver or colon). In relation to radiography, ratio of dose equivalent in tissue or organ to entrance kerma in air at the surface of the person being radiographed.

dose equivalent (*H*)

In units of rem or sievert, product of absorbed dose in tissue multiplied by a weighting factor and sometimes by other modifying factors to account for the potential for a biological effect from the absorbed dose. See *dose*.

dosimeter

Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual. See *film dosimeter* and *thermoluminescent dosimeter*.

dosimetry

Measurement and calculation of internal and external radiation doses.

element

One of the known chemical substances in which the atoms have the same number of protons. Elements cannot be broken down further without changing their chemical properties. Chemical symbols for the elements consist of either a single letter or a combination of letters, some of which descend from the Latin names [e.g., Au from *aurum* (gold), Fe from *ferrum* (iron)]. This glossary indicates *elements* by their names. Specific *isotopes* appear as their standard chemical symbols with the number of protons and neutrons in the nucleus. For example, the isotope of uranium that contains 92 protons and 143 neutrons can appear as ^{235}U, *U-235*, or *uranium-235*.

error

Difference between the correct, true, or conventionally accepted value and the measured or estimated value. Sometimes used to mean estimated uncertainty. See *accuracy* and *uncertainty*.

exchange period (frequency)

Period (weekly, biweekly, monthly, quarterly, etc.) for routine exchange of dosimeters.

exposure

(1) In general, the act of being exposed to ionizing radiation; see *acute exposure* and *chronic exposure*. (2) Measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

external dose

Dose received from radiation (e.g., photons, electrons, and neutrons) that originates outside the body including medical screening examinations.

favorable to claimants

A bias in selecting input parameters and assumptions that would result in a greater probability of causation (and hence greater likelihood of compensability) than if more accurate parameters or assumptions were used. See *probability of causation*.

film

(1) In the context of external dosimetry, radiation-sensitive photographic film in a light-tight wrapping. See *film dosimeter*. (2) X-ray film.

film dosimeter

Package of film for measurement of ionizing radiation exposure for personnel monitoring purposes. A film dosimeter can contain two or three films of different sensitivities, and it can contain one or more filters that shield parts of the film from certain types of radiation. When developed, the film has an image caused by radiation measurable with an optical densitometer. Also called film badge.

filter

Material used (1) in a dosimeter to adjust radiation response to provide an improved tissue equivalent or dose response and (2) in an X-ray machine to selectively absorb photons from the beam to reduce unnecessary exposure of individuals or to improve radiographic quality.

geometric standard deviation (GSD)

In probability theory and statistics, the geometric standard deviation describes the spread of a set of numbers whose preferred average is the geometric mean.

gravel gertie

At NTS, a round room with 2-foot-thick concrete walls and a staging area with two staging bays connected to the round room. Tests were conducted in the gravel gertie with high explosives and uranium devices to measure fallout.

high explosive

Chemical compound or mechanical mixture that, when subjected to heat, impact, friction, shock, or other initiation stimulus, undergoes a rapid chemical change resulting in large volumes of highly heated gases that exert pressure in the surrounding medium.

ingestion

Process of taking a substance into the body through the mouth.

intake

Radioactive material taken into the body by inhalation, absorption through the skin, injection, ingestion, or through wounds.

isotope

One of two or more atoms of a particular element that have the same number of protons (atomic number) but different numbers of neutrons in their nuclei (e.g., ^{234}U, ^{235}U, and ^{238}U). Isotopes have very nearly the same chemical properties. See *element*.

kiloelectron-volt (keV)

Unit of particle energy equal to 1,000 (1×10^3) electron-volts.

megaelectron-volt (MeV)

Unit of particle energy equal to 1 million (1×10^6) electron-volts.

monitor

Device that detects and usually records the presence of radioactivity or radioactive substances.

monitoring

Periodic or continuous determination of the presence or amount of ionizing radiation or radioactive contamination in air, surface water, groundwater, soil, sediment, equipment surfaces, or personnel (for example, bioassay or alpha scans). In relation to personnel,

monitoring includes internal and external dosimetry including interpretation of the measurements.

neutron

Basic nucleic particle that is electrically neutral with mass slightly greater than that of a proton. There are neutrons in the nuclei of every atom heavier than normal hydrogen. See *element*.

nuclide

Stable or unstable isotope of any element. Nuclide relates to the atomic mass, which is the sum of the number of protons and neutrons in the nucleus of an atom. A radionuclide is an unstable nuclide.

photon

Quantum of electromagnetic energy generally regarded as a discrete particle having zero rest mass, no electric charge, and an indefinitely long lifetime. The entire range of electromagnetic radiation that extends in frequency from 10^{23} cycles per second (hertz) to 0 hertz.

probability of causation

For purposes of dose reconstruction for the Energy Employees Occupational Illness Compensation Program Act of 2000, the percent likelihood, at the 99th percentile, that a worker incurred a particular cancer from occupational exposure to radiation.

progeny

Nuclides that result from decay of other nuclides. Also called decay products and formerly called daughter products.

radiation

Subatomic particles and electromagnetic rays (photons) with kinetic energy that interact with matter through various mechanisms that involve energy transfer.

radioactive

Of, caused by, or exhibiting radioactivity.

radioactivity

Property possessed by some elements (e.g., uranium) or isotopes (e.g., ^{14}C) of spontaneously emitting energetic particles (electrons or alpha particles) by the disintegration of their atomic nuclei. See *radionuclide*.

radionuclide

Radioactive nuclide. See *radioactive* and *nuclide*.

rem

Traditional unit of radiation dose equivalent that indicates the biological damage caused by radiation equivalent to that caused by 1 rad of high-penetration X-rays multiplied by a quality factor. The sievert is the International System unit; 1 rem equals 0.01 sievert. The word derives from roentgen equivalent in man; rem is also the plural.

roentgen

Unit of photon (gamma or X-ray) exposure for which the resultant ionization liberates a positive or negative charge equal to 2.58×10^{-4} coulombs per kilogram (or 1 electrostatic unit of electricity per cubic centimeter) of dry air at 0 degrees Celsius and standard atmospheric pressure. An exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher energy photons (generally greater than 100 kiloelectron-volts).

scattering

Change in direction of radiation by refraction or reflection, often accompanied by a decrease in radiation due to absorption by the refracting or reflecting material.

scintillation counter or detector

Combination of phosphor, a photomultiplier tube, and the associated electronic circuits for measuring the light emissions produced in the phosphor by ionizing radiation.

seep

At NTS, uncontrolled slow release of radioactive material with little or no energy. Seeps are not visible and can be detected only by measuring for radiation.

shielding

Material or obstruction that absorbs ionizing radiation and tends to protect personnel or materials from its effects.

sievert (Sv)

International System unit for dose equivalent, which indicates the biological damage caused by radiation. The unit is the radiation value in gray (equal to 1 joule per kilogram) multiplied by a weighting factor for the type of radiation and a weighting factor for the tissue; 1 sievert equals 100 rem.

thermoluminescent dosimeter (TLD)

Device for measuring radiation dose that consists of a holder containing solid chips of material that, when heated, release the stored energy as light. The measurement of this light provides a measurement of absorbed dose. TLDs replaced film dosimeters at essentially all U.S. Department of Energy sites beginning in the 1960s.

thermoluminescent dosimeter chip

Small block or crystal of lithium fluoride in a thermoluminescent dosimeter. For example, a TLD-600 dosimeter contains a chip made from more than 95% ^{6}Li for neutron radiation detection, and a TLD-700 dosimeter contains a chip made from more than 99.9% ^{7}Li for photon and beta radiation detection. Also called crystals.

transuranic (TRU) elements

Elements with atomic numbers above 92 (uranium). Examples include plutonium and americium.

uncertainty

Standard deviation of the mean of a set of measurements. The standard error reduces to the standard deviation of the measurement when there is only one determination. See *accuracy*, *confidence level*, and *error*. Also called standard error.

unmonitored dose

Potential unrecorded dose that could have resulted because a worker was not monitored.

venting

At NTS, prompt, massive, and uncontrolled releases of radioactive material characterized as active releases under pressure, such as when radioactive material is driven out of the ground by steam or gas.

working level (WL)

Unit of concentration in air of the short-lived decay products of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) and ^{220}Rn (^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po) defined as any combination of the short-lived radioactive progeny of radon or thoron in 1 liter of air, without regard to the degree of equilibrium, that results in the ultimate emission of 1.3×10^{5} megaelectron-volts of alpha energy; 1 working level equals 2.083×10^{-5} joule per cubic meter.

working level month (WLM)

Unit of exposure to radon progeny defined as exposure for 1 working month (170 working hours) to a potential alpha energy concentration of 1 working level; 1 working level month equals 1 working level times 170 hours, which is 0.00354 joule-hour per cubic meter. See *working level*.

X-ray

See *X-ray radiation*.

X-ray radiation

Electromagnetic radiation (photons) produced by bombardment of atoms by accelerated particles. X-rays are produced by various mechanisms including bremsstrahlung and electron shell transitions within atoms (characteristic X-rays). Once formed, there is no difference between X-rays and gamma rays, but gamma photons originate inside the nucleus of an atom.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA

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AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

A.1 INTRODUCTION

With the cessation of atmospheric testing at NTS in 1962, the greatest potential for environmental intakes of radioactive material results from the inhalation of radioactive particles that were resuspended from NTS soils into the atmosphere and from ingestion of soils contaminated by atmospheric nuclear weapons tests, reactor tests, and safety tests. The potential inhalation intakes can be estimated from air sampling data in the NTS annual environmental reports (see References section) coupled with extensive soil contamination data from between 1983 and 1991 (McArthur and Kordas 1983, 1985; McArthur and Mead 1987, 1988, 1989; McArthur 1991). Because the air monitoring data were limited to gross alpha and beta measurements, tritium, and isotopes of plutonium (e.g., ^{238}Pu, ^{239}Pu, and ^{240}Pu), inhalation intakes of other relatively long-lived radionuclides that have been identified in NTS soils (e.g., ^{241}Am, ^{60}Co, ^{137}Cs, ^{90}Sr, ^{152}Eu, ^{154}Eu, and ^{155}Eu) are scaled to those of plutonium based on their relative abundance in NTS soils. Ingestion intakes can be estimated by assuming consumption of contaminated NTS soils. To ensure that inhalation and ingestion intakes are not underestimated, the relative abundances of long-lived radionuclides in NTS soils that were determined from the 1991 soil contamination data (McArthur 1991) were decay-corrected to 1963. In addition, to ensure that intakes and resultant doses are not underestimated, correction factors are developed to account for potential exposures to short-lived fission and activation products based on test-specific data from Hicks (1981a, 1981b, 1981c, 1981d). In addition, a correction factor is developed for inhalation intakes that accounts for the phenomenon of early resuspension (Anspaugh et al. 2002).

This approach has been developed to address the unique character of NTS, which is a large outdoor testing facility where potential exposure to radioactive materials was primarily based on residual contamination from atmospheric testing. For most employees of the primary contractor, occupational internal doses can be equated to the doses they potentially received from the resuspension of residual radioactivity from the atmospheric testing (i.e., environmental internal dose). For workers who were primarily indoors (cafeterias, administrative facilities, and maintenance shops), this dose is likely to represent an overestimate of internal exposure. The environmental internal dose is the occupational internal dose, regardless of the recorded external dose. If an internal exposure was suspected, bioassay was performed. Managing radioactive material in the form of devices was episodic and limited to a few workers (e.g., radiation safety and industrial hygiene personnel, miners, and experimenters). These workers are identified on the rosters that were published before the event, and these workers are likely to have bioassay results in the DOE records.

The following paragraphs discuss:

- Air sampling data from the NTS annual environmental reports from 1971 through 2001 and the calculated annual inhalation ^{239}Pu intakes.
- NTS soil contamination data that were gathered and reduced in the late 1980s (McArthur 1991); soil contamination data that are decay-corrected to 1963.
- Methods used to develop inhalation intake scaling factors for radionuclides identified in NTS soils in comparison with intakes of plutonium that were calculated from air sampling data.
- The method used to account for higher air concentrations due to resuspension for 1963 (the first year after suspension of atmospheric testing).

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

- The methods used to develop the correction factors that were used to account for organ dose from inhalation of short-lived radionuclides that no longer persist in the NTS environment in measurable quantities.

- The method used to calculate ingestion intakes from oral consumption of contaminated NTS soils; the method used to account for ingestion dose from short-lived fission and activation products.

- Step-by-step instructions to the dose reconstructor for application of ambient environmental inhalation and ingestion intakes.

Attachment B provides a discussion that includes the results of 30 years of inhalation and ingestion intakes.

A.2 AIR SAMPLING DATA AND INTAKE ESTIMATES

Routine isotopic atmospheric measurements of plutonium at NTS began in 1971 with samplers in 15 locations across the site. Six additional sampling stations were added in 1978. Equipment at fixed locations continuously sampled the ambient air to monitor for radioactive materials. These locations were chosen to provide representative samples from the populated areas on the site and to monitor resuspension of low-fired plutonium spread by safety experiments before 1960 in Areas 2, 3, 4, 7, 9, and 10. Access, worker population, geographical coverage, presence of radioactivity, and availability of electric power were considerations in the site selection for air samplers (Black and Townsend 1997).

In 1988, efforts to monitor radioactive air emissions at NTS were increased as a result of the requirements of DOE Order 5400.1 (DOE 1990). Known and potential effluent sources throughout NTS were assessed for their potential to contribute to public dose (Black and Townsend 1997).

The ^{239}Pu concentrations in Table A-1 for 1989 through 2001 represent the average of the maximum concentrations for a given area in a given year. If maximum values were not provided (i.e., 1971 through 1988), the average of the average concentrations was reported. In addition to the annual area concentrations, Table A-1 lists NTS site average and maximum concentrations, which represent the arithmetic averages of the concentration of all the areas and the maximum of the area maximum or area averages of all the areas, respectively. Potential intakes associated with these concentrations can be calculated under the assumption that an unmonitored worker was occupationally exposed for 2,000 hr/yr with a breathing rate of 2,400 m^3/yr. Table A-2 lists these calculated intakes.

Some covered employees remained on the site continuously for weeks at a time. However, because most of the nonworking hours were spent indoors where ambient air particulate loadings would be much less than the outdoor loadings and because of the conservative assumptions that were used to estimate the values in Table A-2, adjustment of the tabular data is not required to ensure intakes are not underestimated for these individuals. In addition, employees who lived on the site during their workweek would have been housed in Area 12 or Area 23 (Mercury). For most years the values in Table A-1 for these locations are less than the site average values.

It is assumed that plutonium could be any of absorption types S, Super S, or M, depending on which type delivers the maximum organ dose.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

Table A-1. Atmospheric concentrations of ^{239}Pu for sampled areas (Bq/m^3).[a,b]

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 9	Area 10	Area 11	Area 12
1971	1.37E-05	2.45E-05	6.11E-06	ND	4.37E-06	6.36E-06	ND	2.67E-05	7.70E-06	3.37E-06	6.03E-06
1972	5.48E-06	8.29E-06	1.36E-05	ND	5.18E-06	4.96E-05	ND	1.59E-04	1.07E-05	8.99E-06	2.91E-05
1973	3.22E-06	8.25E-06	7.62E-06	ND	3.23E-06	4.44E-06	ND	3.18E-05	1.63E-06	8.99E-06	1.59E-06
1974	2.96E-06	2.52E-06	4.66E-06	ND	1.85E-06	2.93E-06	ND	7.81E-06	2.11E-06	2.96E-06	2.15E-06
1975	1.07E-06	1.41E-06	5.40E-06	ND	1.59E-06	2.32E-06	ND	6.22E-06	2.11E-06	1.81E-06	1.22E-06
1976	1.06E-05	6.36E-06	3.85E-05	ND	5.55E-06	1.64E-05	ND	1.18E-04	7.88E-06	8.73E-06	1.03E-05
1977	9.99E-07	2.41E-06	9.44E-06	ND	1.24E-06	2.05E-06	ND	9.36E-06	1.70E-06	4.48E-06	7.77E-07
1978	1.74E-06	4.92E-06	1.04E-05	ND	2.26E-06	3.66E-06	ND	2.01E-05	1.07E-05	3.96E-06	2.29E-06
1979	2.74E-06	1.72E-05	6.11E-08	ND	7.59E-07	1.46E-06	1.81E-06	1.94E-05	1.07E-05	1.37E-06	8.88E-07
1980	8.51E-07	9.58E-06	4.14E-08	ND	1.08E-06	1.78E-06	1.67E-06	1.67E-05	ND	1.63E-06	7.03E-07
1981	9.62E-07	2.35E-06	5.18E-06	ND	9.18E-07	1.07E-06	1.22E-06	1.19E-05	ND	1.70E-06	7.40E-07
1982	2.26E-06	1.48E-06	2.31E-06	ND	7.36E-07	1.30E-06	2.74E-06	7.96E-06	ND	1.96E-06	9.99E-07
1983	1.15E-06	2.39E-06	3.42E-06	ND	8.40E-07	1.20E-06	1.22E-06	7.92E-06	ND	6.73E-06	8.51E-07
1984	7.03E-07	3.68E-06	8.44E-06	ND	1.40E-06	7.40E-07	1.41E-06	3.77E-05	ND	2.07E-06	6.29E-07
1985	5.55E-07	2.13E-06	7.88E-06	ND	1.13E-06	9.99E-07	9.99E-07	4.92E-05	ND	1.92E-06	8.51E-07
1986	5.48E-06	2.29E-06	2.02E-05	ND	1.02E-06	6.88E-06	1.78E-06	1.04E-05	ND	9.25E-07	1.18E-06
1987	2.02E-06	8.51E-07	1.04E-04	ND	6.11E-07	9.36E-07	5.92E-07	4.07E-06	ND	1.18E-06	5.92E-07
1988	3.40E-06	1.04E-06	7.92E-06	ND	1.02E-06	8.14E-07	5.55E-07	1.89E-06	ND	4.44E-07	5.92E-07
1989	3.16E-05	2.15E-06	1.99E-05	ND	1.86E-06	2.96E-06	9.99E-06	1.30E-05	ND	2.00E-05	2.52E-05
1990	3.66E-06	1.20E-06	1.28E-05	ND	1.14E-06	1.37E-06	1.50E-06	1.84E-05	1.57E-06	3.96E-06	3.85E-07
1991	1.15E-04	7.59E-07	1.42E-05	ND	1.30E-06	2.68E-06	1.20E-06	1.30E-05	1.99E-08	8.29E-06	5.29E-07
1992	5.55E-06	4.07E-06	8.36E-05	ND	2.97E-06	2.69E-06	1.44E-05	3.26E-05	8.88E-06	3.26E-06	1.41E-06
1993	7.51E-06	1.81E-06	1.47E-05	ND	2.96E-06	3.31E-06	2.89E-06	9.99E-05	6.29E-06	1.55E-05	3.11E-05
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	1.50E-06	4.07E-07	8.99E-06	ND	5.66E-07	1.86E-06	4.44E-07	1.44E-05	1.39E-06	1.48E-06	4.07E-07
1996	2.78E-05	ND	1.12E-05	ND	6.07E-07	1.70E-06	1.67E-05	2.26E-05	2.13E-06	7.03E-07	1.37E-07
1997	ND	3.96E-07	ND	ND	ND	ND	ND	ND	9.73E-07	4.07E-07	5.55E-08
1998	1.74E-05	ND	2.49E-06	ND	3.52E-06	4.07E-07	1.01E-06	2.72E-05	ND	3.50E-07	ND
1999	ND	ND	ND	2.18E-06	ND	ND	ND	ND	ND	ND	ND
2000	3.14E-06	ND	9.95E-06	2.18E-06	7.59E-07	1.52E-05	1.26E-06	1.05E-04	ND	ND	ND
2001	1.68E-05	4.62E-07	4.29E-06	6.92E-06	2.53E-06	3.57E-06	6.28E-07	1.86E-05	3.13E-07	ND	ND

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

Year	Area 15	Area 16	Area 18	Area 19	Area 20	Area 23	Area 25	Area 27	Area 28	Site average[c]	Site maximum[d]
1971	ND	7.14E-06	2.96E-06	8.36E-06	ND	3.46E-06	ND	3.11E-06	1.44E-06	8.35E-06	2.67E-05
1972	ND	6.25E-06	5.37E-06	1.01E-04	ND	1.29E-05	ND	6.14E-06	1.89E-06	2.82E-05	1.59E-04
1973	ND	1.63E-06	1.41E-06	2.65E-06	ND	2.07E-06	ND	1.37E-06	1.22E-06	5.41E-06	3.18E-05
1974	ND	2.22E-06	ND	2.44E-06	ND	3.15E-06	3.18E-06	2.66E-06	4.33E-06	3.20E-06	7.81E-06
1975	ND	1.59E-06	ND	1.24E-06	ND	1.63E-06	2.11E-06	2.52E-06	2.59E-06	2.32E-06	6.22E-06
1976	ND	5.77E-06	ND	3.66E-06	ND	2.10E-05	7.44E-06	5.07E-06	2.33E-06	1.78E-05	1.18E-04
1977	ND	9.62E-07	ND	8.51E-07	ND	9.99E-07	1.22E-06	1.15E-06	8.51E-07	2.56E-06	9.44E-06
1978	ND	1.89E-06	ND	2.28E-06	ND	2.15E-06	2.58E-06	3.48E-06	1.44E-06	4.92E-06	2.01E-05
1979	1.92E-06	7.77E-07	ND	7.22E-07	ND	8.25E-07	6.66E-07	5.92E-07	8.51E-07	3.69E-06	1.94E-05
1980	2.36E-06	ND	ND	3.53E-06	ND	1.31E-06	1.13E-06	7.77E-07	5.92E-07	2.73E-06	1.67E-05
1981	3.44E-06	9.62E-07	ND	8.51E-07	ND	1.06E-06	8.99E-07	9.25E-07	5.92E-07	2.17E-06	1.19E-05
1982	1.55E-06	6.29E-07	ND	8.03E-07	ND	7.77E-07	6.29E-07	ND	ND	1.87E-06	7.96E-06
1983	8.25E-07	5.55E-07	ND	1.09E-06	ND	1.04E-06	1.11E-06	ND	ND	2.17E-06	7.92E-06
1984	1.18E-06	1.04E-06	ND	9.25E-07	ND	1.06E-06	1.18E-06	1.78E-06	ND	4.26E-06	3.77E-05
1985	1.48E-06	7.77E-07	ND	1.30E-06	ND	8.14E-07	9.73E-07	1.15E-06	ND	4.81E-06	4.92E-05
1986	1.44E-06	1.04E-06	ND	8.14E-07	ND	2.42E-06	7.59E-07	8.51E-07	ND	3.83E-06	2.02E-05
1987	6.66E-07	5.18E-07	ND	6.29E-07	ND	5.92E-07	8.51E-07	ND	ND	8.43E-06	1.04E-04
1988	8.99E-07	ND	ND	5.00E-07	ND	1.30E-06	5.55E-07	5.55E-07	ND	1.53E-06	7.92E-06
1989	8.62E-07	4.07E-07	ND	3.33E-07	ND	4.33E-06	3.50E-07	1.78E-07	ND	8.87E-06	3.16E-05
1990	3.03E-06	2.16E-07	ND	1.45E-07	ND	3.13E-06	4.18E-07	1.30E-06	ND	3.39E-06	1.84E-05
1991	4.55E-06	1.07E-06	ND	3.26E-07	ND	4.92E-07	9.51E-07	2.86E-07	ND	1.03E-05	1.15E-04
1992	4.07E-05	7.03E-07	ND	3.29E-07	ND	4.70E-07	6.70E-07	5.92E-06	ND	1.30E-05	8.36E-05
1993	1.22E-05	4.81E-07	ND	2.85E-07	ND	2.31E-07	1.26E-07	4.07E-07	ND	1.25E-05	9.99E-05
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	5.92E-06	5.18E-07	ND	3.70E-08	ND	2.75E-07	1.67E-07	ND	ND	2.56E-06	1.44E-05
1996	8.88E-06	6.66E-08	1.30E-07	ND	1.67E-07	2.31E-07	1.55E-07	9.62E-08	ND	5.82E-06	2.78E-05
1997	1.07E-06	7.03E-09	7.40E-07	ND	7.40E-07	2.22E-08	3.74E-08	5.92E-08	ND	4.11E-07	1.07E-06
1998	2.35E-06	ND	1.14E-06	ND	1.21E-06	4.29E-07	2.32E-07	ND	ND	4.81E-06	2.72E-05
1999	4.07E-07	ND	4.07E-07	ND	7.40E-07	ND	2.29E-07	ND	ND	7.93E-07	2.18E-06
2000	9.56E-06	ND	3.78E-07	ND	2.43E-07	ND	4.25E-07	ND	ND	1.34E-05	1.05E-04
2001	5.18E-07	3.53E-07	6.37E-07	ND	2.80E-07	7.51E-08	1.63E-07	ND	ND	3.75E-06	1.86E-05

a. Source: NTS environmental reports in References section.
b. ND = no data.
c. Values represent the arithmetic average of the area average concentrations for 1971 through 1988 and the arithmetic average of the area maximum concentrations for 1989 through 2001.
d. Values represent the maximum of the average area concentrations for 1971 through 1988 and the maximum of the maximum area concentrations for 1989 through 2001.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

Table A-2. Annual inhalation intakes from ^{239}Pu for sampled areas (Bq).[a]

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 9	Area 10	Area 11	Area 12
1971	0.0329	0.0587	0.0147	ND	0.0105	0.0153	ND	0.0640	0.0185	0.0081	0.0145
1972	0.0131	0.0199	0.0327	ND	0.0124	0.1190	ND	0.3810	0.0258	0.0216	0.0698
1973	0.0077	0.0198	0.0183	ND	0.0078	0.0107	ND	0.0763	0.0039	0.0216	0.0038
1974	0.0071	0.0060	0.0112	ND	0.0044	0.0070	ND	0.0187	0.0051	0.0071	0.0052
1975	0.0026	0.0034	0.0130	ND	0.0038	0.0056	ND	0.0149	0.0051	0.0044	0.0029
1976	0.0255	0.0153	0.0924	ND	0.0133	0.0392	ND	0.2824	0.0189	0.0210	0.0248
1977	0.0024	0.0058	0.0226	ND	0.0030	0.0049	ND	0.0225	0.0041	0.0107	0.0019
1978	0.0042	0.0118	0.0250	ND	0.0054	0.0088	ND	0.0481	0.0258	0.0095	0.0055
1979	0.0066	0.0413	0.0001	ND	0.0018	0.0035	0.0044	0.0465	0.0258	0.0033	0.0021
1980	0.0020	0.0230	0.0001	ND	0.0026	0.0043	0.0040	0.0401	ND	0.0039	0.0017
1981	0.0023	0.0056	0.0124	ND	0.0022	0.0026	0.0029	0.0286	ND	0.0041	0.0018
1982	0.0054	0.0036	0.0055	ND	0.0018	0.0031	0.0066	0.0191	ND	0.0047	0.0024
1983	0.0028	0.0057	0.0082	ND	0.0020	0.0029	0.0029	0.0190	ND	0.0162	0.0020
1984	0.0017	0.0088	0.0202	ND	0.0034	0.0018	0.0034	0.0906	ND	0.0050	0.0015
1985	0.0013	0.0051	0.0189	ND	0.0027	0.0024	0.0024	0.1181	ND	0.0046	0.0020
1986	0.0131	0.0055	0.0484	ND	0.0025	0.0165	0.0043	0.0249	ND	0.0022	0.0028
1987	0.0048	0.0020	0.2495	ND	0.0015	0.0022	0.0014	0.0098	ND	0.0028	0.0014
1988	0.0082	0.0025	0.0190	ND	0.0025	0.0020	0.0013	0.0045	ND	0.0011	0.0014
1989	0.0759	0.0052	0.0478	ND	0.0045	0.0071	0.0240	0.0311	ND	0.0480	0.0604
1990	0.0088	0.0029	0.0308	ND	0.0027	0.0033	0.0036	0.0442	0.0038	0.0095	0.0009
1991	0.2753	0.0018	0.0340	ND	0.0031	0.0064	0.0029	0.0311	0.0000	0.0199	0.0013
1992	0.0133	0.0098	0.2007	ND	0.0071	0.0065	0.0346	0.0781	0.0213	0.0078	0.0034
1993	0.0180	0.0044	0.0352	ND	0.0071	0.0079	0.0069	0.2398	0.0151	0.0373	0.0746
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	0.0036	0.0010	0.0216	ND	0.0014	0.0045	0.0011	0.0346	0.0033	0.0036	0.0010
1996	0.0666	0.0000	0.0268	ND	0.0015	0.0041	0.0400	0.0542	0.0051	0.0017	0.0003
1997	ND	0.0010	ND	ND	ND	ND	ND	ND	0.0023	0.0010	0.0001
1998	0.0416	ND	0.0060	ND	0.0084	0.0010	0.0024	0.0653	ND	0.0008	ND
1999	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2000	0.0075	ND	0.0239	0.0052	0.0018	0.0366	0.0030	0.2509	ND	ND	ND
2001	0.0404	0.0011	0.0103	0.0166	0.0061	0.0086	0.0015	0.0447	0.0008	ND	ND

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

Year	Area 15	Area 16	Area 18	Area 19	Area 20	Area 23	Area 25	Area 27	Area 28	Site average	Site maximum
1971	ND	0.0171	0.0071	0.0201	ND	0.0083	ND	0.0075	0.0035	0.0200	0.0640
1972	ND	0.0150	0.0129	0.2424	ND	0.0309	ND	0.0147	0.0045	0.0677	0.3810
1973	ND	0.0039	0.0034	0.0063	ND	0.0050	ND	0.0033	0.0029	0.0130	0.0763
1974	ND	0.0053	ND	0.0059	ND	0.0075	0.0076	0.0064	0.0104	0.0077	0.0187
1975	ND	0.0038	ND	0.0030	ND	0.0039	0.0051	0.0060	0.0062	0.0056	0.0149
1976	ND	0.0139	ND	0.0088	ND	0.0504	0.0178	0.0122	0.0056	0.0428	0.2824
1977	ND	0.0023	ND	0.0020	ND	0.0024	0.0029	0.0028	0.0020	0.0062	0.0226
1978	ND	0.0045	ND	0.0055	ND	0.0052	0.0062	0.0083	0.0035	0.0118	0.0481
1979	0.0046	0.0019	ND	0.0017	ND	0.0020	0.0016	0.0014	0.0020	0.0089	0.0465
1980	0.0057	ND	ND	0.0085	ND	0.0031	0.0027	0.0019	0.0014	0.0070	0.0401
1981	0.0083	0.0023	ND	0.0020	ND	0.0025	0.0022	0.0022	0.0014	0.0052	0.0286
1982	0.0037	0.0015	ND	0.0019	ND	0.0019	0.0015	ND	ND	0.0045	0.0191
1983	0.0020	0.0013	ND	0.0026	ND	0.0025	0.0027	ND	ND	0.0052	0.0190
1984	0.0028	0.0025	ND	0.0022	ND	0.0025	0.0028	0.0043	ND	0.0102	0.0906
1985	0.0036	0.0019	ND	0.0031	ND	0.0020	0.0023	0.0028	ND	0.0115	0.1181
1986	0.0035	0.0025	ND	0.0020	ND	0.0058	0.0018	0.0020	ND	0.0092	0.0484
1987	0.0016	0.0012	ND	0.0015	ND	0.0014	0.0020	0.0000	ND	0.0202	0.2495
1988	0.0022	ND	ND	0.0012	ND	0.0031	0.0013	0.0013	ND	0.0037	0.0190
1989	0.0021	0.0010	ND	0.0008	ND	0.0104	0.0008	0.0004	ND	0.0213	0.0759
1990	0.0073	0.0005	ND	0.0003	ND	0.0075	0.0010	0.0031	ND	0.0081	0.0442
1991	0.0109	0.0026	ND	0.0008	ND	0.0012	0.0023	0.0007	ND	0.0246	0.2753
1992	0.0977	0.0017	ND	0.0008	ND	0.0011	0.0016	0.0142	ND	0.0312	0.2007
1993	0.0293	0.0012	ND	0.0007	ND	0.0006	0.0003	0.0010	ND	0.0300	0.2398
1994	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	0.0142	0.0012	ND	ND	ND	0.0007	0.0004	ND	ND	0.0061	0.0346
1996	0.0213	0.0002	0.0003	0.0000	0.0004	0.0006	0.0004	0.0002	ND	0.0140	0.0666
1997	0.0026	0.0000	0.0018	ND	0.0018	0.0001	0.0001	0.0001	ND	0.0010	0.0026
1998	0.0056	ND	0.0027	ND	0.0029	0.0010	0.0006	ND	ND	0.0115	0.0653
1999	0.0010	ND	0.0010	ND	0.0018	ND	0.0006	ND	ND	0.0019	0.0018
2000	0.0229	ND	0.0009	ND	0.0006	ND	0.0010	ND	ND	0.0322	0.2509
2001	0.0012	0.0008	0.0015	ND	0.0007	0.0002	0.0004	ND	ND	0.0090	0.0447

a. ND = no data.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

A.3 SOIL CONTAMINATION AND DECAY CORRECTIONS

Extensive studies were performed in the 1980s to quantify residual contamination at NTS (McArthur and Kordas 1983, 1985; McArthur and Mead 1987, 1988, 1989; McArthur 1991). Table A-3 lists the results of these studies (McArthur 1991). Table A-4 lists the total areal depositions based on the inventory values in Table A-3 divided by the respective areal size. The results in Table A-4 are representative of areas of NTS that have been shown to contain measurable levels of contamination. These areas actually represent only about one-third of the total area within the boundaries of NTS.

Table A-3. Inventory of contaminated soil (Bq).[a,b]

Area	Area (m^2)	Am-241	Pu-238	Pu-239,240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	6.86E+07	1.554E+11	2.41E+11	8.88E+11	4.07E+10	3.26E+11	5.55E+11	5.55E+11	3.7E+09	1.85E+10
2	5.10E+07	1.073E+11	3.18E+11	8.14E+11	4.44E+10	8.88E+11	1.7E+12	5.18E+11	ND	1.48E+10
3	8.37E+07	1.702E+11	1.15E+11	1.37E+12	3.7E+10	4.44E+11	1.22E+12	6.66E+11	3.7E+09	1.85E+10
4	4.14E+07	2.442E+11	4.81E+11	1.48E+12	5.92E+10	4.44E+11	4.81E+11	3.37E+11	ND	7.4E+09
5	7.51E+06	2.22E+10	3.7E+09	1.78E+11	2.22E+10	1.48E+10	3.33E+10	3.7E+11	7.4E+09	ND
6	8.37E+07	6.29E+10	1.22E+11	3.11E+11	7.4E+09	1.04E+11	1.3E+11	ND	ND	ND
7	5.00E+07	8.14E+10	2.22E+10	5.92E+11	3.7E+10	1.92E+11	3.4E+11	8.14E+11	7.4E+09	1.11E+10
8	3.60E+07	6.29E+11	2.96E+11	4.07E+12	2.11E+11	1.55E+12	9.25E+11	1.63E+11	ND	2.22E+10
9	5.18E+07	1.554E+11	8.14E+10	3.29E+12	2.59E+10	3.22E+11	4.81E+11	8.51E+11	7.4E+09	1.11E+10
10	5.18E+07	7.03E+11	7.03E+11	4.07E+12	3.59E+11	3.11E+12	2.04E+12	8.14E+10	1.11E+10	1.85E+11
11	1.04E+07	1.221E+11	1.85E+10	1.07E+12	ND	1.85E+10	1.11E+10	ND	ND	ND
12	1.03E+08	2.109E+11	3.15E+11	1.44E+12	4.44E+10	7.4E+11	6.29E+11	ND	ND	ND
15	9.14E+07	2.96E+11	2.89E+11	2.33E+12	1.11E+10	7.03E+11	8.14E+11	ND	ND	ND
16	3.70E+07	2.59E+10	5.55E+10	1.37E+11	3.7E+09	1.07E+11	1.37E+11	ND	ND	ND
17	8.13E+07	1.036E+11	1.67E+11	6.66E+11	3.7E+10	5.55E+11	7.03E+11	ND	ND	ND
18	7.07E+07	7.03E+11	2.07E+11	3.7E+12	2.59E+10	3.7E+11	6.29E+11	4.07E+10	3.7E+09	2.96E+10
19	3.84E+08	7.77E+11	1.18E+12	5.18E+12	4.07E+10	1.33E+12	1.15E+12	ND	ND	ND
20	1.61E+07	8.51E+11	1.11E+12	1.52E+12	2.92E+11	2.04E+11	1.59E+11	4.81E+11	5.92E+10	1.78E+11
25	2.33E+06	ND	ND	ND	ND	7.4E+09	3.7E+09	1.48E+10	ND	ND
26	5.18E+05	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	7.77E+04	1.184E+11	1.67E+11	5.18E+11	2.96E+10	5.55E+10	4.81E+10	2.59E+10	3.7E+09	7.4E+09

a. Source: McArthur (1991).
b. ND = no data.

Because the data in Table A-3 are representative of soil contamination in 1991, these values were decay-corrected to the beginning of 1963, the first year after the cessation of atmospheric testing. Table A-5 lists the decay-corrected areal soil deposition.

A.4 SCALING FACTORS FOR INHALATION INTAKE ESTIMATES

Because the air sampling program did not provide isotopic analyses for all identified radionuclides in NTS soils, scaling factors were developed to estimate potential intakes for these radionuclides based on their relative abundances in comparison with ^{239}Pu with soil contamination data (McArthur 1991) decay-corrected to 1963. These area-specific ratios are listed in Table A-6.

The scaling factors in Table A-6 were used in conjunction with the ^{239}Pu intakes in Table A-2 to determine potential environmental intakes of all radionuclides important to dose (Table A-6) that have been identified as persistent in NTS soils. For dose reconstruction, maximum intakes of these radionuclides were calculated by selecting the maximum annual intake of plutonium (i.e., 0.4131 Bq/yr derived for Area 9 in 1972) and multiplying this value by the maximum scaling factor for each of the radionuclides in Table A-6.

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Table A-4. Radionuclide areal soil deposition (Bq/m^2).[a]

Area	Am-241	Pu-238	Pu-239,240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	2.26E+03	3.50E+03	1.29E+04	5.93E+02	4.74E+03	8.09E+03	8.09E+03	5.39E+01	2.70E+02
2	2.10E+03	6.24E+03	1.60E+04	8.70E+02	1.74E+04	3.34E+04	1.02E+04	ND	2.90E+02
3	2.03E+03	1.37E+03	1.64E+04	4.42E+02	5.31E+03	1.46E+04	7.96E+03	4.42E+01	2.21E+02
4	5.89E+03	1.16E+04	3.57E+04	1.43E+03	1.07E+04	1.16E+04	8.13E+03	ND	1.79E+02
5	2.96E+03	4.93E+02	2.36E+04	2.96E+03	1.97E+03	4.43E+03	4.93E+04	9.85E+02	ND
6	7.52E+02	1.46E+03	3.72E+03	8.85E+01	1.24E+03	1.55E+03	ND	ND	ND
7	1.63E+03	4.44E+02	1.18E+04	7.40E+02	3.85E+03	6.81E+03	1.63E+04	1.48E+02	2.22E+02
8	1.75E+04	8.22E+03	1.13E+05	5.86E+03	4.32E+04	2.57E+04	4.52E+03	ND	6.17E+02
9	3.00E+03	1.57E+03	6.36E+04	5.00E+02	6.21E+03	9.29E+03	1.64E+04	1.43E+02	2.14E+02
10	1.36E+04	1.36E+04	7.86E+04	6.93E+03	6.00E+04	3.93E+04	1.57E+03	2.14E+02	3.57E+03
11	1.18E+04	1.79E+03	1.04E+05	ND	1.79E+03	1.07E+03	ND	ND	ND
12	2.06E+03	3.07E+03	1.41E+04	4.33E+02	7.22E+03	6.13E+03	ND	ND	ND
15	3.24E+03	3.16E+03	2.55E+04	1.21E+02	7.69E+03	8.90E+03	ND	ND	ND
16	6.99E+02	1.50E+03	3.70E+03	9.99E+01	2.90E+03	3.70E+03	ND	ND	ND
17	1.27E+03	2.05E+03	8.19E+03	4.55E+02	6.82E+03	8.64E+03	ND	ND	ND
18	9.94E+03	2.93E+03	5.23E+04	3.66E+02	5.23E+03	8.90E+03	5.76E+02	5.23E+01	4.19E+02
19	2.02E+03	3.08E+03	1.35E+04	1.06E+02	3.47E+03	2.99E+03	ND	ND	ND
20	5.30E+04	6.91E+04	9.45E+04	1.82E+04	1.27E+04	9.91E+03	3.00E+04	3.69E+03	1.11E+04
25	ND	ND	ND	ND	3.17E+03	1.59E+03	6.35E+03	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	1.52E+05	2.14E+05	6.67E+05	3.81E+04	7.14E+04	6.19E+04	3.33E+04	4.76E+03	9.52E+03

a. ND = no data.

Table A-5. Radionuclide areal soil deposition (Bq/m^2) decay, corrected to 1963.[a]

Area	Am-241	Pu-238	Pu-239,240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	2.37E+03	4.37E+03	1.29E+04	2.35E+04	9.06E+03	1.57E+04	3.47E+04	4.89E+02	1.35E+04
2	2.20E+03	7.78E+03	1.60E+04	3.45E+04	3.32E+04	6.49E+04	4.35E+04	ND[a]	1.45E+04
3	2.13E+03	1.71E+03	1.64E+04	1.76E+04	1.01E+04	2.84E+04	3.41E+04	4.01E+02	1.11E+04
4	6.16E+03	1.45E+04	3.57E+04	5.67E+04	2.05E+04	2.26E+04	3.48E+04	ND	8.93E+03
5	3.09E+03	6.15E+02	2.37E+04	1.17E+05	3.76E+03	8.63E+03	2.11E+05	8.94E+03	ND
6	7.86E+02	1.82E+03	3.72E+03	3.51E+03	2.36E+03	3.01E+03	ND	ND	ND
7	1.70E+03	5.54E+02	1.19E+04	2.94E+04	7.35E+03	1.33E+04	6.98E+04	1.34E+03	1.11E+04
8	1.83E+04	1.03E+04	1.13E+05	2.33E+05	8.24E+04	5.00E+04	1.94E+04	ND	3.08E+04
9	3.14E+03	1.96E+03	6.36E+04	1.98E+04	1.19E+04	1.81E+04	7.04E+04	1.30E+03	1.07E+04
10	1.42E+04	1.69E+04	7.86E+04	2.75E+05	1.15E+05	7.65E+04	6.74E+03	1.94E+03	1.79E+05
11	1.23E+04	2.23E+03	1.04E+05	ND	3.41E+03	2.09E+03	ND	ND	ND
12	2.15E+03	3.83E+03	1.41E+04	1.72E+04	1.38E+04	1.19E+04	ND	ND	ND
15	3.39E+03	3.94E+03	2.55E+04	4.82E+03	1.47E+04	1.73E+04	ND	ND	ND
16	7.31E+02	1.87E+03	3.70E+03	3.97E+03	5.53E+03	7.20E+03	ND	ND	ND
17	1.33E+03	2.55E+03	8.20E+03	1.81E+04	1.30E+04	1.68E+04	ND	ND	ND
18	1.04E+04	3.66E+03	5.24E+04	1.45E+04	9.99E+03	1.73E+04	2.47E+03	4.75E+02	2.09E+04
19	2.12E+03	3.85E+03	1.35E+04	4.21E+03	6.62E+03	5.81E+03	ND	ND	ND
20	5.54E+04	8.62E+04	9.45E+04	7.23E+05	2.42E+04	1.93E+04	1.28E+05	3.34E+04	5.53E+05
25	ND	ND	ND	ND	6.06E+03	3.09E+03	2.72E+04	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	1.59E+05	2.67E+05	6.67E+05	1.51E+06	1.36E+05	1.21E+05	1.43E+05	4.32E+04	4.76E+05

a. ND = no data.

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Table A-6. Abundance of radionuclides in NTS soils relative to ^{239}Pu decay, corrected to 1963.[a]

Area	Am-241	Pu-238	Pu-239,240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1	0.183	0.338	1.000	1.818	0.700	1.216	2.677	0.038	1.041
2	0.138	0.487	1.000	2.164	2.081	4.067	2.726	ND	0.908
3	0.130	0.104	1.000	1.072	0.619	1.735	2.084	0.024	0.675
4	0.172	0.405	1.000	1.587	0.572	0.632	0.975	ND	0.250
5	0.131	0.026	1.000	4.958	0.159	0.365	8.925	0.378	ND
6	0.212	0.490	1.000	0.944	0.636	0.810	ND	ND	ND
7	0.144	0.047	1.000	2.479	0.620	1.118	5.890	0.113	0.937
8	0.162	0.091	1.000	2.055	0.728	0.442	0.171	ND	0.273
9	0.049	0.031	1.000	0.312	0.187	0.284	1.107	0.020	0.168
10	0.181	0.215	1.000	3.498	1.457	0.973	0.086	0.025	2.271
11	0.119	0.021	1.000	ND	0.033	0.020	ND	ND	ND
12	0.153	0.272	1.000	1.220	0.978	0.848	ND	ND	ND
15	0.133	0.154	1.000	0.189	0.575	0.679	ND	ND	ND
16	0.198	0.505	1.000	1.072	1.495	1.945	ND	ND	ND
17	0.163	0.312	1.000	2.204	1.590	2.053	ND	ND	ND
18	0.199	0.070	1.000	0.278	0.191	0.331	0.047	0.009	0.400
19	0.157	0.285	1.000	0.312	0.491	0.431	ND	ND	ND
20	0.586	0.912	1.000	7.643	0.256	0.204	1.358	0.354	5.849
25	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	0.229	0.321	1.000	0.057	0.107	0.093	0.050	0.007	0.014
Maximum scaling factor	**0.586**	**0.912**	**1.000**	**7.64**	**2.08**	**4.07**	**8.93**	**0.378**	**5.85**
Scaled maximum intake, Bq/yr	**0.223**	**0.347**	**0.381**	**2.91**	**0.792**	**1.55**	**3.40**	**0.144**	**2.23**

a. ND = no data.

A.5 CORRECTION FOR RESUSPENSION FOR EARLY TIMES AFTER ATMOSPHERIC TESTS

Anspaugh et al. (2002) stated that, based on empirical observations, concentration of resuspended radionuclides in air has been noted to display a strong time dependence early after deposition, and this pathway might be important for reoccupation of contaminated property. Anspaugh et al. also stated that there has been no universal agreement that resuspension is an important pathway but that it is now generally accepted that there are a few instances in which the pathway could be the dominant one. Many observations have shown that the rate of resuspension decreases rapidly with time, and that for accident situations resuspension is only of importance (in comparison with the inhalation exposure from the initial cloud passage) over short periods. For this reason, Anspaugh et al. (2002) stated that the resuspension factor model has been widely used to predict the concentration of resuspended radionuclides early after initial deposition while the mass loading model (which uses measurements of dust loading in air and soil contamination data to predict air concentration of radionuclides) has generally been preferred for times long after deposition. However, Anspaugh et al. also stated that it is always preferable to rely on actual measurements that are performed over long periods (such as those in this attachment).

Anspaugh et al. (2002) presented several resuspension models that have been proposed but concluded that they can be over- or under-predictive at various times after deposition in comparison with empirical observations. However, with expanded datasets from Hicks (1981e) and others in the

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1980s, Anspaugh et al. proposed a resuspension model that more accurately describes the observed results over the entire timespan of the expanded dataset for NTS:

$$S_f = \left[(1\times10^{-5})\,e^{-0.07t} + (6\times10^{-9})\,e^{-0.003t} + (1\times10^{-9})\right] \times (1\times10^{\pm1})\ m^{-1} \qquad \text{(A-1)}$$

A depiction of Equation A-1 is provided in Figure A-1 from time *t* equals zero to 1,000 days after detonation. As Figure A-1 shows, the resuspension factor S_f ranges from about 10^{-5} early after deposition, falls rapidly during the first 100 or so days to a value of about 10^{-8}, and then approaches a value of 10^{-9} after a few years. The factor of 10 at the end of the equation is a statement of uncertainty in the model. If the mass loading approach is more predictive at times long after initial deposition and the resuspension proposed by Anspaugh et al. (2002) is predictive of the observed results over the expanded dataset (including those developed in the 1980s), the factor of 10^{-9} could be taken to be the resuspension factor that would be predictive of the mass loading process that is thought to be more important during the times when air monitoring data are available (i.e., 1971 through 2001; see Section A.2). When the Anspaugh et al. proposed resuspension model (i.e., Equation A-1) is integrated from 180 to 545 days and compared to the result of the integral of the constant 10^{-9} over the same period, a factor is developed that can be used to correct the intakes derived from air sampling data (i.e., times long after initial deposition) for the early resuspension phenomenon that has been observed at NTS. The period of integration was selected to begin at day

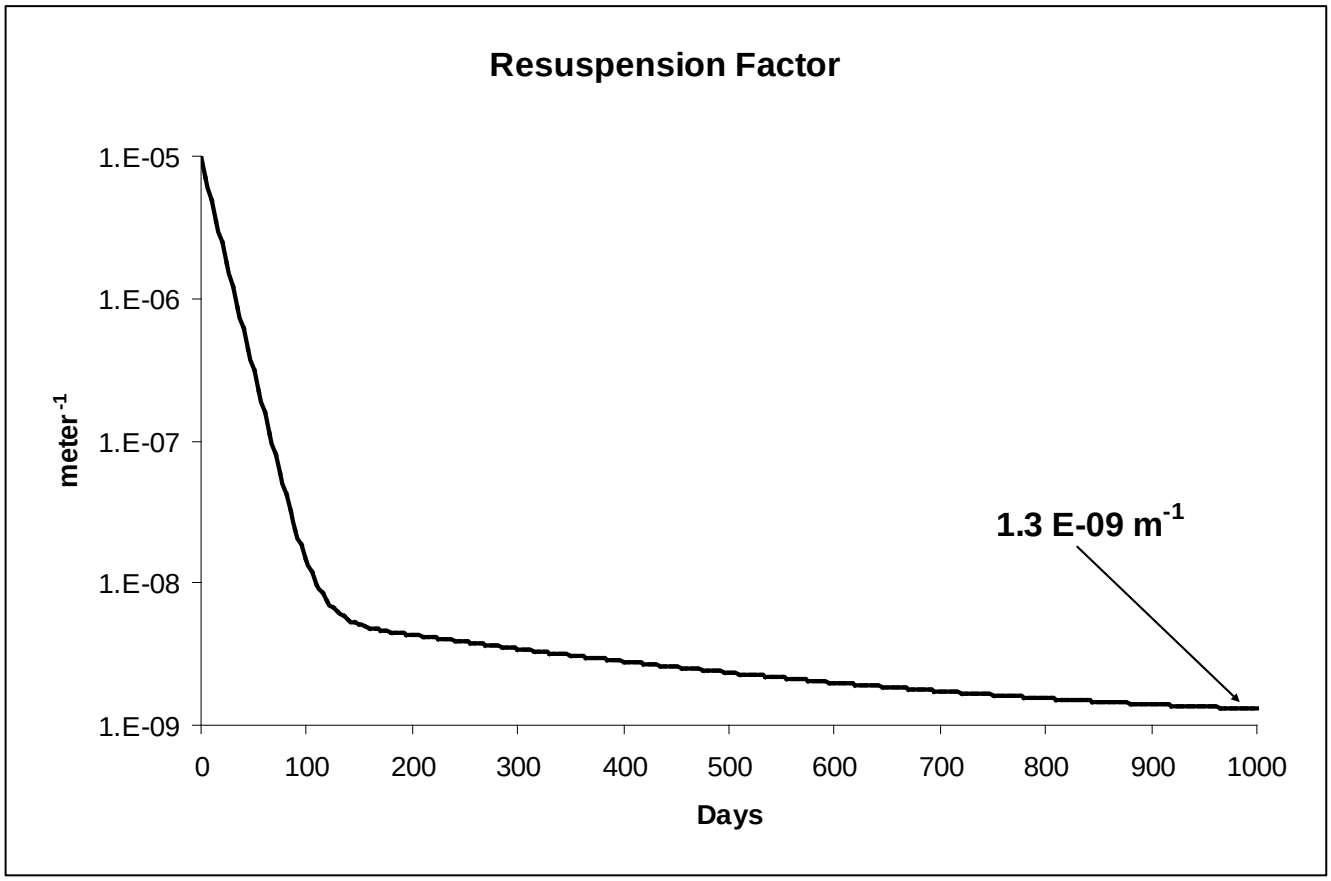

Figure A-1. Resuspension factor as a function of time after initial deposition.

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180 because the last atmospheric tests at NTS were in July 1962 and, therefore, about 180 days had passed before the beginning of 1963, the starting date for reconstruction of internal dose at NTS in the absence of bioassay results for the employee. For the Anspaugh et al. model, the early resuspension correction factor has been determined to be 3.12. In a similar manner, correction factors for 1964 and 1965 were determined to be 1.72 and 1.24, respectively. Therefore, for dose reconstruction, the scaled maximum inhalation intakes in Table A-6 should be multiplied by these factors to account for early resuspension from 1963 through 1965. These resultant intakes are listed in Table A-7. If necessary, these intakes can be prorated for times less than a year for a best estimate if the worker was on the site for a fraction of the year.

Table A-7. Scaled inhalation intakes corrected for early resuspension in 1963 (Bq/yr).

Year of intake	Am-241	Pu-238	Pu-239, 240	Co-60	Cs-137	Sr-90	Eu-152	Eu-154	Eu-155
1963	0.70	1.08	1.19	9.08	2.47	4.84	10.61	0.45	6.96
1964	0.38	0.59	0.65	4.98	1.35	2.65	5.81	0.25	3.81
1965	0.28	0.43	0.47	3.61	0.98	1.92	4.22	0.18	2.77
All subsequent years	0.223	0.347	0.381	2.91	0.792	1.55	3.40	0.144	2.23

A.6 CORRECTIONS FOR INHALATION DOSE FROM SHORT-LIVED FISSION AND ACTIVATION PRODUCTS

During the early and mid-1960s, workers could have been exposed to fallout from atmospheric testing that contained short-lived fission and activation products (^{144}Ce, ^{106}Ru, etc.) that have not persisted in NTS soils in measurable quantities. For dose reconstruction, two methods are described to account for possible exposure to these radionuclides.

Potential inhalation dose from short-lived fission and activation products can be estimated using data developed by Hicks (1981e). Hicks provided estimates of ground deposition of 152 fission products and 25 neutron-induced nuclides from nuclear weapons tests. The data for these calculations were for the last atmospheric tests NTS conducted in 1962 as a function of time after detonation. Spreadsheets were developed to multiply the relative abundance of each of these radionuclides by its associated International Commission on Radiological Protection (ICRP) Publication 68 (ICRP 1995) inhalation organ DCF (Bunker 1999) to determine the relative importance of each of the 177 radionuclides to total organ dose. With the exception of ^{90}Sr, the inhalation DCFs were for the absorption type (i.e., S, M, or F) that produced the largest dose to the organ of interest. For ^{90}Sr, only absorption type F was used. In addition, because ICRP Publication 68 organ DCFs represent the 50-year committed dose, the IMBA computer program was used to develop the annual organ-specific DCF for ^{241}Am, which was used in the calculations to better represent the relative importance of ^{241}Am, which delivers dose to the affected organ over long periods. Similarly, annual organ-specific DCFs were developed for ^{90}Sr to provide a more accurate time-dependent correction factor.

The development of the short-lived fission and activation product correction factors based on the Hicks data must be adjusted for fractionation. Fractionation is a phenomenon due to chemical and physical separation of the radionuclides in the fireball in the first few minutes after detonation. Within the first minute after detonation, the vaporized soil components condense with other refractory elements and begin to fall to the surface. The volatile elements (except krypton and xenon) and their progeny condense in 6 to 8 minutes and begin falling to the surface (Hicks 1981e). Because the Hicks data were developed to estimate offsite levels of fallout and resultant dose, fractionation effects were simulated in these data by the removal of a fraction of the refractory nuclides from the calculated

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abundances. In general, air drops were assumed to be unfractionated and offsite fallout from surface and cratering tests was assumed to have 0.4 of the refractory elements. For all other types of tests, offsite fallout was assumed to have 0.5 of the refractory elements present. Therefore, the refractory elements (beryllium, sodium, manganese, iron, cobalt, copper, yttrium, zirconium, niobium, barium, rare earths, thorium, uranium, neptunium, plutonium, americium, and curium) in the Hicks data must be adjusted to produce the best estimate of their enriched abundances in the onsite environment to which workers could have been exposed. Adjustment factors for each radionuclide were determined from data in Hicks (1984); this report provided relative abundances of radionuclides assuming no fraction, 50% fraction, and 90% fraction of refractory elements. From these data, ratios were developed for the 50% fractionation case (Table A-8). These ratios were used to deplete the refractory elements in the far-field (i.e., offsite) environment to estimate doses to offsite individuals. Therefore, to enrich the near-field (i.e., onsite) environment, the inverse of these ratios was applied to the Hicks SMALL BOY data (see below). These inverse ratios were applied twice because the Hicks SMALL BOY data were provided to estimate fallout in the offsite environment. The first application results in the data that represent no fractionation while the second application results in data that are enriched with refractory elements.

In Table A-8, the radionuclides with ratios less than 1.0 represent the radionuclides that condense as refractory elements while the radionuclides with ratios greater than 1.0 are assumed to behave as volatile elements. Although strontium is a refractory element, for these calculations the assumption is that it behaves like a volatile element because its fission precursors are noble gases (i.e., volatile elements).

The fission and activation product correction factor was developed based on the relative contribution of ^{90}Sr to total organ dose. Strontium-90 was chosen because Hicks (1984) provided time-dependent abundances for this radionuclide and ^{90}Sr continues to persist in the NTS environment. Therefore, by determining the relative importance of organ dose from ^{90}Sr to the total dose from all 177 radionuclides, a multiplication factor was developed by which the various organ doses from the ^{90}Sr intakes (Table A-7) can be multiplied to account for short-lived fission and activation products. For example, using the Hicks data for STORAX SMALL BOY, which was the next-to-last atmospheric test at NTS on July 14, 1962 (STORAX LITTLE FELLER I was the last atmospheric test on July 17, 1962), it was determined that the relative importance of ^{90}Sr dose to the lung to the total dose from all 177 radionuclides varied, in a mostly linear fashion, from 0.00284 to 0.0589 from 1 to 365 days after detonation, respectively (see Figure A-2). Using the trend line function, an expression for the relative importance of ^{90}Sr dose y to total dose as a function of the number of days after detonation x was developed:

$$y = 0.0001x + 0.0074 \quad \text{(A-2)}$$

To ensure favorability to claimants, the relative importance of ^{90}Sr lung dose to the total lung dose from all fission and activation products was examined for several tests including TEAPOT TURK in 1955 and LITTLE FELLER I in 1962 (Hicks 1981a, 1981b, 1981c, 1981d). The slope of the trend lines that predict the relative importance of ^{90}Sr dose was determined to be 0.0001x for STORAX SMALL BOY, 0.0002x for STORAX LITTLE FELLER I (Figure A-3) and TEAPOT TURK (see Figure A-4). Because the slope of the trend line is directly proportional to the relative importance of the ^{90}Sr dose to total dose (i.e., the larger the slope, the larger the relative importance of ^{90}Sr dose), the tests with the smallest slopes result in the highest multiplicative correction factors for fission and activation products. Therefore, to ensure the organ dose from short-lived fission and activation products is not underestimated, the Hicks (1984) data for the STORAX SMALL BOY test were

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Table A-8. Far-field refractory enrichment ratios.

Radionuclide	Ratio	Radionuclide	Ratio	Radionuclide	Ratio	Radionuclide	Ratio	Radionuclide	Ratio	Radionuclide	Ratio
Be-7	0.68	Br-84	1.36	Ru-106	1.36	Pd-109	1.36	Sn-129	1.36	Ce-141	0.90
Na-24	0.68	Kr85m	1.36	Rh-106	1.36	Ag-109m	1.36	Sb-129	1.36	Ba-142	0.68
Mn-54	0.68	Kr-87	1.36	Rh-107	1.36	Pd-111m	1.37	Te-129m	1.36	La-142	0.68
Fe-55	0.68	Kr-88	1.36	Pd-107m	1.36	Pd-111	1.36	Te-129	1.36	La-143	0.68
Fe-59	0.68	Rb-88	1.36	Pd-109	1.36	Ag-111m	1.36	Sb-130m	1.36	Ce-143	0.68
Cu-64	0.68	Rb-89	1.36	Ag-109m	1.36	Ag-111	1.36	Sb-130	1.36	Pr-143	0.68
Cu-67	0.68	Sr-89	1.36	Pd-111m	1.37	Pd-112	1.36	I-130	1.36	Ce-144	0.68
W-181	1.36	Sr-90	1.36	Pd-111	1.36	Ag-112	1.36	Sb-131	1.36	Pr-144	0.68
W-185	1.35	Sr-91	1.19	Ag-111m	1.36	Ag-113	1.36	Te-131m	1.36	Pr-145	0.68
W-187	1.36	Y-91m	1.19	Ag-111	1.36	Ag-115	1.36	Te-131	1.36	Ce-146	0.68
W-188	1.36	Y-91	1.19	Pd-112	1.36	Cd-115m	1.36	I-131	1.36	Pr-146	0.68
U-237	0.68	Sr-92	0.68	Ag-112	1.36	Cd-115	1.36	Te-132	1.36	Pr-147	0.68
U-239	0.68	Y-92	0.68	Ag-113	1.36	In-115m	1.37	I-132	1.36	Nd-147	0.68
U-240	0.68	Sr-93	0.68	Ag-115	1.36	Cd-117	1.36	Te-133m	1.36	Nd-149	0.68
Np-239	0.68	Y-93	0.68	Cd-115m	1.36	In-117m	1.36	Te-133	1.36	Pm-149	0.68
Np240m	0.69	Y-94	0.68	Cd-115	1.36	In-117	1.36	I-133	1.36	Pm-150	0.68
Np-240	0.68	Y-95	0.68	In-115m	1.37	Cd-118	1.36	Xe-133m	1.36	Nd-151	0.68
Am-241	0.68	Zr-95	0.68	Cd-117	1.36	In-118	1.36	Xe-133	1.36	Pm-151	0.68
Cm-242	0.68	Nb-95	0.68	In-117m	1.36	Cd-119	1.36	Te-134	1.36	Pm-152	0.68
Ge-75	1.36	Zr-97	0.68	In-117	1.36	In-119m	1.36	I-134	1.36	Sm-153	0.68
Ge-77	1.36	Nb-97m	0.68	Tc-101	1.36	In-119	1.36	I-135	1.36	Sm-155	0.68
As-77	1.36	Nb-97	0.68	Mo-102	1.36	Sn-121	1.36	Xe-135m	1.36	Eu-155	0.68
Se-77m	1.36	Nb-98	0.68	Tc-102m	1.36	Sn-123m	1.37	Xe-135	1.36	Sm-156	0.68
Ge-78	1.36	Mo-99	0.68	Tc-102	1.36	Sn-123	1.36	Cs-136	1.36	Eu-156	0.68
As-78	1.36	Tc-99m	0.68	Ru-103	1.36	Sn-125	1.36	Cs-137	1.36	Eu-157	0.68
As-79	1.37	Mo-101	1.36	Rh-103m	1.36	Sb-125	1.36	Ba-137m	1.36	Eu-158	0.68
Se-79m	1.36	Tc-101	1.36	Tc-104	1.36	Sb-126	1.36	Xe-138	1.36	Eu-159	0.68
Br-80	1.36	Mo-102	1.36	Ru-105	1.36	Sn-127	1.36	Cs-138	1.36	Gd-159	0.68
Se-81m	1.36	Tc-102m	1.36	Rh-105m	1.36	Sb-127	1.36	Cs-139	1.36	Tb-161	0.68
Se-81	1.36	Tc-102	1.36	Rh-105	1.36	Te-127	1.36	Ba-139	1.36		
Br-82	1.36	Ru-103	1.36	Ru-106	1.36	Sn-128	1.36	Ba-140	1.16		
Se-83	1.36	Rh-103m	1.36	Rh-106	1.36	Sb-128m	1.37	La-140	1.16		
Br-83	1.36	Rh-105m	1.36	Rh-107	1.36	Sb-128	1.37	Ba-141	0.90		
Kr-83m	1.37	Rh-105	1.36	Pd-107m	1.36	Sn-129m	1.36	La-141	0.90		

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

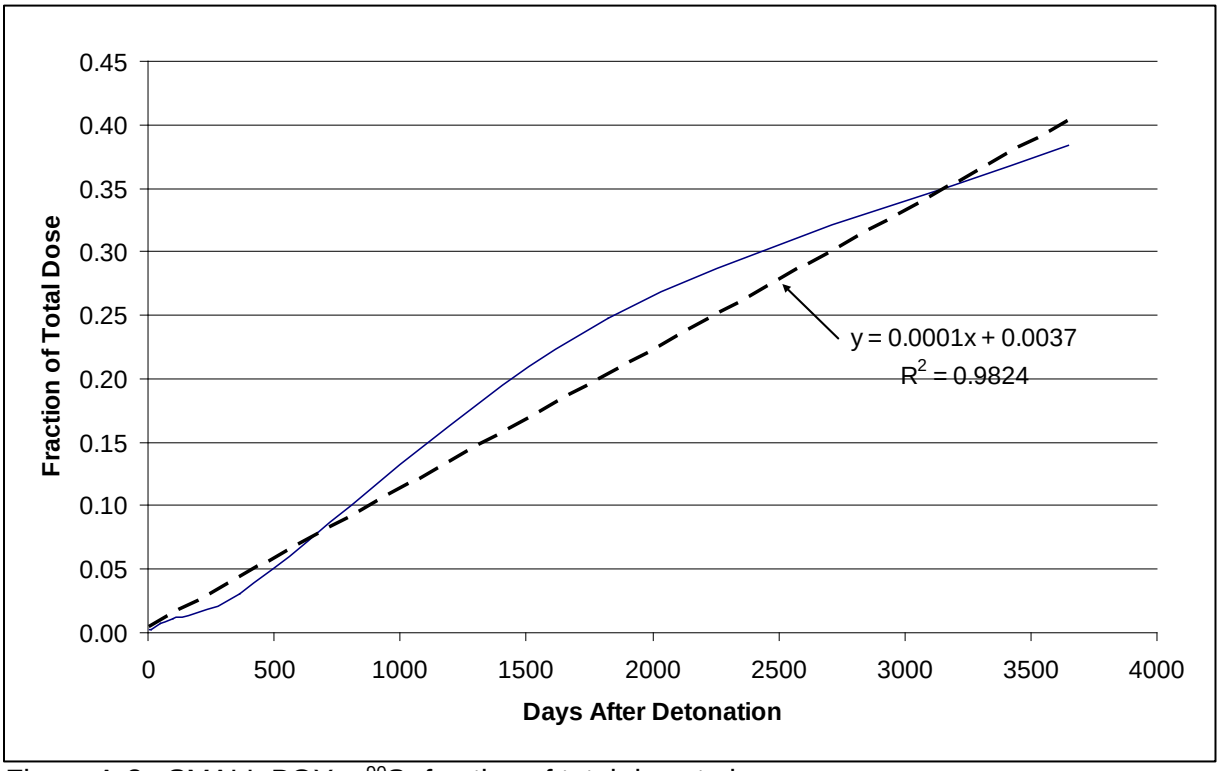

Figure A-2. SMALL BOY – ^{90}Sr fraction of total dose to lungs.

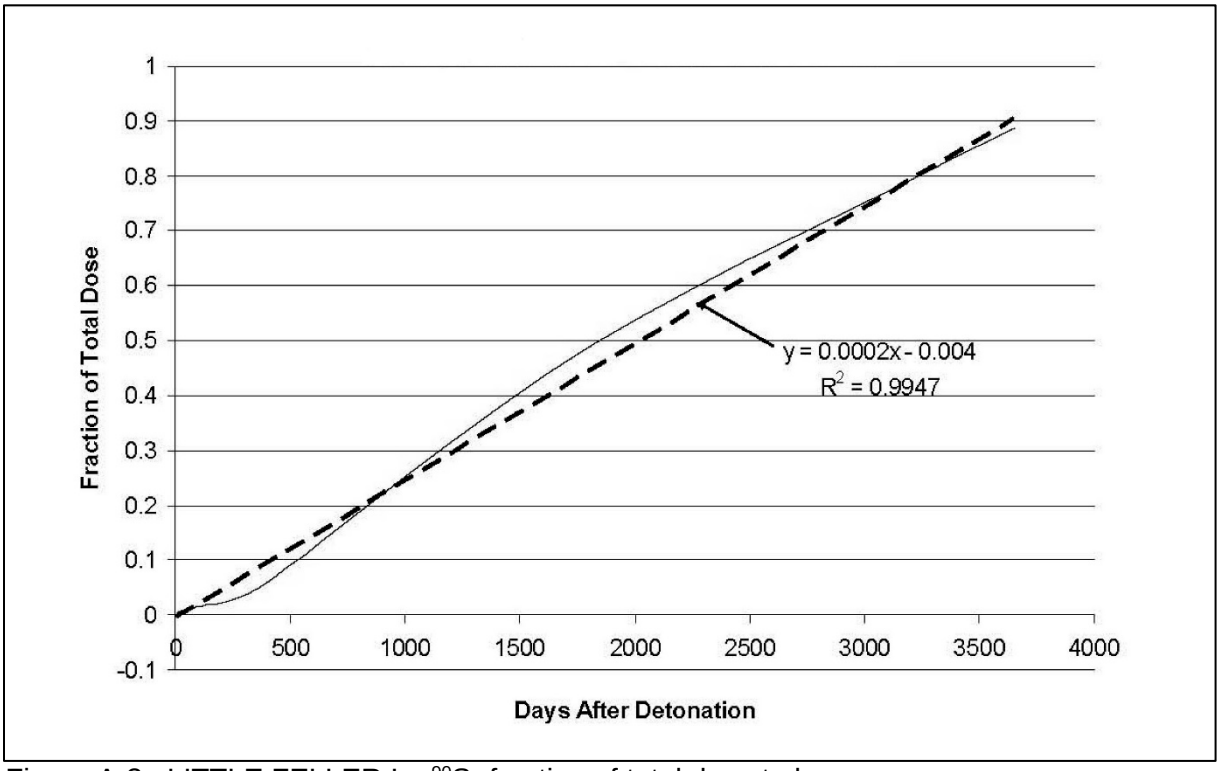

Figure A-3. LITTLE FELLER I – ^{90}Sr fraction of total dose to lungs.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

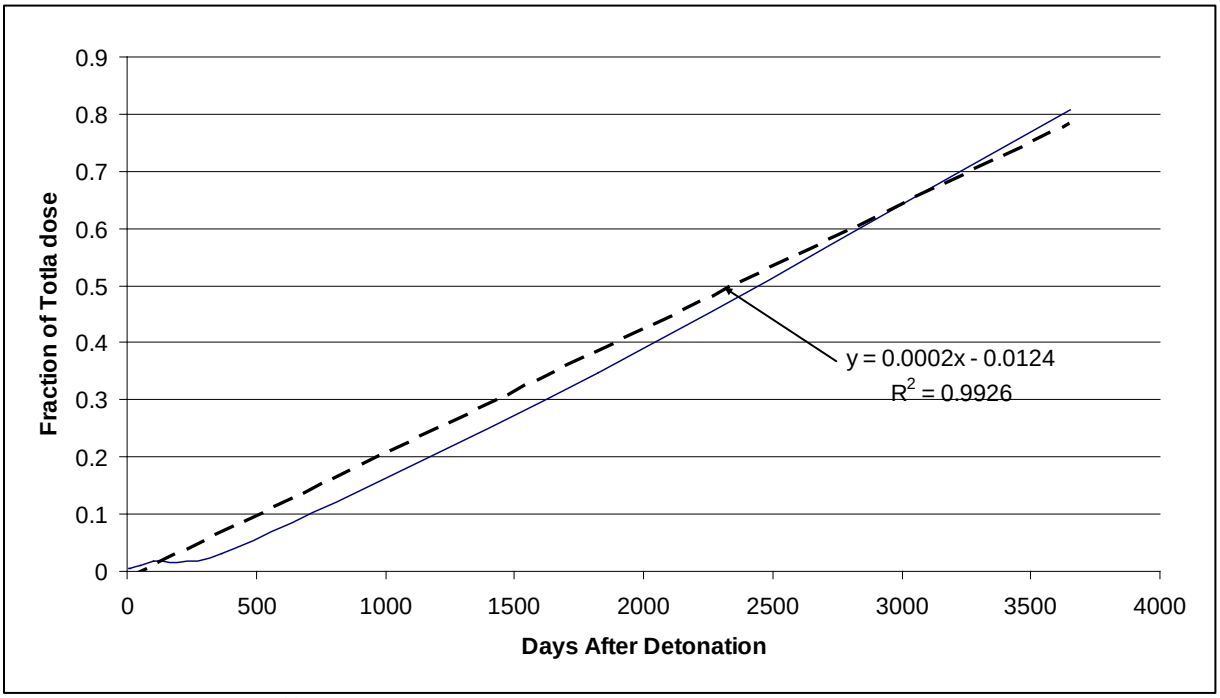

Figure A-4. TURK – ^{90}Sr fraction of total dose to lungs.

selected to be used to determine the fission and activation product dose correction factor. This assumption is justified by the fact that the test was very near the last atmospheric test (i.e., STORAX LITTLE FELLER I) and would therefore have been the test most likely to produce the short-lived fission and activation product intakes for workers at NTS after 1962 (the period for which organ dose from environmental intakes is calculated).

Integrating Equation A-2 for SMALL BOY from 0 to 365 days and dividing the result by 365 (the value selected to be used to determine the fission and activation product dose correction factor. This assumption is justified by the fact that the test was very near the last atmospheric test (i.e., STORAX LITTLE FELLER I) and would therefore have been the test most likely to produce the short-lived fission and activation product intakes for workers at NTS after 1962 (the period for which organ dose from environmental intakes is calculated).

That represents the integrated total dose for 1 year, it was determined that for the first year after detonation the lung dose from ^{90}Sr represented 0.0000738 or about 0.00738% of the dose from all 177 radionuclides. Therefore, the inverse of the value would produce a factor of 13,600 by which the lung dose from the ^{90}Sr intake (Table A-7) could be multiplied to account for inhalation dose from short-lived fission and activation products. Similar integrations were performed for subsequent years through 1972.

Correction factors to account for inhalation intakes of short-lived fission and activation products have been developed for all organs using the Hicks data for STORAX SMALL BOY (Table A-9). These correction factors were based on the relationships that Figures A-5 through A-11 show.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

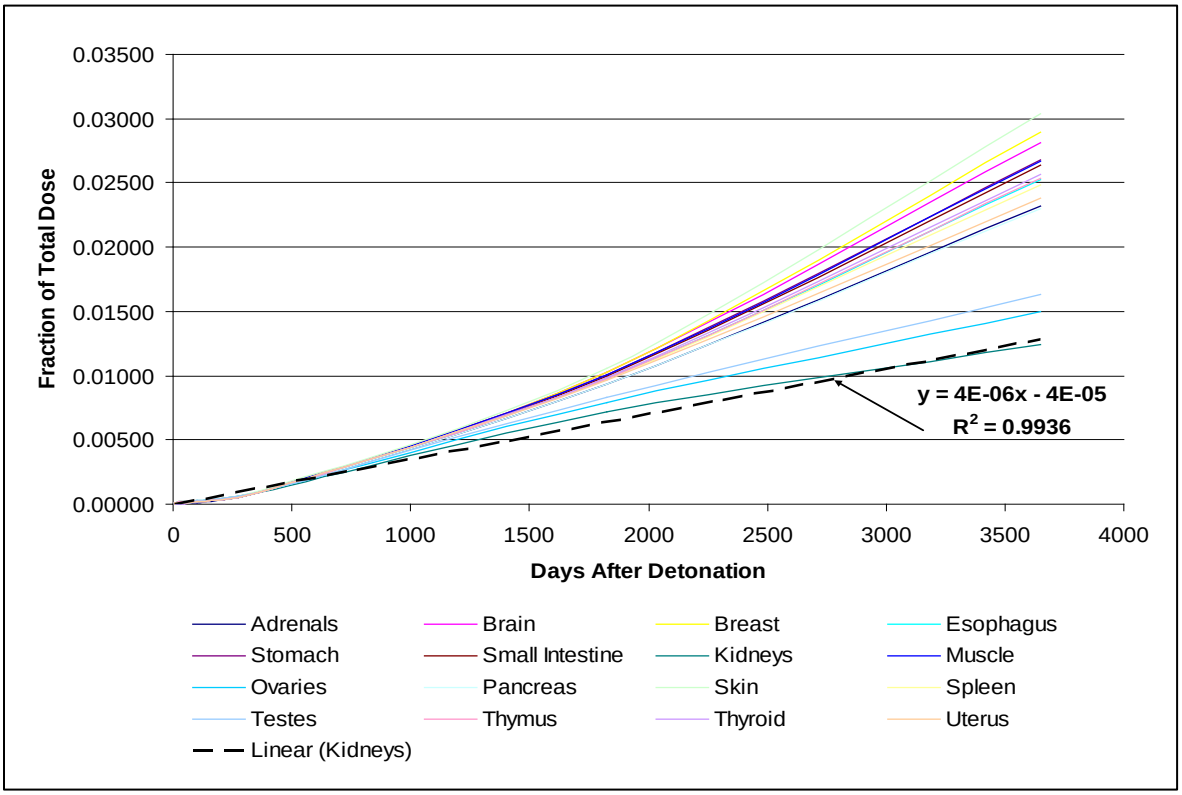

Figure A-5. Strontium-90 fraction of total dose.

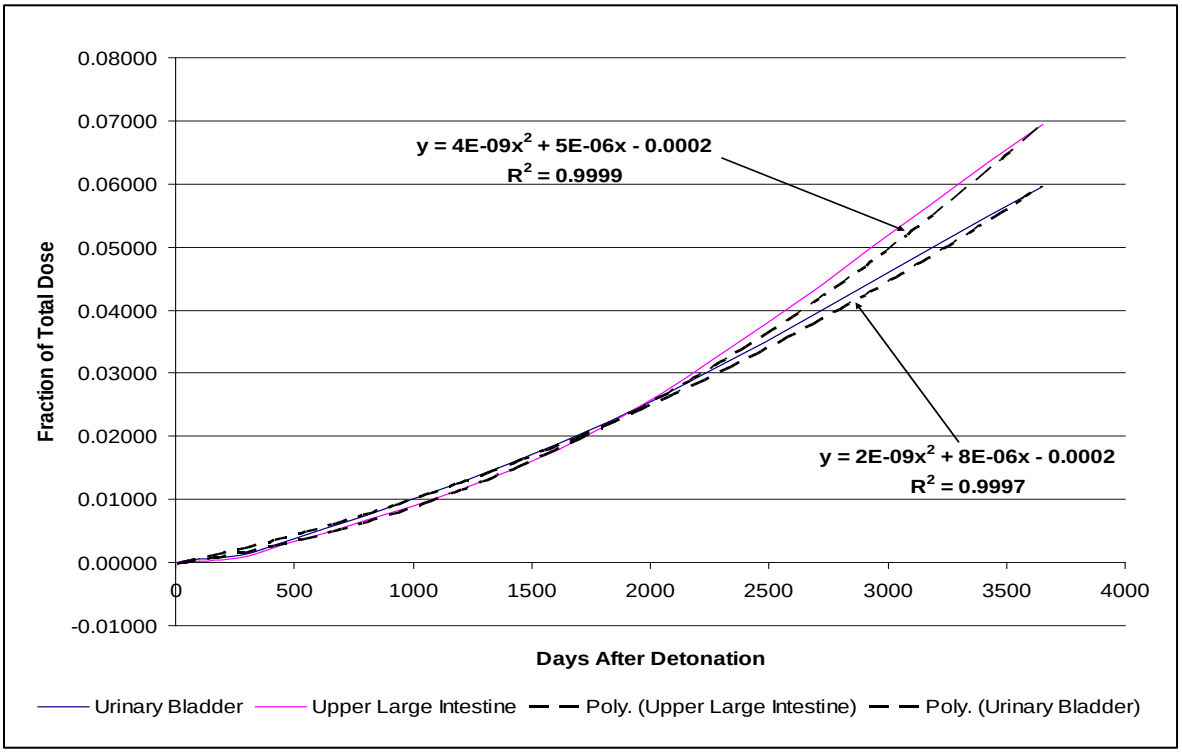

Figure A-6. Strontium-90 fraction of total dose.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

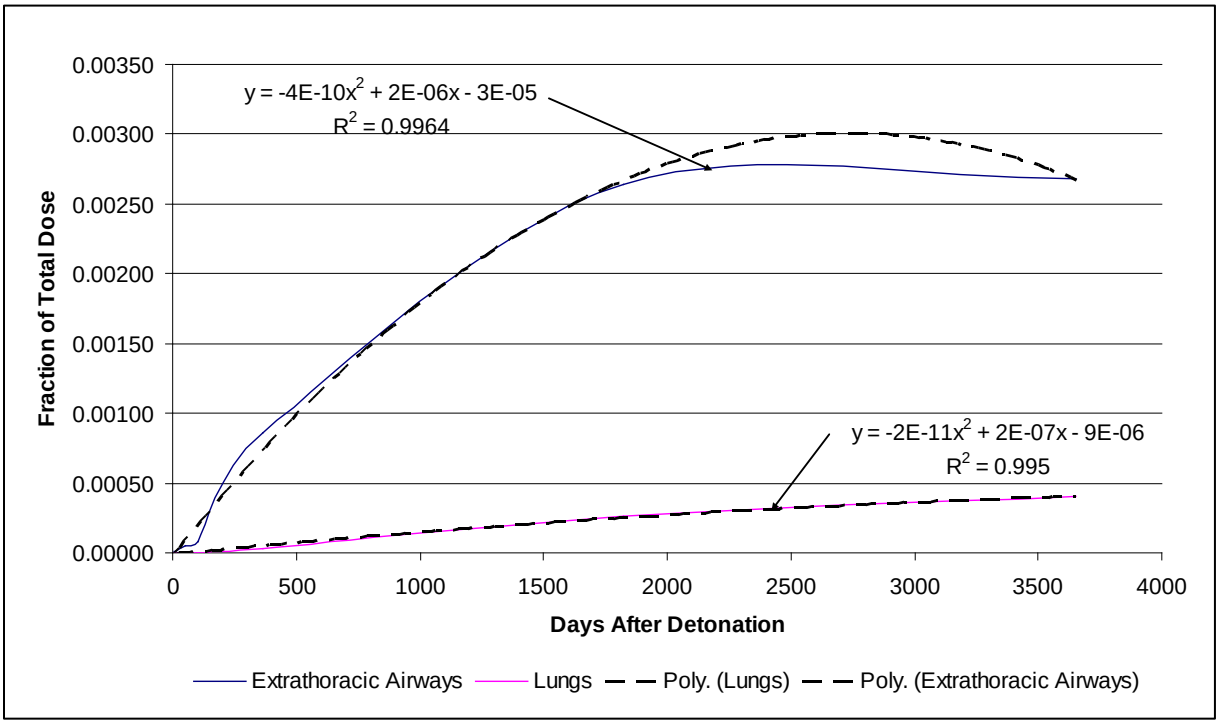

Figure A-7. Strontium-90 fraction of total dose.

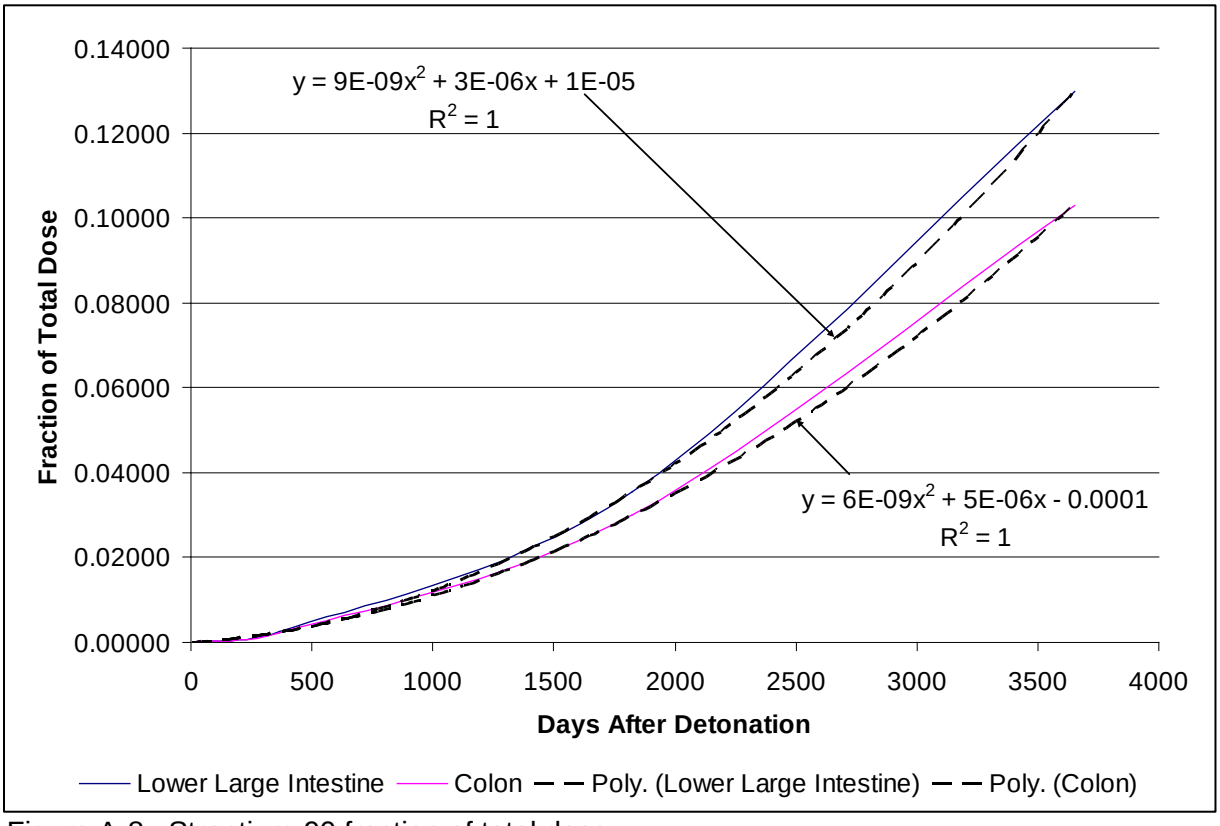

Figure A-8. Strontium-90 fraction of total dose.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

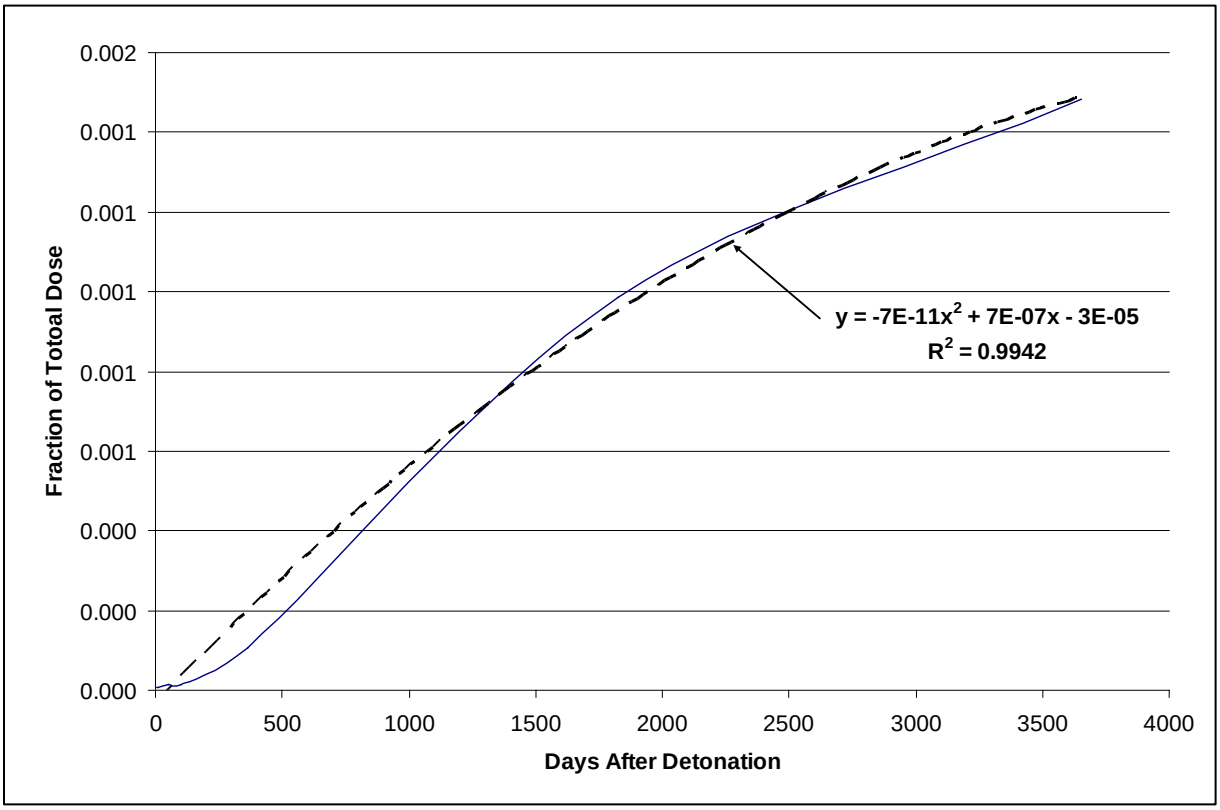

Figure A-9. Strontium-90 fraction of total dose to the liver.

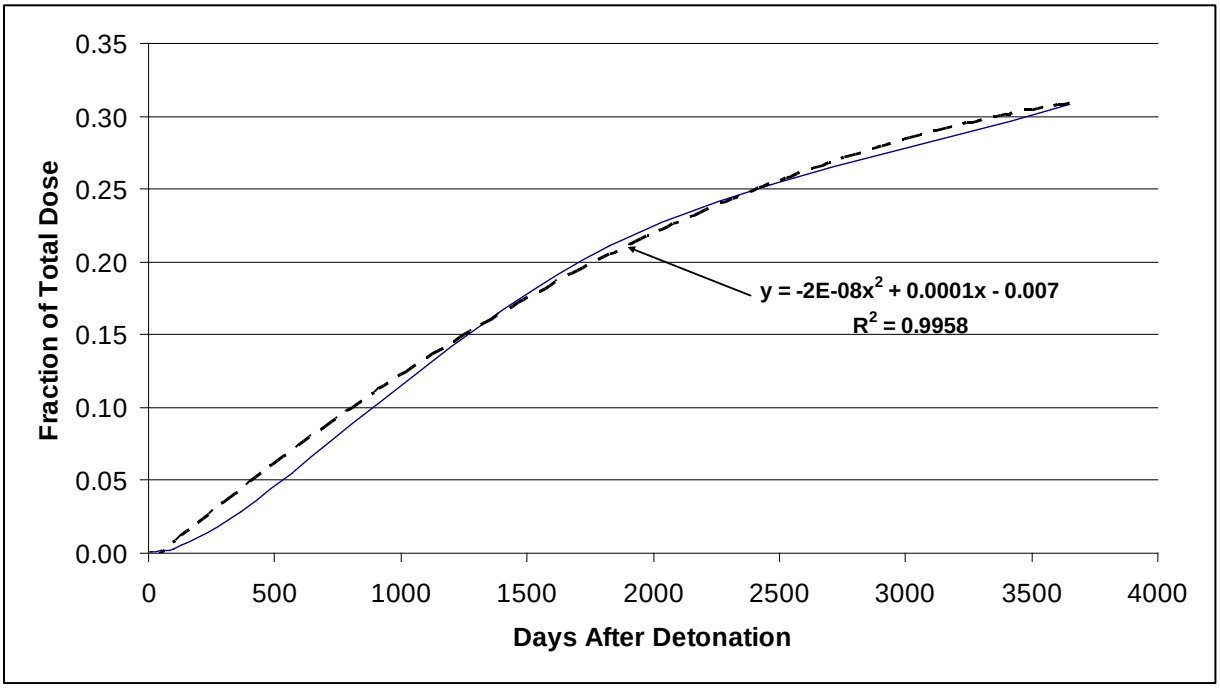

Figure A-10. Strontium-90 fraction of total dose to the red bone marrow.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

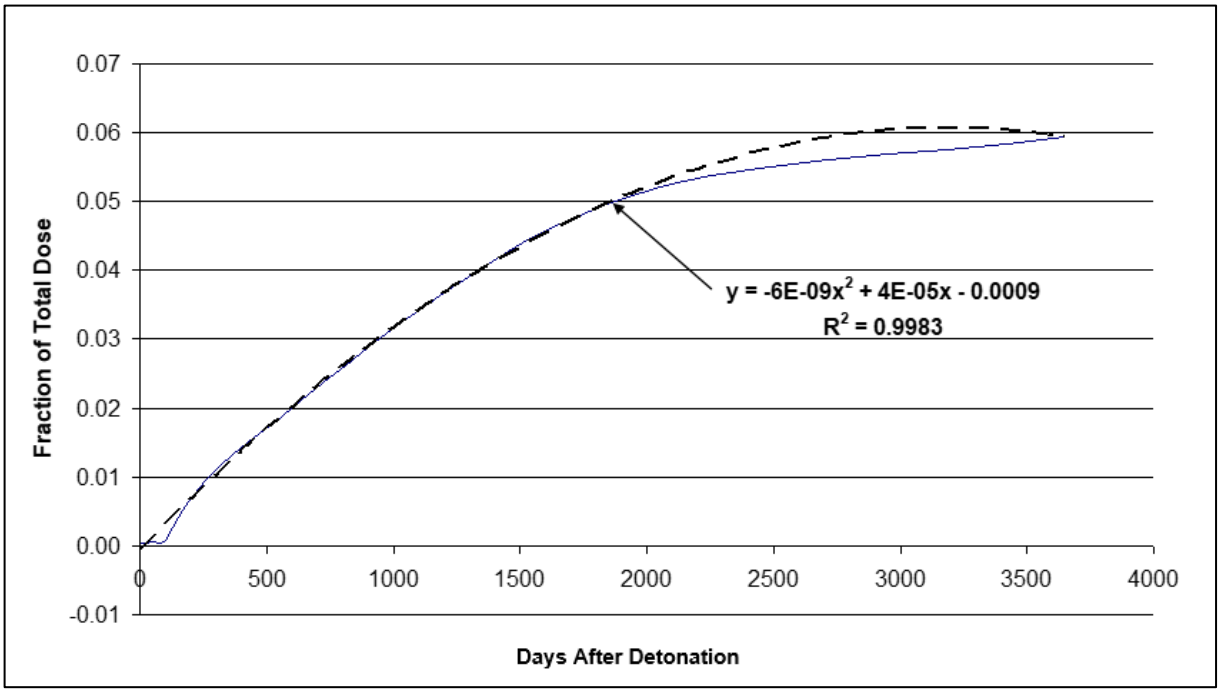

Figure A-11. Strontium-90 fraction of total dose to the bone surface.

Table A-9. Organ-specific inhalation dose fission and activation product correction factors.

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Skin, adrenals, thymus, SI, spleen, skin, muscle, uterus, pancreas, kidneys, breast, testes, esophagus, ovaries, brain, stomach, thyroid, gall bladder	730	364	242	182	145	121	104	90.7	80.6	72.5
ULI	458	179	99.2	64.0	45.0	33.4	25.9	20.6	16.8	14.0
Urinary bladder	335	149	91.3	63.6	47.5	37.2	30.1	24.9	21.0	18.0
Lungs	34,900	14,200	7,960	5,150	3,630	2,700	2,100	1,660	1,360	1,130
ET, ET1, ET2, LN(TH), LN(ET)	1,570	827	598	492	438	412	412	412	412	412
LLI	420	142	70.8	42.4	28.2	20.1	15.1	11.7	9.4	7.6
Colon	390	148	79.4	50.0	34.5	25.2	19.3	15.2	12.3	10.2
Liver	9,260	4,620	1,540	1,190	988	858	769	706	661	629
Red bone marrow	37.9	18.2	12.8	10.4	10.4	10.4	10.4	10.4	10.4	10.4
Bone surfaces	78.5	40.1	28.1	22.4	22.4	22.4	22.4	22.4	22.4	22.4

The IMBA computer program was used to determine the organ doses from the scaled intakes in Table A-7 for a period of 10 years. These doses were multiplied by the correction factors in Table A-9 to determine the additional dose that should be added to account for potential dose from inhalation of short-lived fission and activation products. The organ-specific fission and activation product doses are listed in Table A-10.

Table A-10. Inhalation dose from short-lived fission and activation products (rem).

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Adrenals	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Bladder	1.86E-04	6.99E-05	3.45E-05	2.26E-05	1.81E-05	1.51E-05	1.29E-05	1.12E-05	9.73E-06	8.53E-06
Brain	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Breast	2.08E-07	3.57E-08	1.65E-08	1.37E-08	1.18E-08	1.01E-08	8.70E-09	7.50E-09	6.49E-09	5.58E-09
Gall bladder	2.08E-07	3.57E-08	1.65E-08	1.37E-08	1.18E-08	1.01E-08	8.70E-09	7.50E-09	6.49E-09	5.58E-09
Heart wall	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Kidney	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Liver	1.93E-03	8.57E-04	3.71E-04	2.70E-04	2.33E-04	2.07E-04	1.85E-04	1.67E-04	1.52E-04	1.39E-04
Muscle	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Ovaries	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Pancreas	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Testes	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Thyroid	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
RBM	4.08E-04	7.00E-04	6.65E-04	6.09E-04	5.59E-04	5.18E-04	4.84E-04	4.57E-04	4.35E-04	4.16E-04
Bone surface	1.23E-03	2.03E-03	2.00E-03	1.91E-03	1.83E-03	1.77E-03	1.72E-03	1.69E-03	1.66E-03	1.64E-03
Stomach	1.69E-04	7.22E-05	4.14E-05	3.02E-05	2.57E-05	2.26E-05	2.01E-05	1.81E-05	1.63E-05	1.47E-05
SI	1.85E-04	7.67E-05	4.36E-05	3.15E-05	2.68E-05	2.35E-05	2.09E-05	1.87E-05	1.69E-05	1.53E-05
ULI	4.70E-04	1.36E-04	5.98E-05	3.59E-05	2.73E-05	2.19E-05	1.81E-05	1.52E-05	1.29E-05	1.11E-05
LLI	1.38E-03	3.26E-04	1.24E-04	6.66E-05	4.74E-05	3.63E-05	2.90E-05	2.37E-05	1.98E-05	1.67E-05
Skin	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Spleen	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Thymus	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Uterus	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
ET	2.22E-03	6.97E-04	3.78E-04	2.60E-04	2.32E-04	2.19E-04	2.17E-04	2.15E-04	2.14E-04	2.13E-04
Lung	7.67E-03	2.96E-03	1.55E-03	1.08E-03	8.84E-04	7.46E-04	6.40E-04	5.52E-04	4.80E-04	4.18E-04
Colon	7.82E-04	2.08E-04	8.57E-05	4.85E-05	3.57E-05	2.78E-05	2.26E-05	1.86E-05	1.57E-05	1.34E-05
ET1	1.63E+00	4.74E-01	2.48E-01	1.64E-01	1.46E-01	1.38E-01	1.38E-01	1.38E-01	1.38E-01	1.38E-01
ET2	5.83E-04	2.24E-04	1.30E-04	9.60E-05	8.63E-05	8.10E-05	7.92E-05	7.78E-05	7.66E-05	7.55E-05
LN(ET)	3.27E-04	1.50E-04	9.15E-05	7.03E-05	6.34E-05	5.95E-05	5.77E-05	5.63E-05	5.51E-05	5.40E-05
LN(TH)	3.27E-04	1.50E-04	9.15E-05	7.03E-05	6.34E-05	5.95E-05	5.77E-05	5.63E-05	5.51E-05	5.40E-05
Esophagus	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

The application of the early fission and activation product correction factor through 1972 intakes is favorable to claimants because the Hicks (1984) data verifies that after 10 years, more than 90% of the total dose for all organs is delivered by ^{241}Am, ^{137}Cs, and/or ^{90}Sr. Further, as times after detonation become greater, the relative importance of ^{241}Am, ^{137}Cs, and ^{90}Sr becomes greater and, because the organ doses from these radionuclides are already accounted for by the scaled intakes (Table A-7), the dose from these radionuclides is doubled.

A.7 INGESTION PATHWAY

To account for potential intakes from inadvertent ingestion of contaminated soil, the area-specific radionuclide soil deposition data in Table A-5 were converted to volumetric data (i.e., Bq/mg) by assuming a radionuclide relaxation depth of 2.3 cm and a soil density of 1.5 g/cm^3 (DOE 2003). The area-specific radionuclide soil concentrations are listed in Table A-11.

Table A-11. Radionuclide soil concentration by area (Bq/g).[a]

Area	Am-241	Pu-238	Pu-239,240	Co-60	Cs 137	Sr-90	Eu-152	Eu-154	Eu-155
1	0.069	0.127	0.375	0.682	0.263	0.456	1.005	0.014	0.391
2	0.064	0.226	0.463	1.001	0.963	1.882	1.262	ND	0.420
3	0.062	0.050	0.475	0.509	0.294	0.824	0.989	0.012	0.321
4	0.179	0.420	1.036	1.644	0.593	0.655	1.010	ND	0.259
5	0.090	0.018	0.686	3.401	0.109	0.250	6.122	0.259	ND
6	0.023	0.053	0.108	0.102	0.069	0.087	ND	ND	ND
7	0.049	0.016	0.344	0.852	0.213	0.384	2.024	0.039	0.322
8	0.530	0.297	3.280	6.741	2.389	1.450	0.562	ND	0.894
9	0.091	0.057	1.844	0.575	0.344	0.524	2.042	0.038	0.311
10	0.411	0.491	2.279	7.973	3.321	2.217	0.195	0.056	5.177
11	0.357	0.065	3.005	ND	0.099	0.060	ND	ND	ND
12	0.062	0.111	0.408	0.498	0.399	0.346	ND	ND	ND
15	0.098	0.114	0.740	0.140	0.426	0.502	ND	ND	ND
16	0.021	0.054	0.107	0.115	0.160	0.209	ND	ND	ND
17	0.039	0.074	0.238	0.524	0.378	0.488	ND	ND	ND
18	0.301	0.106	1.518	0.421	0.290	0.502	0.072	0.014	0.607
19	0.061	0.111	0.391	0.122	0.192	0.169	ND	ND	ND
20	1.607	2.500	2.741	20.946	0.701	0.559	3.723	0.969	16.031
25	ND	ND	ND	ND	0.176	0.090	0.789	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	4.620	7.749	19.340	43.835	3.953	3.493	4.143	1.252	13.804

a. ND = no data.

If the assumption is made that the workers ingested 100 mg of soil each day, which is favorable to claimants [EPA (1989) recommends a value of 50 mg/d], and that full-time employment was 250 d/yr, annual ingestion can be calculated. The area-specific annual ingestion rates are listed in Table A-12.

For most radionuclides, Area 30 provided the highest areal deposition and resultant intakes. Area 30 is relatively small (150 km^2) and inaccessible, and is on the Western edge of NTS. It has rugged terrain and includes the northern reaches of Fortymile Canyon. In 1968, it was the site of Project BUGGY, the first nuclear row-charge experiment in the PLOWSHARE Program. As a result of the test, a trench 255 m long, 77 m wide, and 206 m deep was created. The test resulted in large quantities of vitrified sand. Because of the bias that is introduced when Area 30 is included, the maximum annual intakes in Table A-12 have been provided with Area 30 areal concentrations

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

Table A-12. Area-specific and maximum annual ingestion rates (Bq/yr).[a]

Area	Am-241	Pu-238	Pu-239/240	Co-60	Cs 137	Sr-90	Eu-152	Eu-154	Eu-155
1	1.72	3.17	9.38	17.06	6.56	11.41	25.12	0.35	9.77
2	1.59	5.64	11.57	25.03	24.08	47.06	31.54	ND	10.51
3	1.54	1.24	11.87	12.72	7.34	20.59	24.73	0.29	8.01
4	4.47	10.49	25.90	41.10	14.83	16.37	25.24	ND	6.47
5	2.24	0.45	17.15	85.03	2.73	6.25	153.05	6.48	0.00
6	0.57	1.32	2.69	2.54	1.71	2.18	ND	ND	ND
7	1.23	0.40	8.59	21.29	5.33	9.61	50.59	0.97	8.05
8	13.24	7.43	81.99	168.52	59.73	36.25	14.05	ND	22.34
9	2.27	1.42	46.11	14.38	8.60	13.10	51.04	0.94	7.76
10	10.29	12.27	56.98	199.31	83.02	55.42	4.88	1.41	129.41
11	8.93	1.61	75.12	0.00	2.47	1.51	ND	ND	ND
12	1.56	2.77	10.20	12.45	9.98	8.65	ND	ND	ND
15	2.45	2.85	18.49	3.49	10.64	12.56	ND	ND	ND
16	0.53	1.35	2.68	2.87	4.01	5.21	ND	ND	ND
17	0.97	1.85	5.94	13.09	9.44	12.19	ND	ND	ND
18	7.54	2.65	37.95	10.54	7.24	12.55	1.79	0.34	15.17
19	1.53	2.79	9.78	3.05	4.80	4.21	ND	ND	ND
20	40.17	62.49	68.51	523.64	17.54	13.98	93.06	24.23	400.77
25	ND	ND	ND	ND	4.39	2.24	19.73	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	115.50	193.72	483.50	1,095.89	98.83	87.33	103.56	31.30	345.10
Max.[b]	**40.17**	**62.49**	**81.99**	**523.64**	**83.02**	**55.42**	**153.05**	**24.23**	**400.77**

a. ND = no data.
b. Maximum value with Area 30 excluded.

excluded. The Area 30 intakes should be used only if it can be determined that the worker was assigned to and primarily worked in Area 30.

To determine the relative importance of the ingestion pathway, a hypothetical ingestion scenario was used that assumed 30 years of the Table A-12 maximum intakes and used the IMBA computer program to determine organ doses from these intakes. The annual organ doses from ingestion of ^{238,239}Pu and ^{241}Am greater than 0.001 rem are listed in Table A-13. With the exception of the red bone marrow and bone surfaces, the annual doses from the Table A-12 maximum ingestion rates of ^{60}Co, ^{137}Cs, and ^{152,154,155}Eu were all less than 0.001 rem. For the red bone marrow and bone surfaces, the annual doses were all less than 0.002 rem.

As with the inhalation intakes discussed in Section A.5, ingestion doses need to be adjusted for potential dose from short-lived fission and activation products that are no longer persistent in NTS soils in measurable amounts. The organ-specific fission and activation product correction factors were developed (for the reasons discussed in Section A.5) based on the relative contribution of 90Sr to the total ingestion dose using the Hicks (1981c) data from the STORAX SMALL BOY test in July 1962. As in Section A.5 for inhalation dose, organ-specific relationships were developed for the ^{90}Sr fraction of total dose. These relationships are shown in Figures A-12 through A-17. With the exception of fractional dose to bone surfaces and red bone marrow, these relationships were valid out to 10 years after detonation. For bone surfaces and red bone marrow, the time-dependent relationships were determined for the first year and for the last 9 years.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

Table A-13. Annual organ doses from ingestion of ^{238,239}Pu and ^{241}Am (rem).

Year	Liver	Ovaries	Testes	RBM	Bone surface	LLI
1963	<0.001	<0.001	<0.001	<0.001	0.002	0.001
1964	0.001	<0.001	<0.001	<0.001	0.007	0.001
1965	0.002	<0.001	<0.001	0.001	0.011	0.001
1966	0.003	<0.001	<0.001	0.001	0.016	0.001
1967	0.004	<0.001	<0.001	0.002	0.020	0.001
1968	0.005	<0.001	<0.001	0.002	0.024	0.001
1969	0.005	<0.001	<0.001	0.002	0.028	0.001
1970	0.006	<0.001	<0.001	0.002	0.032	0.001
1971	0.007	<0.001	<0.001	0.003	0.035	0.001
1972	0.008	<0.001	<0.001	0.003	0.039	0.001
1973	0.008	<0.001	<0.001	0.003	0.043	0.001
1974	0.009	<0.001	<0.001	0.003	0.046	0.001
1975	0.010	<0.001	<0.001	0.003	0.050	0.001
1976	0.010	<0.001	<0.001	0.004	0.053	0.001
1977	0.011	<0.001	<0.001	0.004	0.057	0.001
1978	0.011	<0.001	<0.001	0.004	0.060	0.001
1979	0.012	<0.001	<0.001	0.004	0.063	0.001
1980	0.013	0.001	0.001	0.004	0.066	0.001
1981	0.013	0.001	0.001	0.004	0.070	0.001
1982	0.014	0.001	0.001	0.004	0.073	0.001
1983	0.014	0.001	0.001	0.004	0.076	0.001
1984	0.015	0.001	0.001	0.005	0.079	0.001
1985	0.015	0.001	0.001	0.005	0.082	0.001
1986	0.016	0.001	0.001	0.005	0.085	0.001
1987	0.016	0.001	0.001	0.005	0.088	0.001
1988	0.017	0.001	0.001	0.005	0.091	0.001
1989	0.017	0.001	0.001	0.005	0.094	0.001
1990	0.018	0.001	0.001	0.005	0.096	0.001
1991	0.018	0.002	0.002	0.005	0.099	0.001
1992	0.019	0.002	0.002	0.005	0.102	0.001
1993	0.019	0.002	0.002	0.005	0.105	0.001
1994	0.019	0.002	0.002	0.005	0.105	<0.001
1995	0.019	0.002	0.002	0.005	0.103	<0.001
1996	0.018	0.002	0.002	0.005	0.101	<0.001
1997	0.018	0.002	0.002	0.004	0.099	<0.001
1998	0.017	0.002	0.002	0.004	0.098	<0.001
1999	0.017	0.001	0.001	0.004	0.096	<0.001
2000	0.017	0.001	0.001	0.004	0.095	<0.001
2001	0.016	0.001	0.001	0.004	0.093	<0.001
2002	0.016	0.001	0.001	0.003	0.092	<0.001
2003	0.016	0.001	0.001	0.003	0.090	<0.001
2004	0.015	0.001	0.001	0.003	0.089	<0.001
2005	0.015	0.001	0.001	0.003	0.088	<0.001
2006	0.015	0.001	0.001	0.003	0.086	<0.001
2007	0.014	0.001	0.001	0.003	0.085	<0.001

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

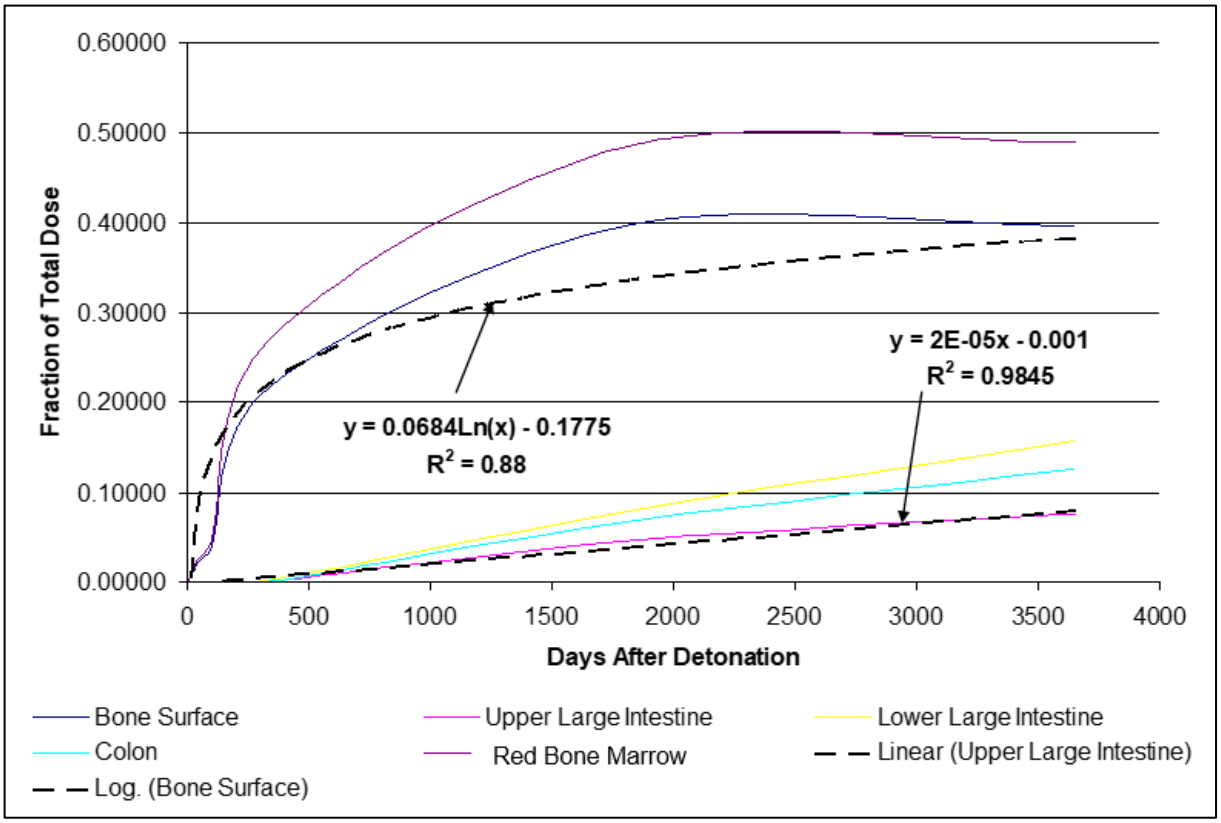

Figure A-12. Strontium-90 fraction of total ingestion dose.

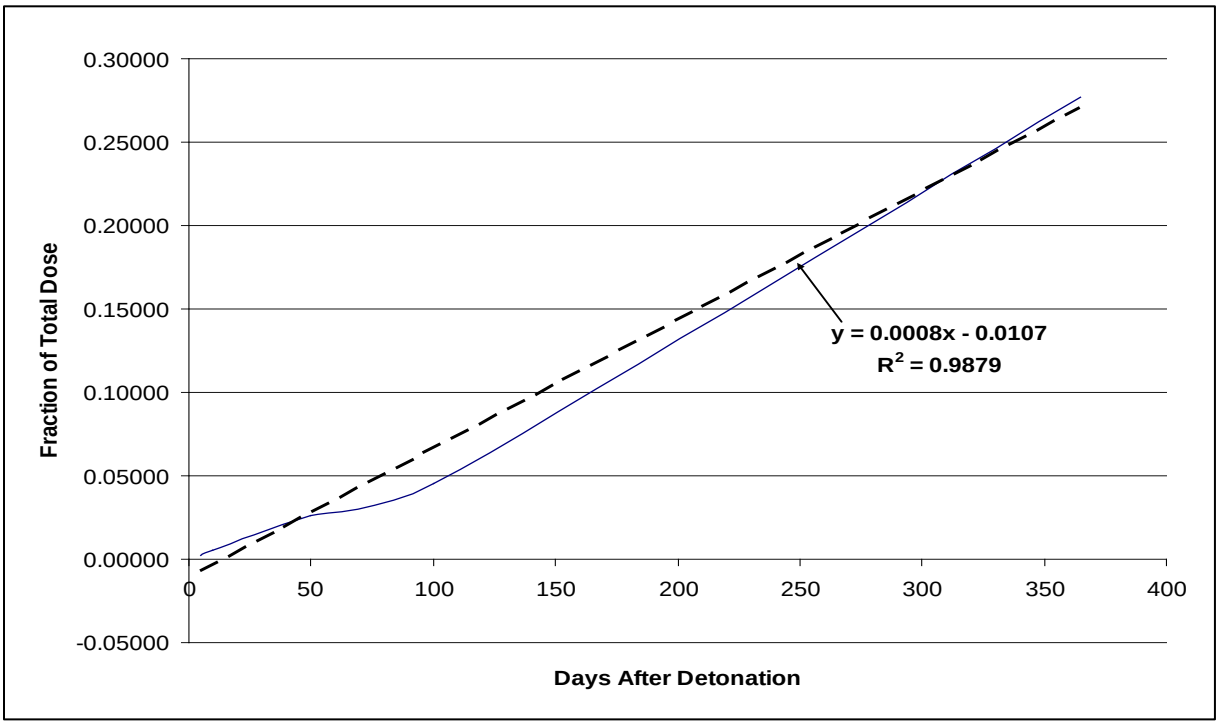

Figure A-13. Strontium-90 fraction of total ingestion dose to red bone marrow.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

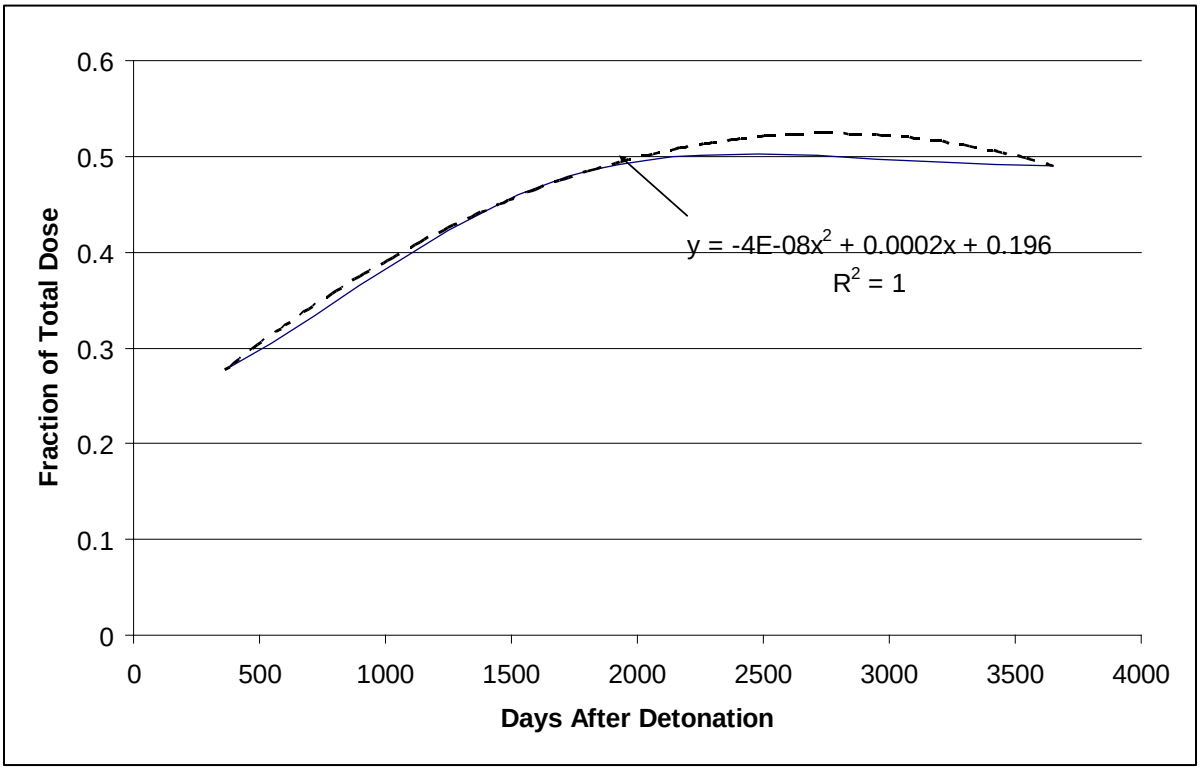

Figure A-14. Strontium-90 fraction of total ingestion dose to red bone marrow.

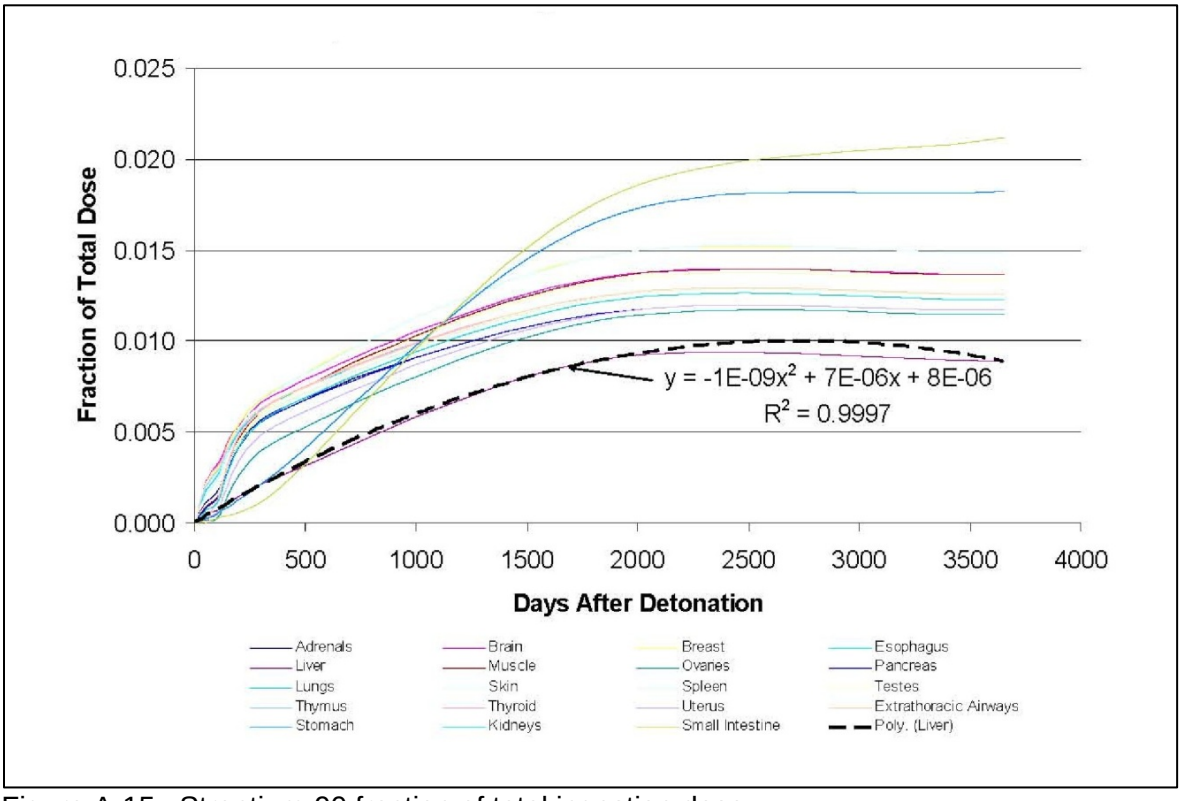

Figure A-15. Strontium-90 fraction of total ingestion dose.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

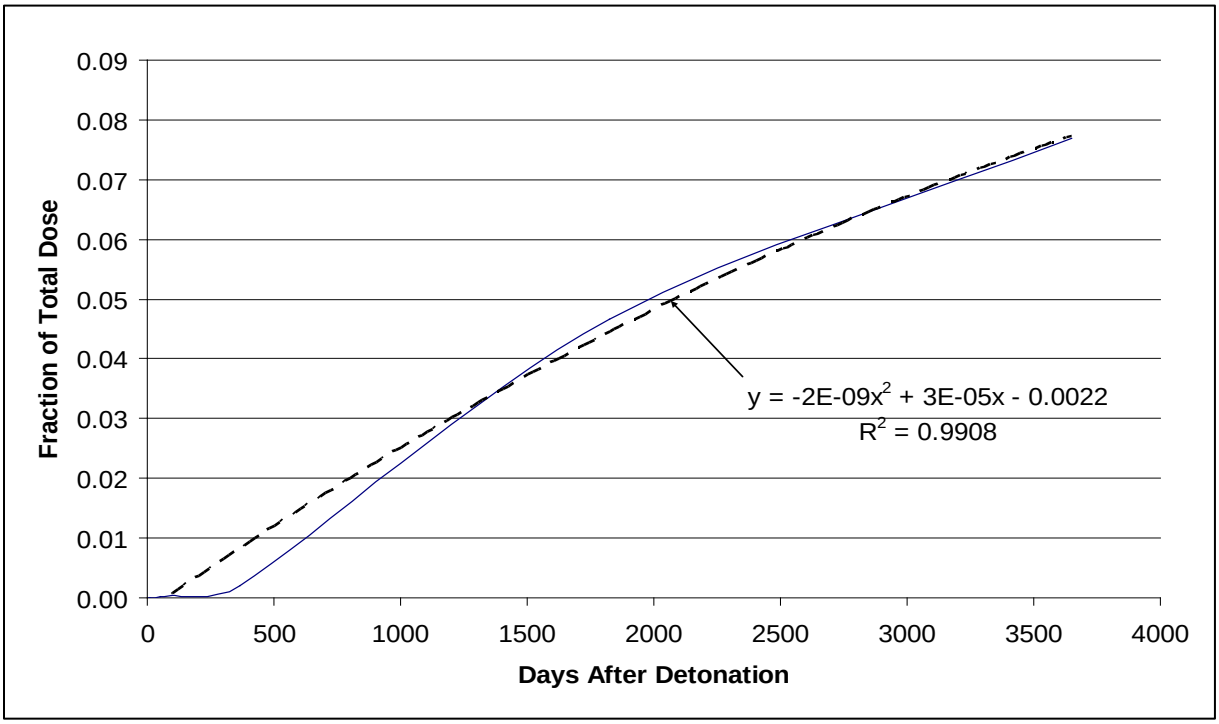

Figure A-16. Strontium-90 fraction of ingestion dose to the upper large intestine.

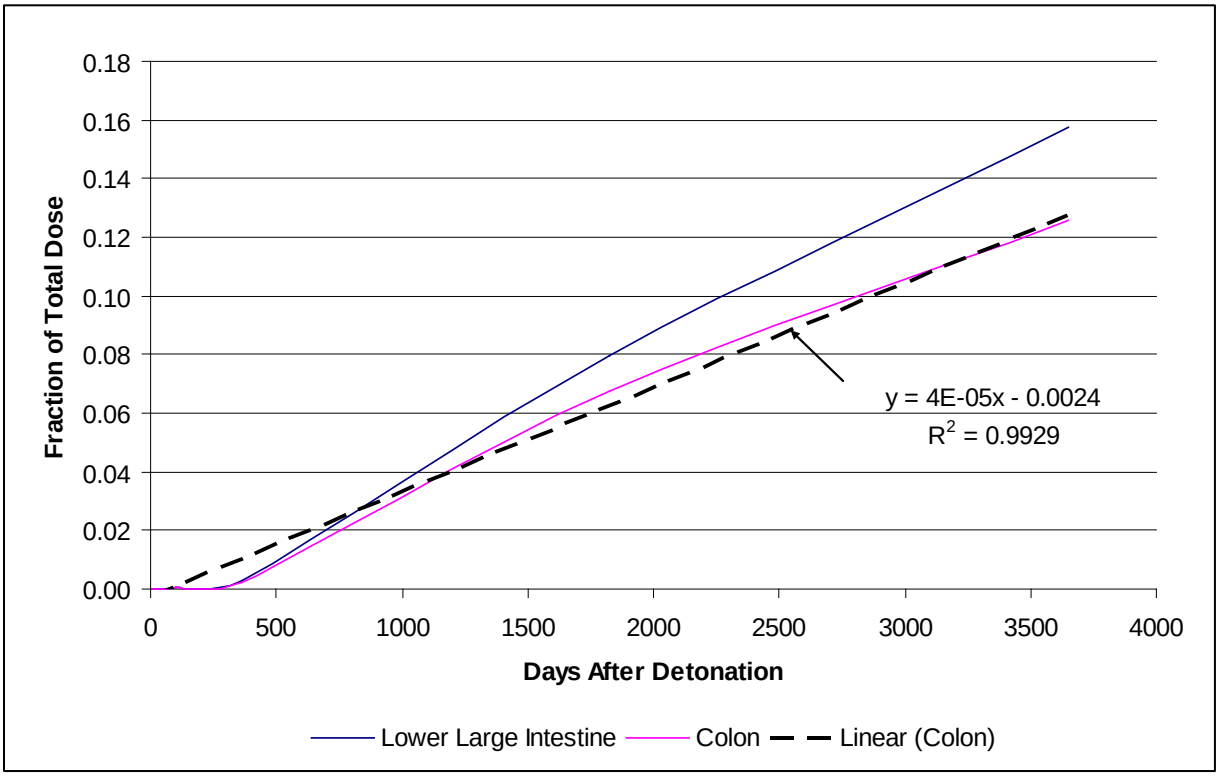

Figure A-17. Strontium-90 fraction of total ingestion dose.

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

To account for fractionation, the refractory elements included in the STORAX SMALL BOY Hicks (1981c) data were multiplied by a factor of 2. Increasing the abundance of the refractory elements provides a more reasonable estimate of their relative contribution to total dose. As for the inhalation correction factors, these radionuclide- and time-dependent relative abundances are multiplied by their organ-specific ingestion DCFs (Bunker 1999) to determine the radionuclide-specific, relative importance to total dose as a function of time after detonation. Because of the large difference between the 50-year committed DCF and the annual DCF for ^{241}Am, the IMBA computer program was used to calculate the annual ingestion DCFs, which were then used rather than the 50-year committed DCFs. The same method was used for ^{90}Sr annual DCFs. To ensure that organ doses were not underestimated, the f1 factor for each radionuclide was chosen to provide the largest dose to the specific organ of interest.

The ingestion correction factors were evaluated over a 10-year period. This is because ^{144}Ce and ^{106}Ru continue to provide relatively large ingestion doses through 5 years after detonation. Therefore, to capture their contributions to total dose, the correction factor integration times were extended to 10 years if the relative contribution of ^{144}Ce and ^{106}Ru to total dose was less than 3% for all organs. In addition, at the end of 10 years, more than 95% of the total ingestion dose is delivered by ^{90}Sr and ^{137}Cs; their dose is accounted for by the ingestion intakes in Table A-12.

Using the relationships shown in Figures A-12 through A-17, short-lived fission and activation product ingestion correction factors were developed (Table A-14). As with the inhalation fission and activation product factors, these correction factors are multiplied by the organ-specific ^{90}Sr annual doses (from the intakes in Table A-12 [i.e., 55.42 Bq/yr]) to calculate additional ingestion dose from short-lived fission and activation products.

Table A-14. Organ-specific ingestion fission and activation product correction factors.

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Adrenals, breast, brain, skin, bladder, stomach, kidneys, muscle, pancreas, brain, esophagus, SI, liver, ovaries ET, ET1, ET2, LM(ET), LN(TH), lungs, skin, spleen, testes, thymus, thyroid, uterus, gall bladder	416	219	155	123	106	95.0	88.1	84.0	82.0	81.8
ULI	514	184	95.2	58.2	39.3	18.6	16.3	14.6	13.4	12.4
Bone surface, RBM	3.8	3.1	2.7	2.5	2.3	2.3	2.3	2.3	2.3	2.3
LLI, colon	417	208	138	25.6	20.4	17.4	14.6	12.8	11.3	10.2

To simplify the application of organ-specific ingestion dose from short-lived fission and activation products, the IMBA computer program was used to determine the organ-specific annual doses for the ^{90}Sr intake of 55.42 Bq/yr for 1963 through 1972 (Table A-15). These doses are multiplied by the Table A-14 organ-specific correction factors to provide the annual doses from ingestion of short-lived fission and activation products (Table A-16).

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE
BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

Table A-15. Organ-specific annual ingestion doses (rem) for the ^{90}Sr intake of 55.42 Bq/yr.

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Adrenals	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Urinary bladder	5.68E-06	6.42E-06	6.67E-06	6.87E-06	7.04E-06	7.18E-06	7.31E-06	7.41E-06	7.50E-06	7.58E-06
Bone surface	1.58E-04	3.74E-04	5.47E-04	6.98E-04	8.32E-04	9.50E-04	1.06E-03	1.15E-03	1.23E-03	1.31E-03
Brain	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Breast	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Esophagus	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Stomach	3.42E-06	3.78E-06	3.95E-06	4.09E-06	4.21E-06	4.31E-06	4.40E-06	4.47E-06	4.54E-06	4.59E-06
Small intestine	4.71E-06	5.07E-06	5.24E-06	5.38E-06	5.50E-06	5.60E-06	5.69E-06	5.76E-06	5.83E-06	5.88E-06
Upper large intestine	3.42E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05	3.43E-05
Lower large intestine	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04
Colon	4.36E-03	2.26E-03	1.51E-03	1.14E-03	9.16E-04	7.71E-04	6.61E-04	5.84E-04	5.21E-04	4.71E-04
Kidneys	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Liver	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Muscle	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Ovaries	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Pancreas	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Red bone marrow	1.08E-04	2.66E-04	3.87E-04	4.86E-04	5.69E-04	6.37E-04	6.94E-04	7.42E-04	7.81E-04	8.14E-04
Extrathoracic airways	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Lungs	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Skin	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Spleen	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Testes	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Thymus	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Thyroid	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Uterus	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06

Table A-16. Organ-specific doses (rem) from ingestion of fission and activation products.

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Adrenals	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Bladder	2.36E-03	1.55E-03	1.15E-03	9.50E-04	8.45E-04	7.76E-04	7.31E-04	7.02E-04	6.85E-04	2.21E-04
Brain	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Breast	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Gall bladder	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Heart wall	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Kidney	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Liver	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Muscle	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Ovaries	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Pancreas	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Testes	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Thyroid	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
RBM	4.12E-04	2.66E-04	3.87E-04	4.86E-04	5.69E-04	6.37E-04	6.94E-04	7.42E-04	7.81E-04	8.14E-04
Bone surface	6.01E-04	1.31E-03	1.75E-03	2.09E-03	2.35E-03	2.56E-03	2.76E-03	2.94E-03	3.11E-03	3.05E-03
Stomach	1.42E-03	9.00E-04	6.79E-04	5.71E-04	5.13E-04	4.74E-04	4.48E-04	4.31E-04	4.21E-04	1.41E-04
SI	1.96E-03	1.18E-03	8.79E-04	7.29E-04	6.49E-04	5.96E-04	5.61E-04	5.39E-04	5.27E-04	1.43E-04
ULI	1.53E-02	5.87E-03	3.11E-03	1.96E-03	1.36E-03	7.26E-04	6.30E-04	5.64E-04	5.14E-04	1.34E-04
LLI	4.84E-02	2.50E-02	1.66E-02	3.47E-03	2.66E-03	2.23E-03	1.92E-03	1.68E-03	1.49E-03	1.34E-03
Skin	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Spleen	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Thymus	2.11E-06	2.47E-06	2.64E-06	2.77E-06	2.89E-06	3.00E-06	3.08E-06	3.16E-06	3.22E-06	3.28E-06
Uterus	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
ET	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Lung	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Colon	2.80E-02	1.45E-02	9.66E-03	2.07E-03	1.59E-03	1.33E-03	1.15E-03	1.01E-03	8.94E-04	8.06E-04
ET1	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
ET2	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
LN(ET)	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
LN(TH)	8.78E-04	6.12E-04	4.75E-04	4.09E-04	3.73E-04	3.49E-04	3.32E-04	3.20E-04	3.13E-04	1.40E-04
Esophagus	2.89E-04	2.07E-04	1.62E-04	1.41E-04	1.29E-04	1.21E-04	1.16E-04	1.13E-04	1.11E-04	5.02E-05

ATTACHMENT A
AMBIENT ENVIRONMENTAL INTAKES AT THE NEVADA TEST SITE BASED ON AIR SAMPLING AND SOIL CONTAMINATION DATA (continued)

A.8 INSTRUCTION TO DOSE RECONSTRUCTORS FOR ASSIGNMENT OF ENVIRONMENTAL INTAKES

With the exception of cases that can be worked after 1992 with the use of the bounding assumptions from ORAUT-OTIB-0018 (ORAUT 2005), environmental inhalation and ingestion intakes in Tables A-7 and A-12, respectively, should be applied starting in 1963. In addition, for applicable years of employment and affected organs, the annual doses in Tables A-10 and A-16 should be applied to account for dose from inhalation and ingestion of short-lived fission and activation products. These intakes and resultant doses should be entered into the IREP analysis with a constant distribution because they are reasonable overestimates of the actual intakes and doses. These doses need to be entered into the IREP analysis and they should be entered as 30-to-250-keV photons with a constant distribution. Best estimate intakes are 10% of the intakes in Tables A-7 and A-12 and if assigned, the resultant doses should be assigned as a log normal distribution with a GSD of 3.0.

ATTACHMENT B
TOTAL ANNUAL ORGAN DOSES FROM 30 YEARS OF INHALATION AND INGESTION INTAKES AND SOURCES OF OVERESTIMATED ORGAN DOSE

In the previous sections, methods were presented to account for organ dose from ambient environmental inhalation and ingestion intakes of radioactive materials in the NTS atmosphere and soils. To illustrate the importance of these pathways, the IMBA computer program was used to determine organ doses from 30 years of the inhalation intakes in Table A-7 and the ingestion intakes in Table A-12. These 30-year organ doses and the fractional contribution for each of the radionuclides persistent in NTS soils are listed in Table B-1. To correct for exposure to short-lived fission and activation products, the dose reconstructor should add annual doses that were greater than or equal to 0.001 rem from Tables 4-9 and 4-14 as 30-to-250-keV photons with a constant distribution. The doses shown in table B-1 are for purposes of illustration only and should not be entered into the IREP analysis. These doses will be accounted for by the assignment of the maximum intakes in Tables 4-7 and 4-11 and repeated in Tables A-7 and A-12 for all years of employment.

ATTACHMENT B
TOTAL ANNUAL ORGAN DOSES FROM 30 YEARS OF INHALATION AND INGESTION INTAKES AND SOURCES OF OVERESTIMATED ORGAN DOSE (continued)

Table B-1. Total annual organ doses greater than or equal to 0.001 rem from 30 years of inhalation and ingestion intakes (rem).

Year	Radiation type	Liver	Ovaries	Testes	RBM	Bone surface	LLI	ET	Lung	Colon	ET1	ET2	LN(ET)	LN(TH)
1963	Alpha	0.001	<0.001	<0.001	<0.001	0.006	0.001	0.004	0.007	0.001	0.005	0.004	<0.001	0.001
1964	Alpha	0.003	<0.001	<0.001	0.002	0.017	0.001	0.009	0.006	0.001	0.003	0.009	0.001	0.003
1965	Alpha	0.005	<0.001	<0.001	0.002	0.026	0.001	0.009	0.005	0.001	0.002	0.009	0.001	0.004
1966	Alpha	0.006	<0.001	<0.001	0.003	0.033	0.001	0.009	0.004	0.001	0.002	0.009	0.002	0.006
1967	Alpha	0.008	<0.001	<0.001	0.003	0.040	0.001	0.009	0.004	0.001	0.002	0.009	0.003	0.007
1968	Alpha	0.009	<0.001	<0.001	0.004	0.046	0.001	0.008	0.004	0.001	0.002	0.008	0.003	0.008
1969	Alpha	0.010	<0.001	<0.001	0.004	0.052	0.001	0.008	0.004	0.001	0.002	0.008	0.004	0.009
1970	Alpha	0.011	<0.001	<0.001	0.004	0.058	0.001	0.008	0.004	0.001	0.002	0.008	0.004	0.011
1971	Alpha	0.012	<0.001	<0.001	0.005	0.065	0.001	0.008	0.004	0.001	0.002	0.008	0.005	0.012
1972	Alpha	0.013	0.001	0.001	0.005	0.070	0.001	0.008	0.004	0.001	0.002	0.008	0.005	0.013
1973	Alpha	0.015	0.001	0.001	0.005	0.076	0.001	0.008	0.004	0.001	0.002	0.008	0.006	0.014
1974	Alpha	0.016	0.001	0.001	0.006	0.082	0.001	0.008	0.004	0.001	0.002	0.008	0.006	0.016
1975	Alpha	0.017	0.001	0.001	0.006	0.088	0.001	0.008	0.005	0.001	0.002	0.008	0.007	0.017
1976	Alpha	0.018	0.001	0.001	0.006	0.093	0.001	0.008	0.005	0.001	0.002	0.008	0.007	0.018
1977	Alpha	0.019	0.001	0.001	0.006	0.098	0.001	0.008	0.005	0.001	0.002	0.008	0.007	0.019
1978	Alpha	0.020	0.002	0.002	0.006	0.104	0.001	0.008	0.005	0.001	0.002	0.008	0.008	0.020
1979	Alpha	0.021	0.002	0.002	0.007	0.109	0.001	0.008	0.005	0.001	0.002	0.008	0.008	0.022
1980	Alpha	0.021	0.002	0.002	0.007	0.114	0.001	0.008	0.005	0.001	0.002	0.008	0.008	0.023
1981	Alpha	0.022	0.002	0.002	0.007	0.119	0.001	0.008	0.005	0.001	0.002	0.008	0.009	0.024
1982	Alpha	0.023	0.002	0.002	0.007	0.124	0.001	0.008	0.005	0.001	0.002	0.008	0.009	0.025
1983	Alpha	0.024	0.002	0.002	0.007	0.129	0.001	0.008	0.005	0.001	0.002	0.008	0.009	0.026
1984	Alpha	0.025	0.002	0.002	0.008	0.134	0.001	0.008	0.005	0.001	0.002	0.008	0.009	0.027
1985	Alpha	0.026	0.002	0.002	0.008	0.139	0.001	0.008	0.005	0.001	0.002	0.008	0.010	0.028
1986	Alpha	0.027	0.002	0.002	0.008	0.144	0.001	0.008	0.005	0.001	0.002	0.008	0.010	0.029
1987	Alpha	0.027	0.002	0.002	0.008	0.149	0.001	0.008	0.005	0.001	0.002	0.008	0.010	0.030
1988	Alpha	0.028	0.002	0.002	0.008	0.153	0.001	0.008	0.005	0.001	0.002	0.008	0.010	0.031
1989	Alpha	0.029	0.002	0.002	0.008	0.158	0.001	0.008	0.005	0.001	0.002	0.008	0.011	0.032
1990	Alpha	0.030	0.002	0.002	0.008	0.162	0.001	0.008	0.005	0.001	0.002	0.008	0.011	0.033
1991	Alpha	0.030	0.003	0.003	0.009	0.167	0.001	0.008	0.005	0.001	0.002	0.008	0.011	0.034
1992	Alpha	0.031	0.003	0.003	0.009	0.171	0.001	0.008	0.005	0.001	0.002	0.008	0.011	0.035
1993	Alpha	0.031	0.003	0.003	0.009	0.172	<0.001	0.006	0.003	<0.001	<0.001	0.006	0.011	0.035

ATTACHMENT B
TOTAL ANNUAL ORGAN DOSES FROM 30 YEARS OF INHALATION AND INGESTION INTAKES AND SOURCES OF OVERESTIMATED ORGAN DOSE (continued)

Year	Radiation type	Liver	Ovaries	Testes	RBM	Bone surface	LLI	ET	Lung	Colon	ET1	ET2	LN(ET)	LN(TH)
1994	Alpha	0.030	0.003	0.003	0.008	0.169	<0.001	0.004	0.002	<0.001	<0.001	0.004	0.011	0.035
1995	Alpha	0.030	0.003	0.003	0.008	0.166	<0.001	0.003	0.002	<0.001	<0.001	0.003	0.011	0.035
1996	Alpha	0.029	0.003	0.003	0.007	0.163	<0.001	0.002	0.001	<0.001	<0.001	0.002	0.011	0.035
1997	Alpha	0.028	0.002	0.003	0.007	0.160	<0.001	0.001	0.001	<0.001	<0.001	0.001	0.011	0.035
1998	Alpha	0.028	0.002	0.002	0.006	0.158	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.010	0.034
1999	Alpha	0.027	0.002	0.002	0.006	0.155	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.010	0.034
2000	Alpha	0.026	0.002	0.002	0.006	0.153	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.010	0.033
2001	Alpha	0.026	0.002	0.002	0.006	0.151	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.033
2002	Alpha	0.025	0.002	0.002	0.005	0.148	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.032
2003	Alpha	0.025	0.002	0.002	0.005	0.146	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.032
2004	Alpha	0.024	0.002	0.002	0.005	0.144	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	0.031
2005	Alpha	0.024	0.002	0.002	0.005	0.142	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	0.031
2006	Alpha	0.023	0.002	0.002	0.005	0.140	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	0.030
2007	Alpha	0.023	0.002	0.002	0.005	0.138	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.029
2008	Alpha	0.022	0.002	0.002	0.004	0.136	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.029
2009	Alpha	0.022	0.002	0.002	0.004	0.134	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.028
2010	Alpha	0.021	0.002	0.002	0.004	0.132	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.027
2011	Alpha	0.021	0.002	0.002	0.004	0.130	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	0.026
2012	Alpha	0.021	0.002	0.002	0.004	0.128	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	0.026
1963	Photons E>250 keV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
1964	Photons E>250 keV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
1965	Photons E>250 keV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
1963	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
1964	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
1965	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1966	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1967	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1968	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1969	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1970	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1971	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1972	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

ATTACHMENT B
TOTAL ANNUAL ORGAN DOSES FROM 30 YEARS OF INHALATION AND INGESTION INTAKES AND SOURCES OF OVERESTIMATED ORGAN DOSE (continued)

Year	Radiation type	Liver	Ovaries	Testes	RBM	Bone surface	LLI	ET	Lung	Colon	ET1	ET2	LN(ET)	LN(TH)
1973	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1974	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1975	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1976	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1977	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1978	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1979	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1980	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1981	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1982	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1983	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1984	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1985	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1986	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1987	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1988	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1989	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1990	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1991	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1992	Electrons E>15 keV	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1993	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1994	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1995	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1996	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1997	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1998	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1999	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
2000	Electrons E>15 keV	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001