DOE Review Release 05/03/2010

Document Title: **Area IV of the Santa Susana Field Laboratory, the Canoga Avenue Facility, the Downey Facility, and the De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International) – Occupational Internal Dose**	Document Number: ORAUT-TKBS-0038-5 Revision: 01 Effective Date: 04/26/2010 Type of Document: TBD Supersedes: Revision 00

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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/22/2006	00	Technical basis document for Energy Technology Engineering Center – Occupational Internal Dose. First approved issue. Initiated by Melton H. Chew.
04/26/2010	01	Revision to change the site name to Area IV of the Santa Susana Field Laboratory, the Canoga Avenue Facility, the Downey Facility, and the De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International. Updated required language in Section 5.1. Additional information added on the solubility of uranium aluminide and sensitivity of bioassay analyses. Added Attachment G, Sensitivity of Bioassay Analyses by Bioassay Code U. S. Testing and Other Laboratories. Acronyms added for ICRP, kCi, kg, mo, POC, TTF, wk, µCi, µm, and §. Changes are being made to Section 5.1.3, Scope, as requested by DOL to clarify which organizations performed work eligible for compensation. Reporting levels and MDAs were adjusted in Table 5-3 for NSEC. A paragraph was deleted from Section 5.2, Internal Dosimetry Overview. The abbreviation “UR” for uranium radiometric was added to Section 5.3.1.3. Last paragraph of Section 5.3.1.4 was modified to clarify the sensitivity (reporting level) vs. MDA. The numbers and order in the documents for tables 5-7 and 5-8 were switched. An additional footnote was added to Table 5-9. Minor changes were made to the references and glossary. A list of figures was added to Attachment B. The figures and descriptions in Attachment A were reordered, the descriptions of two forms were combined, and in some cases descriptions were added to the same page as the figures. Attachment D was split into two attachments (D and E) and the original attachments E and F were re-lettered to F and G. The Table in Attachment G was split into in-vitro and in-vivo tables. Numerous minor edits were also made to clarify or improve the readability of the document without changing the technical content. Added Attributions and Annotations section. Activity fractions for reactors and related facilities were eliminated and references to OTIB-0054 were added. Added SEC information and added information in Section 5.3.1.5 pertaining to the use of CEP data. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of document. Training required: As determined by the Objective Manager. Initiated by Melton H. Chew.

Trademark Information

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AERD	Atomic Energy Research Department
AETR	Advanced Epithermal Thorium Reactor
AI	Atomics International
AMAD	activity median aerodynamic diameter
ATR	Advanced Test Reactor
Bq	becquerel
CF	critical or criticality facility
cm	centimeter
CMD	count median diameter
CTF	critical or criticality test facility
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ETEC	Energy Technology Engineering Center
ETR	Engineering Test Reactor
EU	enriched uranium
F	fast (solubility rate)
FSCF	(SNAP) Flight System Critical Facility
g	gram
GIF	Gamma Irradiation Facility
HDEHP	bis-(2-ethylhexyl) phosphoric acid
HEU	highly enriched uranium
HMRFSR	Heavy Metal Reflected Fast Spectrum Reactor
hr	hour
HRTM	Human Respiratory Tract Model
in.	inch
ICRP	International Commission on Radiological Protection
IREP	Interactive RadioEpidemiological Program
IVLC	*in vivo* lung count
JAERI	Japan Atomic Energy Research Institute
kCi	kilocurie
keV	kiloelectron-volt, 1,000 electron-volts
KEWB	Kinetics Experiment Water Boiler Reactor
kg	kilogram
L	liter
L-85	alternate name for the WBNS after 1972
LLD	lower limit of detection

M	moderate (solubility rate)
MDA	minimum detectable amount
MFP	mixed fission product
mg	milligram
min	minute
mL	milliliter
mo	month
MPBB	maximum permissible body burden
MPC	maximum permissible concentration
MPLB	maximum permissible lung burden
NAA	North American Aviation
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NMDF	Nuclear Materials Development Facility
NRTS	National Reactor Testing Station
NSEC	Nuclear Science and Engineering Corporation
OCY	Old Conservation Yard
OMR	organic moderated reactor
OMRE	Organic Moderated Reactor Experiment
ORNL	Oak Ridge National Laboratory
oz	ounce
pCi	picocurie
POC	probability of causation
PUA	code for plutonium activity determined by autoradiography
PUB	code for plutonium activity determined using a proportional counter to count alpha particles
R&D	research and development
RMHF	Radiation Materials Handling Facility
RSRMS	Radiation Safety Records Management System
S	slow (solubility rate)
S10FS	SNAP 10 Flight Simulation Reactor
S2DR	SNAP 2 Development Reactor
S8DR	SNAP 8 Development Reactor
S8ER	SNAP 8 Experimental Reactor
SER	SNAP Experimental Reactor
SGR	Sodium Graphite Reactor
SNAP	Systems for Nuclear Auxiliary Power
SRE	Sodium Reactor Experiment
SSFL	Santa Susana Field Laboratory
STIR	Shield Test and Irradiation Reactor (Modified STR)
STR	Shield Test Reactor
TBC	total-body count
TBD	technical basis document
TTA	thenoyltrifluoroacetone
TTF	transient test facility
UAl_x	uranium aluminide
UCLA	University of California, Los Angeles

UF	uranium fluorometric
UR	uranium radiometric
U.S.C.	United States Code
UST	United States Testing (Company)
W	watt
WBC	whole-body count
WBNS	Water Boiler Neutron Source
wk	week
ZnS(Ag)	zinc sulfide scintillation crystal activated with silver
µCi	microcurie
µg	microgram
µL	microliter
µm	micrometer
§	section or sections

5.1 INTRODUCTION

Technical basis documents 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 historic background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

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

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work (NIOSH 2007).

The statute also includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (NIOSH 2007):

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

[1] The U.S. Department of Labor (DOL) is ultimately responsible under the EEOICPA for determining the POC.

5.1.1 Purpose

The purpose of this TBD is to describe internal dosimetry systems and practices at Area IV of the Santa Susana Field Laboratory, Canoga Avenue Facility, Downey Facility, and De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International). This document discusses historical and current practices in relation to the evaluation of internal exposure data for monitored and unmonitored workers.

5.1.2 Special Exposure Cohort Petition Information

Although NIOSH found that it is not possible to completely reconstruct radiation doses for the SEC classes below, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at the Area IV, Canoga Avenue, De Soto Avenue, or Downey facilities during the SEC periods stated below, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

Class Added to the SEC

Area IV of SSFL (1955-1958)

- All employees of the Department of Energy (DOE), its predecessor agencies, and DOE contractors and subcontractors who worked in any area of Area IV of the Santa Susana Field Laboratory for a number of work days aggregating at least 250 work days from January 1, 1955 through December 31, 1958, or in combination with work days within the parameters established for one or more other classes of employees in the SEC (Sebelius 2009).

NIOSH determined in 2009 (NIOSH 2009) that it cannot estimate internal exposures with sufficient accuracy during the period from 1955 through 1958. This includes the time from the beginning of Area IV radiological activities in 1955, to late 1958 (selected as December 31, 1958 for SEC evaluation purposes). NIOSH intended the end of the SEC period to correspond with the date after which a routine bioassay program existed at SSFL and after which sufficient internal monitoring was thought to have been identified. Later in 2009 after further data review, NIOSH determined that sufficient data are not available for adequate dose reconstruction until January 1, 1965; NIOSH subsequently initiated a second SEC class for Area IV for the years 1959-1964, as described below

Classes Recommended by NIOSH for addition to the SEC

Area IV of SSFL (1959-1964)

- All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area of Area IV of the Santa Susana Field Laboratory from January 1, 1959 through December 31, 1964, 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 included in the Special Exposure Cohort (NIOSH 2010a).

Through the course of ongoing dose reconstruction, continued data capture efforts, and investigations associated with SEC-00093, NIOSH determined in 2010 (NIOSH 2010a) that it cannot estimate with sufficient accuracy the potential internal exposures to various radionuclides to which the proposed class may have been subjected during the time period from January 1, 1959 through December 31,

1964. NIOSH found that it is likely feasible to reconstruct external dose, including occupational medical dose, for Area IV of the Santa Susana Field Laboratory workers with sufficient accuracy.

Canoga Avenue Facility

- All employees of the Department of Energy, its predecessor agencies, and its contractors and subcontractors who worked at the Canoga Avenue Facility, Los Angeles, California, from January 1, 1955 through December 31, 1960 for a number of working 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 2010b).

NIOSH determined in 2010 (NIOSH 2010b) that it cannot estimate internal exposures with sufficient accuracy during the period from 1955 through 1960. This includes the entire covered period for the Canoga Avenue Facility. NIOSH found that it is likely feasible to reconstruct external dose, including occupational medical dose, for Canoga Avenue workers with sufficient accuracy.

Downey Facility

- All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Downey Facility in Los Angeles County, California, from January 1, 1948 through December 31, 1955, 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 included in the Special Exposure Cohort (NIOSH 2010c).

NIOSH determined in 2010 (NIOSH 2010c) that it cannot estimate internal exposures with sufficient accuracy during the period from 1948 through 1955. This includes the entire covered period for the Downey Facility so only partial dose reconstructions will be performed for individuals who do not qualify for inclusion in the SEC.

De Soto Avenue Facility

- All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the De Soto Avenue Facility in Los Angeles County, California, from January 1, 1959 through December 31, 1964, 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 included in the Special Exposure Cohort (NIOSH 2010d).

NIOSH determined in 2010 (NIOSH 2010d) that it cannot estimate internal exposures with sufficient accuracy during the period from 1959 through 1964. The De Soto Avenue Facility has a covered period of DOE 1959-1995 and DOE Remediation 1998. Therefore, dose reconstructions will be performed for 1965 through 1995 and partial dose reconstructions will be performed for individuals who do not qualify for inclusion in the SEC for 1959 through 1964.

5.1.3 Scope

The SSFL facility, which includes four locations, has been identified in various ways over time. This TBD uses SSFL to refer to all locations unless more specific location information is warranted. In that context, SSFL includes Area IV of the Santa Susana Field Laboratory [SSFL, which has also been

known as Nuclear Development Field Laboratory, Liquid Metal Engineering Center, and Energy Technology Engineering Center (ETEC)], portions of the Downey facility, the Canoga Avenue Facility, and the De Soto facility.

North American Aviation (NAA) entered into a contract with AEC to conduct nuclear research operations at Area IV and the Downey, Canoga and De Soto sites. At that time, Atomics International, an internal division of NAA, was the company's designated nuclear research and development division. In addition to the employees of the AI division, other employees of NAA who worked at any of the above sites during the AEC contract period are potentially eligible for EEOICPA benefits.

SSFL facilities, operated by The Boeing Company and its predecessors (North American Aviation), have played an important role in the development of the U.S. nuclear program. SSFL operations have involved research and development (R&D) in the areas of development and testing of nuclear reactors, nuclear support operations, and non-nuclear energy (Sapere and Boeing 2005, p. 2-2). This TBD is part of the overall SSFL Site Profile, which describes plant facilities and processes, historical information, and environmental data in relation to dose reconstruction for SSFL workers. It contains supporting documentation to assist in the evaluation of occupational internal doses from these processes in accordance with the *Internal Dose Reconstruction Implementation Guideline* (NIOSH 2002).

The methods and concepts of measuring occupational internal doses to workers have evolved since the beginning of SSFL operations. An objective of this document is to provide supporting technical data to evaluate internal SSFL occupational doses that can reasonably be associated with worker radiation exposures covered by the EEOICPA legislation.

In addition, this document presents the technical basis of methods used to prepare SSFL worker dose information for input to the NIOSH Interactive RadioEpidemiological Program (IREP) software. Information on measurement uncertainties is an integral component of the approach. This document describes the evaluation of uncertainty for SSFL exposure and dose records.

5.2 INTERNAL DOSIMETRY OVERVIEW

Section 2 of this Site Profile (ORAUT 2006) contains some of the following discussion of historical activities. However, this TBD discusses the information in the context of internal dosimetry.

From 1948 to 1955, the Atomic Energy Research Department (AERD) of North American Aviation (NAA) occupied a portion of Building 001 at the Downey Plant on Lakewood Boulevard in the City of Downey, California. On April 21, 1952, AERD constructed a small aqueous homogeneous reactor in an area that is now a loading dock. The reactor and its associated *exponential pile* were apparently used as a source of neutrons for reactor physics experiments. The Water Boiler Neutron Source (WBNS) used a 93%-enriched uranyl sulfate solution and operated at power levels up to 4 W. The WBNS operated at Downey until December 1955. In 1956, it was dismantled and moved to a facility at the SSFL. Little information is available about the specific uses of the area after the WBNS relocation. All available records indicate that the Plant was not left in a contaminated condition, and this was confirmed by a survey in 2000 (Liddy and Rutherford 2001). Other radioisotopes at the Downey Plant were apparently used for industrial radiography and were not a likely source of internal exposure [1].

In 1956, NAA formed SSFL as one of its divisions to replace AERD. Between 1956 and 1960, SSFL performed nuclear R&D at a facility known as the Canoga Avenue Facility (Vanowen Building, Building 038) in Canoga Park, California. SSFL designed, developed, and operated two small, aqueous, 93%-enriched uranyl sulfate research reactors at the Canoga Avenue Facility; the reactors

were designated L-47 and L-77. The maximum power ratings were 5 W and 10 W, respectively. Other operations included reactor design, fuel development, and radiochemistry. L-47 operated between August 1957 and June 1958, and L-77 operated between May 1958 and February 1960. The reactors were in the southeast corner of the building which is now a loading dock. Historical information indicates that the areas that supported nuclear operations were routinely surveyed until and after the removal of all radioactive material. No contamination above the current limits for unrestricted use was found. This was confirmed by a 1995 survey of the facility by the U.S. Nuclear Regulatory Commission (Rutherford 2002). Exposure of subsequent occupants to contamination levels of importance for internal dose reconstruction of the building would be unlikely [2].

In 1959, SSFL moved to a new facility on De Soto Avenue in Canoga Park and transferred all radiological activities from the Canoga Avenue Facility, including the L-77 reactor, to the new facility. Until 1983 nuclear operations were conducted at the De Soto facility in Buildings 101 and 104 (until 1984 these buildings were known as 001 and 004, respectively). Work continued at a "much-reduced level" in Building 104 until the mid-1990s. The L-77 reactor in Room 416-61 of Building 104 was decontaminated and decommissioned in the late 1970s. The facility was released for unrestricted use in February 1982. Many nuclear fuel manufacturing operations were conducted in the 1960s and 1970s in Buildings 101 and 104. These operations used 2%- to 93%-enriched uranium metal and composites. Most notable of these was fuel for the Advanced Test Reactor (ATR), which used uranium-aluminum alloy plates. This operation was the source of internal exposures that were difficult to evaluate because of the unanticipated insolubility and small particle size (when airborne) of the alloy. Attachment A summarizes these problems. Attachment H evaluates the impact of the uranium aluminide-specific model on intake and dose calculations.

Two other operations in Building 104 at the De Soto facility involved radioactive material. The Gamma Irradiation Facility (GIF) used sealed ^{137}Cs and ^{60}Co sources for hardness testing and food irradiation research. Biannual leak tests of these sources confirmed that internal exposures from these devices were unlikely. Operations ended in the late 1980s and, after the removal of all equipment, the State of California released the GIF for unrestricted use in July 1999. The other Building 104 operation, the Mass Spectroscopy Laboratory or Helium Laboratory, analyzed radioactive samples for helium content. Operations ended in 1995; the mass spectroscopy equipment was sent to Richland, Washington. In 1998, all remaining support equipment was removed and the facility was decontaminated. In October 1998, the State released the Helium Laboratory for unrestricted use. Thirteen separate radiation surveys in Buildings 101 and 104 demonstrated that no residual contamination existed that would be of interest for dose reconstruction (Boeing 2003).

SSFL consisted of four administrative areas and a buffer zone. NAA established Area IV in 1953 as a nuclear R&D facility. Starting in 1954, several nuclear reactors and critical assemblies were built in Area IV; but no nuclear operations took place until 1955. In 1959, a significant incident occurred when a sodium-cooled, graphite-moderated reactor in Building 4143 [the Sodium Reactor Experiment (SRE)] had a loss of coolant, which resulted in damage to 13 fuel assemblies (Sapere and Boeing 2005, pp. 2-1, 2-3, 2-5). A government-owned, contractor-operated organization was formed to conduct non-nuclear research at the site, which was renamed the Energy Technology Engineering Center (ETEC) in 1978. Most nuclear research programs and operations ended in 1988. All research ended in 1998. ETEC was given the job of decontaminating and decommissioning (D&D) at the former nuclear facilities. D&D is complete at many of the facilities in Area IV, but some of this work is still ongoing.

SSFL documents from the early 1960s describe all the elements of a comprehensive radiation safety program including a laboratory with bioassay capability. The program was under central direction and covered the facilities operated by SSFL (Lang undated, Lang 1960). There is one possible exception. The Organic Moderated Reactor Experiment (OMRE) was a SSFL facility at the National Reactor Testing Station (NRTS) in Arco, Idaho. NRTS apparently provided dosimetry services to SSFL

personnel (Lang 1960). It is uncertain, based on current information if any bioassay results were sent to SSFL.

SSFL established health and safety files on each employee that contained radiation exposure records, injury records, and other "pertinent" data. Even though records were established for each employee, this does not imply that all personnel were monitored. Only persons working in "radiation areas" were required to wear film badges and, in some cases, pocket dosimeters and finger rings. *In-vitro* bioassay samples were only obtained from workers whose assignments involved "potential internal exposure to radioactive materials" (Lang undated, Lang 1960). Between 1948 and 1999, the entire workforce of Rocketdyne/Atomics International employees numbered 46,970, most of whom were engaged in non-nuclear activities. A 2006 study determined 5,801 workers were monitored for external or internal radiation: 3,569 external radiation only, 58 internal radiation only, and 2,174 both internal and external radiation (Boice 2006). All personnel exposure records were retained at the site and are accessible and available (Sapere and Boeing 2005, p. 3-12).

The environmental monitoring program at Area IV was established in May 1954 before construction of the first radiological facility. Stack air emissions were measured in all facilities with radiological work areas or where unencapsulated or unpackaged radioactive material was handled. Gross alpha and beta activity was monitored on a weekly basis (Sapere and Boeing 2005, p. 3-13). From 1959 to the present, ambient gross beta activity in air has been measured continuously in five locations. From 1963 on, gross alpha activity was also measured. At present, ambient air samples are analyzed for isotopic content (Sapere and Boeing 2005, p. 3-15).

By 1959, routine urine samples were requested on Fridays, and each monitored employee was required to submit the first voiding on Monday morning (after an absence from work of 48 hr or more). The time of the previous voiding was recorded to determine the excretion rate. If the Monday morning sample was verified as positive, a series of 24-hr samples was collected to determine the body burden. Employees were requested to fill these samples on Sunday (Kellehar 1959). Appropriate adjustments to this schedule were made for weekend work, etc. Uranium urinalyses were performed for fuel fabrication workers, and gross beta or mixed fission product (MFP) urinalyses were performed for many workers at SSFL and the Canoga Avenue Facility. Commercial laboratories were available for analysis of alpha emitters other than uranium and for soft beta emitters (Alexander 1959). And eventually, most routine samples were analyzed by a vendor. Special samples were requested when an intake was suspected or if a routine sample exceeded 10% of the urinary excretion expected from 1 maximum permissible body burden (MPBB). Special samples were analyzed by the onsite laboratory, the commercial lab, or both (Kellehar 1966a).

Entry into the bioassay program at SSFL was apparently based on job assignment [3]. By the early 1960s, the bioassay program "normally" consisted of urinalysis for personnel whose work assignments involved "potential exposure to radioactive materials." The frequency of sampling varied from one to four per year, depending on the nature of the employee's work, past exposure history, etc. (Lang undated). A 1963 procedure called for completion of a "Request for Film Badge and Bioassay Services" form for new employees who required such services (Garcia 1963). Figure B-1 in Attachment B is an example. The Health and Safety Operation Unit completed the bottom portion, which included a place to specify bioassay for the employee.

In 1970, standards for bioassay sampling were published (Staszesky 1970). Work in areas where unencapsulated radioactive material was present required baseline and termination urine samples. A new baseline could be required for a change in job assignment. For new operations, a "pilot" bioassay program consisting of weekly urine samples could be required until a pattern was established. Regular work in these areas required a routine quarterly urine sample, but monthly samples could be required in a case of high exposure potential. Periodic fecal samples and *in vivo* counts could also be required. Employees who performed work in these areas only periodically were

subject to semiannual urine samples. Personnel such as project engineers, industrial engineers, etc., who frequently entered these areas but did not perform hands-on work, provided routine annual urine samples.

By the mid-1970s, the definition of who was included in the routine bioassay monitoring program had changed to "personnel whose work assignments potentially expose them to respirable-sized radioactive aerosols" (Hart 1979). By the late 1980s, the criterion was "personnel whose work assignments potentially expose them to radioactive aerosols" (Tuttle 1989). Quarterly urine sampling was standard through the 1980s (Hart 1979; 1980a,b,c; Eggleston 1983, 1984; Tuttle 1985, 1986a,b,c, 1988a,b, 1989).

Special bioassay that consisted of more frequent urine sampling was in place very early (1960), and in the mid-1970s fecal sampling was also used but "only when gross internal contamination" was suspected (Hart 1979). Using the concept of an MPBB, an excretion rate was determined for each radionuclide that would indicate that 1 MPBB had been received. For several years before 1968, the policy was to restrict employees from work in potential airborne areas until their body burdens were less than 25% of the MPBB (Alexander 1968a). Starting in January 1968, SSFL imposed a restriction from work in areas with potential airborne exposure (or in some cases from all radiation areas) if the bioassay results indicated the receipt of 50% or more of the MPBB. The restriction remained in place until two consecutive bioassay samples indicated that the remaining deposition was less than 25% of the MPBB (Staszesky 1970).

It appears that the first *in vivo* counting occurred in 1967 at a U.S. Atomic Energy Commission (AEC)-funded facility at the University of California, Los Angeles (UCLA). These counts were performed in conjunction with the insoluble enriched uranium (EU) intakes described in Attachment A. Although these counts were frequently referred to as whole-body counts (WBCs) or total-body counts (TBCs) in site documents, they were really attempts to quantify the amount of ^{235}U activity in the lung. At that time chest (lung) counting was in its infancy, and standard calibration methods using phantoms had not been developed. SSFL ultimately determined that the results of these counts were significant overestimates. From 1968 to 1983, *in vivo* counting was done on the site using portable counters operated by Helgeson Nuclear Services. Most of these counts were also chest counts for EU. Work with unirradiated highly enriched uranium (HEU) ended in 1983, and no more chest counts occurred (Tuttle 1986b). WBCs for fission and activation products apparently occurred during and after this period, probably in conjunction with suspected exposures or new projects [4].

Even though SSFL ended research activities with radioactive materials in 1988, the internal dosimetry program continued; most of the features of the program are listed above [5].

The bioassay records in the individual files generally consist of:

- Individual personnel McBee Keysort cards (Figure B-2, Attachment B), which were used to track the type, frequency, and week of sample collection. In addition, the card summarized individual results. The cards can be difficult to read due to the quality of the copies, and dose reconstructors should refer to the forms listed below for urine and fecal data. This card might be the only place that *in vivo* data are listed. Two versions were produced and used from 1963 to 1966 and from 1967 to 1970, respectively. The latter continued in use at least until 1983. This card was the successor to one that recorded only results before 1963 (example not included).

- Bioassay Data Sheets (Figures B-3 and B-4, Attachment B), which were two-page forms that contained all the information on analyses conducted by the onsite laboratory. Some, if not most, offsite analysis results were apparently transferred to this form.

- Individual analysis results sheets (Figures B-5 to B-10, Attachment B), which contained all the information on analyses conducted by offsite laboratories. This form might show the calculated result (even if it was below the limit of detection), the sensitivity of the analysis, and the uncertainty.

- Wound Monitoring Reports (Figure B-11, Attachment B). The entries on this form are self-explanatory.

- Individual hand-drawn or computer-generated plots of bioassay data, apparently done as follow-up to high results. Some can be difficult to read due to the quality of the copies.

- Incident workups after high bioassay results. These might contain data summaries in a more legible and understandable form than information in other locations because they were produced by health physicists familiar with the data.

5.3 *IN VITRO* MINIMUM DETECTABLE ACTIVITIES, COUNTING METHODS, AND REPORTING PROTOCOLS

5.3.1 *In Vitro* Urine Analysis

5.3.1.1 1948 to 1957

It appears that no bioassay program existed before August 1958. Useful source term data or facility-specific ambient airborne concentrations are probably not available. This unmonitored period includes the operation of the WBNS from 1948 to 1955 at the Downey Plant, the operation of the L-47 reactor at the Canoga Avenue Facility, and operations at SSFL from 1954 to 1957 (including, for example, the operation of the WBNS in 1956 and 1957). Documents that might indicate environmental releases or incidents from these facilities have not been found. Bioassay data after 1957 in similar facilities, such as the WBNS or L-77 reactor, might be the only data available to the dose reconstructor as an indicator of missed dose. Because these data would be from a different period, dose reconstructors should be cautious in applying them.

5.3.1.2 1958 to 1966

According to Kellehar (1966a) the bioassay program was initiated in August 1958. As mentioned above, routine bioassay was normally by urinalysis at a frequency of 3 months. At first, gross alpha or gross beta measurements were made of the samples. Specific radionuclides could be determined "where required" (Lang 1960). Some detail has been found on early urinalysis methods. In addition to the in-house laboratory capability, bioassay services were contracted to the following vendors:

- U. S. Nuclear, Burbank, California
- Controls for Radiation, Cambridge, Massachusetts
- Biomedical Procedures, North Hollywood, California
- Bio-Science Laboratories, Santa Monica, California
- Atomic Corporation of America, Panorama City, California
- United States Testing Company (UST), Richland, Washington

Information on what vendors were used by the site and when they were used has been captured in a bioassay data base. Due to various problems with the other laboratories (Fisher 1963), it appears that Bio-Science Laboratories analyzed the most samples early in this period. In 1964, SSFL initiated a contract with UST, which became International Technology Analytical Services, Quanterra Environmental Services, and finally Severn Trent Laboratories. UST appears to have been the main laboratory vendor between 1965 and 1968. After that time various vendors were used.

SSFL Uranium Methods [A and B (fluorometric) and EU (radiometric)]

The use of Method A and Method B to designate uranium bioassay methods apparently changed over the years. In general, it should be easy to distinguish fluorometric methods if the units were reported; fluorometric results were reported in mass (micrograms or milligrams) per unit volume rather than in radioactivity per unit volume. The fluorometric methods fused uranium from raw urine with sodium fluoride and measured the fluorescence when the compound was exposed to ultraviolet light. The uranium fluorescence can be quenched by certain heavy metal ions, and the primary difference between the two methods was that Method A considered these quenching effects negligible and that Method B took into account possible quenching effects (Mason and Burr 1958).

Due to its higher specific activity, EU activity could be determined by counting. The procedure involved digesting the urine, removing some of the interfering cations, and electroplating the uranium onto nickel disks. The disks were counted in a proportional counter (Mason and Burr 1958).

No specific information on sensitivities for the in-house laboratory was obtained. The following values for the contractor laboratories should be used for dose reconstruction because they should be comparable to the in-house laboratory [6].

Vendor Uranium Methods [codes: 1A (fluorometric) and 1B (radiometric)]

The fluorometric method was implemented during the first half of 1948 at AEC sites (ORAUT 2010, p. 30). In May 1959, U. S. Nuclear quoted a price for fluorometric analysis with a minimum measurable concentration of 0.002 µg/mL based on a minimum volume of 1 L (Shepard 1959). Controls for Radiation quoted 0.0001 µg/mL based on a minimum volume of 150 mL (O'Brien 1959). NSEC gave its minimum measurable concentration as 0.0002 µg/mL (Edelmann 1959).

The early radiometric methods generally used separation chemistry followed by counting on a gas-flow proportional counter or a ZnS(Ag) scintillation counter (ORAUT 2010, p. 30). Shepard (1959) quoted a minimum measurable concentration of 7.5 dpm/L for radiometric determination of EU. NSEC gave its minimum measurable concentration for EU as 20 dpm/24-hr sample (NSEC 1957).

Gross Alpha

Shepard (1959) gave a minimum measurable concentration of 7.5 dpm/L for gross alpha counting. NSEC gave its minimum measurable concentration as 2.0 dpm/mL (NSEC 1957).

Gross Beta

Shepard (1959) gave a minimum measurable concentration of 75 dpm/L for gross beta counting. NSEC gave its minimum measurable concentration as 4.0 dpm/mL (NSEC 1957).

Mixed Fission Products

The early procedure for MFPs was generally to add strontium carrier to the aluminum oxide solution for the plutonium procedure, then to precipitate lanthanum hydroxide. This procedure extracted rare earths and strontium with yields ranging from 90% for cerium to 23% for strontium. The dried planchet was counted for beta activity with an approximate minimum detectable amount (MDA) of 60 dpm/sample (ORAUT 2010, p. 34). This procedure separated and counted radionuclides of alkaline earths and rare earths such as strontium, yttrium, barium, lanthanum, cerium, europium, and promethium. It might not have accounted for radionuclides of ruthenium, cesium, zinc, cobalt, manganese, niobium, or zirconium (ORAUT 2010, p. 34). NSEC gave its minimum measurable concentration as 10.0 dpm/mL (NSEC 1957).

Polonium-210

Bio-Science used electrodeposition on a nickel disk and counting in a low-background proportional counter. The sensitivity quoted was 0.001 dpm/mL (Lee 1963).

Plutonium

One of the first plutonium bioassay analyses consisted of lanthanum fluoride precipitation, thenoyltrifluoroacetone (TTA) extraction, and gross alpha counting. Electrodeposition on a stainless-steel disk was followed by counting with nuclear track emulsion (autoradiography). Plutonium bioassay results are available as early as 1963. The urine maximum permissible concentration (MPC) that indicated 1 MPBB was listed as 4 dpm/24 hr. Therefore, in keeping with normal practice at the time, 0.4 dpm/24 hr would be the sensitivity required [7]. Bio-Science quoted a sensitivity for plutonium bioassay of 0.00006 dpm/mL, but stated that it would have to subcontract the analyses (Lee 1963).

Strontium-90

Bio-Science coprecipitated ^{90}Sr and ^{90}Y with calcium as oxalates. Yttrium-90 was isolated and purified using a *milking* procedure with tributylphosphate, assayed, and reported as ^{90}Sr equivalent. The method assumed that ^{90}Sr and ^{90}Y were in secular equilibrium. If not, counting could be delayed for ingrowth. The sensitivity quoted was 0.1 dpm/mL (Lee 1963).

Tritium

Tritium was not a significant personnel exposure hazard from research reactor operations, primarily due to the low power levels. However, 15 kCi of tritium in a triple-walled container was in Room 416-51 in Building 004 at the De Soto Facility until November 1967 (Alexander 1967a). The earliest viable method for tritium analysis seems to have been liquid scintillation counting of raw urine in a scintillation cocktail. NSEC gave its minimum measurable concentration as 2,220 dpm/mL (0.001 µCi/mL) (NSEC 1957).

Thorium

No details of early thorium analyses were found. Tracerlab analyzed three urine samples for SSFL in 1959. The detection limit was 0.2 µg/125-mL sample (Tracerlab 1959).

5.3.1.3 1967 to 1974

Partial documentation on bioassay methods from 1967 to 1974 was found. The sources of these data were mainly statements of work for bioassay services. These documents are believed to refer to services offered by UST (Kellehar 1966b, 1967; Spielman 1968; Bales 1969; Staszesky 1971). A review of the bioassay data captured confirmed that UST was the primary vendor during this period. Many of the methods listed in this TBD were undoubtedly in place before 1967.

Uranium Fluorometric (Procedure A)

The sample was acidified. A 100-µL aliquot was analyzed directly. Recovery was 93% ±18%. The detection limit was 0.5 µg/L. A fluorophotometer was used to measure the uranium.

Uranium Fluorometric (Procedure B)

Uranium was extracted from the ashed residual salts with methyl isobutyl ketone using a salting solution of acid lammonium hydroxide. A fluorophotometer was used to measure the uranium present. Recovery was 83% ±8%. The detection limit was 0.05 µg/L.

Uranium Radiometric (UR)

Uranium was isolated as in Procedure B above. It was measured by a gas-flow proportional counter or a ZnS(Ag) scintillation counter. Recovery was 83% ±8%. The detection limit was 0.5 dpm/sample. At SSFL the standard sample volume per day was 1,500 mL. The result was the total alpha activity.

Plutonium (Procedure A)

Plutonium was isolated by coprecipitation as the fluoride, extraction with TTA, and electrodeposition. Autoradiography was used to detect the plutonium. Recovery was 82% ±14%. The detection limit was 0.05 dpm/sample. At SSFL the standard sample volume per day was 1,500 mL. Plutonium results would have included activity from ^{238}Pu, ^{239}Pu, and ^{240}Pu, but not ^{241}Pu or ^{241}Am.

Plutonium (Procedure B)

Plutonium was isolated as in Procedure A and counted in a gas-flow proportional counter. Recovery was 85% ±10%. The detection limit was 0.5 dpm/sample. At SSFL the standard sample volume per day was 1,500 mL. Plutonium results would have included activity from ^{238}Pu, ^{239}Pu, and ^{240}Pu, but not ^{241}Pu or ^{241}Am.

Tritium

Tritium was determined by liquid scintillation counting of an aliquot of the sample. Recovery was 100% ±10%. The detection limit was 5,000 dpm/mL.

Polonium

Polonium was spontaneously deposited on a silver disk from a dilute hydrochloric acid solution of the residual salts. The disk was alpha counted. Recovery was 93% ±7%. The detection limit was 0.5 dpm/sample.

Strontium

Strontium was isolated by precipitation as the oxalate and then as the nitrate. Yttrium was removed by a nitric acid wash. Barium was removed as the chromate. Strontium was precipitated as the carbonate and counted with a gas-flow proportional counter. This provided a gross strontium result. Recovery was 85% ±9%. The detection limit was 4 dpm/sample. After the ingrowth of ^{90}Y (in 2 wk), the ^{90}Y was isolated as the hydroxide, and then as the oxalate, which was burned to the oxide and counted in a gas-flow proportional counter. The ^{90}Sr was computed from the ^{90}Y, which was in secular equilibrium at separation time. Recovery was 78% ±11%. The detection limit was 4 dpm/sample.

Thorium

Thorium was isolated by a double fluoride precipitation and extraction with TTA followed by spectrophotometric determination with morin. Recovery was 78% ±12%. The detection limit was 1.0 µg for a 1,000-mL sample. Thorium-232 was determined by planchetting the thorium fraction and alpha counting. The detection limit was 0.5 dpm/sample.

Phosphorus-32

Phosphorus-32 was separated first as the phosphomolybdate and then as the magnesium ammonium phosphate, which was planchetted and beta counted in a gas-flow proportional counter. Recovery was 86% ±7%. The detection limit was 4 dpm/sample.

Sulfur-35

The sample was ashed to drive off tritium and carbon and counted by liquid scintillation techniques. Recovery was 95% ± 10%. The detection limit was 10 dpm per sample for a 1-mL sample aliquot.

Carbon-14

Carbon-14 was determined by liquid scintillation techniques. Recovery was 65% ±15%. The detection limit was 10 dpm for a 1-mL sample aliquot.

Gross Alpha

Gross alpha was determined by extracting most actinides from a 9N nitric acid solution into diethyl ether. This provided recoveries from 80% to 99% of most actinides. The detection limit was 1 dpm/sample.

Gross Beta

Gross beta was determined from a beta count of the ashed residual salts. A ^{40}K correction could be made. Recovery was 95% ±5%. The detection limit was 2 dpm for a 50-mL sample.

Promethium-147

Promethium-147 was chemically isolated by precipitation as the fluoride and extraction into TTA then counted by liquid scintillation techniques. Recovery was 83% ±10%. The detection limit was 5 dpm/sample. In 1967, for at least one case of suspected promethium exposure (^{147}Pm-oxide), bioassay analyses were performed on urine and fecal samples (Alexander 1967a).

Americium and Curium

Americium and curium were isolated from contaminating actinides with bis-2-(ethylhexyl) phosphoric acid (HDEHP) in toluene extraction out of 4N HNO_3. Americium and curium were extracted into the HDEHP toluene solution at a pH of 4.5, back-extracted using 4N HNO_3, electrodeposited, and counted using alpha spectroscopy. The recovery was 80% ±15% with a detection limit of 0.5 dpm/sample.

Gross Fission Products

Gross fission products were precipitated as the oxalate from a basic solution, planchetted, and beta counted in a gas-flow proportional counter. Recovery for all fission products averaged 82% ±5%. The detection limit was 5 dpm/sample based on the counting efficiency of the radiologically critical isotopes ^{90}Sr and ^{90}Y. A *gamma scan* was used for routine detection of certain gamma-emitting radionuclides. The gamma scan was performed by counting a sample in the well of a NaI(Tl) crystal and feeding the pulses to a multichannel pulse height analyzer. The simultaneous measurement of more than one radionuclide using gamma energy analysis precluded making accurate statements about detection limits and precision. The laboratory offered a table of detection limits per sample

based on experience; this information appears in Attachment F. Lower detection limits than those in the table were available at extra cost. Other gamma-emitting radionuclides could be determined.

5.3.1.4 1975 to 1988

The following analytical methods were taken from a series of annual reports (Hart 1979, 1980a,b,c; Eggleston 1983, 1984; Tuttle 1985). The measurement type in parentheses (e.g., "UR") appears in many personnel bioassay records. The detection limits should have improved over the years, but a listing was not found. The reports list positive results for the year and, in some cases, follow-up results. The follow-up results were examined to see if the lowest value reported as nonzero could be determined. In general, there were not enough data to provide a satisfactory result. Therefore, dose reconstructors will have to use the detection limits in the previous section or, in some cases, on the individual results.

Uranium Radiometric (UR) and Uranium Fluorometric (UF)

Uranium was extracted from an acidic solution of ashed urine using aluminum nitrate, tetrapropyl ammonium hydroxide, and methyl isobutyl ketone. The uranium was recovered by back-extracting into water by evaporating to ketone. The water solution was planchetted for alpha counting for the UR analysis. The result was the total alpha activity.

Fluorometric analysis required removal of an appropriate aliquot of the water solution before planchetting for pelletizing with NaF-LiF. The pellet was analyzed for uranium with a fluorometer. Most uranium samples were apparently analyzed by using both techniques.

Mixed Fission Products (FP1)

MFPs were precipitated from a basic oxalate media. By adjustment of pH and oxalate concentrations, elements that are amphoteric or that form oxalate complexes in the form of excess oxalate were also precipitated. Alkali metals such as ^{137}Cs did not precipitate. In addition, volatile fission products such as ^{131}I were lost. The precipitate was washed with NAOH and water and planchetted for counting.

Mixed Fission Products (FP2)

FP2 used the same extraction procedure as FP1; however, the soluble oxalate precipitates were gamma counted for ^{137}Cs and other gamma emitters. The results from the FP1 analysis and the FP2 analysis were summed and reported as a single value.

Mixed Fission Products (FP3)

This analysis was the same as FP2 except oxalate-insoluble results were reported separately as FP3a and oxalate-soluble results were reported separately as FP3b. The FP3a analysis was assumed to indicate ^{90}Sr, but other radionuclides, such as ^{60}Co, might also have been detected. Further analysis was used to quantify ^{90}Sr specifically and to identify interfering radionuclides if significant quantities occurred. The FP3b analysis was selective for ^{137}Cs using gamma-ray spectroscopy (Tuttle 1988a).

Plutonium (PUA, PUB)

After reduction to plutonium (III) and (IV) with hydroxylamine hydrochloride, plutonium was precipitated with lanthanum fluoride. This isolated the plutonium from most elements (including uranium), except for thorium, rare earths, and actinides. After oxidation of plutonium with sodium nitrate in acid media, extraction of plutonium was performed with 0.5 M TTA in xylene. After

extraction, the aqueous solution containing plutonium was neutralized and concentrated by heating. After oxidation of the plutonium in a basic media, it was electrodeposited on a stainless-steel disc. The plutonium activity was determined by autoradiography (PUA) for greater sensitivity or counted for alpha radiation with a proportional counter (PUB). Plutonium results would have included activity from ^{238}Pu, ^{239}Pu, and ^{240}Pu, but not ^{241}Pu. The PUA analysis was chemically selective for plutonium and excluded the ^{241}Am that is generally present (Tuttle 1986b).

Gross Beta, High Level (GBH)

The gross sample was evaporated to dryness then organically digested by hydrogen peroxide and nitric acid. The natural potassium (^{40}K) correction was determined by diluting the ashed salts to a known volume and removing an aliquot for flame spectrophotometry. The remaining solution was evaporated to near dryness, planchetted, and counted for beta radiation with a proportional counter. The radioactivity in the urine sample due to ^{40}K was subtracted from the gross count.

Gross Alpha (GA1a)

This analysis was specific for uranium and plutonium, which were extracted from ashed urine salts using aluminum nitrate, tetrapropylammonium hydroxide, and methyl isobutyl ketone. Transuranic elements did not extract to any appreciable extent. Uranium or plutonium (or both) was recovered by back-extracting into water by evaporating the ketone. The uranium or plutonium was electrodeposited on a stainless-steel disc and autoradiographed.

Gross Alpha (GA1b)

This was the same analysis as GA1a except the extraction solution was planchetted and counted for alpha radiation with a proportional counter.

Gross Alpha (GA2)

This analysis was specific for all alpha emitters. Metabolized actinides were converted to states suitable for coprecipitation with alkaline earth phosphates by digesting the gross urine sample in 10% nitric acid. The actinides were coprecipitated with calcium phosphate by neutralizing the acid solution with ammonia. The precipitate was washed, planchetted, and counted for alpha radiation with a proportional counter.

Appendix G lists the sensitivities by bioassay code for UST and the other laboratories. These were assumed by the SSFL bioassay program to be the defaults. If another value was reported by the laboratory (for example, "<2.2 dpm/day"), that value was taken to be the sensitivity (reporting level). Dose reconstructors should refer to Attachment G for a comprehensive list of the bioassay codes and the SSFL default isotopes and sensitivities for each code during the site's history. See Section 5.6 for guidance on determining MDAs from the sensitivities in Attachment G.

5.3.1.5 1989 to 2005

By 1989, all R&D activities had ended. All work with radioactive materials since then has been in conjunction with ongoing D&D activities. Controls for Environmental Pollution (CEP), International Technology (IT) (formerly UST), Eberline, and Teledyne (now Teledyne Brown Engineering) were the main bioassay vendors. CEP performed bioassay analyses in 1991, 1992, and 1993. Sample results from CEP are considered invalid and these results should not be used for determination of intake. However, if results of samples analyzed by CEP are found in a worker's record, the worker should be considered as monitored for the purposes of assigning dose. No analytical procedures were recovered for this period, but they were probably based on the earlier methods discussed above. The

collection methods, etc., appear to be very similar to those used in previous years. The routine sampling strategy was to use generic screening urinalyses (gross alpha and gross beta minus ^{40}K). If positive results were found, dose assessments were performed using default radionuclide mixtures or more specific analyses were performed (Barnes 1999). Periodic *in vivo* measurements were performed to detect intakes from gamma emitters likely to be present at SSFL (^{137}Cs, ^{60}Co, ^{154}Eu, etc.).
Particle size measurements were generally not performed in conjunction with routine workplace monitoring. Worker breathing-zone air samples were collected (Barnes 1999), but it is unclear if this information was incorporated into individuals' dosimetry records.

Since 1992, bioassay results returned from the vendor have been entered into a computer database (Boeing Canoga Park Internal Dosimetry Tracking System). A database with results back to about 1960 was developed from results hand-entered for an epidemiology study (Boice 2006). In general, the entire sample was not used for the requested analysis; therefore, multiple results for one sample are possible.

According to the health physicist responsible for internal dosimetry in 2005, no positive results have been reported since 1998. The sensitivities required for each analysis were published (Barnes 1999) and are listed in Table 5-6 in Section 5.6.

5.3.2 *In Vitro* Methods for Individual Radionuclides

The methods for individual radionuclides are covered for the specific periods under the sample types (i.e., urine and fecal).

5.3.3 Fecal Sample Analysis

Although fecal sampling was mentioned both as a routine and a special bioassay method in site documents, little detail has been found about the analytical methods used. In 1967 all bioassay samples were wet ashed with nitric acid and hydrogen peroxide. A salt fusion was added for fecal samples to ensure recovery of all radionuclides. An aliquot was apparently analyzed using methods similar to those discussed for urine sampling.

Detection limits for various isotopes in fecal samples were found for 1967. From 1975 to 1988, when the number of total and positive tests was well documented, only a few fecal samples were mentioned, but this might have been because this series of reports did not always make the distinction between fecal and urine sampling, that latter of which was by far the more common bioassay medium.

In 1967 bioassay analyses were performed on fecal samples for a case of suspected promethium exposure (Alexander 1967b). Fecal samples for uranium were also apparently taken in conjunction with the investigation into the uranium aluminide exposures in 1967 (see Attachment A). Tables of total samples and positive results for 1975 and 1976 show analysis type codes for uranium fecal samples (F-UF and F-UR), but it appears that no such analyses occurred in those years (Hart 1979, 1980a). In 1982, positive PUA fecal results were reported for two individuals (one sample each) (Tuttle 1985).

Due to the lack of information found, the urine MDAs for gross alpha or gross beta listed in Table 5-3 in Section 5.6 should be converted to dpm/day and used for fecal analyses before 1967 if the sensitivity was not reported by the laboratory [8]. From 1967 on, the values in Table 5-4 in Section 5.6 should provide estimates favorable to claimants because detection limits probably were lower with time [9].

Table 5-1 lists the frequencies for *in vitro* monitoring.

Table 5-1. Internal dose control program (*in vitro*).

Routine monitoring type	Period	Frequency
Urine, single void[a]	1958–1988	Quarterly, semiannual, annual, based on job
Urine, single void, H-3	1958–1966	Weekly, based on job

a. Sample requested on Friday; first voiding on Monday morning requested. Positive samples were verified and followed with at least one 24-hr sample collected on Sunday.

5.4 *IN VIVO* MINIMUM DETECTABLE ACTIVITIES, COUNTING METHODS, AND REPORTING PRACTICES

5.4.1 Whole-Body Counting

Although Helgeson Nuclear Services regularly visited the site to conduct chest counts for ^{235}U (see Section 5.3.2), WBCs for fission or activation products were apparently not part of the routine bioassay program at SSFL. Between 1975 and 1988, only 25 counts on 25 individuals were summarized in annual reports. In the same period, 385 chest counts were completed. All WBCs were reported positive for ^{137}Cs [10]. Ten counts were performed in 1977, and 15 were performed in 1979. The counts were probably performed when intakes were suspected but could have been project-ending counts. Although only ^{137}Cs was reported in the summaries, undoubtedly a wide spectrum was scanned that would have detected other high-energy gamma emitters such as ^{60}Co with a reasonably low detection level [11]. Barnes (1999) stated that WBCs occurred "periodically," but the meaning of that term is not clear.

5.4.2 Chest Counting

In 1967, the first chest (lung) counts for uranium using a medical system were performed at UCLA. The 186-keV gamma ray from the decay of ^{235}U was used to quantify the amount of EU in the lung by scintillation spectrometry (Tuttle 1986a). Calibration of this system was crude; it used a point source rather than a distributed source that would better simulate the radioactivity in a lung. The point source contained more ^{234}U than the uranium fuel, so the activity-to-mass conversion was off by about a factor of 2. Moreover, no chest-wall thickness corrections were made. The first two corrections amounted to initial lung burdens that were about a factor of 4 too high. The correction for chest-wall thickness would have depended on each individual. This system was not used after 1967. It is uncertain to what extent corrections were made to individual employee records. Dose reconstructors could use these data for overestimates that would be favorable to claimants. For more realistic calculations, it would be best to rely on urine and fecal data if those data are available.

Starting in 1968, Helgeson Nuclear Services provided lung-counting services using equipment and techniques specifically developed to measure lung deposits of uranium. The first counts in 1968 were performed with a 0.5-in. by 8-in. NaI(Tl) detector in the shadow shield used for WBCs. A crude Masonite phantom was used for calibration, and the results included a chest-wall thickness correction. The individual was raised on an air mattress until the chest was flush with the bottom of the detector. The counts took 40 min. The results were reported in milligrams of ^{235}U ±2 sigma, with the uncertainty based on counting statistics alone (Helgeson 1968).

By 1977, two 5-in.-diameter, thin-window phoswich detectors were used, which provided a reduction in Compton scattered background by a factor of 4 in the ^{235}U region. In addition, the counting chamber was fully shielded. These changes enabled reduction of the counting time to 20 min. The calibration was similar to that described for 1968 but was cross-checked with the phantom used at Oak Ridge National Laboratory (ORNL). The minimum sensitivity was reported to be 30 to 60 µg of ^{235}U and 1 to 3 mg of natural uranium or DU (Helgeson 1978, 1983). Calibration was performed with a phantom that contained a known amount of ^{235}U and a known chest-wall thickness. The resultant

gross pulse height spectrum was adjusted for background by subtracting an assumed background spectrum that consisted of a straight line passing through the gross count values just below and just above the pulse height spectrum region corresponding to 186 keV. The net count was adjusted for chest-wall thickness and converted to mass of ^{235}U based on the calibration (Tuttle 1986a).

Until 1981 the results of lung count measurements were reported as zero if a result was below the 2-sigma uncertainty based on counting statistics. The results were reported as the actual value if they were equal to or greater than the 2-sigma uncertainty. Starting in 1981 Helgeson Nuclear Services was asked to report all values regardless of the assigned uncertainty. An analysis of uncensored data along with counts of three individuals with no history of uranium exposure was reported in 1986 (Tuttle 1986a). This analysis estimated that the Helgeson results were biased high by 32.5 µg of ^{235}U when only natural levels were present. This suggested that the straight-line approach to subtracting background was not appropriate when measuring background subjects. At values approaching the maximum permissible lung burden (MPLB), the background subtraction method was less important. The MPLB for ^{235}U was 245 µg. Dose reconstructors can consider the values reported by Helgeson as overestimates favorable to claimants. For a more realistic estimate, dose reconstructors should adjust the lung count results by assuming a linear relationship of the bias between 0 and 1 MPLB as indicated in Attachment C. Above 1 MPLB, no adjustment in the results is recommended.

Helgeson apparently also performed special counts as requested by the site. These included counts for ^{241}Am and might have included counts for plutonium and thorium. Where these counts appear in worker records, dose reconstructors should consider a less-than value as the reporting level (decision level) and the MDA should be taken as twice the less-than value [12]. Helgeson was purchased by Neutron Products around 2003.

Table 5-2 lists the frequencies for *in vivo* monitoring.

Table 5-2. Internal dose control program (*in vivo*).

Routine monitoring type	Period	Frequency
Chest count U-235 (UCLA)	1967–1968[a]	Monthly as long as count indicated >½ of lung burden (0.02 µCi)
Chest count U-235 (ORNL)	1967[b]	One time
Chest count U-235 (Helgeson)	1968–1983 (EU work ended in 1983)	Three times/yr, 14–21 personnel selected for measurement each time
WBC Cs-137 (Helgeson)	1977, 1979	Uncertain[c]
WBC (Helgeson/Neutron Products)	1989–2005	Periodically[d]

a. Counts performed to follow up suspected enriched UAl_x exposures in the powder room. The UCLA counter was not used after April 1968 (Tschaeche 1968a).
b. Counts of one employee as a cross-check on the UCLA calibration (Alexander 1967a).
c. It is unknown if these counts were routine or special.
d. Frequency not specified in Barnes (1999).

5.5 UNCERTAINTY

At SSFL the uncertainty for a single bioassay measurement was not reported consistently. Reviewed statements of work for bioassay services do not contain any specification for reporting uncertainty. UST results were apparently reported with a 2-sigma uncertainty if they were above the MDA. Bio-Science reported a 95% confidence interval (at least in some cases). The individual analysis results sheets (Figures B-5 to B-10, Attachment B) might show the uncertainty for individual measurements. Due to the calibration and other problems discussed above, the estimated error in the early UCLA lung-counting results for ^{235}U was ±200% at 1 sigma. The stated uncertainty for the Helgeson lung counts was about ±25% at 1 sigma (Tschaeche 1968b).

5.6 DETECTION LIMITS

Urine results above the lower limit of detection (LLD), sensitivity, MDA, etc., were used to calculate the percentage of the MPBB received by the worker. The normalized result (1,500 mL/d) was divided by a standard excretion rate for 1 MPBB to produce this percentage. If possible, the worker followed with additional urine samples until the results were less than the laboratory LLD, which was the lowest value at which radioactivity was considered to be present with reasonable certainty (Tuttle 1989). No exact definitions of these terms have been found. In effect, the detection limit value was used as the reporting level. Most results appear to have been reported with an uncertainty of 2-sigma error or a 95% confidence interval. If the uncertainty included zero, the result was considered to be background (i.e., no radioactivity detected in the sample). Assuming the uncertainties in the background and the sample were equal, the detection limits published in site documents were closer to decision levels [13]. That is, there is only an approximate 5% chance that results at this level are really background results (false positives). The MDAs would be approximately twice these values to ensure that there is only an approximate 5% chance that results at the MDA would not be detected (false negatives). The detection limits recovered are listed in the tables as the reporting levels. Because the detection limits in the tables were mainly collected from contract documents, the reported sensitivity (less-than values) in the worker records should be used to determine the MDA in lieu of the values listed in these tables. If no sensitivity is reported, then dose reconstructors should use the MDA listed in Tables 5-3 to 5-6.

Tables 5-3 to 5-6 list MDAs and reporting levels for periods corresponding to the bioassay methods discussed in Sections 5.3 and 5.4. The reporting levels are listed in the units quoted in the references, which are generally the units of the results. However, various volumes were used to report the results. In general, the excretions assumed when reporting per sample or per day were 1,500 mL for urine samples and 135 g for fecal samples [14].

Table 5-3. Detection limits, 1958 to 1966.[a]

Radionuclide	Method/ description	MDA[b]	Reporting level[c]
Gross alpha	Urine	15 dpm/L (U. S. Nuclear)	7.5 dpm/L
Gross beta	Urine	150 dpm/L (U. S. Nuclear)	75 dpm/L
Gross beta (minus K-40)	Urine	0.4 dpm/mL (Bio-Science) 0.04 dpm/mL (UST)	0.2 dpm/mL 0.02 dpm/mL
H-3	Urine	10,000 dpm/mL (Bio-Science) 10,000 dpm/mL (UST)	5,000 dpm/mL 5,000 dpm/mL
MFP (gross)	Urine	0.2 dpm/mL (Bio-Science) 0.04 dpm/mL (UST)	0.1 dpm/mL 0.02 dpm/mL
Po-210	Urine	0.02 dpm/mL (Bio-Science) 0.02 dpm/mL (UST)	0.01 dpm/mL 0.01 dpm/mL
Plutonium	Urine	0.0006 dpm/mL -(UST)	0.0003 dpm/mL
Sr-90	Urine	0.2 dpm/mL (BioScience) 0.04 dpm/mL (UST)	0.1 dpm/mL 0.02 dpm/mL
Thorium	Urine	0.0004 µg/mL (Bio-Science) 0.0004 µg/mL (UST)	0.0002 µg/mL 0.0002 µg/mL
Uranium	UF-1A Urine	0.004 µg/mL (U. S. Nuclear) 0.0002 µg/mL (Controls for Rad.) 0.0004 µg/mL (Bio-Science) 0.0004 µg/mL (UST)	0.002 µg/mL 0.0001 µg/mL 0.0002 µg/mL 0.0002 µg/mL
Uranium (enriched)	UR-1B Urine	15 dpm/L (U. S. Nuclear) 0.012 dpm/mL (Bio-Science) 0.012 dpm/mL (UST)	7.5 dpm/L 20.006 dpm/mL 0.006 dpm/mL

a. The date of the reference to the reporting levels, which are the best information available for 1958 to 1966.

b. Assumed to be twice the sensitivity (see text). The reported sensitivity (less-than values) in the worker records should be used to determine the MDA in lieu of the values listed in this table. These values should also be used for the in-house laboratory.
c. U. S. Nuclear from Shepard (1959), Controls for Radiation from O'Brien (1959), NSEC from Edelmann (1959) and NSEC (1957), Bio-Science from Lee (1963), and Tracerlab from Tracerlab (1959). UST results that were considered to be less than detectable generally have the reporting level included with the result.

Table 5-4. Detection limits, 1967 to 1974.[a,b]

Radionuclide	Method/ description	MDA[c]	Reporting level[d]
Ca-45	Urine	10 dpm/mL	5 dpm/mL
Ca-45	Urine	0.06 dpm/mL	0.03 dpm/mL
Ca-45	Feces	30 dpm/sample	15 dpm/sample
Cs-137	FP3b Urine	60 dpm/sample	30 dpm/sample
Gross alpha	Urine	0.02 dpm/mL	0.01 dpm/mL
Gross alpha	Urine	0.010 dpm/mL	0.005 dpm/mL
Gross alpha	Feces	4 dpm/sample	2 dpm/sample
Gross beta (less K-40)	Urine	0.08 dpm/mL	0.04 dpm/mL
Gross beta	Feces	4 dpm/sample	2 dpm/sample
H-3	Urine	10,000 dpm/mL	5,000 dpm/mL
I-131	Urine	0.12 dpm/mL	0.06 dpm/mL
I-131	Urine	0.4 dpm/mL	0.2 dpm/mL
MFP (gross)	Urine	0.04 dpm/mL	0.02 dpm/mL
MFP (gross)	Feces	16 dpm/sample	8 dpm/sample
Plutonium	Urine	0.8 dpm/sample (estimated)	0.4 dpm/sample (estimated)
Plutonium	Radiographic Urine	0.0006 dpm/mL	0.0003 dpm/mL
Plutonium	Procedure A Feces	2 dpm/sample	1 dpm/sample
Plutonium	Procedure B Feces	4 dpm/sample	2 dpm/sample
Polonium	Urine	0.02 dpm/mL	0.01 dpm/mL
Polonium	Feces	6 dpm/sample	3 dpm/sample
Pm-147	Urine	0.10 dpm/sample	0.05 dpm/sample
Radium	Urine	0.010 dpm/mL	0.005 dpm/mL
Radium	Feces	20 dpm/sample	10 dpm/sample
Sr-90	Urine	0.04 dpm/mL	0.02 dpm/mL
Sr-90	Feces	16 dpm/sample	8 dpm/sample
Sr-90	FP3a Urine	60 dpm/day	30 dpm/day
Thorium	Urine	0.002 µg/mL	0.001 µg/mL
Thorium	Feces	6 µg/sample	3 µg/sample
Uranium	UF Urine	0.006 µg/mL (10-mL volume)	0.003 µg/mL (10-mL volume)
Uranium	UF Urine	0.0004 µg/mL (100-mL volume)	0.0002 µg/mL (100-mL volume)
Uranium	UF Feces	4 µg/sample	2 µg/sample
Uranium (enriched)	UR Urine	0.012 dpm/mL	0.006 dpm/mL
Uranium (enriched)	UR Feces	4 dpm/sample	2 dpm/sample
U-235	IVLC (UCLA)	0.8 mg	0.4 mg
U-235	IVLC (Helgeson)	60–120 µg (depends on chest-wall thickness)	30–60 µg

a. IVLC = *in vivo* lung count.
b. The date of the reference to the reporting levels, which are the best information available for 1967 to 1974.

c. Assumed to be twice the sensitivity (see text). The reported sensitivity (less-than values) in the worker records should be used to determine the MDA in lieu of the values listed in this table.
d. U-235 IVLC (UCLA) from Saxe (1967a). *In vitro* values are primarily from UST contract documents (Kellehar 1966b, 1967; Spielman 1968; Bales 1969; Staszesky 1971).

Table 5-5. Detection limits, 1975 to 1988.[a]

Radionuclide	Method/description	MDA[b]	Reporting level[c]
Cs-137	FP3b Urine	60 dpm/sample	30 dpm/sample
Cs-137	WBC	4 nCi	2 nCi
Plutonium	PUA Urine	0.0990 dpm/sample	0.0495 dpm/sample
Sr-90	FP3a Urine	60 dpm/d	30 dpm/d
U-235	IVLC (Helgeson)	60–120 µg (depends on chest wall thickness)	30-60 µg
Uranium (total)	UF Urine	0.60 µg/d	0.30 µg/d
Uranium (enriched)	UR Urine	7.5 dpm/d	3.75 dpm/d

a. The date of the reference to the reporting levels, which are the best information available for 1975 to 1988.
b. Assumed to be twice the sensitivity (see text). The reported sensitivity (less-than values) in the worker records should be used to determine the MDA in lieu of the values listed in this table.
c. Sr-90, U (total), and EU (1987, 1988) from Tuttle (1988b, 1989).

Table 5-6. Detection limits, 1989 to 2005.[a]

Radionuclide	Method/ description	MDA[b]	Reporting level[c]
Gross alpha	Urine	15 dpm/1,500 mL	7.5 dpm/1,500 mL
Gross beta	Urine	30 dpm/1,500 mL	15 dpm/1,500 mL
Gross beta, corrected for K-40	Urine	45 dpm/1,500 mL	22.5 dpm/1,500 mL
Gamma scan	Urine	60 dpm/1,500 mL	30 dpm/1,500 mL
Sr-90	Urine	6 dpm/1,500 mL	3 dpm/1,500 mL
UF	Urine	15 µg/1,500 mL	7.5 µg/1,500 mL
Uranium alpha spectroscopy	Urine	3 dpm/1,500 mL	1.5 dpm/1,500 mL
Thorium alpha spectroscopy	Urine	3 dpm/1,500 mL	1.5 dpm/1,500 mL
Plutonium alpha spectroscopy	Urine	3 dpm/1,500 mL	1.5 dpm/1,500 mL
Am-241	Urine	0.90 dpm/1,500 mL	0.45 dpm/1,500 mL
H-3, distillation	Urine	3000 dpm/1,500 mL	1,500 dpm/1,500 mL
H-3, electrolytic enrichment	Urine	60 dpm/1,500 mL	30 dpm/1,500 mL
WBC (Co-60)	WBC	4 nCi	2 nCi

a. The date of the reference to the reporting levels, which are the best information available for 1989 to 2005.
b. Assumed to be twice the sensitivity (see text). The reported sensitivity (less-than values) in the worker records should be used to determine the MDA in lieu of the values listed in this table.
c. Sensitivity reported in Barnes (1999, Table D-1).

5.7 SAMPLE KIT INFORMATION

Table 5-7 lists sample kit information summarized from various site documents.

Table 5-7. Excreta sample media and types.[a]

Media	Sample description
Urine	Routine samples. Single voiding collected on Monday morning before returning to work. Collected in single bottle. Also referred to as *rate samples*. Positive samples were followed up with additional rate sample for verification. Time of sample collection and previous voiding were recorded. Normally collected in a 16-oz container. By 1999, 1-L polyethylene containers were used. It appears that one full container (900–1,000 mL) was collected and collection time noted.
Urine	24-hr samples. Used for follow-up to verify rate samples or for incidents. One or more samples could be requested. Single samples were collected at home on Sunday. Collected in 32-oz or 1-L polyethylene containers.
Urine	Spot samples. For follow-up to incidents, spot sample could be collected as soon as possible. This sample was probably collected in 16-oz container.
Feces	Could be requested in conjunction with urine samples as follow-up to incidents. No descriptions of historical fecal kits were located. By 1999, single voiding samples were collected in 83-oz polyethylene containers. The minimum mass that was considered adequate was 30 g.

a. No codes to identify sample kits were used at SSFL. Requests were color-coded for a time, but these do not appear in the individual records.

5.8 SOLUBILITY TYPE, ACTIVITY FRACTION, AND PARTICLE SIZE BY FACILITY

In the absence of any measurements or studies, NIOSH guidance requires the use of default solubility classes and particle size values from the International Commission on Radiological Protection (NIOSH 2002, pp. 15–16). With one exception, facility-specific solubility and particle size data for SSFL have not been found. Activity fractions were not available with the exception of those for limited fuel fabrication operations. For research reactors using highly enriched fuels, values from Shleien, Slaback, and Birky (1998) have been listed as an approximation. In some cases, default assumptions from Barnes (1999, Table D-3) have been used to estimate the activation products using a ratio to the fission products. Table 5-8 lists this information.

The behavior of UAl_x in the powder room workers was found to differ from the standard ICRP absorption types. A study in 2005 (Leggett, Eckerman, and Boice 2005) developed a new model that fits the excretion data. This model cannot be directly implemented in IMBA. Calculations performed using other software indicate that the standard ICRP 66 models (types F, M and S) with IMBA will generally provide favorable to claimant dose estimates for chronic intakes. For acute intakes where the application of types F, M, and S all yield a POC<52%, alternate software will be required to model the behavior of UAl_x in the lungs. In this case, contact the Principal Internal Dosimetrist for assistance. See Attachments A and H for additional details.

Several non-nuclear energy research programs were conducted in Area IV. The primary non-nuclear R&D activities were performed at the Liquid Metal Engineering Center, which became ETEC. The facilities that performed non-nuclear research are not included in Table 5-8 unless they were also used for nuclear research (Sapere and Boeing 2005, p. 2-12).

In the 1960s, a test was conducted that involved dropping a 1-kg DU slug from a helicopter. The slug was apparently never recovered. No contamination was found in the area (Sapere and Boeing 2005 p. 2-13). It is unlikely that this event would contribute significantly to the internal dose of occupationally exposed workers, and it has not been included [15].

Table 5-8. Solubility type, activity fraction, and particle size by facility.[a]

Facility[b]	Compound[c]	RN[d]	Particle size[e] (µm AMAD)	Activity fraction[f]
Downey Plant **Building 001** WBNS reactor 1948–1955 **Canoga Avenue Facility** **Building 038** L-47, L-77 reactors 1956–1960 **De Soto Facility** **Building 104** L-77 reactor 1960–1979? **Area IV, SSFL** **Building 4073** KEWB reactor 1956–1966 **Building 4093** L-85 reactor 1956–1980	Homogeneous water boiler-type reactors – 93%-enriched uranyl sulfate solution in H_2O. Reactors operated at low power levels (4-10 W).	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
De Soto Facility **Building 101** Powder room & new powder room 1966–1968 & 1979–1982	Uranium aluminide fuel fabrication –alloy of uranium and aluminum. See Attachment A for information on solubility. See Attachment H for the impact of the uranium aluminide-specific model on intake and dose calculations.	U-234	1	See Table 5-9
		U-235	1	See Table 5-9
		U-236	1	See Table 5-9
		U-238	1	See Table 5-9
Building 4143 SRE 1957–1964 *Decontaminated* *1974–1983* *Storage facility* *1983–1999* *Demolished* *1999*	High-temperature, sodium-cooled, graphite-moderated EU reactor (site of loss-of-coolant accident in 1959) – unalloyed uranium metal thermally bonded by NaK in stainless-steel tubes. 1957-July 1959, core was 2.78% EU September 1960, 2nd core began operation. Core was 7.6 % (weight) Th-232 with 93% EU (AI 1959)	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	

Facility[b]	Compound[c]	RN[d]	Particle size[e] (µm AMAD)	Activity fraction[f]
		Eu-154	5	
		Th-232	5	
		H-3	NA	
Building 4010 SER 1959–1960 S8ER 1963–1965 **Building 4024** S2DR 1961–1962 S10FS 1965–1966 SNAP TTF 1971 **Building 4028** STR 1961–1964 STIR 1964–1972 **Building 4059** S8DR 1968–1969	SNAP reactors – "fully enriched" uranium dispersed in zirconium hydride fuel rods	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	
		Eu-154	5	
		H-3	NA	
Building 4012 SNAP CTF 1962–1968 HMRFSR 1970–1972 **Building 4373** SNAP CTF 1957–1963 **Building 4019** SNAP FSCF 1964–1965	Critical test facilities – SNAP development test facilities (fully EU dispersed in zirconium hydride fuel rods)	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
Building 4009 OMR CF	Critical test facilities – civilian nuclear power test facilities, EU low-power reactors. HEU and DU used and stored also.	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	

Facility[b]	Compound[c]	RN[d]	Particle size[e] (µm AMAD)	Activity fraction[f]
1958–1967 SGR CF 1958–1967 *High-energy rate forging* 1980s *DU storage* Early 1990s		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	
		Eu-154	5	
Building 4100 AETR test facility 1960–1974 Radiation Instrument Calibration and Radiological Sample Counting Laboratory 1985–present	Critical test facilities – thorium- and uranium-fueled reactors – 20 different reactor core configurations studied. The AETR's first 9 core configurations (through 1965) contained various amounts of U-233 and Th-232 and were driven by 93% EU fuel (Mountford and Morewitz 1965). The activity fractions are the medians of the cores studied. Only very small amounts of the other radionuclides listed were likely to have been produced, but they were listed as radionuclides of concern by Boeing.	Sr-90	5	
		Cs-137	5	
		U-233	5	9.81E-01
		U-234	5	1.83E-02
		U-235	5	5.71E-04
		U-238	5	6.63E-06
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Eu-152	5	
		Eu-154	5	
		Th-232	5	1.05E-03
		H-3	NA	
Bldgs. 4003 **4163, 4041,** **4654, 4689,** **4653, 4606,** **4773** SRE Support Complex 1954–1964 Analysis of SNAP fuel burn-up & irradiation experiments 1965–1973	Nuclear support operations – SRE fuel assembly (uranium and thorium metal slugs), contained radioactive "hot cave," tanks, hoods, and lines until 1975. SRE fuel loaded in 1960 was 7.6 % (weight) Th-232 with 93% EU (AI 1959)	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	
		Eu-154	5	

Facility[b]	Compound[c]	RN[d]	Particle size[e] (µm AMAD)	Activity fraction[f]
		Th-232	5	
Building 4005 Uranium Carbide Fuel Pilot Plant 1958-1993	Nuclear support operations – pilot plant for uranium-carbide fuel production in 1966-1977, first using DU and then EU	U-234	5	
		U-235	5	
		U-238	5	
Building 4011 Radiation Instrumentation Calibration Laboratory 1984–1996	Nuclear support operations – sealed sources. In 1960, a radioactive liquid spill from OMRE shipping cask occurred west of building.	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	
		Eu-154	5	
Building 4030 Van deGraaff Accelerator 1960–1964	Nuclear support operations – neutron source, used H-3 target	H-3	NA	1
Building 4020 Hot Laboratory 1957–1988 *D&D Completed 1999*	Nuclear support operations – used to examine fuel from SRE, SER, S2DR, S8DR, S10FS-3, and outside reactors. Fuel disassembled or separated from cladding.	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	
		Eu-154	5	
		Pm-147	5	
Building 4023 Liquid Metals Component	Nuclear support operations – tests with sodium loops containing radioactive contaminants	Sr-90	5	
		Cs-137	5	
		Co-60	5	

Facility[b]	Compound[c]	RN[d]	Particle size[e] (µm AMAD)	Activity fraction[f]
Test Building 1962–1986		Eu-152	5	
		Eu-154	5	
Building 4029 Radioactive Measurement Facility 1959–1974	Nuclear support operations – leaking calibration source contaminated source well	Ra-226	5	1
Building 4055 NMDF 1967–1979	Nuclear support operations – development work involving Pu DU work 1967	U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
Building 4064 Fuel Storage Facility 1958–1993 *D&D in 1997*	Nuclear support operations – secure storage of unirradiated fuel (EU and Pu); after removal of fissionable material in mid-1980s, radioactive waste (soil) stored until 1993.	Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	
		Eu-154	5	
Bldgs. 4021, 4022 RMHF 1959–present	Nuclear support operations – radioactive waste processing from onsite programs; 2005 storage area from D&D activities	Sr-90	5	See ORAUT (2007)
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Am-241	5	
		Co-60	5	
		Eu-152	5	
		Eu-154	5	

Facility[b]	Compound[c]	RN[d]	Particle size[e] (µm AMAD)	Activity fraction[f]
		H-3	NA	
Building 4363 Mechanical Component Development & Counting 1956–1963	Nuclear support operations – in 1962, work done on contaminated component from SRE accident	Sr-90	5	0.5
		Cs-137	5	0.5
17th Street Drainage 1959?–1999	Areas of known contamination – runoff from SNAP facilities	Cs-137	5	1.0
OCY Late 1960s–late 1970s	Areas of known contamination – spill detected in 1976 (MFPs suspected)	Sr-90	5	0.5
		Cs-137	5	0.5
Building 4886 Former Sodium Disposal Facility 1956–1978	Areas of known contamination – storage drums contaminated with residual radioactivity. SRE fuel loaded in 1960 was 7.6 % (weight) Th-232 with 93% EU (AI 1959)	Sr-90	5	
		Cs-137	5	
		U-234	5	
		U-235	5	
		U-238	5	
		Pu-238	5	
		Pu-239	5	
		Pu-240	5	
		Pu-241	5	
		Th-232	5	
		H-3	NA	

a. The Acronyms and Abbreviations list spells out the terms in this table.
b. Facilities were combined for this analysis if they were similar and had a common list of radionuclides of concern.
c. If chemical compounds were not available, the best description found is listed.
d. RN = radionuclide; radionuclides are the radionuclides of concern from Sapere and Boeing (2005, Tables 2-1, 2-2 and Section 2.0). Radionuclides were not included if they were an activation product limited to steel and rebar, had a short half-life, were a naturally occurring isotope consistent with natural background, or had not been observed in soil measurements. This list may be expanded to include radionuclides that were likely present during operations at the reactor facilities using ORAUT (2007).
e. Defaults used except for the powder room.
f. Activity fractions for fission products calculated from available information for non-reactor facilities. ORAUT (2007) provides guidance on the assignment of radionuclide-specific intakes of mixed fission and activation products when air sampling or urinalysis data associated with reactors or reactor fuels are available only as gross or total beta activity or gross or total gamma activity.

5.9 FACILITY-SPECIFIC RADIONUCLIDE CONVERSIONS

SSFL fabricated fuel for the ATR and the Engineering Test Reactor (ETR) in 1966, 1967, and 1968 at the De Soto Facility in Room 1110-62, Building 101 (known at the time as Building 001); Attachment D contains details. A second fuel fabrication campaign for the ATR was completed in 1979 and 1980; Attachment E contains details. These are the only two operations for which facility-specific data were made available. These data are summarized in Table 5-9.

Table 5-9. Facility-specific radionuclide conversions.

Process description	Activity per unit mass (Bq/g uranium)			
	U-234	U-235	U-236	U-238
EU fuel fabrication, Room 1110-62 (powder room), Building 101, De Soto Facility, 1966–1967	1.35E+06	7.44E+04	7.31E+03	7.50E+02
ATR EU fuel fabrication, 1979–1982 Building 101, De Soto Facility	2.37E+06	7.44E+04	1.14E+04	6.79E+02

5.10 RADON

For dose reconstruction under EEOICPA, occupational radon exposure is exposure to radon emanating from sources other than those that occur naturally in the area. Dose reconstructors must subtract the natural background level of radon exposure from any measured values when assessing occupational exposure (NIOSH 2002, p. 32). SSFL was not a processing or storage location for large quantities of ^{226}Ra or ^{222}Rn. Radon measurements were made from December 1989 to February 1990 in several facilities; none of the areas measured exceeded 2 pCi/L, and all but one was less than 1 pCi/L [18].

5.11 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.

[1] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007. This statement is based on the fact that industrial radiography sources are sealed sources which have been subject to leak testing from the earliest days of their use.

[2] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007. By definition, unrestricted use limits are protective of the general public.

[3] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007. This observation is based on the descriptions of the bioassay program in several site documents. It appears to have been formalized in Garcia (1963) if not sooner.

[4] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007. Examples of these counts were observed in the site records. See Section 5.4.1.

[5] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007. See Barnes (1999) for a description of the internal dosimetry program in the later years.

[6] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
This statement is based on the assumption that all of the early laboratories had essentially the same technical capabilities.

[7] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
Ten percent of the amount indicating one MPBB. See the description in Section 5.2.

[8] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
This method provides a reasonable workaround for fecal samples where the sensitivity is not reported.

[9] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
This statement is based on the observation that the radiochemistry techniques for analyzing bioassay samples have improved over time and counting equipment has become better and more reliable.

[10] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
During the time frame discussed, it was common to detect ^{137}Cs in individuals exposed only to radioactive fallout from weapons tests. This statement does not imply that the results were necessarily due to site activities.

[11] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
It is a common practice when performing gamma spectroscopy to identify all prominent peaks in the energy spectrum. The sensitivity statement is based on the fact that ^{60}Co has high energy gamma rays that are readily detected in whole body counting systems.

[12] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
See section 5.6 for the rationale behind this statement.

[13] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
The level at which radioactivity is determined to be present with reasonable certainty is termed the “decision level” or “critical level.”

[14] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
Determined from an inspection of various site documents.

[15] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.

The contamination, if any, resulting from this incident is likely confined to a relatively small subsurface area.

[16] Potter, Eugene. M. H. Chew & Associates. Consultant Health Physicist. October 2007.
Results are from a DOE indoor radon study of multiple facilities, reported in 1991.

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GLOSSARY

cladding
The outer layer of material encasing a reactor fuel element (e.g., aluminum or zirconium). Cladding promotes the transfer of heat from the fuel to the coolant and contains fission products and activation products that result from the fissioning of the fuel.

core
That part of the reactor consisting of the fuel and some of the control elements for reactor operation.

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

fission
A nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.

fission product
Radionuclides resulting from fission.

ionizing radiation
Electromagnetic or particulate radiation capable of producing charged particles through interactions with matter.

in vitro
Literally, in glass; outside the living body and in an artificial environment; internal bioassay sampling, such as fecal samples or urine samples.

in vivo
Literally, in the living; in the living body of a plant or animal; bioassay sampling by whole-body counting.

isotope
Nuclides having the same number of protons in their nuclei (same atomic number), but a differing number of neutrons (different mass number).

lower limit of detection (LLD)
Minimum level at which a particular device can detect and quantify exposure or radiation. Also called limit of detection and detection limit or level.

natural uranium
Uranium that has not been through an enrichment process.

radiation
Energy transferred through air or some other media in the form of particles or waves (see ionizing radiation).

radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, gamma or X-rays, or neutrons from unstable atoms.

radionuclide

A radioactive species of an atom characterized by the constitution of its nucleus specified by atomic number (the number of protons) and the mass number (equal to the number of protons plus neutrons).

type

The rate of absorption from lung to blood of inhaled radioactive materials and includes types F (fast), M (moderate), and S (slow).

U.S. Atomic Energy Commission (AEC)

An agency established by the U.S. Government for oversight of nuclear weapons and power production; a predecessor to the U.S. Department of Energy.

zirconium

A metallic element highly resistant to corrosion and often used to make cladding for nuclear fuel. It is sometimes alloyed in small amounts in the fuel itself.

ATTACHMENT A
SUMMARY OF URANIUM FUEL FABRICATION INTERNAL DOSIMETRY ISSUES
Page 1 of 2

SSFL began fabricating reactor fuel elements in the fall of 1965. SSFL fabricated fuel for the ATR and the ETR from 1966 to 1968 at the De Soto Facility. In Room 1110-62 of Building 101 (known at the time as Building 001), briquettes of an alloy of 93% EU and aluminum known as uranium aluminide (UAl_x) were formed in an electric arc melting furnace. These briquettes were crushed to form a powder, which was cold-pressed into compacts that became the cores of the fabricated fuel plates. The room where these activities took place was known as the *powder room*. The work was performed at six workstations: Weighing station 1, a melting station, a crushing and sieving station, weighing station 2, a compact-forming station, and a deburring station. The operations were performed with containment thought to be appropriate for the type of operation and the hazard of the material. From one to four air samplers operated in the room near the workstations.

In 1967 after 15 mo of operation, urine bioassay data indicated that the material was probably insoluble and, therefore, that the air activity was not being compared to the appropriate MPC. Although the uranium was more than 93% ^{235}U by weight, ^{234}U accounted for more than 96% of its activity. The insoluble MPC for ^{234}U was a factor of 6 lower than the soluble MPC. This led to the conclusions that the regulatory standard (weekly average MPC) had been exceeded on a number of occasions and that equipment and procedures for controlling the airborne uranium were insufficient.

An internal investigation determined that the primary reason for the ineffective confinement of the uranium was leakage from the crushing glovebox seal, from the fume hood of weighing station 2, and from the arc furnace. Temporary measures were put in place until more permanent controls could be implemented. These changes were put in place and the project was completed. Along with the engineering changes, workers were required to wear full-face respirators and lapel air samplers (Saxe 1967b). At some point, operations were relocated to the *new powder room*.

Of 83 wk of operation, the MPC for insoluble ^{234}U (1×10^{-10} µCi/cm^3) was exceeded in 33 wk. Twenty-one personnel who had worked in the powder room were monitored by chest counting. Three of these personnel were determined to have exceeded the MPBB and received work restrictions. The results for the other workers ranged from no detectable intake to less than 1 MPBB.

On August 15, 1967, a report of regulatory violations was submitted to the AEC. The report included the corrective measures taken (Sax 1967b). Inquiries by the AEC led to a review of an earlier fuel fabrication project, the Japan Atomic Energy Research Institute (JAERI), which took place in Room 1110-061. This operation involved uranium metal plates enriched to 20% by weight. The activity of the material was still approximately 90% ^{234}U. This operation did not involve crushing, but deburring the edges of the plates occurred during the process. This apparently took place outside ventilated enclosures until January 1967. An investigation into the JAERI fuel operation led to the conclusion that the average weekly concentration for insoluble ^{234}U had been exceeded six times during the operation in November and December 1966. The soluble standard (6×10^{-10} µCi/cm^3) would not have been exceeded. The insoluble standard was used because of the experience with UAl_x and the lack of evidence that uranium metal should be treated differently. Using this standard, five people had been exposed to concentrations greater than the AEC MPC. None of these people were involved in the ATR or ETR project (Remley 1967). Urinary excretion was measured on all five workers. The data were consistent with short-term exposures with small lung depositions. However, one of the workers initially showed a lung burden 1.5 times the MPBB. As stated in the main text, lung counting was its infancy during this time. The estimate for this worker was later reduced to 0.5 MPBB, based on the difference in enrichments between the JAERI material and the calibration source for the lung counter at UCLA.

ATTACHMENT A
SUMMARY OF URANIUM FUEL FABRICATION INTERNAL DOSIMETRY ISSUES

Air samples collected before 1966 were reviewed, and no concentrations exceeded 1×10^{-10} µCi/cm^3 (Saxe 1967c). A particle size study consisting of two general area air samples from the powder room indicated that the particles were less than 1-µm count median diameter (CMD) (Alexander 1967c). The actual CMD and geometric standard deviation were not provided in the reference; therefore, the AMAD could not be determined. In the only other particle size reference found, Baurmash (1967) measured the particle size distribution for a UO_2 grinding operation in the "processing room in Bldg. 1." The CMD reported for this operation was 0.195 µm with a geometric standard deviation of 1.66. The mass median diameter was calculated as 0.42 µm. Using a density of 10.97 g/cm^3 for UO_2, the AMAD for this aerosol is 1.39 µm. While this information is extremely limited, it points out that small particle sizes were at least possible during uranium fuel fabrication. Therefore, dose reconstructors should consider a 1-µm AMAD particle size for these operations in addition to the default assumption.

A study of the solubility of UAl_x in simulated lung fluid was completed by SSFL in 1968. While the original study has not been found, a reference to it indicates that UAl_x was about 10 times more insoluble than the most insoluble uranium compound (U_3O_8) measured by ORNL (Alexander 1968b). ICRP (1979) lists U_3O_8 as a class Y compound. The quality of the SSFL study is uncertain. ICRP (1994) lists the most insoluble compounds of uranium as type S.

As part of an epidemiological study, doses from intakes of radionuclides were estimated for workers employed during a 52-yr period at Rocketdyne/SSFL. Based on this work, Leggett, Eckerman, and Boice (2005) summarized the behavior of UAl_x in the powder room workers and described material-specific parameter values of the International Commission on Radiological Protection (ICRP) Human Respiratory Tract Model (HRTM) (ICRP 1994) needed to fit the data. See Attachment H for an evaluation of the impact of the uranium aluminide-specific model on intake and dose calculations.

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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LIST OF FIGURES

Figure B-1 shows an example of an AI Request for Film Badge and Bioassay Services form.

Figure B-2 shows the individual personnel McBee Keysort card. The following numbers correspond to the handwritten numbers on the card. The cards were set up for a 4-yr period (Kellehar 1966a).

1. Frequency
2. Week of collection
3. Date of each specimen collection, wound, and nasal smear
4. Indication of analysis results; degree of positive results in any year
5. Type of analyses required
6. Changes in work affecting analyses and/or specimen collection (reverse side)
7. Special bioassays (reverse)

This is the master record for internal dosimetry results. This lists the type of analysis and the per-day results of those analyses.

Date is the date the sample was obtained from the individual. Type lists the type of sample obtained. Method is a code to identify the procedure used. An incomplete record exists of the specific laboratory techniques associated with these methods. When results are listed as "<XXX," *XXX* is used as the reporting level rather than the value listed in the table.

In general, unless otherwise noted, listed results are in dpm per day (for radiological data) or micrograms per day (for fluorometric or other chemical analyses). Results were standardized to a 1,500-mL/d urine excretion rate or a 135-g/d fecal excretion rate. The results line up with the methods. Statistical errors were generally not provided but can be obtained by manual search of the source data.

The back side of the Keysort card sometimes has additional bioassay data. No results are listed on this side of the card, but it can be useful for determining the work location of the individual and possibly the type of work being done at the time.

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EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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PM-1
Appendix A-1
July 1, 1963
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ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

TO: Health and Safety Laboratory Unit ADDRESS: 779-21 Headquarters #004

FROM: Health and Safety Operations Unit ADDRESS:

PHONE: DATE:

SUBJECT: Request for Film Badge and Bioassay Services

To be Completed by Employee Requiring Services

In accordance with federal, state and local regulations, a complete occupational radiation history is maintained on employees subject to personnel monitoring and/or bioassay. Therefore, please fill in the information requested below.

1. Name_____ 2. Serial #_____

3. Social Security #_____ 4. Birth Date_____

Occupational Exposure - Previous History

5. Previous Employments Involving Radiation Exposure - List Name and Address of Employers	6. Dates of Employment (From-To)	7. Periods of Exposure

NOTE: If you listed one of the Military Services as a former employer where radiation exposure was involved, please give Service Serial Number_____.

Certification: I certify that the exposure history listed in columns 5, 6, and 7 is correct and complete to the best of my knowledge and belief.

_____
Employee's Signature Date

To Be Completed by Health and Safety Operations Unit

Work Area Code #_____ Film Badge Type $\beta\gamma$ _____ $\beta\gamma\eta$ _____

Employee's Supervisor_____

Will bioassay services be required? Yes No

Signed:_____
Health and Safety Operations

Figure B-1. Example of an AI Request for Film Badge and Bioassay Services form, 1963.

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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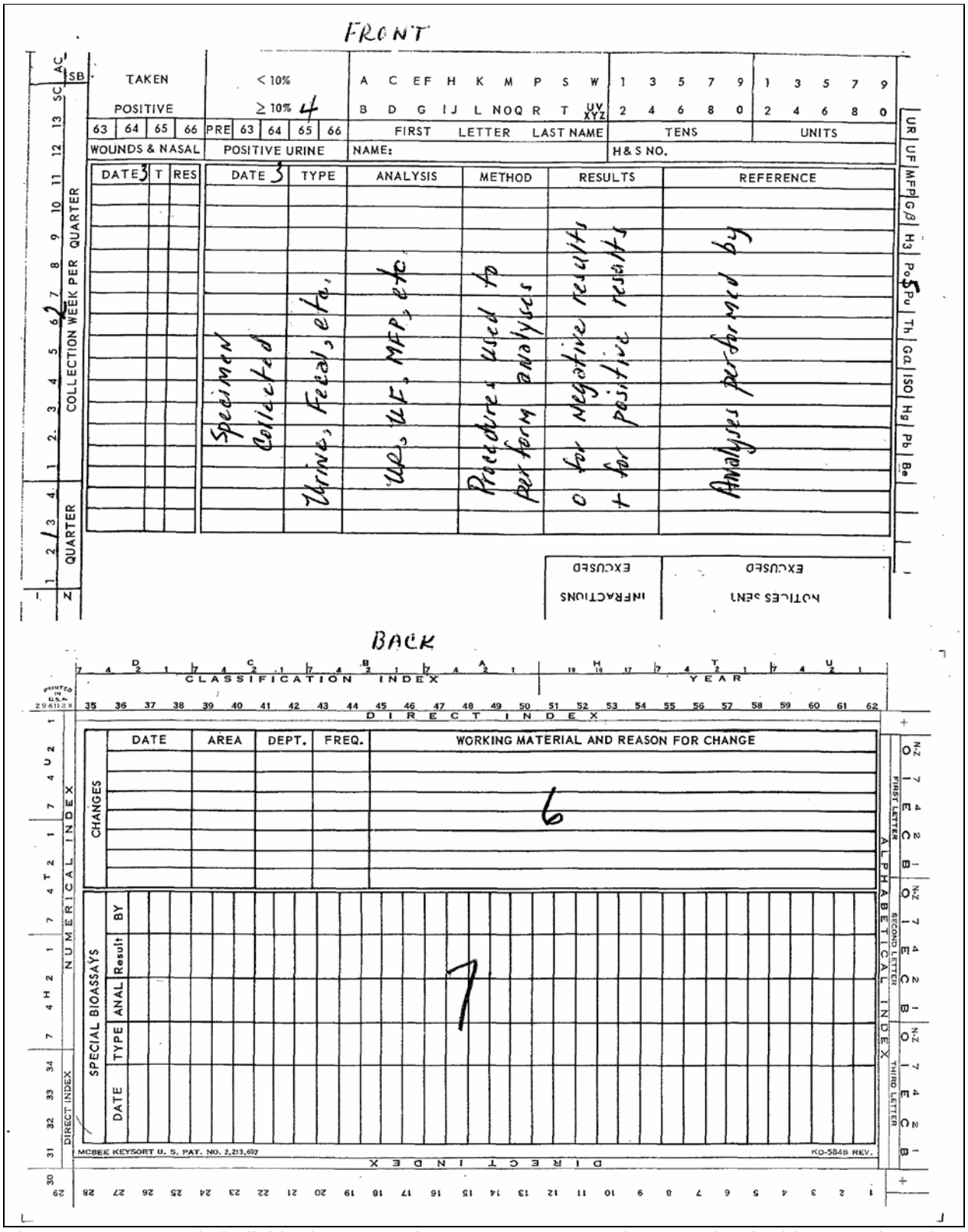

Figure B-2. Example individual personnel McBee Keysort card, 1966. (Both sides are shown).

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS

Special bioassays might also be listed on this side of the card; these generally suggest that the bioassay was taken in response to a specific incident. However, absence of bioassay data on this side of the card should not be interpreted as an indication that the individual was never involved in an incident.

Figures B-3 and B-4 show the front and back of the Bioassay Data Sheet. This sheet records bioassay results when a determination was made in the SSFL laboratory (it also appears to have been used to log in and document vendor results that were sent in tabular form). It was designed to be a multipurpose form for use with all types of analyses.

The general concept of the sheet was that all steps of a hand calculation could be performed by entering the appropriate data and performing the indicated mathematical operations. The calculations on this side of the page were preliminary; the sample results are listed on the second page of this form.

Some results are penciled in on the top right corner of the page. The calculations are relatively straightforward. They are typical for a radiochemical or radiological laboratory. Multiple count blocks were provided; it appears this was used to log in sequential counts to determine half-lives of the isotopes. Information blocks are self-explanatory.

Only those blocks on the form pertinent to the type of measurement were filled in, so the dose reconstructor can use this to determine the type of sample.

Figure B-5 shows an example Bio-Science Laboratories UF Bioassay Data Sheet.

These are the record of entry reports from the vendor laboratory that processed urine and fecal bioassay results. These records should be correlated to the bioassay summary records on the McBee Keysort cards (Figure B-2). The individual's name is usually written in pencil in the upper left margin.

The Source Number probably refers to an identification code for SSFL, the Report Date is the date the results were available, and the number in the Patient block is the Health Physics ID Number used to identify the person. The meaning of the No. Spec. Type entry is not known at this time. It is sometimes blank.

Entry Date refers to the date that the sample was received for processing. In general, it is 1 to 2 d after the date the sample was obtained by Rocketdyne from the individual. This date is from the McBee Keysort card.

Results are generally reported in micrograms of uranium per 100 mL of samples. Positive samples usually have values prorated into per-day rates using 1,500 mL/d as a urine excretion rate and 135 g/d for a fecal excretion rate.

Dividing the UR values by the UF values results in a specific activity for the sample. This specific activity can then be used to estimate the general enrichment level of the uranium to which the individual was exposed. For simplicity, for low intakes, the SSFL practice was to model the intake as pure ^{234}U (which results in overestimation of true dose).

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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BIOASSAY DATA SHEET

☐ Routine ☐ Special - Date, Time of Incident_____
Name_____ Area_____ H.&S.#____

For Person-nel Expo-sure Record	Date Sampled	Sample Type	Analysis	Method	Quarter Dose, rem	Quarter / Yr	Reference

Sampling Data	1	Specimen H.&S.#					
	2	Type (Urine, Feces, etc.)					
	3	Date, Time of Previous Void ΔD_1					
	4	Date, Time Specimen Voided* ΔD_2					
	5	Mid-excretory to First Count ΔT_1	hrs				
	6	Vol. or Wt. of Specimen	ml-mg				
Preparation Data	7	Analysis					
	8	Method					
	9	Vol. or Wt. Analyzed (Sample)	ml-mg				
	10	Date, Time Ppt. Began ΔD_3					
	11	Start of Ppt. to First Count ΔT_2	hrs				
	12	Ppt. or Residue + Planchet Wt.	mg				
	13	Planchet Wt.	mg				
	14	Ppt. or Residue Wt.	mg				
	15	Planchet Area	cm^2				
	16	Ppt. or Residue Thickness	mg/cm^2				
Radiometric — First β Count Additional Counts on Back	17	Date, Time Count Began ΔD_4					
	18	Total Count Ng_1	c				
	19	Counting Time Tg_1	min				
	20	Gross Count Rg_1	c/m				
	21	K40 Rk_1**	c/m				
	22	Background Control Rb_1	c/m				
	23	Net Count ± Rs_1	c/m				
	24	Fssa					
	25	Efficiency Factor					
	26	Total Activity per Sample	d/m				
	27	Total Activity per Specimen	d/m				
	28	24 Hr. Volume	d/m				
	29	Analysis by					
	30	Reference					
Radiometric — First α Count Additional Counts on Back	31	Analysis					
	32	Method					
	33	Vol. or Wt. Analyzed (Sample)	ml-mg				
	34	Date, Time, Count Began α ΔD_4					
	35	Total Count α Ng_1	c				
	36	Counting Time α Tg_1	min				
	37	Gross Count α Rg_1	c/m				
	38	Background Control α Rb_1	c/m				
	39	Net Count ± α Rs_1	c/m				
	40	Fssa					
	41	Efficiency Factor					
	42	Total Activity per Sample	d/m				
	43	Total Activity per Specimen	d/m				
	44	24 hr. Volume	d/m				
	45	Analysis by					
	46	Reference					

Figure B-3. Example Bioassay Data Sheet, front (used by onsite laboratory).

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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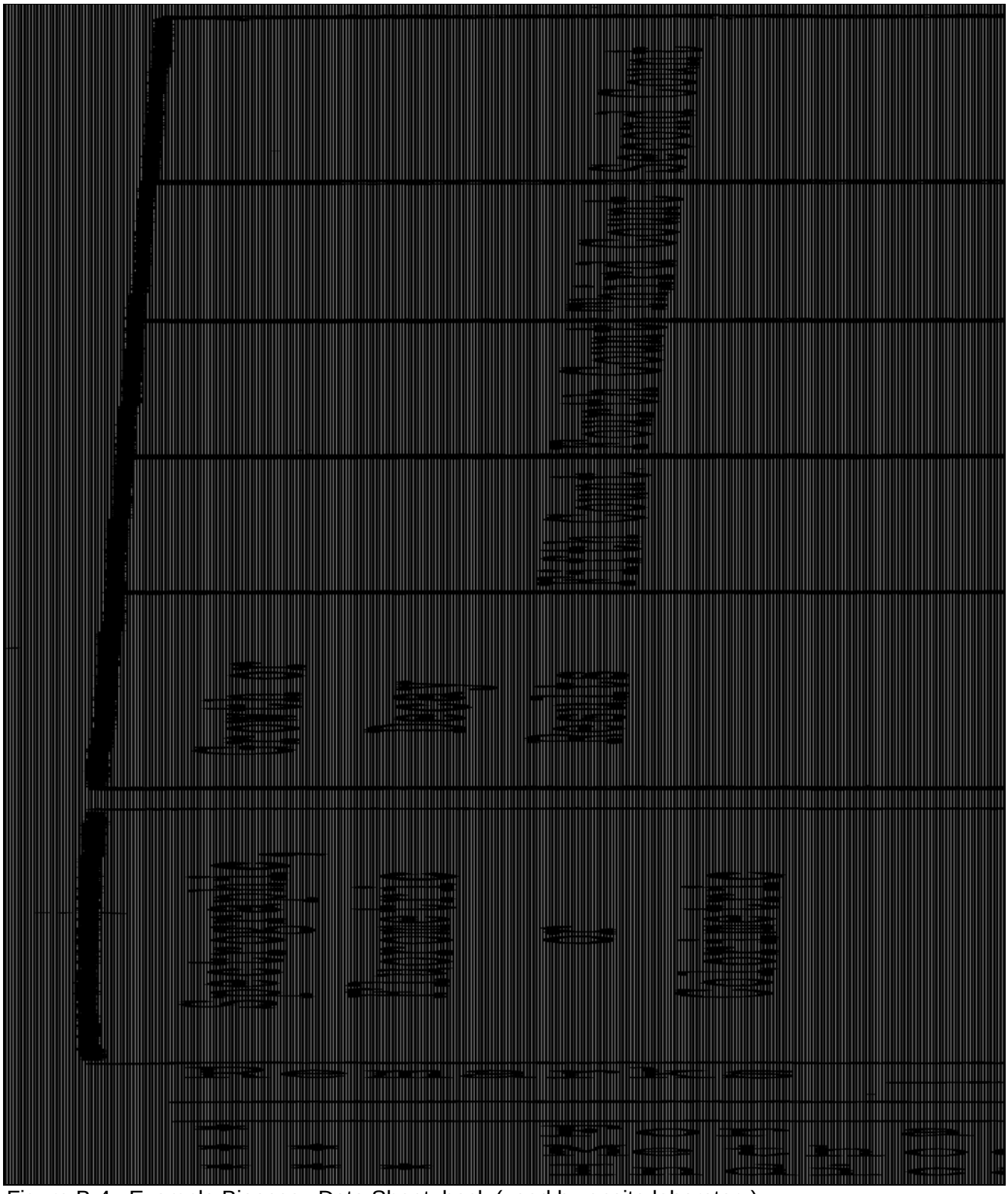

Figure B-4. Example Bioassay Data Sheet, back (used by onsite laboratory).

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EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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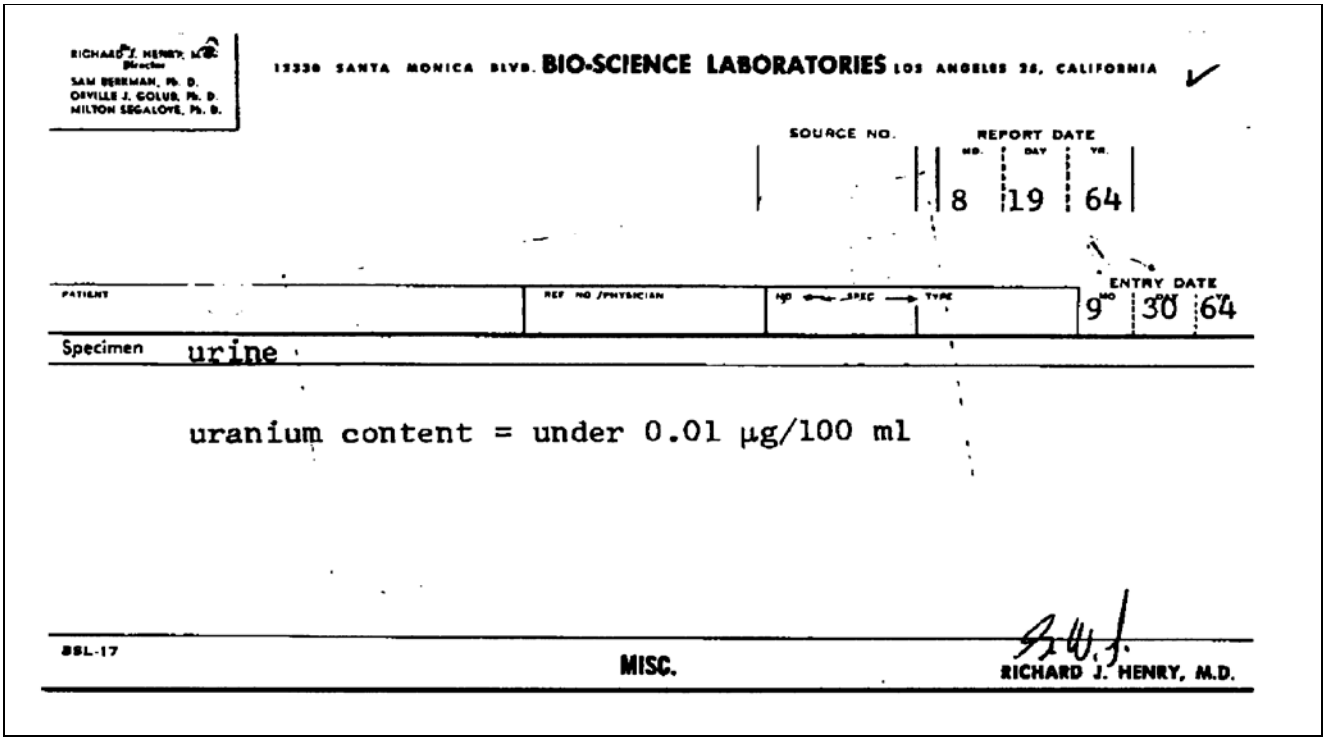

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12330 SANTA MONICA BLVD. **BIO-SCIENCE LABORATORIES** LOS ANGELES 25, CALIFORNIA

SOURCE NO. | REPORT DATE NO. 8 DAY 19 YR. 64

PATIENT | REF NO /PHYSICIAN | NO SPEC TYPE | ENTRY DATE NO. 9 DAY 30 YR. 64

Specimen urine

uranium content = under 0.01 µg/100 ml

BSL-17

MISC.

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Figure B-5. Example Bio-Science Laboratories UF bioassay data sheet.

Figure B-6 shows an example of a Bio-Science Laboratories UR bioassay data sheet. Figure B-7 shows two more examples that include bottle tags listing the exact times of sample collection.

These are the record of entry reports from the vendor laboratory that processed urine and fecal bioassay results. These records should be correlated to the McBee Keysort card (Figure B-2). Two versions were used (see Figure B-7 for a comparison).

The individual's name is usually written in pencil in the upper left margin. The Source No. generally lists a sample number. The Report Date is the date the results were available. The number in the Patient block is the sample number to identify the person. The meaning of the No. Spec. Type entry is not known at this time.

Entry Date refers to the date that the sample was received for processing. In general, it is 1 to 2 d after the date the sample was obtained by Rocketdyne from the individual. This date is from the McBee Keysort card.

Background refers to the background on the alpha counter (generally counts per hour). Counter efficiency is the efficiency of the counter used, and Recovery is the efficiency of the chemical recovery during the chemical preparation of the sample.

Urine Vol., ml, is the amount of sample actually analyzed, and Gross is the counter results uncorrected for background.

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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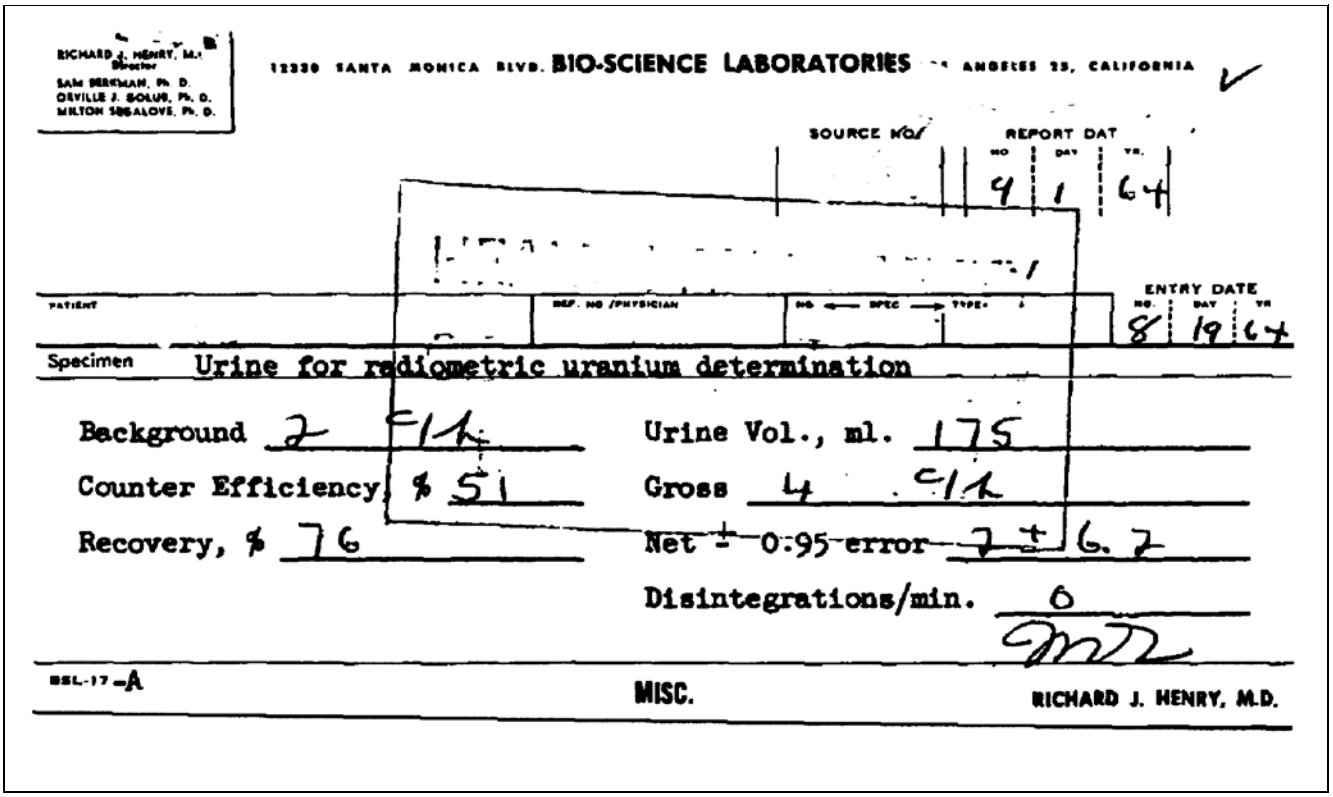

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12330 SANTA MONICA BLVD. **BIO-SCIENCE LABORATORIES** ANGELES 25, CALIFORNIA

SOURCE NO. REPORT DAT
MO DAY YR.
4 1 64

PATIENT | REF. NO /PHYSICIAN | NO. SPEC. TYPE | ENTRY DATE
8 19 64

Specimen Urine for radiometric uranium determination

Background 2 c/1
Counter Efficiency % 51
Recovery, % 76

Urine Vol., ml. 175
Gross 4 c/1
Net ± 0.95 error 2 ± 6.7
Disintegrations/min. 0

BSL-17-A MISC. RICHARD J. HENRY, M.D.

Figure B-6. Example Bio-Science Laboratories UR bioassay data sheet.

Net - 0.95 error is the net count rate (gross – background) with a 95% statistical error indicated. If the error exceeds the net count, it is considered a nondetect. If the net exceeds the error, it is considered a detect. The basis for this calculation of error (i.e., count times, normal or Poisson, etc.) is not available.

Disintegrations/min is the net activity determined for the sample. In some cases, "XX dpm/day" is written in. This is the sample result prorated to a daily excretion rate using a 1,500-mL assumption for daily urine volume and a 135 g/d rate for feces.

Disintegrations are calculated by (Net CPM) ÷ (Counter Efficiency/100) × (Recovery/100) (assuming that the Counter Efficiencies are written in percentage; fractional "percentages" are more likely true efficiency fractions and would not need conversion from percentage).

Dividing the UR values by the UF values results in a specific activity for the sample. This specific activity can then be used to estimate the general enrichment level of the uranium to which the individual was exposed. For simplicity, for low intakes, SSFL practice was to model the intake as pure ^{234}U (which results in overestimation of true dose).

This is the vendor record for results for UF sampling from UST. The calculations are self-explanatory. See the previous discussion of the Bio-Science UR record for additional data.

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
Page 9 of 12

V

Name ..... Dept ..... H.P.# .....
Date 31 July 61 2 Comp
Time of Monday A.M. void 0400
Time of previous void 2200

Name ..... Dept. .....
H.P.# ..... Date: 12-11-61
Time of Monday A.M. Void 6:30
Time of Previous Void 10:00 PM
2 Comp

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12229 SANTA MONICA BLVD. **BIO-SCIENCE LABORATORIES** LOS ANGELES 25, CALIFORNIA

SOURCE NO. | REPORT DATE NO. 8 | DAY 10 | YR. 61

Atomics International

PATIENT | REF. NO./PHYSICIAN | NO. ← SPEC. → TYPE: Urine | ENTRY DATE NO. 8 | DAY 3 | YR. 61

Specimen Urine for radiometric uranium determination

200 ml. = 6 gross c/h = 2 ± 6.2 net c/h

BSL-17

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SOURCE NO. | REPORT DATE NO. 12 | DAY 27 | YR. 61

Atomics International

PATIENT | REF. NO./PHYSICIAN | NO. ← SPEC. → TYPE | ENTRY DATE NO. 12 | DAY 14 | YR. 61

Specimen Urine for radiometric uranium determination

Background 4 ± 1 c/h
Counter Efficiency, % 54
Recovery, % 82

Urine Vol., ml. 200
Gross 9 c/h
Net ± 0.95 error 5 ± 7.1 c/h
Disintegrations/min. .....

BSL-17 -A

MISC.

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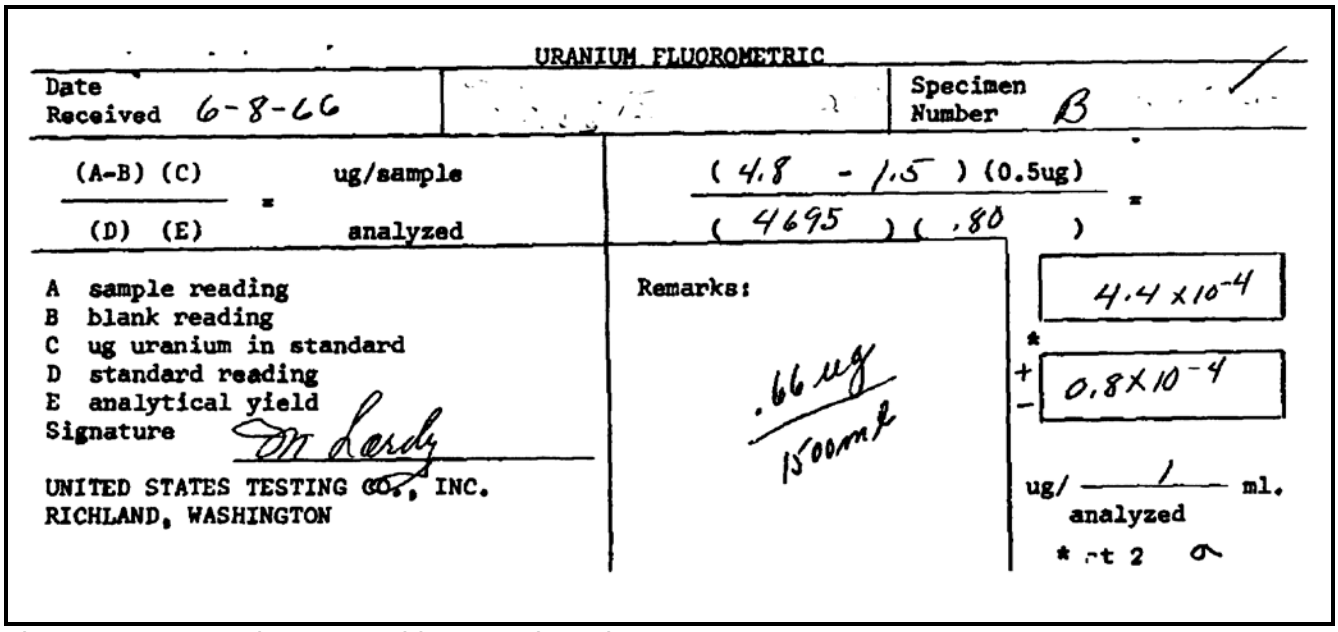
Figure B-7. Example Bio-Science Laboratories UR bioassay data sheets showing bottle tags.

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
Page 10 of 12

Specimen Number contains the individual's Health Physics Identification Number, and a sample number was generally written in the center box.

Figure B-8 shows an example of a UST UF bioassay data sheet.


URANIUM FLUOROMETRIC

Date Received 6-8-66

Specimen Number B

(A-B) (C) / (D) (E) = ug/sample analyzed

(4.8 - 1.5) (0.5ug) / (4695) (.80) =

A sample reading
B blank reading
C ug uranium in standard
D standard reading
E analytical yield
Signature M Lerby
UNITED STATES TESTING CO., INC.
RICHLAND, WASHINGTON

Remarks:

.66 ug / 1500 ml

4.4 x 10⁻⁴

* + − 0.8 x 10⁻⁴

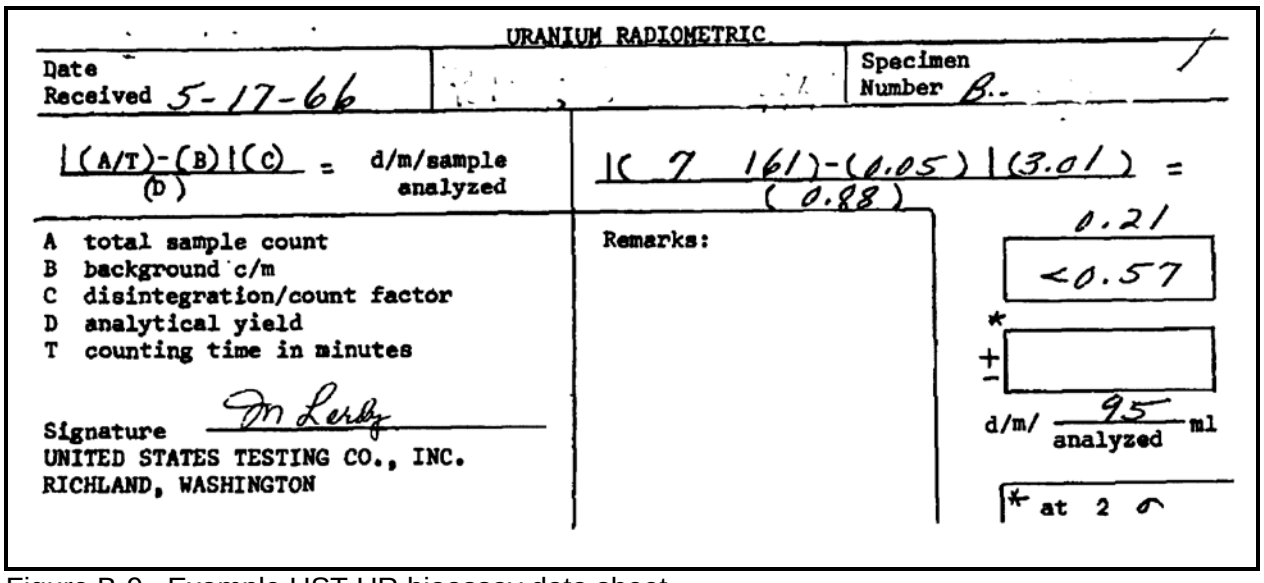
ug/ 1 ml. analyzed

* at 2 σ

Figure B-8. Example UST UF bioassay data sheet.

Date Received is the date the sample arrived at the laboratory. This was generally 1 to 2 d after the collection date. The actual date the sample was obtained is on the McBee Keysort card. These sheets should be correlated to that card.

Figure B-9 shows an example of a UST UR bioassay data sheet.


URANIUM RADIOMETRIC

Date Received 5-17-66

Specimen Number B..

|(A/T)-(B)|(C) / (D) = d/m/sample analyzed

|(7 161)-(0.05)|(3.01) / (0.88) =

A total sample count
B background c/m
C disintegration/count factor
D analytical yield
T counting time in minutes

Signature M Lerby
UNITED STATES TESTING CO., INC.
RICHLAND, WASHINGTON

Remarks:

0.21

* + − <0.57

d/m/ 95 analyzed ml

* at 2 σ

Figure B-9. Example UST UR bioassay data sheet.

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
Page 11 of 12

This is the vendor record for results for UR sampling from UST. The calculations are self-explanatory. See the previous discussion of the Bio-Science UR record description for additional data.

Specimen Number contains the individual's Health Physics Identification Number. A sample number was generally written in the center box.

Date Received is the date the sample arrived at the laboratory. This was generally 1 to 2 d after the collection date. The actual date the sample was obtained is on the McBee Keysort card. These sheets should be correlated to that card.

Figure B-10 shows an example of a UST MFP bioassay data sheet for MFPs.

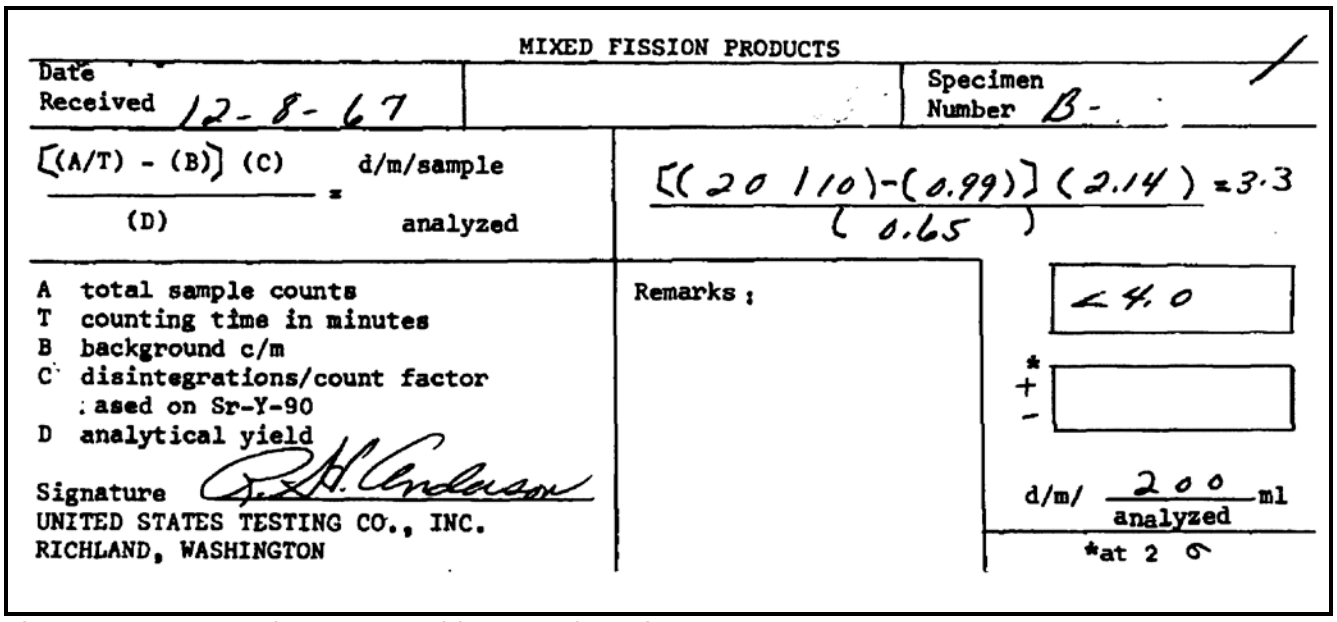


Figure B-10. Example UST MFP bioassay data sheet.

The calculations are self-explanatory. Specimen Number contains the individual's Health Physics Identification Number. A sample number was generally written in the center box.

Date Received is the date the sample arrived at the laboratory. This was generally 1 to 2 d after the collection date. The actual date the sample was obtained is on the McBee Keysort card. These sheets should be correlated to that card.

These measurements were generally defaulted to ^{137}Cs. In addition, one should be aware that ^{137}Cs was generally assumed to be accompanied by ^{90}Sr in a 50%/50% mix. Analyses of MFP results should therefore account both for ^{137}Cs exposures and ^{90}Sr exposures as being coincident.

Based on laboratory analyses directly comparing ^{137}Cs and ^{90}Sr values, the mixture ratio for ^{137}Cs and ^{90}Sr during D&D operations after 1991 was approximately 85% ^{137}Cs to 15% ^{90}Sr. In 1999 the ratio published in the site TBD was 90% ^{137}Cs to 10% ^{90}Sr for SSFL locations other than Building 4059.

ATTACHMENT B
EXAMPLE INTERNAL DOSIMETRY RECORD DOCUMENTS
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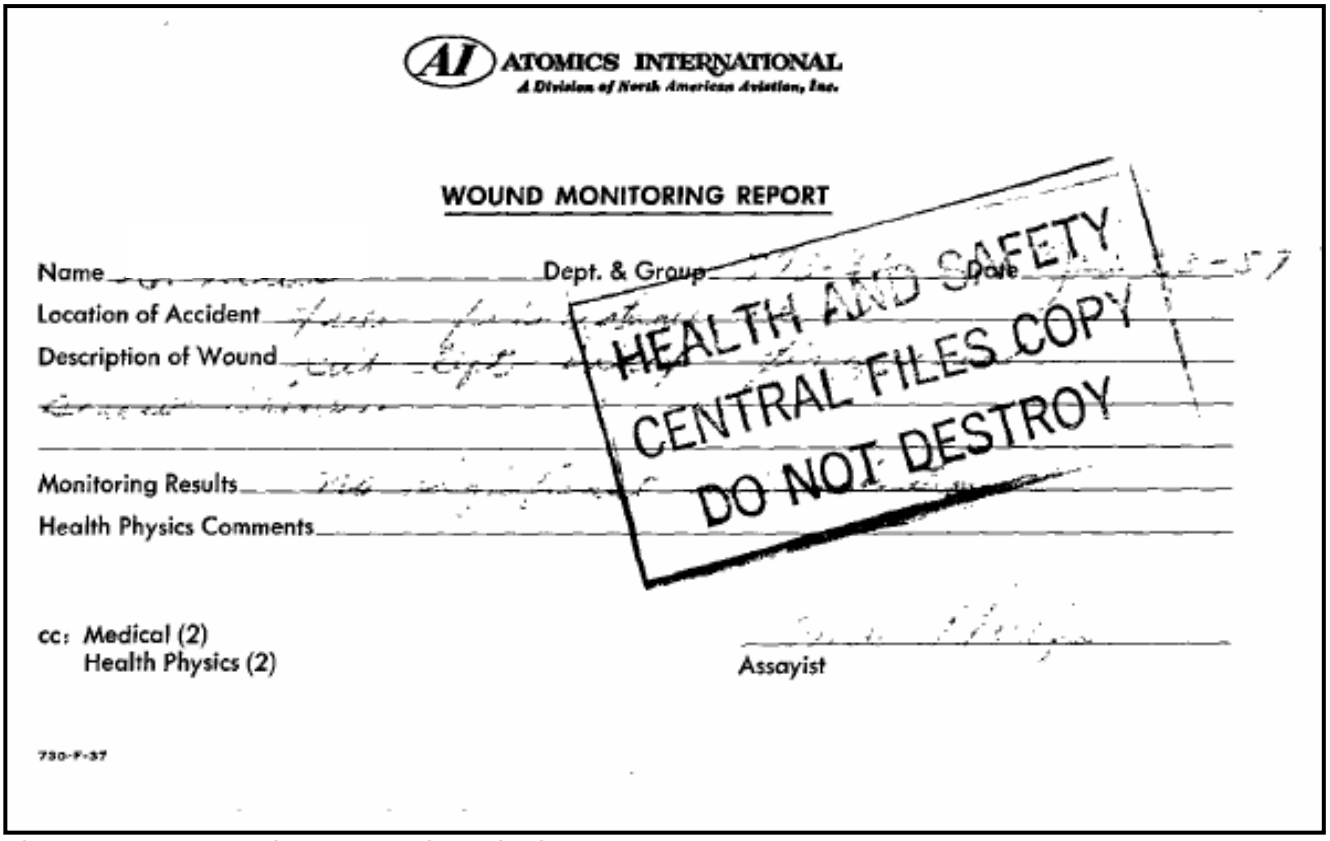
Figure B-11 shows an example of an AI Wound Monitoring Report.



ATOMICS INTERNATIONAL
A Division of North American Aviation, Inc.

WOUND MONITORING REPORT

Name _____ Dept. & Group _____ Date _____

Location of Accident _____

Description of Wound _____

_____

_____

Monitoring Results _____

Health Physics Comments _____

HEALTH AND SAFETY
CENTRAL FILES COPY
DO NOT DESTROY

cc: Medical (2)
Health Physics (2)

_____
Assayist

730-F-37

Figure B-11. Example AI Wound Monitoring Report.

ATTACHMENT C
ADJUSTMENT TO HELGESON NUCLEAR SERVICES ^{235}U LUNG COUNTS, 1981 to 1983

Measured (µg U-235)	Actual (µg U-235)
32.5	0
40	8.6
50	20.2
60	31.7
70	43.2
80	54.8
90	66.3
100	77.8
110	89.4
120	101
130	112
140	124
150	135
160	147
170	159
180	170
190	182
200	193
210	205
220	216
230	228
240	239
245	245

ATTACHMENT D
ISOTOPIC COMPOSITION OF ATR-ETR FUEL USED IN THE POWDER ROOM, 1966 to 1967

Date received	Isotopic composition (weight percent)			
	U-234	U-235	U-236	U-238
06/27/1966	0.579	93.2	0.304	5.917
06/27/1966	0.571	93.2	0.301	5.928
10/12/1966	0.516	93.15	0.310	6.010
10/13/1966	0.656	93.16	0.295	5.900
11/11/1966	0.563	93.14	0.289	6.000
12/08/1966	0.591	93.11	0.326	5.970
12/08/1966	0.627	93.13	0.286	5.960
01/20/1967	0.563	93.09	0.305	6.020
02/06/1967	0.570	93.15	0.320	5.956
02/08/1967	0.580	93.17	0.290	5.961
02/09/1967	0.550	93.14	0.310	6.001
02/10/1967	0.570	93.19	0.270	5.966
02/11/1963	0.630	93.14	0.300	5.929
03/11/1967	0.660	93.17	0.300	5.872
03/16/1967	0.610	93.13	0.350	5.912
04/16/1967	0.500	93.13	0.340	6.030
06/19/1967	0.557	93.23	0.324	5.860
06/22/1967	0.582	93.16	0.304	5.950
06/23/1967	0.600	93.14	0.290	5.972
06/23/1967	0.580	93.12	0.294	6.010
06/23/1967	0.570	93.14	0.301	6.000
Average	0.582	93.152	0.305	5.958
Standard deviation	0.039	0.033	0.019	0.048
Specific activity (µCi/g)	6,263.14	2.16	64.70	0.340
Fractional specific activity (µCi/g U)	36.46	2.01	0.20	0.020
Fractional specific activity (Bq/g U)	1.35E+06	7.44E+04	7.31E+03	7.50E+02

Data from Tschaeche (1968c)

ATTACHMENT E
ISOTOPIC COMPOSITION OF URANIUM USED FOR ATR FUEL FABRICATION, 1979 to 1982

Date	Isotopic composition (weight percent)			
	U-234	U-235	U-236	U-238
10/18/1979	1.006	93.145	0.525	5.234
01/29/1980	1.145	93.142	0.498	5.348
05/12/1980	1.007	93.141	0.472	5.379
12/03/1980	1.007	93.142	0.476	5.374
07/28/1981	1.004	93.14	0.455	5.648
11/02/1981	1.002	93.136	0.455	5.407
03/02/1982	0.9977	93.141	0.448	5.414
Average	1.024	93.141	0.476	5.401
Standard deviation	0.0534	0.0027	0.0276	0.1246
Specific activity (µCi/g)	6,263.14	2.16	64.70	0.340
Fractional specific activity (µCi/g-U)	64.141	2.012	0.308	0.018
Fractional specific activity (Bq/g-U)	2.37E+06	7.44E+04	1.14E+04	6.79E+02

Data from Moore (1979, 1980a,b,c, 1981a,b, 1982).

ATTACHMENT F
DETECTION LIMITS FOR GAMMA SCANS OF BIOASSAY SAMPLES, 1967 to 1975

Isotope(s)	Detection limit (dpm/sample)
Na-24	80
Co-60	75
Sc-46	60
Cs-134	175
Ba-La-140	250
Co-58	50
K-40	500
Ru-l06	500
Zn-65	100
Cu-64	300
Mn-56	70
Mn-54	60
Ga-72	140
Zr-Nb-95	20
Cs-137	50
As-76	120
Ru-103	50
Zn-69m	50
I-131	60
Cr-51	400
Np-239	80
Ce-141	60
Ce-Pr-144	500

ATTACHMENT G
SENSITIVITY OF BIOASSAY ANALYSES BY BIOASSAY CODE, UST AND OTHER LABORATORIES

Table G-1. *In vitro* analyses (Barnes 2006).

Code in bioassay cards	Analysis type	Sensitivity per day[a] (1,500 mL)	Units for sensitivity	Typical analysis volume (mL)	Default isotope	Vendor[b]
AP	Gross alpha	15	dpm	100	Pu-239	
FP1	Fission products (1)	30	dpm	200	Sr-90	UST
FP2	Fission products (2)	60	dpm	300	Cs-137	UST
FP3A	Fission products (3a)	30	dpm	300	Sr-90	UST
FP3B	Fission products (3b)	60	dpm	300	Cs-137	UST
GA1A	Gross alpha (1a)	1.5	dpm	100	Pu-239	UST
GA1B	Gross alpha (1b)	9	dpm	100	Pu-239	UST
GA2	Gross alpha (2)	15	dpm	100	Pu-239	UST
GBH	Gross beta high level	750	dpm	50	Sr-90	UST
H3	Tritium	2.25E+06	dpm	10	H-3	UST
I131	Iodine-131	300	dpm	250	I-131	UST
MFP2B	Fission products (2)	60	dpm	300	Cs-137	UST
MFPB	Fission products (beta)	30	dpm	300	Sr-90	
MFPG	Fission products (gamma)	30	dpm	300	Cs-137	
PUA	Plutonium (a)	0.0495	dpm	1,000	Pu-239	UST
PUB	Plutonium (b)	0.0495	dpm	1,000	Pu-239	UST
PUB(O)	Plutonium (b) (optional)	0.75	dpm	1,000	Pu-239	UST
SR90	Strontium 90	30	dpm	200	Sr-90	UST
TH	Thorium	0.99	µg	1,000	Th-232	UST
UF	Uranium fluorometric	0.3	µg	10	U-238	UST
U-ISO	Uranium isotopic	3.75	dpm	200	U-235	
UR	Uranium radiometric	3.75	dpm	200	U-235	UST
U-TOT	Uranium total	0.3	µg	10	U-238	

a. Considered to be the "default MDAs" by AI; values listed on the cards (for example, "<2.2 dpm/day") were used as the MDA, if available. However, these values were apparently used as screening or reporting levels and the MDA is assumed to be twice these values for dose reconstruction purposes.
b. Blank indicates that the vendor was not recorded on the bioassay card.

Table G-2. *In vivo* analyses (Barnes 2006).

Code in bioassay cards	Analysis type	Sensitivity	Units for sensitivity[a]	Default isotope	Vendor
IVLC	*In vivo* lung count	40	µg	U-235	UST
TBC	Total-body count	2.8	nCi	Cs-137	UST
WBC	Whole-body count	2.8	nCi	Cs-137	Helgeson

a. The MDA is assumed to be twice these values for dose reconstruction purposes.

ATTACHMENT H
CALCULATION OF DOSES FROM INTAKES OF URANIUM ALUMINIDE
Page 1 of 18

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1.0 PURPOSE

Leggett, Eckerman, and Boice (2005) recently proposed a modification to the ICRP International Commission on Radiological Protection Publication 66 human respiratory tract model (HRTM) that specifically addresses the biokinetics of uranium aluminide (UAl) (ICRP 1994). This modification, which this Attachment refers to as *Type K* (versus Type F, M, or S) material, was based on occupational bioassay data collected at the Rocketdyne/Atomics International Facility in California. This Attachment evaluates the impact of this model on intake and dose calculations.

2.0 THE MODEL

The Type K model is based on the standard Type S aerosol with the modifications to the mechanical clearance parameters and dissolution parameters of the HRTM listed on Table H-1.

Table H-1. Parameters for Type S and Type K uranium.

Parameter	S	K
s_p	0.1	0.0001
s_{pt}	100	0.004
s_t	0.0001	0.004
TAI1 -> Tbb1	0.02	0.006
TAI2 -> Tbb1	0.001	0.006
TAI3 -> Tbb1	0.0001	0.006

It is important to note that the changes in the mechanical clearance parameters are for the transformed compartments only, which means that the Type K model cannot be directly implemented in the Integrated Modules for Bioassay Analysis (IMBA) computer program. Finally, based on the Leggett, Eckerman, and Boice (2005) paper an aerosol size of 1 μm activity median aerodynamic diameter (AMAD) is recommended for exposure to UAl at the Rocketdyne/Atomics International Facility.

Type K, M, and S models were implemented in the Mathcad® 13 computer program (Mathsoft® 2006) to calculate urinary excretion and dose. A comparison of the urinary excretion following unit intakes of these materials is shown in Figure H-1, which is a benchmark of Figure 7 in the Leggett, Eckerman, and Boice (2005) paper. In Figure H-1, the dots are the values of the Type K excretion curve digitized from Figure 7 in Leggett, Eckerman, and Boice and the lines are the excretion rates calculated here. This plot provides some evidence that the Type K model was accurately implemented.

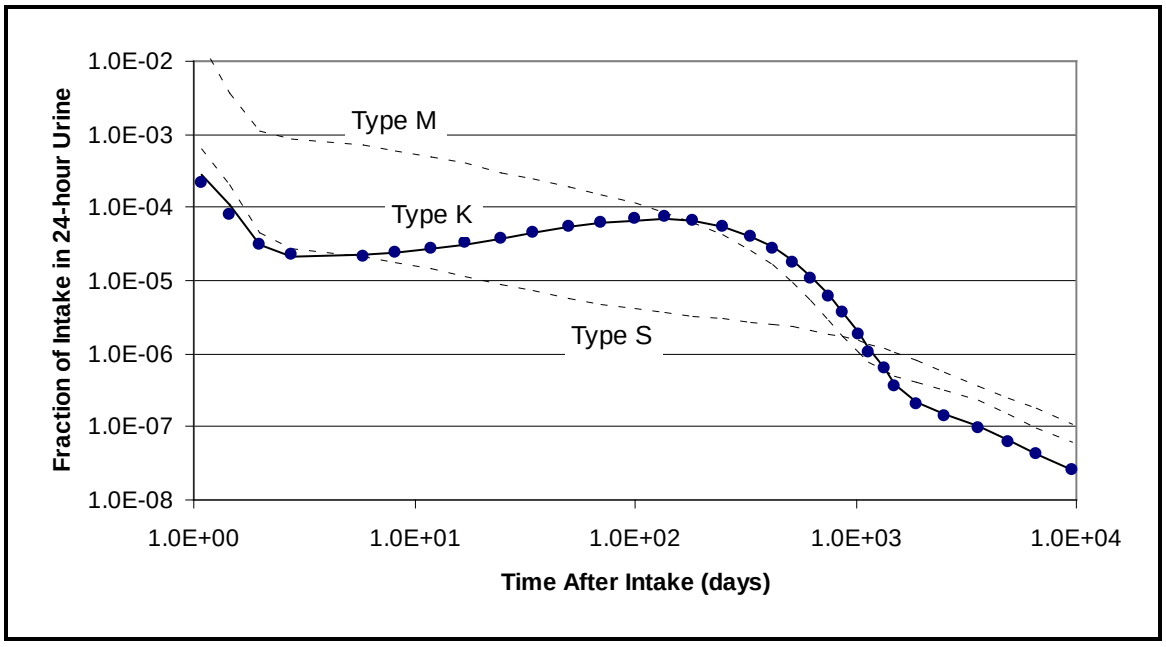

Figure H-1. Comparison of urinary excretion patterns following inhalation intakes of 5 μm AMAD Type M and Type S ^{234}U and 1 μm AMAD Type K ^{234}U.

3.0 LIMITING SOLUBILITY CLASSES

The general approach taken here is to examine the dose to organs from various exposure scenarios to determine if and when Type K ^{234}U delivers a dose that is higher than the dose from Type F, M, or S ^{234}U. If Type K delivers the highest dose, it is "limiting" and the case cannot be evaluated with IMBA. Otherwise, the case can be evaluated with a standard type using IMBA. In other words, the standard models in IMBA can be used as long as the product of the DCF and 1/IRF exceeds that of Type K.

Each table in Attachment H consists of three parts:

- The first is a matrix of intake-to-organ-dose conversion factors (DCFs) for ^{234}U. The DCFs give the 50-year committed organ dose in units of Sv per total intake. For example, in the case of a 10-d chronic intake of 1 Bq/d the total intake is (10 d)(1 Bq/d) = 10 Bq. The DCFs are given for 1 μm AMAD Type K uranium (referred to as K1) and 5 μm AMAD Type K (referred to as K5), F, M, and S uranium.

- The second matrix contains the urine intake retention fractions (irf) for the given time after an acute intake or the start of a chronic intake. For an acute intake the irf(t) is the fraction of a unit intake in the 24-hr urine sample collected on day t after intake. For a chronic intake the irf(t) is the Bq of ^{234}U in the 24-hr urine sample collected on the day after the end of the chronic intake. For example, in the case of a 10-d chronic intake, the urine sample is collected from t = 10 days to t = 11 days.

- Finally, in the third matrix the organ dose *H* in Sv implied by 1 Bq/d of uranium excreted on day t is given:

$$H = \left(\frac{1\,Bq}{irf\,(t)} \right) \left(DCF\,\frac{Sv}{Bq} \right)$$

For a given intake scenario the organ doses are calculated for all organs and solubility classes of uranium. The solubility class with the highest dose is referred to as the "limiting" solubility class. The results of Attachment H are summarized in the following tables.

4.0 CONCLUSIONS AND RECOMMENDATIONS

As can be seen in Table H-2, except for relatively short chronic intakes, the standard solubility types F, M, and S are limiting.[1] This means that for typical dose assessments that involve chronic intakes one can use standard solubility types and not risk underestimating the dose to organs. The situation is more complex for acute intakes, as can be seen in Table H-3. Here Type K uranium can be limiting for most organs if urine samples are taken days after an intake and for nonsystemic organs if samples are taken years after an intake. In these situations custom dose assessments that use software other than IMBA might be required, so these cases should be referred to the Principal Internal Dosimetrist for evaluation. In summary, standard models may be used for calculating dose to any organ resulting from a chronic UAl intake of 365 days or more as long as the urine data were collected more than 365 days after the start of the intake. The PID should be consulted for guidance in other cases that do not fit this criterion or use other types of bioassay data to estimate the dose.

[1] For the stomach wall, 5 μm Type K uranium was limiting for a 10,000-day chronic intake, but it was only 1% greater than Type M.

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CALCULATION OF DOSES FROM INTAKES OF URANIUM ALUMINIDE

Table H-2. Limiting uranium solubility class for chronic intakes. The time (e.g., 10 d) is the duration of the chronic intake. The 24-hr urine sample was collected on the last day of the chronic intake.

	Chronic 10 days	Chronic 100 days	Chronic 1000 days	Chronic 10000 days
Adrenals	K1	K1	S	F
UB_Wall	K1	K1	S	F
Bone_Sur	K1	K1	S	F
Brain	K1	K1	S	F
Breasts	K1	K1	S	F
St_Wall	K1	K1	S	K5
SI_Wall	K1	K1	S	S
ULI_Wall	K1	S	S	S
LLI_Wall	K1	S	S	S
Kidneys	K1	K1	S	S
Liver	K1	K1	S	F
ET1-bas	K1	S	S	S
ET2-bas	S	S	S	S
LN-ET	S	S	S	S
BBi-bas	K1	S	S	S
BBi-sec	K1	S	S	S
bbe-sec	K1	S	S	S
AI	S	S	S	S
LN-Th	S	S	S	S
Muscle	K1	K1	S	F
Ovaries	K1	K1	S	F
Pancreas	K1	K1	S	F
R_Marrow	K1	K1	S	F
Skin	K1	K1	S	F
Spleen	K1	K1	S	F
Testes	K1	K1	S	F
Thymus	K1	K1	S	F
Thyroid	K1	K1	S	F
GB_Wall	K1	K1	S	F
Ht_Wall	K1	K1	S	F
Uterus	K1	K1	S	F
Lung	K1	S	S	S
ET	S	S	S	S
Colon	K1	S	S	S
Oesophagus	K1	K1	S	F
Remainder	K1	K1	S	F

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Table H-3. Limiting uranium solubility class for an acute intake. The time (e.g., 2 d) is when the urine sample was collected.

	Acute 2 days	Acute 5 days	Acute 10 days	Acute 40 days	Acute 100 days	Acute 400 days	Acute 1000 days	Acute 10000 days
Adrenals	K1	K1	K1	S	F	F	F	F
UB_Wall	K1	K1	K1	S	F	F	F	F
Bone_Sur	K1	K1	K1	S	F	F	F	F
Brain	K1	K1	K1	S	F	F	F	F
Breasts	K1	K1	K1	S	F	F	F	F
St_Wall	K1	K1	K1	S	F	F	F	F
SI_Wall	K1	K1	K1	S	F	F	F	K5
ULI_Wall	K1	K1	K1	S	S	F	F	K5
LLI_Wall	K1	K1	K5	S	S	F	F	K5
Kidneys	K1	K1	K1	S	F	F	F	F
Liver	K1	K1	K1	S	F	F	F	F
ET1-bas	K1	K1	K1	S	F	F	F	K5
ET2-bas	S	S	S	S	S	S	S	K5
LN-ET	S	S	S	S	S	S	S	S
BBi-bas	K5	S	S	S	S	S	K5	K5
BBi-sec	K1	K5	S	S	S	S	K5	K5
bbe-sec	K1	K1	K1	S	S	S	K5	K5
AI	S	S	S	S	S	S	S	K1
LN-Th	S	S	S	S	S	S	S	S
Muscle	K1	K1	K1	S	F	F	F	F
Ovaries	K1	K1	K1	S	F	F	F	F
Pancreas	K1	K1	K1	S	F	F	F	F
R_Marrow	K1	K1	K1	S	F	F	F	F
Skin	K1	K1	K1	S	F	F	F	F
Spleen	K1	K1	K1	S	F	F	F	F
Testes	K1	K1	K1	S	F	F	F	F
Thymus	K1	K1	K1	S	F	F	F	F
Thyroid	K1	K1	K1	S	F	F	F	F
GB_Wall	K1	K1	K1	S	F	F	F	F
Ht_Wall	K1	K1	K1	S	F	F	F	F
Uterus	K1	K1	K1	S	F	F	F	F
Lung	K1	S	S	S	S	S	S	K5
ET	S	S	S	S	S	S	S	K5
Colon	K1	K1	K1	S	S	F	F	K5
Oesophagus	K1	K1	K1	S	F	F	F	F
Remainder	K1	K1	K1	S	F	F	F	F

Table H-4. Acute intake, urine bioassay at 2 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	3.050E-05	3.874E-05	4.410E-05	1.125E-03	6.380E-03

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	1.305E-03	5.451E-04	2.015E-04	8.531E-05	6.165E-05	K1
UB_Wall	1.309E-03	5.469E-04	2.021E-04	8.559E-05	6.185E-05	K1
Bone_Sur	3.747E-02	1.565E-02	6.186E-03	2.434E-03	1.755E-03	K1
Brain	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.165E-05	K1
Breasts	1.305E-03	5.451E-04	2.015E-04	8.531E-05	6.164E-05	K1
St_Wall	1.316E-03	5.585E-04	2.134E-04	8.572E-05	6.168E-05	K1
SI_Wall	1.334E-03	5.786E-04	2.313E-04	8.633E-05	6.173E-05	K1
ULI_Wall	1.480E-03	7.479E-04	3.826E-04	9.149E-05	6.217E-05	K1
LLI_Wall	1.820E-03	1.140E-03	7.329E-04	1.034E-04	6.318E-05	K1
Kidneys	1.373E-02	5.732E-03	2.349E-03	8.893E-04	6.405E-04	K1
Liver	5.138E-03	2.146E-03	8.512E-04	3.333E-04	2.402E-04	K1
ET1-bas	1.381E-03	6.688E-04	3.326E-04	8.953E-05	6.239E-05	K1
ET2-bas	5.093E-01	7.565E-01	1.709E+00	1.115E-02	6.181E-05	S
LN-ET	4.302E-02	6.264E-02	3.021E+00	5.613E-04	6.168E-05	S
BBi-bas	9.866E-02	1.101E-01	1.046E-01	2.569E-03	6.172E-05	K5
BBi-sec	1.583E+00	1.250E+00	1.115E+00	3.365E-02	6.638E-05	K1
bbe-sec	1.702E+00	7.257E-01	6.814E-01	1.859E-02	6.441E-05	K1
AI	9.180E-01	3.607E-01	1.478E+00	6.907E-03	6.175E-05	S
LN-Th	3.237E-01	2.190E-01	1.042E+01	2.304E-03	6.164E-05	S
Muscle	1.305E-03	5.451E-04	2.016E-04	8.531E-05	6.165E-05	K1
Ovaries	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
Pancreas	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
R_Marrow	3.867E-03	1.615E-03	6.399E-04	2.513E-04	1.812E-04	K1
Skin	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
Spleen	1.305E-03	5.451E-04	2.015E-04	8.531E-05	6.164E-05	K1
Testes	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
Thymus	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
Thyroid	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
GB_Wall	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
Ht_Wall	1.305E-03	5.451E-04	2.016E-04	8.531E-05	6.164E-05	K1
Uterus	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
Lung	1.153E+00	5.885E-01	9.326E-01	1.452E-02	6.340E-05	K1
ET	5.083E-01	7.551E-01	1.709E+00	1.113E-02	6.181E-05	S
Colon	1.627E-03	9.166E-04	5.332E-04	9.662E-05	6.260E-05	K1
Oesophagus	1.305E-03	5.451E-04	2.014E-04	8.531E-05	6.164E-05	K1
Remainder	1.431E-03	5.981E-04	2.238E-04	9.344E-05	6.748E-05	K1

Table H-5. Acute intake, urine bioassay at 5 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	2.178E-05	2.056E-05	2.196E-05	7.349E-04	4.212E-03

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	1.827E-03	1.027E-03	4.046E-04	1.305E-04	9.337E-05	K1
UB_Wall	1.833E-03	1.030E-03	4.059E-04	1.310E-04	9.368E-05	K1
Bone_Sur	5.246E-02	2.948E-02	1.242E-02	3.725E-03	2.658E-03	K1
Brain	1.827E-03	1.027E-03	4.044E-04	1.305E-04	9.337E-05	K1
Breasts	1.827E-03	1.027E-03	4.046E-04	1.305E-04	9.336E-05	K1
St_Wall	1.843E-03	1.052E-03	4.286E-04	1.312E-04	9.342E-05	K1
SI_Wall	1.867E-03	1.090E-03	4.645E-04	1.321E-04	9.350E-05	K1
ULI_Wall	2.073E-03	1.409E-03	7.683E-04	1.400E-04	9.416E-05	K1
LLI_Wall	2.549E-03	2.147E-03	1.472E-03	1.583E-04	9.569E-05	K1
Kidneys	1.922E-02	1.080E-02	4.716E-03	1.361E-03	9.701E-04	K1
Liver	7.194E-03	4.042E-03	1.709E-03	5.101E-04	3.638E-04	K1
ET1-bas	1.934E-03	1.260E-03	6.679E-04	1.370E-04	9.449E-05	K1
ET2-bas	7.130E-01	1.425E+00	3.432E+00	1.707E-02	9.361E-05	S
LN-ET	6.024E-02	1.180E-01	6.067E+00	8.589E-04	9.342E-05	S
BBi-bas	1.381E-01	2.074E-01	2.101E-01	3.932E-03	9.348E-05	S
BBi-sec	2.216E+00	2.355E+00	2.240E+00	5.149E-02	1.005E-04	K5
bbe-sec	2.383E+00	1.367E+00	1.368E+00	2.845E-02	9.755E-05	K1
AI	1.285E+00	6.793E-01	2.968E+00	1.057E-02	9.352E-05	S
LN-Th	4.532E-01	4.126E-01	2.093E+01	3.525E-03	9.336E-05	S
Muscle	1.827E-03	1.027E-03	4.048E-04	1.305E-04	9.337E-05	K1
Ovaries	1.827E-03	1.027E-03	4.045E-04	1.305E-04	9.336E-05	K1
Pancreas	1.827E-03	1.027E-03	4.045E-04	1.305E-04	9.336E-05	K1
R_Marrow	5.415E-03	3.043E-03	1.285E-03	3.846E-04	2.745E-04	K1
Skin	1.827E-03	1.027E-03	4.044E-04	1.305E-04	9.336E-05	K1
Spleen	1.827E-03	1.027E-03	4.046E-04	1.305E-04	9.336E-05	K1
Testes	1.827E-03	1.027E-03	4.044E-04	1.305E-04	9.336E-05	K1
Thymus	1.827E-03	1.027E-03	4.045E-04	1.305E-04	9.336E-05	K1
Thyroid	1.827E-03	1.027E-03	4.044E-04	1.305E-04	9.336E-05	K1
GB_Wall	1.827E-03	1.027E-03	4.044E-04	1.305E-04	9.336E-05	K1
Ht_Wall	1.827E-03	1.027E-03	4.049E-04	1.305E-04	9.336E-05	K1
Uterus	1.827E-03	1.027E-03	4.044E-04	1.305E-04	9.336E-05	K1
Lung	1.614E+00	1.108E+00	1.873E+00	2.222E-02	9.602E-05	S
ET	7.117E-01	1.422E+00	3.431E+00	1.703E-02	9.361E-05	S
Colon	2.277E-03	1.726E-03	1.071E-03	1.479E-04	9.482E-05	K1
Oesophagus	1.827E-03	1.027E-03	4.045E-04	1.305E-04	9.336E-05	K1
Remainder	2.003E-03	1.127E-03	4.495E-04	1.430E-04	1.022E-04	K1

Table H-6. Acute intake, urine bioassay at 10 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	2.556E-05	1.923E-05	1.603E-05	5.439E-04	2.690E-03

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	1.557E-03	1.098E-03	5.544E-04	1.764E-04	1.462E-04	K1
UB_Wall	1.562E-03	1.102E-03	5.562E-04	1.770E-04	1.467E-04	K1
Bone_Sur	4.471E-02	3.153E-02	1.702E-02	5.032E-03	4.162E-03	K1
Brain	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
Breasts	1.557E-03	1.098E-03	5.544E-04	1.764E-04	1.462E-04	K1
St_Wall	1.571E-03	1.125E-03	5.872E-04	1.772E-04	1.463E-04	K1
SI_Wall	1.592E-03	1.166E-03	6.364E-04	1.785E-04	1.464E-04	K1
ULI_Wall	1.767E-03	1.507E-03	1.053E-03	1.892E-04	1.475E-04	K1
LLI_Wall	2.172E-03	2.297E-03	2.017E-03	2.139E-04	1.499E-04	K5
Kidneys	1.638E-02	1.155E-02	6.462E-03	1.839E-03	1.519E-03	K1
Liver	6.131E-03	4.323E-03	2.342E-03	6.892E-04	5.697E-04	K1
ET1-bas	1.649E-03	1.347E-03	9.151E-04	1.851E-04	1.480E-04	K1
ET2-bas	6.077E-01	1.524E+00	4.703E+00	2.306E-02	1.466E-04	S
LN-ET	5.134E-02	1.262E-01	8.314E+00	1.160E-03	1.463E-04	S
BBi-bas	1.177E-01	2.219E-01	2.879E-01	5.312E-03	1.464E-04	S
BBi-sec	1.888E+00	2.519E+00	3.069E+00	6.957E-02	1.574E-04	S
bbe-sec	2.031E+00	1.462E+00	1.875E+00	3.843E-02	1.528E-04	K1
AI	1.095E+00	7.266E-01	4.067E+00	1.428E-02	1.465E-04	S
LN-Th	3.863E-01	4.413E-01	2.868E+01	4.763E-03	1.462E-04	S
Muscle	1.557E-03	1.098E-03	5.547E-04	1.764E-04	1.462E-04	K1
Ovaries	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
Pancreas	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
R_Marrow	4.615E-03	3.254E-03	1.761E-03	5.197E-04	4.299E-04	K1
Skin	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
Spleen	1.557E-03	1.098E-03	5.543E-04	1.764E-04	1.462E-04	K1
Testes	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
Thymus	1.557E-03	1.098E-03	5.543E-04	1.764E-04	1.462E-04	K1
Thyroid	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
GB_Wall	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
Ht_Wall	1.557E-03	1.098E-03	5.548E-04	1.764E-04	1.462E-04	K1
Uterus	1.557E-03	1.098E-03	5.542E-04	1.764E-04	1.462E-04	K1
Lung	1.375E+00	1.186E+00	2.566E+00	3.003E-02	1.504E-04	S
ET	6.065E-01	1.521E+00	4.702E+00	2.302E-02	1.466E-04	S
Colon	1.941E-03	1.847E-03	1.467E-03	1.998E-04	1.485E-04	K1
Oesophagus	1.557E-03	1.098E-03	5.543E-04	1.764E-04	1.462E-04	K1
Remainder	1.707E-03	1.205E-03	6.159E-04	1.932E-04	1.601E-04	K1

Table H-7. Acute intake, urine bioassay at 40 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	4.864E-05	2.596E-05	6.442E-06	2.183E-04	4.279E-04

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.192E-04	S
UB_Wall	8.208E-04	8.162E-04	1.384E-03	4.408E-04	9.222E-04	S
Bone_Sur	2.349E-02	2.335E-02	4.234E-02	1.254E-02	2.616E-02	S
Brain	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.192E-04	S
Breasts	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
St_Wall	8.254E-04	8.335E-04	1.461E-03	4.415E-04	9.197E-04	S
SI_Wall	8.362E-04	8.634E-04	1.583E-03	4.446E-04	9.204E-04	S
ULI_Wall	9.283E-04	1.116E-03	2.619E-03	4.712E-04	9.269E-04	S
LLI_Wall	1.141E-03	1.701E-03	5.016E-03	5.327E-04	9.420E-04	S
Kidneys	8.606E-03	8.554E-03	1.608E-02	4.580E-03	9.550E-03	S
Liver	3.221E-03	3.202E-03	5.826E-03	1.717E-03	3.581E-03	S
ET1-bas	8.662E-04	9.980E-04	2.276E-03	4.611E-04	9.302E-04	S
ET2-bas	3.193E-01	1.129E+00	1.170E+01	5.745E-02	9.216E-04	S
LN-ET	2.698E-02	9.347E-02	2.068E+01	2.891E-03	9.196E-04	S
BBi-bas	6.186E-02	1.643E-01	7.162E-01	1.323E-02	9.202E-04	S
BBi-sec	9.922E-01	1.866E+00	7.634E+00	1.733E-01	9.897E-04	S
bbe-sec	1.067E+00	1.083E+00	4.664E+00	9.574E-02	9.604E-04	S
AI	5.756E-01	5.382E-01	1.012E+01	3.557E-02	9.207E-04	S
LN-Th	2.030E-01	3.269E-01	7.133E+01	1.187E-02	9.191E-04	S
Muscle	8.181E-04	8.135E-04	1.380E-03	4.394E-04	9.192E-04	S
Ovaries	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
Pancreas	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
R_Marrow	2.425E-03	2.411E-03	4.380E-03	1.295E-03	2.702E-03	S
Skin	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
Spleen	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
Testes	8.180E-04	8.135E-04	1.378E-03	4.394E-04	9.191E-04	S
Thymus	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
Thyroid	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
GB_Wall	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
Ht_Wall	8.181E-04	8.135E-04	1.380E-03	4.394E-04	9.191E-04	S
Uterus	8.180E-04	8.135E-04	1.378E-03	4.394E-04	9.191E-04	S
Lung	7.227E-01	8.782E-01	6.384E+00	7.480E-02	9.453E-04	S
ET	3.187E-01	1.127E+00	1.170E+01	5.734E-02	9.216E-04	S
Colon	1.020E-03	1.368E-03	3.650E-03	4.976E-04	9.334E-04	S
Oesophagus	8.181E-04	8.135E-04	1.379E-03	4.394E-04	9.191E-04	S
Remainder	8.970E-04	8.926E-04	1.532E-03	4.812E-04	1.006E-03	S

Table H-8. Acute intake, urine bioassay at 100 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	6.737E-05	3.430E-05	4.090E-06	1.146E-04	1.002E-04

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	5.907E-04	6.156E-04	2.172E-03	8.373E-04	3.927E-03	F
UB_Wall	5.926E-04	6.176E-04	2.179E-03	8.401E-04	3.939E-03	F
Bone_Sur	1.696E-02	1.767E-02	6.669E-02	2.389E-02	1.118E-01	F
Brain	5.907E-04	6.155E-04	2.171E-03	8.373E-04	3.927E-03	F
Breasts	5.907E-04	6.156E-04	2.172E-03	8.373E-04	3.926E-03	F
St_Wall	5.959E-04	6.307E-04	2.301E-03	8.414E-04	3.929E-03	F
SI_Wall	6.038E-04	6.533E-04	2.494E-03	8.473E-04	3.932E-03	F
ULI_Wall	6.702E-04	8.446E-04	4.125E-03	8.980E-04	3.960E-03	S
LLI_Wall	8.241E-04	1.287E-03	7.901E-03	1.015E-03	4.024E-03	S
Kidneys	6.214E-03	6.473E-03	2.532E-02	8.728E-03	4.080E-02	F
Liver	2.326E-03	2.423E-03	9.177E-03	3.272E-03	1.530E-02	F
ET1-bas	6.254E-04	7.552E-04	3.586E-03	8.788E-04	3.974E-03	F
ET2-bas	2.306E-01	8.543E-01	1.843E+01	1.095E-01	3.937E-03	S
LN-ET	1.948E-02	7.073E-02	3.258E+01	5.509E-03	3.929E-03	S
BBi-bas	4.466E-02	1.244E-01	1.128E+00	2.522E-02	3.931E-03	S
BBi-sec	7.164E-01	1.412E+00	1.202E+01	3.302E-01	4.228E-03	S
bbe-sec	7.705E-01	8.195E-01	7.347E+00	1.825E-01	4.103E-03	S
AI	4.156E-01	4.073E-01	1.594E+01	6.779E-02	3.933E-03	S
LN-Th	1.465E-01	2.474E-01	1.124E+02	2.261E-02	3.926E-03	S
Muscle	5.907E-04	6.156E-04	2.173E-03	8.373E-04	3.927E-03	F
Ovaries	5.907E-04	6.156E-04	2.172E-03	8.373E-04	3.926E-03	F
Pancreas	5.907E-04	6.155E-04	2.172E-03	8.373E-04	3.926E-03	F
R_Marrow	1.751E-03	1.824E-03	6.899E-03	2.467E-03	1.154E-02	F
Skin	5.907E-04	6.155E-04	2.171E-03	8.373E-04	3.926E-03	F
Spleen	5.907E-04	6.156E-04	2.172E-03	8.373E-04	3.926E-03	F
Testes	5.906E-04	6.155E-04	2.171E-03	8.373E-04	3.926E-03	F
Thymus	5.907E-04	6.155E-04	2.172E-03	8.373E-04	3.926E-03	F
Thyroid	5.907E-04	6.155E-04	2.171E-03	8.373E-04	3.926E-03	F
GB_Wall	5.907E-04	6.155E-04	2.171E-03	8.373E-04	3.926E-03	F
Ht_Wall	5.907E-04	6.156E-04	2.174E-03	8.373E-04	3.926E-03	F
Uterus	5.906E-04	6.155E-04	2.171E-03	8.373E-04	3.926E-03	F
Lung	5.218E-01	6.645E-01	1.006E+01	1.425E-01	4.038E-03	S
ET	2.301E-01	8.527E-01	1.842E+01	1.093E-01	3.937E-03	S
Colon	7.364E-04	1.035E-03	5.749E-03	9.483E-04	3.988E-03	S
Oesophagus	5.907E-04	6.155E-04	2.172E-03	8.373E-04	3.926E-03	F
Remainder	6.477E-04	6.754E-04	2.413E-03	9.171E-04	4.298E-03	F

Table H-9. Acute intake, urine bioassay at 400 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	3.071E-05	1.564E-05	2.552E-06	1.790E-05	4.584E-06

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	1.296E-03	1.350E-03	3.482E-03	5.358E-03	8.580E-02	F
UB_Wall	1.300E-03	1.355E-03	3.493E-03	5.376E-03	8.608E-02	F
Bone_Sur	3.721E-02	3.876E-02	1.069E-01	1.529E-01	2.442E+00	F
Brain	1.296E-03	1.350E-03	3.480E-03	5.358E-03	8.580E-02	F
Breasts	1.296E-03	1.350E-03	3.482E-03	5.358E-03	8.580E-02	F
St_Wall	1.307E-03	1.383E-03	3.688E-03	5.384E-03	8.585E-02	F
SI_Wall	1.325E-03	1.433E-03	3.997E-03	5.422E-03	8.592E-02	F
ULI_Wall	1.470E-03	1.852E-03	6.612E-03	5.747E-03	8.652E-02	F
LLI_Wall	1.808E-03	2.824E-03	1.266E-02	6.497E-03	8.793E-02	F
Kidneys	1.363E-02	1.420E-02	4.059E-02	5.586E-02	8.914E-01	F
Liver	5.103E-03	5.315E-03	1.471E-02	2.094E-02	3.343E-01	F
ET1-bas	1.372E-03	1.656E-03	5.747E-03	5.624E-03	8.683E-02	F
ET2-bas	5.058E-01	1.874E+00	2.953E+01	7.006E-01	8.602E-02	S
LN-ET	4.273E-02	1.551E-01	5.221E+01	3.525E-02	8.584E-02	S
BBi-bas	9.798E-02	2.727E-01	1.808E+00	1.614E-01	8.590E-02	S
BBi-sec	1.572E+00	3.097E+00	1.927E+01	2.113E+00	9.238E-02	S
bbe-sec	1.690E+00	1.797E+00	1.178E+01	1.168E+00	8.964E-02	S
AI	9.117E-01	8.932E-01	2.554E+01	4.338E-01	8.594E-02	S
LN-Th	3.215E-01	5.425E-01	1.801E+02	1.447E-01	8.580E-02	S
Muscle	1.296E-03	1.350E-03	3.483E-03	5.358E-03	8.580E-02	F
Ovaries	1.296E-03	1.350E-03	3.481E-03	5.358E-03	8.580E-02	F
Pancreas	1.296E-03	1.350E-03	3.481E-03	5.358E-03	8.580E-02	F
R_Marrow	3.841E-03	4.001E-03	1.106E-02	1.579E-02	2.522E-01	F
Skin	1.296E-03	1.350E-03	3.480E-03	5.358E-03	8.580E-02	F
Spleen	1.296E-03	1.350E-03	3.482E-03	5.358E-03	8.580E-02	F
Testes	1.296E-03	1.350E-03	3.480E-03	5.358E-03	8.580E-02	F
Thymus	1.296E-03	1.350E-03	3.481E-03	5.358E-03	8.580E-02	F
Thyroid	1.296E-03	1.350E-03	3.480E-03	5.358E-03	8.580E-02	F
GB_Wall	1.296E-03	1.350E-03	3.480E-03	5.358E-03	8.580E-02	F
Ht_Wall	1.296E-03	1.350E-03	3.484E-03	5.358E-03	8.580E-02	F
Uterus	1.296E-03	1.350E-03	3.480E-03	5.358E-03	8.580E-02	F
Lung	1.145E+00	1.457E+00	1.612E+01	9.121E-01	8.824E-02	S
ET	5.048E-01	1.870E+00	2.953E+01	6.992E-01	8.602E-02	S
Colon	1.615E-03	2.270E-03	9.215E-03	6.069E-03	8.713E-02	F
Oesophagus	1.296E-03	1.350E-03	3.481E-03	5.358E-03	8.580E-02	F
Remainder	1.421E-03	1.481E-03	3.868E-03	5.869E-03	9.392E-02	F

Table H-10. Acute intake, urine bioassay at 1000 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	2.173E-06	1.160E-06	1.524E-06	1.116E-06	2.306E-06

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	1.832E-02	1.820E-02	5.829E-03	8.597E-02	1.706E-01	F
UB_Wall	1.838E-02	1.826E-02	5.849E-03	8.625E-02	1.711E-01	F
Bone_Sur	5.260E-01	5.226E-01	1.790E-01	2.453E+00	4.855E+00	F
Brain	1.832E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
Breasts	1.832E-02	1.820E-02	5.829E-03	8.597E-02	1.706E-01	F
St_Wall	1.848E-02	1.865E-02	6.175E-03	8.638E-02	1.707E-01	F
SI_Wall	1.872E-02	1.932E-02	6.692E-03	8.699E-02	1.708E-01	F
ULI_Wall	2.078E-02	2.498E-02	1.107E-02	9.219E-02	1.720E-01	F
LLI_Wall	2.555E-02	3.807E-02	2.120E-02	1.042E-01	1.748E-01	F
Kidneys	1.927E-01	1.914E-01	6.795E-02	8.961E-01	1.772E+00	F
Liver	7.213E-02	7.166E-02	2.463E-02	3.359E-01	6.646E-01	F
ET1-bas	1.939E-02	2.233E-02	9.622E-03	9.022E-02	1.726E-01	F
ET2-bas	7.149E+00	2.526E+01	4.945E+01	1.124E+01	1.710E-01	S
LN-ET	6.040E-01	2.092E+00	8.742E+01	5.656E-01	1.707E-01	S
BBi-bas	1.385E+00	3.678E+00	3.027E+00	2.589E+00	1.708E-01	K5
BBi-sec	2.222E+01	4.176E+01	3.227E+01	3.391E+01	1.837E-01	K5
bbe-sec	2.389E+01	2.423E+01	1.972E+01	1.873E+01	1.782E-01	K5
AI	1.289E+01	1.204E+01	4.276E+01	6.960E+00	1.709E-01	S
LN-Th	4.544E+00	7.315E+00	3.015E+02	2.322E+00	1.706E-01	S
Muscle	1.832E-02	1.821E-02	5.832E-03	8.597E-02	1.706E-01	F
Ovaries	1.832E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
Pancreas	1.832E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
R_Marrow	5.429E-02	5.394E-02	1.851E-02	2.533E-01	5.015E-01	F
Skin	1.832E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
Spleen	1.832E-02	1.820E-02	5.829E-03	8.597E-02	1.706E-01	F
Testes	1.831E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
Thymus	1.832E-02	1.820E-02	5.828E-03	8.597E-02	1.706E-01	F
Thyroid	1.832E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
GB_Wall	1.832E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
Ht_Wall	1.832E-02	1.821E-02	5.834E-03	8.597E-02	1.706E-01	F
Uterus	1.831E-02	1.820E-02	5.827E-03	8.597E-02	1.706E-01	F
Lung	1.618E+01	1.965E+01	2.698E+01	1.463E+01	1.754E-01	S
ET	7.135E+00	2.522E+01	4.943E+01	1.122E+01	1.710E-01	S
Colon	2.283E-02	3.061E-02	1.543E-02	9.737E-02	1.732E-01	F
Oesophagus	1.832E-02	1.820E-02	5.828E-03	8.597E-02	1.706E-01	F
Remainder	2.008E-02	1.997E-02	6.476E-03	9.416E-02	1.867E-01	F

Table H-11. Acute intake, urine bioassay at 10000 days after intake.

	K1 DCF (Sv/Bq)	K5 DCF (Sv/Bq)	S DCF (Sv/Bq)	M DCF (Sv/Bq)	F DCF (Sv/Bq)
Adrenals	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
UB_Wall	3.993E-08	2.119E-08	8.914E-09	9.625E-08	3.946E-07
Bone_Sur	1.143E-06	6.062E-07	2.728E-07	2.737E-06	1.119E-05
Brain	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Breasts	3.979E-08	2.112E-08	8.884E-09	9.593E-08	3.933E-07
St_Wall	4.015E-08	2.163E-08	9.411E-09	9.640E-08	3.935E-07
SI_Wall	4.068E-08	2.241E-08	1.020E-08	9.708E-08	3.938E-07
ULI_Wall	4.515E-08	2.897E-08	1.687E-08	1.029E-07	3.966E-07
LLI_Wall	5.552E-08	4.416E-08	3.232E-08	1.163E-07	4.031E-07
Kidneys	4.186E-07	2.220E-07	1.036E-07	1.000E-06	4.086E-06
Liver	1.567E-07	8.312E-08	3.753E-08	3.748E-07	1.532E-06
ET1-bas	4.213E-08	2.591E-08	1.467E-08	1.007E-07	3.980E-07
ET2-bas	1.553E-05	2.930E-05	7.536E-05	1.254E-05	3.943E-07
LN-ET	1.312E-06	2.426E-06	1.332E-04	6.311E-07	3.935E-07
BBi-bas	3.009E-06	4.266E-06	4.614E-06	2.889E-06	3.937E-07
BBi-sec	4.827E-05	4.843E-05	4.918E-05	3.784E-05	4.235E-07
bbe-sec	5.191E-05	2.811E-05	3.005E-05	2.090E-05	4.109E-07
AI	2.800E-05	1.397E-05	6.517E-05	7.767E-06	3.939E-07
LN-Th	9.872E-06	8.485E-06	4.595E-04	2.591E-06	3.933E-07
Muscle	3.980E-08	2.112E-08	8.888E-09	9.593E-08	3.933E-07
Ovaries	3.979E-08	2.112E-08	8.881E-09	9.593E-08	3.933E-07
Pancreas	3.979E-08	2.111E-08	8.882E-09	9.593E-08	3.933E-07
R_Marrow	1.180E-07	6.257E-08	2.822E-08	2.826E-07	1.156E-06
Skin	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Spleen	3.979E-08	2.112E-08	8.883E-09	9.593E-08	3.933E-07
Testes	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Thymus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Thyroid	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
GB_Wall	3.979E-08	2.111E-08	8.881E-09	9.593E-08	3.933E-07
Ht_Wall	3.980E-08	2.112E-08	8.891E-09	9.593E-08	3.933E-07
Uterus	3.979E-08	2.111E-08	8.880E-09	9.593E-08	3.933E-07
Lung	3.516E-05	2.280E-05	4.113E-05	1.633E-05	4.045E-07
ET	1.550E-05	2.925E-05	7.534E-05	1.252E-05	3.943E-07
Colon	4.961E-08	3.550E-08	2.351E-08	1.087E-07	3.994E-07
Oesophagus	3.979E-08	2.111E-08	8.883E-09	9.593E-08	3.933E-07
Remainder	4.363E-08	2.317E-08	9.870E-09	1.051E-07	4.305E-07
IRF	2.468E-08	1.308E-08	1.014E-07	5.740E-08	2.323E-07

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	1.612E+00	1.615E+00	8.765E-02	1.671E+00	1.693E+00	F
UB_Wall	1.618E+00	1.620E+00	8.795E-02	1.677E+00	1.699E+00	F
Bone_Sur	4.630E+01	4.635E+01	2.691E+00	4.768E+01	4.819E+01	F
Brain	1.612E+00	1.614E+00	8.762E-02	1.671E+00	1.693E+00	F
Breasts	1.612E+00	1.615E+00	8.765E-02	1.671E+00	1.693E+00	F
St_Wall	1.627E+00	1.654E+00	9.285E-02	1.679E+00	1.694E+00	F
SI_Wall	1.648E+00	1.714E+00	1.006E-01	1.691E+00	1.695E+00	K5
ULI_Wall	1.829E+00	2.215E+00	1.665E-01	1.792E+00	1.707E+00	K5
LLI_Wall	2.249E+00	3.377E+00	3.189E-01	2.026E+00	1.735E+00	K5
Kidneys	1.696E+01	1.698E+01	1.022E+00	1.742E+01	1.759E+01	F
Liver	6.349E+00	6.356E+00	3.703E-01	6.530E+00	6.596E+00	F
ET1-bas	1.707E+00	1.981E+00	1.447E-01	1.754E+00	1.713E+00	K5
ET2-bas	6.293E+02	2.241E+03	7.436E+02	2.185E+02	1.697E+00	K5
LN-ET	5.316E+01	1.855E+02	1.315E+03	1.100E+01	1.694E+00	S
BBi-bas	1.219E+02	3.262E+02	4.552E+01	5.033E+01	1.695E+00	K5
BBi-sec	1.955E+03	3.703E+03	4.852E+02	6.592E+02	1.823E+00	K5
bbe-sec	2.103E+03	2.149E+03	2.965E+02	3.642E+02	1.769E+00	K5
AI	1.134E+03	1.068E+03	6.430E+02	1.353E+02	1.696E+00	K1
LN-Th	4.000E+02	6.488E+02	4.534E+03	4.513E+01	1.693E+00	S
Muscle	1.612E+00	1.615E+00	8.770E-02	1.671E+00	1.693E+00	F
Ovaries	1.612E+00	1.615E+00	8.763E-02	1.671E+00	1.693E+00	F
Pancreas	1.612E+00	1.614E+00	8.763E-02	1.671E+00	1.693E+00	F
R_Marrow	4.779E+00	4.784E+00	2.784E-01	4.924E+00	4.977E+00	F
Skin	1.612E+00	1.614E+00	8.763E-02	1.671E+00	1.693E+00	F
Spleen	1.612E+00	1.615E+00	8.765E-02	1.671E+00	1.693E+00	F
Testes	1.612E+00	1.614E+00	8.762E-02	1.671E+00	1.693E+00	F
Thymus	1.612E+00	1.614E+00	8.764E-02	1.671E+00	1.693E+00	F
Thyroid	1.612E+00	1.614E+00	8.763E-02	1.671E+00	1.693E+00	F
GB_Wall	1.612E+00	1.614E+00	8.763E-02	1.671E+00	1.693E+00	F
Ht_Wall	1.612E+00	1.615E+00	8.772E-02	1.671E+00	1.693E+00	F
Uterus	1.612E+00	1.614E+00	8.762E-02	1.671E+00	1.693E+00	F
Lung	1.424E+03	1.743E+03	4.058E+02	2.845E+02	1.741E+00	K5
ET	6.281E+02	2.236E+03	7.434E+02	2.181E+02	1.697E+00	K5
Colon	2.010E+00	2.715E+00	2.320E-01	1.893E+00	1.719E+00	K5
Oesophagus	1.612E+00	1.614E+00	8.764E-02	1.671E+00	1.693E+00	F
Remainder	1.768E+00	1.772E+00	9.738E-02	1.830E+00	1.853E+00	F

Table H-12. Chronic intake (10 days) with urine bioassay on day after end of intake.

	K1 DCF (Sv/intake)	K5 DCF (Sv/intake)	S DCF (Sv/intake)	M DCF (Sv/intake)	F DCF (Sv/intake)
Adrenals	3.978E-07	2.111E-07	8.881E-08	9.590E-07	3.932E-06
UB_Wall	3.991E-07	2.118E-07	8.912E-08	9.622E-07	3.945E-06
Bone_Sur	1.143E-05	6.062E-06	2.727E-06	2.737E-05	1.119E-04
Brain	3.978E-07	2.111E-07	8.878E-08	9.590E-07	3.932E-06
Breasts	3.978E-07	2.111E-07	8.881E-08	9.590E-07	3.932E-06
St_Wall	4.014E-07	2.163E-07	9.408E-08	9.637E-07	3.932E-06
SI_Wall	4.066E-07	2.240E-07	1.020E-07	9.705E-07	3.932E-06
ULI_Wall	4.514E-07	2.897E-07	1.687E-07	1.028E-06	3.965E-06
LLI_Wall	5.551E-07	4.416E-07	3.231E-07	1.163E-06	4.029E-06
Kidneys	4.186E-06	2.221E-06	1.036E-06	9.999E-06	4.086E-05
Liver	1.567E-06	8.311E-07	3.753E-07	3.748E-06	1.532E-05
ET1-bas	3.982E-07	2.590E-07	1.466E-07	1.007E-06	3.979E-06
ET2-bas	1.553E-04	2.930E-04	7.577E-04	1.254E-04	3.934E-06
LN-ET	1.312E-05	2.426E-05	1.332E-03	6.308E-06	3.934E-06
BBi-bas	3.012E-05	4.268E-05	4.615E-05	2.890E-05	3.932E-06
BBi-sec	4.826E-04	4.843E-04	4.915E-	3.781E-04	3.932E-
bbe-sec	5.190E-04	2.811E-04	3.004E-04	2.089E-04	3.932E-06
AI	2.800E-04	1.397E-04	6.540E-04	7.766E-05	3.932E-06
LN-Th	9.873E-05	8.485E-05	4.594E-03	2.591E-05	3.932E-06
Muscle	3.978E-07	2.111E-07	8.886E-08	9.590E-07	3.932E-06
Ovaries	3.978E-07	2.111E-07	8.879E-08	9.590E-07	3.932E-06
Pancreas	3.978E-07	2.111E-07	8.879E-08	9.590E-07	3.932E-06
R_Marrow	1.179E-06	6.257E-07	2.821E-07	2.826E-06	1.156E-05
Skin	3.978E-07	2.111E-07	8.878E-08	9.590E-07	3.932E-06
Spleen	3.978E-07	2.111E-07	8.881E-08	9.590E-07	3.932E-06
Testes	3.978E-07	2.111E-07	8.878E-08	9.590E-07	3.932E-06
Thymus	3.978E-07	2.111E-07	8.880E-08	9.590E-07	3.932E-06
Thyroid	3.978E-07	2.111E-07	8.878E-08	9.590E-07	3.932E-06
GB_Wall	3.978E-07	2.111E-07	8.878E-08	9.590E-07	3.932E-06
Ht_Wall	3.978E-07	2.111E-07	8.889E-08	9.590E-07	3.932E-06
Uterus	3.978E-07	2.111E-07	8.878E-08	9.590E-07	3.932E-06
Lung	3.515E-04	2.280E-04	4.119E-04	1.632E-04	3.932E-06
ET	1.550E-04	2.924E-04	7.576E-04	1.252E-04	3.934E-06
Colon	4.960E-07	3.550E-07	2.351E-07	1.086E-06	3.993E-06
Oesophagus	3.978E-07	2.111E-07	8.880E-08	9.590E-07	3.932E-06
Remainder	4.362E-07	2.316E-07	9.867E-08	1.050E-06	4.304E-06
IRF	4.884E-04	7.151E-04	9.028E-04	2.952E-02	2.189E-01

	K1 (Sv)	K5 (Sv	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	8.146E-04	2.952E-04	9.838E-05	3.249E-05	1.796E-05	K1
UB_Wall	8.172E-04	2.962E-04	9.872E-05	3.260E-05	1.802E-05	K1
Bone_Sur	2.340E-02	8.477E-03	3.021E-03	9.273E-04	5.111E-04	K1
Brain	8.146E-04	2.952E-04	9.834E-05	3.249E-05	1.796E-05	K1
Breasts	8.146E-04	2.952E-04	9.838E-05	3.249E-05	1.796E-05	K1
St_Wall	8.219E-04	3.025E-04	1.042E-04	3.265E-05	1.796E-05	K1
SI_Wall	8.326E-04	3.132E-04	1.130E-04	3.288E-05	1.796E-05	K1
ULI_Wall	9.243E-04	4.051E-04	1.869E-04	3.483E-05	1.811E-05	K1
LLI_Wall	1.137E-03	6.175E-04	3.579E-04	3.940E-05	1.840E-05	K1
Kidneys	8.572E-03	3.106E-03	1.148E-03	3.388E-04	1.866E-04	K1
Liver	3.209E-03	1.162E-03	4.157E-04	1.270E-04	6.997E-05	K1
ET1-bas	8.154E-04	3.622E-04	1.624E-04	3.412E-05	1.817E-05	K1
ET2-bas	3.180E-01	4.097E-01	8.393E-01	4.249E-03	1.797E-05	S
LN-ET	2.687E-02	3.393E-02	1.475E+00	2.137E-04	1.797E-	S
BBi-bas	6.168E-02	5.968E-	5.112E-02	9.791E-04	1.796E-	K
BBi-	9.882E-01	6.773E-01	5.444E-	1.281E-02	1.796E-05	K1
bbe-sec	1.063E+00	3.931E-01	3.328E-01	7.078E-03	1.796E-05	K1
AI	5.733E-01	1.954E-01	7.244E-01	2.631E-03	1.796E-05	S
LN-Th	2.022E-01	1.187E-01	5.089E+0	8.778E-04	1.796E-05	S
Muscle	8.146E-04	2.952E-04	9.843E-05	3.249E-05	1.796E-05	K1
Ovaries	8.146E-04	2.952E-04	9.835E-05	3.249E-05	1.796E-05	K1
Pancreas	8.146E-04	2.952E-04	9.835E-05	3.249E-05	1.796E-05	K1
R_Marrow	2.414E-03	8.750E-04	3.125E-04	9.574E-05	5.280E-05	K1
Skin	8.146E-04	2.952E-04	9.834E-05	3.249E-05	1.796E-05	K1
Spleen	8.146E-04	2.952E-04	9.838E-05	3.249E-05	1.796E-05	K1
Testes	8.146E-04	2.952E-04	9.834E-05	3.249E-05	1.796E-05	K1
Thymus	8.146E-04	2.952E-04	9.837E-05	3.249E-05	1.796E-05	K1
Thyroid	8.146E-04	2.952E-04	9.834E-05	3.249E-05	1.796E-05	K1
GB_Wall	8.146E-04	2.952E-04	9.834E-05	3.249E-05	1.796E-05	K1
Ht_Wall	8.146E-04	2.952E-04	9.846E-05	3.249E-05	1.796E-05	K
Uterus	8.146E-04	2.952E-04	9.834E-05	3.249E-05	1.796E-05	K
Lung	7.198E-01	3.188E-01	4.563E-01	5.529E-03	1.796E-05	K
ET	3.174E-01	4.089E-01	8.392E-01	4.242E-03	1.797E-05	S
Colon	1.016E-03	4.964E-04	2.604E-04	3.679E-05	1.824E-05	K
Oesophagus	8.146E-04	2.952E-04	9.837E-05	3.249E-05	1.796E-05	K
Remainder	8.932E-04	3.239E-04	1.093E-04	3.557E-05	1.966E-05	K

Table H-13. Chronic intake (100 days) with urine bioassay on day after end of intake.

	K1 DCF (Sv/intake)	K5 DCF (Sv/intake)	S DCF (Sv/intake)	M DCF (Sv/intake)	F DCF (Sv/intake)
Adrenals	3.970E-06	2.106E-06	8.859E-07	9.572E-06	3.924E-05
UB_Wall	3.983E-06	2.113E-06	8.890E-07	9.603E-06	3.937E-05
Bone_Sur	1.142E-04	6.058E-05	2.725E-05	2.735E-04	1.119E-03
Brain	3.970E-06	2.106E-06	8.856E-07	9.572E-06	3.924E-05
Breasts	3.970E-06	2.106E-06	8.859E-07	9.571E-06	3.924E-05
St_Wall	4.005E-06	2.158E-06	9.386E-07	9.618E-06	3.926E-05
SI_Wall	4.058E-06	2.236E-06	1.017E-06	9.686E-06	3.929E-05
ULI_Wall	4.506E-06	2.894E-06	1.687E-06	1.027E-05	3.957E-05
LLI_Wall	5.542E-06	4.411E-06	3.229E-06	1.161E-05	4.022E-05
Kidneys	4.186E-05	2.220E-05	1.035E-05	1.000E-04	4.086E-04
Liver	1.566E-05	8.309E-06	3.750E-06	3.747E-05	1.532E-04
ET1-bas	4.204E-06	2.585E-06	1.464E-06	1.005E-05	3.971E-05
ET2-bas	1.553E-03	2.930E-03	7.536E-03	1.254E-03	3.930E-05
LN-ET	1.312E-04	2.426E-04	1.331E-02	6.309E-05	3.926E-05
BBi-bas	3.009E-04	4.266E-04	4.614E-04	2.889E-04	3.926E-05
BBi-sec	4.826E-03	4.843E-03	4.918E-03	3.784E-03	4.237E-05
bbe-sec	5.190E-03	2.811E-03	3.005E-03	2.090E-03	4.115E-05
AI	2.800E-03	1.397E-03	6.515E-03	7.766E-04	3.930E-05
LN-Th	9.872E-04	8.485E-04	4.588E-02	2.590E-04	3.924E-05
Muscle	3.970E-06	2.107E-06	8.864E-07	9.572E-06	3.924E-05
Ovaries	3.970E-06	2.106E-06	8.857E-07	9.572E-06	3.924E-05
Pancreas	3.970E-06	2.106E-06	8.857E-07	9.571E-06	3.924E-05
R_Marrow	1.178E-05	6.252E-06	2.818E-06	2.824E-05	1.155E-04
Skin	3.970E-06	2.106E-06	8.857E-07	9.571E-06	3.924E-05
Spleen	3.970E-06	2.106E-06	8.859E-07	9.571E-06	3.924E-05
Testes	3.970E-06	2.106E-06	8.856E-07	9.571E-06	3.924E-05
Thymus	3.970E-06	2.106E-06	8.858E-07	9.571E-06	3.924E-05
Thyroid	3.970E-06	2.106E-06	8.857E-07	9.571E-06	3.924E-05
GB_Wall	3.970E-06	2.106E-06	8.857E-07	9.571E-06	3.924E-05
Ht_Wall	3.970E-06	2.107E-06	8.867E-07	9.572E-06	3.924E-05
Uterus	3.970E-06	2.106E-06	8.856E-07	9.571E-06	3.924E-05
Lung	3.515E-03	2.280E-03	4.112E-03	1.633E-03	4.042E-05
ET	1.550E-03	2.925E-03	7.534E-03	1.252E-03	3.930E-05
Colon	4.951E-06	3.547E-06	2.350E-06	1.084E-05	3.985E-05
Oesophagus	3.970E-06	2.106E-06	8.858E-07	9.571E-06	3.924E-05
Remainder	4.354E-06	2.312E-06	9.846E-07	1.049E-05	4.296E-05
IRF	5.252E-03	3.249E-03	1.485E-03	4.860E-02	2.644E-01

	K1 (Sv)	K5 (Sv)	S (Sv)	M (Sv)	F (Sv)	Biggest
Adrenals	7.559E-04	6.481E-04	5.966E-04	1.969E-04	1.484E-04	K1
UB_Wall	7.583E-04	6.503E-04	5.987E-04	1.976E-04	1.489E-04	K1
Bone_Sur	2.174E-02	1.864E-02	1.835E-02	5.627E-03	4.233E-03	K1
Brain	7.559E-04	6.481E-04	5.964E-04	1.969E-04	1.484E-04	K1
Breasts	7.559E-04	6.481E-04	5.966E-04	1.969E-04	1.484E-04	K1
St_Wall	7.625E-04	6.641E-04	6.321E-04	1.979E-04	1.485E-04	K1
SI_Wall	7.726E-04	6.881E-04	6.849E-04	1.993E-04	1.486E-04	K1
ULI_Wall	8.579E-04	8.906E-04	1.136E-03	2.113E-04	1.497E-04	S
LLI_Wall	1.055E-03	1.357E-03	2.175E-03	2.389E-04	1.521E-04	S
Kidneys	7.970E-03	6.832E-03	6.971E-03	2.058E-03	1.546E-03	K1
Liver	2.982E-03	2.557E-03	2.526E-03	7.710E-04	5.795E-04	K1
ET1-bas	8.004E-04	7.955E-04	9.860E-04	2.068E-04	1.502E-04	S
ET2-bas	2.957E-01	9.017E-01	5.075E+00	2.580E-02	1.487E-04	S
LN-ET	2.498E-02	7.466E-02	8.964E+00	1.298E-03	1.485E-	S
BBi-bas	5.729E-02	1.313E-01	3.107E-01	5.944E-03	1.485E-	S
BBi-sec	9.189E-01	1.490E+00	3.312E+00	7.786E-02	1.603E-	S
bbe-sec	9.882E-01	8.651E-01	2.024E+00	4.300E-02	1.557E-	S
AI	5.331E-01	4.299E-01	4.388E+00	1.598E-02	1.487E-	S
LN-Th	1.880E-01	2.611E-01	3.090E+01	5.329E-03	1.484E-	S
Muscle	7.559E-04	6.484E-04	5.970E-04	1.969E-04	1.484E-	K1
Ovaries	7.559E-04	6.481E-04	5.965E-04	1.969E-04	1.484E-	K1
Pancreas	7.559E-04	6.481E-04	5.965E-04	1.969E-04	1.484E-	K1
R_Marrow	2.243E-03	1.924E-03	1.898E-03	5.810E-04	4.369E-	K1
Skin	7.559E-04	6.481E-04	5.965E-04	1.969E-04	1.484E-	K1
Spleen	7.559E-04	6.481E-04	5.966E-04	1.969E-04	1.484E-	K1
Testes	7.559E-04	6.481E-04	5.964E-04	1.969E-04	1.484E-	K1
Thymus	7.559E-04	6.481E-04	5.966E-04	1.969E-04	1.484E-	K1
Thyroid	7.559E-04	6.481E-04	5.965E-04	1.969E-04	1.484E-	K1
GB_Wall	7.559E-04	6.481E-04	5.965E-04	1.969E-04	1.484E-	K1
Ht_Wall	7.559E-04	6.484E-04	5.972E-04	1.969E-04	1.484E-04	K1
Uterus	7.559E-04	6.481E-04	5.964E-04	1.969E-04	1.484E-04	K1
Lung	6.692E-01	7.017E-01	2.769E+00	3.360E-02	1.529E-04	S
ET	2.951E-01	9.002E-01	5.074E+00	2.576E-02	1.487E-04	S
Colon	9.427E-04	1.092E-03	1.583E-03	2.230E-04	1.507E-04	S
Oesophagus	7.559E-04	6.481E-04	5.966E-04	1.969E-04	1.484E-04	K1
Remainder	8.290E-04	7.115E-04	6.631E-04	2.158E-04	1.625E-04	K1

Table H-14. Chronic intake (1000 days) with urine bioassay on day after end of intake.

	K1 DCF (Sv/intake)	K5 DCF (Sv/intake)	S DCF (Sv/intake)	M DCF (Sv/intake)	F DCF (Sv/intake)
Adrenals	3.888E-05	2.063E-05	8.646E-06	9.377E-05	3.845E-04
UB_Wall	3.902E-05	2.070E-05	8.677E-06	9.409E-05	3.858E-04
Bone_Sur	1.135E-03	6.020E-04	2.700E-04	2.718E-03	1.112E-02
Brain	3.888E-05	2.063E-05	8.643E-06	9.377E-05	3.845E-04
Breasts	3.888E-05	2.063E-05	8.646E-06	9.377E-05	3.845E-04
St_Wall	3.924E-05	2.115E-05	9.174E-06	9.424E-05	3.847E-04
SI_Wall	3.977E-05	2.193E-05	9.962E-06	9.491E-05	3.850E-04
ULI_Wall	4.424E-05	2.849E-05	1.663E-05	1.007E-04	3.878E-04
LLI_Wall	5.461E-05	4.368E-05	3.208E-05	1.141E-04	3.942E-04
Kidneys	4.184E-04	2.219E-04	1.032E-04	9.996E-04	4.085E-03
Liver	1.561E-04	8.281E-05	3.723E-05	3.735E-04	1.527E-03
ET1-bas	4.122E-05	2.542E-05	1.442E-05	9.852E-05	3.892E-04
ET2-bas	1.553E-02	2.930E-02	7.535E-02	1.254E-02	3.855E-04
LN-ET	1.311E-03	2.426E-03	1.317E-01	6.290E-04	3.847E-04
BBi-bas	3.008E-03	4.265E-03	4.614E-03	2.887E-03	3.849E-04
BBi-sec	4.826E-02	4.843E-02	4.918E-02	3.783E-02	4.147E-04
bbe-sec	5.190E-02	2.811E-02	3.005E-02	2.090E-02	4.021E-04
AI	2.799E-02	1.397E-02	6.511E-02	7.762E-03	3.851E-04
LN-Th	9.871E-03	8.484E-03	4.522E-01	2.588E-03	3.845E-04
Muscle	3.889E-05	2.063E-05	8.651E-06	9.377E-05	3.845E-04
Ovaries	3.888E-05	2.063E-05	8.644E-06	9.377E-05	3.845E-04
Pancreas	3.888E-05	2.063E-05	8.644E-06	9.377E-05	3.845E-04
R_Marrow	1.170E-04	6.208E-05	2.792E-05	2.804E-04	1.147E-03
Skin	3.888E-05	2.063E-05	8.644E-06	9.377E-05	3.845E-04
Spleen	3.888E-05	2.063E-05	8.646E-06	9.377E-05	3.845E-04
Testes	3.888E-05	2.063E-05	8.643E-06	9.377E-05	3.845E-04
Thymus	3.888E-05	2.063E-05	8.645E-06	9.377E-05	3.845E-04
Thyroid	3.888E-05	2.063E-05	8.644E-06	9.377E-05	3.845E-04
GB_Wall	3.888E-05	2.063E-05	8.644E-06	9.377E-05	3.845E-04
Ht_Wall	3.889E-05	2.063E-05	8.654E-06	9.377E-05	3.845E-04
Uterus	3.888E-05	2.063E-05	8.643E-06	9.377E-05	3.845E-04
Lung	3.515E-02	2.279E-02	4.109E-02	1.633E-02	3.957E-04
ET	1.550E-02	2.924E-02	7.534E-02	1.251E-02	3.855E-04
Colon	4.870E-05	3.502E-05	2.327E-05	1.065E-04	3.906E-04
Oesophagus	3.888E-05	2.063E-05	8.645E-06	9.377E-05	3.845E-04
Remainder	4.273E-05	2.269E-05	9.632E-06	1.029E-04	4.218E-04
IRF	2.752E-02	1.459E-02	3.594E-03	6.675E-02	2.733E-01

	K1 (Sv)	K5 (Sv	S (Sv	M (Sv)	F (Sv	Biggest
Adrenals	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
UB_Wall	1.418E-03	1.419E-03	2.414E-03	1.410E-03	1.412E-03	S
Bone_Sur	4.124E-02	4.126E-02	7.512E-02	4.072E-02	4.068E-02	S
Brain	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Breasts	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
St_Wall	1.426E-03	1.450E-03	2.552E-03	1.412E-03	1.408E-03	S
SI_Wall	1.445E-03	1.503E-03	2.772E-03	1.422E-03	1.409E-03	S
ULI_Wall	1.607E-03	1.953E-03	4.627E-03	1.509E-03	1.419E-03	S
LLI_Wall	1.984E-03	2.994E-03	8.925E-03	1.709E-03	1.442E-03	S
Kidneys	1.520E-02	1.521E-02	2.871E-02	1.497E-02	1.495E-02	S
Liver	5.672E-03	5.675E-03	1.036E-02	5.595E-03	5.587E-03	S
ET1-bas	1.498E-03	1.742E-03	4.012E-03	1.476E-03	1.424E-03	S
ET2-bas	5.643E-01	2.008E+00	2.096E+01	1.879E-01	1.410E-03	S
LN-ET	4.763E-02	1.663E-01	3.664E+01	9.423E-03	1.408E-03	S
BBi-bas	1.093E-01	2.923E-01	1.284E+00	4.325E-02	1.408E-03	S
BBi-sec	1.753E+00	3.319E+00	1.368E+01	5.667E-01	1.517E-03	S
bbe-sec	1.886E+00	1.927E+00	8.360E+00	3.131E-01	1.471E-03	S
AI	1.017E+00	9.574E-01	1.811E+01	1.163E-01	1.409E-03	S
LN-Th	3.586E-01	5.815E-01	1.258E+02	3.877E-02	1.407E-03	S
Muscle	1.413E-03	1.414E-03	2.407E-03	1.405E-03	1.407E-03	S
Ovaries	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Pancreas	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
R_Marrow	4.251E-03	4.255E-03	7.768E-03	4.201E-03	4.197E-03	S
Skin	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Spleen	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Testes	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Thymus	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Thyroid	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
GB_Wall	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Ht_Wall	1.413E-03	1.414E-03	2.408E-03	1.405E-03	1.407E-03	S
Uterus	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Lung	1.277E+00	1.562E+00	1.143E+01	2.446E-01	1.448E-03	S
ET	5.632E-01	2.004E+00	2.096E+01	1.874E-01	1.410E-03	S
Colon	1.769E-03	2.400E-03	6.474E-03	1.595E-03	1.429E-03	S
Oesophagus	1.413E-03	1.414E-03	2.405E-03	1.405E-03	1.407E-03	S
Remainder	1.553E-03	1.555E-03	2.680E-03	1.542E-03	1.543E-03	S

Table H-15. Chronic intake (10000 days) with urine bioassay on day after end of intake.

	K1 DCF (Sv/intake)	K5 DCF (Sv/intake	S DCF (Sv/intake)	M DCF (Sv/intake	F DCF (Sv/intake)
Adrenals	3.021E-04	1.603E-04	6.437E-05	7.313E-04	3.002E-03
UB_Wall	3.034E-04	1.610E-04	6.466E-05	7.345E-04	3.015E-03
Bone_Sur	1.042E-02	5.528E-03	2.374E-03	2.500E-02	1.023E-01
Brain	3.021E-04	1.603E-04	6.434E-05	7.313E-04	3.002E-03
Breasts	3.021E-04	1.603E-04	6.437E-05	7.313E-04	3.002E-03
St_Wall	3.057E-04	1.655E-04	6.964E-05	7.360E-04	3.005E-03
SI_Wall	3.109E-04	1.733E-04	7.752E-05	7.428E-04	3.008E-03
ULI_Wall	3.557E-04	2.389E-04	1.442E-04	8.008E-04	3.036E-03
LLI_Wall	4.594E-04	3.908E-04	2.986E-04	9.351E-04	3.100E-03
Kidneys	4.148E-03	2.200E-03	9.812E-04	9.914E-03	4.052E-02
Liver	1.457E-03	7.732E-04	3.284E-04	3.496E-03	1.431E-02
ET1-bas	3.255E-04	2.082E-04	1.207E-04	7.788E-04	3.050E-03
ET2-bas	1.552E-01	2.930E-01	7.535E-01	1.252E-01	3.013E-03
LN-ET	1.303E-02	2.421E-02	1.126E+00	6.083E-03	3.005E-03
BBi-bas	2.999E-02	4.261E-02	4.611E-02	2.866E-02	3.007E-03
BBi-sec	4.824E-01	4.841E-01	4.917E-01	3.781E-01	3.304E-03
bbe-sec	5.188E-01	2.810E-01	3.001E-01	2.088E-01	3.179E-03
AI	2.799E-01	1.397E-01	6.376E-01	7.744E-02	3.009E-03
LN-Th	9.863E-02	8.480E-02	3.643E+00	2.568E-02	3.002E-03
Muscle	3.021E-04	1.603E-04	6.441E-05	7.313E-04	3.002E-03
Ovaries	3.021E-04	1.603E-04	6.434E-05	7.313E-04	3.002E-03
Pancreas	3.021E-04	1.603E-04	6.435E-05	7.313E-04	3.002E-03
R_Marrow	1.079E-03	5.723E-04	2.478E-04	2.587E-03	1.059E-02
Skin	3.021E-04	1.603E-04	6.434E-05	7.313E-04	3.002E-03
Spleen	3.021E-04	1.603E-04	6.436E-05	7.313E-04	3.002E-03
Testes	3.021E-04	1.603E-04	6.434E-05	7.313E-04	3.002E-03
Thymus	3.021E-04	1.603E-04	6.436E-05	7.313E-04	3.002E-03
Thyroid	3.021E-04	1.603E-04	6.434E-05	7.313E-04	3.002E-03
GB_Wall	3.021E-04	1.603E-04	6.434E-05	7.313E-04	3.002E-03
Ht_Wall	3.021E-04	1.603E-04	6.444E-05	7.313E-04	3.002E-03
Uterus	3.021E-04	1.603E-04	6.434E-05	7.313E-04	3.002E-03
Lung	3.514E-01	2.278E-01	4.055E-01	1.631E-01	3.114E-03
ET	1.549E-01	2.924E-01	7.532E-01	1.249E-01	3.013E-03
Colon	4.003E-04	3.042E-04	2.106E-04	8.585E-04	3.064E-03
Oesophagu	3.021E-04	1.603E-04	6.436E-05	7.313E-04	3.002E-03
Remainder	3.411E-04	1.812E-04	7.392E-05	8.241E-04	3.381E-03
IRF	2.868E-02	1.521E-02	6.705E-03	6.851E-02	2.799E-01

	K1 (Sv)	K5 (Sv)	S (Sv	M (Sv	F (Sv)	Biggest
Adrenals	1.053E-02	1.054E-02	9.600E-03	1.067E-02	1.072E-02	F
UB_Wall	1.058E-02	1.059E-02	9.643E-03	1.072E-02	1.077E-02	F
Bone_Sur	3.634E-01	3.634E-01	3.540E-01	3.649E-01	3.654E-01	F
Brain	1.053E-02	1.054E-02	9.595E-03	1.067E-02	1.072E-02	F
Breasts	1.053E-02	1.054E-02	9.600E-03	1.067E-02	1.072E-02	F
St_Wall	1.066E-02	1.088E-02	1.039E-02	1.074E-02	1.073E-02	K5
SI_Wall	1.084E-02	1.139E-02	1.156E-02	1.084E-02	1.075E-02	S
ULI_Wall	1.240E-02	1.571E-02	2.151E-02	1.169E-02	1.085E-02	S
LLI_Wall	1.602E-02	2.569E-02	4.453E-02	1.365E-02	1.107E-02	S
Kidneys	1.447E-01	1.446E-01	1.463E-01	1.447E-01	1.447E-01	S
Liver	5.081E-02	5.083E-02	4.898E-02	5.103E-02	5.112E-02	F
ET1-bas	1.135E-02	1.369E-02	1.800E-02	1.137E-02	1.090E-02	S
ET2-bas	5.412E+00	1.926E+01	1.124E+02	1.828E+00	1.076E-02	S
LN-ET	4.544E-01	1.592E+00	1.679E+02	8.879E-02	1.073E-02	S
BBi-bas	1.046E+00	2.801E+00	6.877E+00	4.184E-01	1.074E-02	S
BBi-sec	1.682E+01	3.183E+01	7.333E+01	5.519E+00	1.180E-02	S
bbe-sec	1.809E+01	1.847E+01	4.476E+01	3.048E+00	1.136E-02	S
AI	9.761E+00	9.185E+00	9.509E+01	1.130E+00	1.075E-02	S
LN-Th	3.439E+00	5.575E+00	5.433E+02	3.749E-01	1.072E-02	S
Muscle	1.053E-02	1.054E-02	9.606E-03	1.067E-02	1.072E-02	F
Ovaries	1.053E-02	1.054E-02	9.595E-03	1.067E-02	1.072E-02	F
Pancreas	1.053E-02	1.054E-02	9.597E-03	1.067E-02	1.072E-02	F
R_Marrow	3.763E-02	3.763E-02	3.696E-02	3.776E-02	3.783E-02	F
Skin	1.053E-02	1.054E-02	9.595E-03	1.067E-02	1.072E-02	F
Spleen	1.053E-02	1.054E-02	9.598E-03	1.067E-02	1.072E-02	F
Testes	1.053E-02	1.054E-02	9.595E-03	1.067E-02	1.072E-02	F
Thymus	1.053E-02	1.054E-02	9.598E-03	1.067E-02	1.072E-02	F
Thyroid	1.053E-02	1.054E-02	9.595E-03	1.067E-02	1.072E-02	F
GB_Wall	1.053E-02	1.054E-02	9.595E-03	1.067E-02	1.072E-02	F
Ht_Wall	1.053E-02	1.054E-02	9.610E-03	1.067E-02	1.072E-02	F
Uterus	1.053E-02	1.054E-02	9.595E-03	1.067E-02	1.072E-02	F
Lung	1.225E+01	1.498E+01	6.047E+01	2.381E+00	1.112E-02	S
ET	5.402E+00	1.922E+01	1.123E+02	1.823E+00	1.076E-02	S
Colon	1.396E-02	2.000E-02	3.141E-02	1.253E-02	1.095E-02	S
Oesophagus	1.053E-02	1.054E-02	9.598E-03	1.067E-02	1.072E-02	F
Remainder	1.189E-02	1.191E-02	1.102E-02	1.203E-02	1.208E-02	F