DOE Review Release 04/07/2010

Document Title:	Document Number:	ORAUT-TKBS-0058
Site Profile for Battelle Memorial Institute, King Avenue and West Jefferson Sites, Columbus, Ohio	Revision:	00
	Effective Date:	03/26/2010
	Type of Document	TBD
	Supersedes:	None

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☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
03/26/2010	00	New site profile for the Battelle Memorial Institute sites in Columbus, Ohio (King Avenue) and West Jefferson, Ohio (West Jefferson). Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Janet L. Westbrook and Vincent A. King.

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ACRONYMS AND ABBREVIATIONS

AARR	Argonne Advanced Research Reactor
AEC	U.S. Atomic Energy Commission
AGC	Alpha-Gamma Cell
AGCRSP	Army Gas-Cooled Reactor Systems Program
AGN	Aerojet General Nucleonics
Al	aluminum
AI	Atomics International (Co)
ANL	Argonne National Laboratory
AP	anterior-posterior
APPR	Army Package Power Reactor
ARB	Army Reactor Branch
ATL-A	Advanced Technology Labs (American Standard Corp)
ATR	Advanced Test Reactor (INEL)
AWE	atomic weapons employer
BCD	Battelle Columbus Division
BCL	Battelle Columbus Laboratories (i.e., Battelle Memorial Institute)
BCLDP	Battelle Columbus Laboratories Decommissioning Project
BMI	Battelle Memorial Institute
BRR	Battelle Research Reactor
BWR	Boiling-water reactor
BZ	Breathing zone
CA, CAA	Controlled Access Area (at JN-1); the Contaminated Control Area was apparently a subsection of the Controlled Access Area
CAL	Critical Assembly Facility, i.e., JN-2 in 1957-1963
CAM	continuous air monitor
CATI	computer-assisted telephone interview
CEMP	Columbus Environmental Management Project
CFR	Code of Federal Regulations
Ci	curie
CEMP	Columbus Environmental Management Project
CETR	Consolidated Edison Thorium Reactor
Con Ed	Consolidated Edison (Co)
CP-6	Same as AARR
CPP	Chemical Processing Plant (INEL)
CXR	chest X-ray
d	day
DCF	dose correction factor
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
dpm	disintegrations per minute
E of C	Evidence of contamination (used in badge records)
EDTA	Ethylenediaminetetraacetic acid (used experimentally)
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESD	entrance skin dose
ESR	Engineering Storage Room in JN-1
ETR	Engineering Testing Reactor (INEL)
EU	enriched uranium

FEMP	Fernald Environmental Management Project (Fernald site)
ft	foot
g	gram
GA	General Atomics (company)
GCRE	Gas-Cooled Reactor Experiment
HAPO	Hanford Atomic Power Operations
HC	hot cell
HEC	High Energy Cell (JN-1)
HEDL	Hanford Engineering Development Laboratory
HERLA	High-Energy Research Laboratory Area
HEU	highly enriched uranium (to 93% or more)
HIP	Hot Isostatic Processing (facility)
HLC	High Level Cell (JN-1)
HP	Health physicist
HTGR	High Temperature Gas[-Cooled] Reactor
hr	hour
HVL	half-value layer
ICRP	International Commission on Radiological Protection
in.	inch
INEL, INL	Idaho National Engineering Laboratory
JN	Prefix for some West Jefferson buildings (north part of the site)
JS	Prefix for some West Jefferson buildings (south part of the site)
KA	King Avenue (site)
keV	kiloelectron-volt, 1,000 electron-volts
kg	kilogram
KPA	kinetic phosphorescence analysis
L	liter
LAMPF	Los Alamos Meson Physics Facility
LAMPRE	Los Alamos Molten Plutonium Reactor Experiment
LAT	lateral
lb	pound
LLC	Low Level Cell (JN-1)
LLNL	Lawrence Livermore National Laboratory
mCi	millicurie
MDL	minimum detection level
MED	Manhattan Engineer District
MeV	megaelectron-volt, 1 million electron-volts
MFP	mixed fission products
mg	milligram
MGCR	Maritime Gas-Cooled Reactor
MHW	Multihundred watt - a type of plutonium (Pu-238) fuel for RTGs
millirem	millirem
mL	milliliter
ML-1	Mobile Low-power (reactor) (Army program)
MPBB	Maximum permissible body burden
mR	milliroentgen

mrad	millirad
MTC	Mechanical Test Cell (in JN-1)
MW	megawatt
NAC	Nuclear Assurance Corporation
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurement
NIOSH	National Institute for Occupational Safety and Health
NLO	National Lead Company of Ohio (Fernald)
NMSR	Nuclear Merchant Ship Reactor
NPR	Nonpower reactor or neutron production reactor
NRC	U.S. Nuclear Regulatory Commission
NRTS	Same as ETR facility
NSEC	Nuclear Science and Engineering Corporation
NTA	nuclear track emulsion, type A
NYOO	New York Operations Office
OBD	Old Back Dock (JN-1)
OID	AEC's Office of Isotopes Development
OMRE, OME	Organic-Moderated Reactor Experiment, aka Organic Moderated Solvent Burning Experiment (INEL)
ONWI	Battelle's Office of Nuclear Waste Isolation
OOA	Old Operating Area (JN-1)
ORNL	Oak Ridge National Laboratory
PA	posterior-anterior
PRTR	Plutonium Recycle Test Reactor (Hanford)
PWR	Pressurized-water reactor
PyC	Pyrolitic carbon
R&D	research and development
RAL	Radioanalytical Laboratory, which was in the former plutonium lab in JN-2
RCRA	Resource Conservation and Recovery Act
RD, AEC-RD, AEC-DRD	AEC's Research Division
RFI	Rocky Flats
RR	[Battelle] Research reactor
RTG	Radioisotope thermoelectric generator
s	second
S&M	Surveillance and maintenance (before decontamination)
SAP	Sintered aluminum powder
SME	Salt-Moderated Experiment (reactor)
SNAP	Systems for Auxiliary Nuclear Power (reactor series for space, etc.)
SNM	Special Nuclear Material
SRDB Ref ID	Site Research Database reference identification number
SS	stainless steel (as a material specification); Super S (as a biosolubility class)
T	Uranium (e.g., U metal was also called T metal)
TLD	thermoluminescent dosimeter
TNT	Thorium nitrate tetrahydrate
TREAT	Transient Reactor Test Facility (INEL)
TRU	transuranic

U.S.C.	United States Code
µCi	microcurie
UCRL	University of California (Lawrence) Radiation Laboratory
µm	micrometer (0.001 meter)
UNH	Uranyl nitrate hexahydrate, i.e., $UO_2(NO_3)2 \cdot 6\ H_2O$
µg	microgram
VMR	Variable Moderator Reactor
w/o	weight percent (when used in describing, e.g., alloy forms)
WJ	West Jefferson (site)
wk	week
WTR	Westinghouse Test Reactor (Pennsylvania)
X	Uranium (e.g., U metal was also called X metal)
XP-pad	Staging area/pad; Not a radiological area, but had RCRA closure significance
ZPR	The critical assembly facility (JN-2)
§	section or sections

1.0 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 [AWE] facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA, as amended, provides for employees who worked at an AWE facility during the contract period and/or during the residual period.

Under EEOICPA, employment at an AWE facility is categorized as either (1) during the DOE contract period (i.e., when the AWE was processing or producing material that emitted radiation and was used in the production of an atomic weapon), or (2) during the residual contamination period (i.e., periods that NIOSH has determined there is the potential for significant residual contamination after the period in which weapons-related production occurred). For contract period employment, all occupationally derived radiation exposures at covered facilities must be included in dose reconstructions. This includes radiation exposure related to the Naval Nuclear Propulsion Program and any radiation exposure received from the production of commercial radioactive products that were concurrently manufactured by the AWE facility during the covered period. NIOSH does not consider the following exposures to be occupationally derived (NIOSH 2007a):

- 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

For employment during the residual contamination period, only the radiation exposures defined in 42 U.S.C. § 7384n(c)(4) [i.e., radiation doses received from DOE-related work] must be included in dose reconstructions. Doses from medical X-rays are not reconstructed during the residual contamination period (NIOSH 2007a). It should be noted that under subparagraph A of 42 U.S.C. § 7384n(c)(4), radiation associated with the Naval Nuclear Propulsion Program is specifically excluded from the employee's radiation dose. This exclusion only applies to those AWE employees who worked during the residual contamination period. Also, under subparagraph B of 42 U.S.C. § 7384n(c)(4), radiation from a source not covered by subparagraph A that is not distinguishable through reliable documentation from radiation that is covered by subparagraph A is considered part of the employee's radiation dose. This site profile covers only exposures resulting from nuclear weapons-related work. Exposures resulting from non-weapons-related work, if applicable, will be covered elsewhere.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 7.0.

2.0 SITE DESCRIPTION

The Department of Energy Worker Advocacy Web site (December 26, 2006) gives the following information:

> Battelle Laboratories – King Avenue
>
> Also known as: Battelle Columbus Laboratories (BCL); Battelle Memorial Institute (BMI)
>
> State: Ohio
>
> Location: Columbus
>
> Time period: AWE 1943–1986; DOE 1986–2000
>
> Facility type: Atomic Weapons Employer, Department of Energy
>
> Battelle Laboratories – West Jefferson
>
> Also known as: Battelle Columbus Laboratories (BCL); Battelle Memorial Institute (BMI); West Jefferson Plutonium Facilities
>
> State: Ohio
>
> Location: Columbus [West Jefferson]
>
> Time period: AWE 1956–1975; Residual Radiation 1976-–1985; DOE 1986–present (remediation)
>
> Facility type: Atomic Weapons Employer, Department of Energy
>
> Facility Description: From 1943 to 1986, BMI performed atomic energy research and development [R&D] for DOE and its predecessor agencies. The Battelle Laboratories have two separate locations in Columbus: King Avenue and West Jefferson. Battelle's research supported the government's fuel and target fabrication program, including fabrication of uranium and fuel elements, reactor development, submarine propulsion, fuel reprocessing, and the safe e of reactor vessels and piping. The following activities were performed at the King Avenue site: processing and machining enriched, natural, and depleted uranium and thorium; fabricating fuel elements; analyzing radiochemicals; and studying power metallurgy. The following activities were performed at the West Jefferson site: operation of a large hot cell facility and a research reactor. Reactor operations began in October 1956, and ended in December 1974. The reactor was defueled and partially dismantled in 1975 and Battelle's license was changed to possession-only status.

In this site summary document, BMI and BCL (the Columbus-based division of BMI operations) are referred to as Battelle. Both the Battelle King Avenue and West Jefferson sites are included in this site summary. When it is necessary to distinguish between the two sites, they will be referred to as King Avenue and West Jefferson, respectively.

Battelle was a research institution and undertook a wide variety of radiologically significant projects as part of its Manhattan Engineer District (MED)/AEC/Energy Research and Development Administration

(ERDA)/DOE work and its defense and commercial work. These projects ranged from low-level biological and industrial radiotracer work to high-level work involving alpha gloveboxes and hot cells.

The relative locations of the King Avenue and West Jefferson sites are shown in Figure 2-1 (BCL 1974). Individual plan views of the King Avenue and West Jefferson sites are shown in Figures 2-2 and 2-3, respectively (Jenson 2003). Plan views are also available for the Melting Facility at Building 3 (Kirsch 2000a); the Building 4 Radioisotope Laboratory and various subareas (Sunderman and Dickerson 1962; Brown 1966); the Hot Cell Laboratory (JN-1) and subareas (Wastren 2001; Sunderman and Dickerson 1962; Dickerson 1956; Brown 1966); the Critical Assembly Laboratory (JN-2) (Hogan et al. 1958; Jankowski and Chastain 1958; Kirsch 1987); the Battelle Research Reactor (BRR, JN-3) (Chastain et al. 1955; Chastain 1957; Anno and Plummer 1962); the Plutonium Laboratory (JN-4) (Flynn et al. 1987; Freas et al. 1971; Rudolph, Kirsch, and Toy 1984); the King Avenue site (Sunderman and Dickerson 1962; BMI 1977); and the West Jefferson site (Evans and Woodward 1979; BCL 2002).

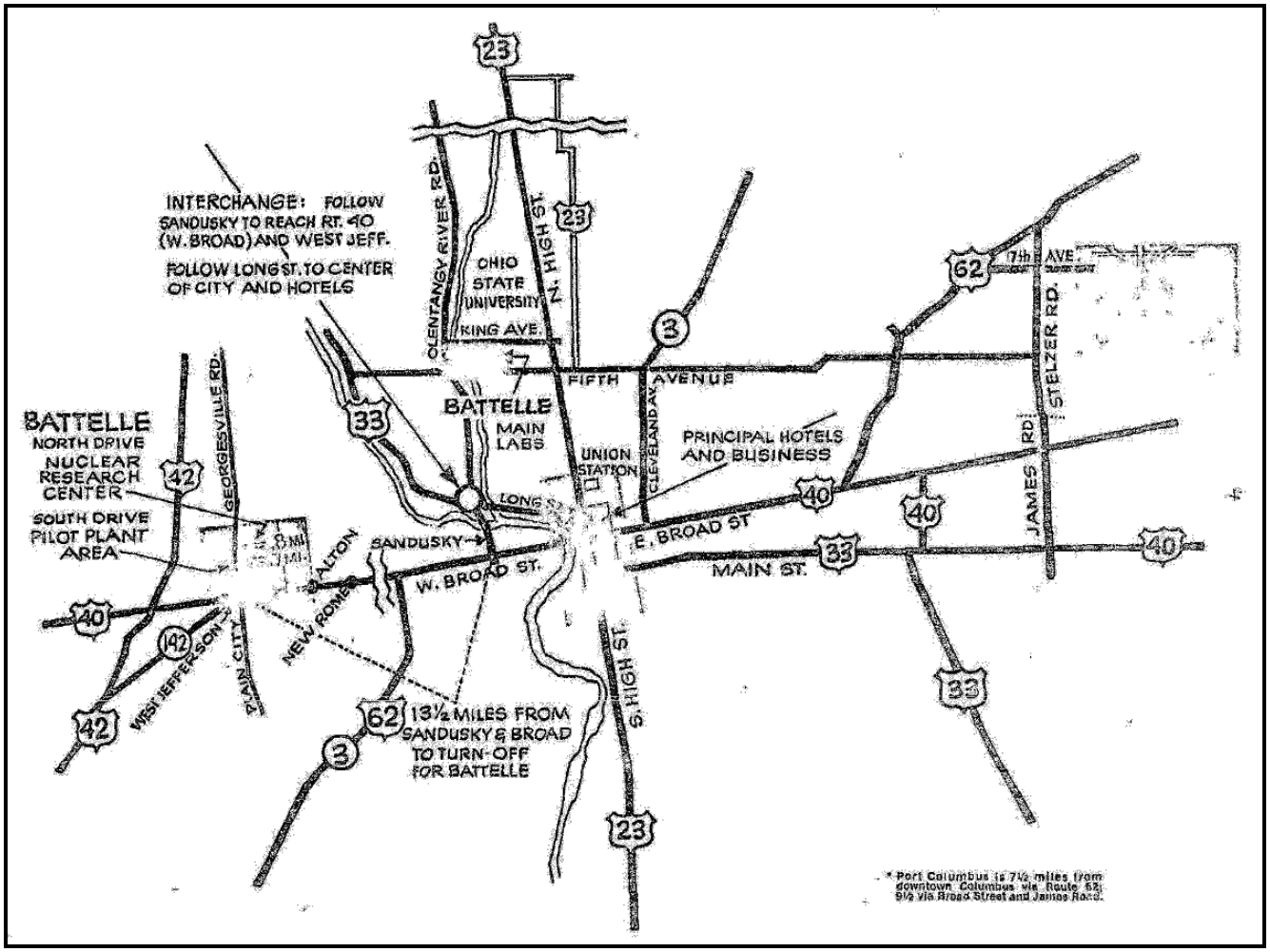

Figure 2-1. Relative locations of the King Avenue and West Jefferson sites.

2.1 BUILDINGS OF CONCERN AND THE ASSOCIATED RADIOACTIVE MATERIALS AND OPERATIONS

Attachment A provides an overview chronology of significant events at Battelle, including the start and end of operations. Attachment B is a list of buildings, their major subareas and uses, and the dates of their use. Attachment E lists the incidents that were reported at the site. Most of these did not result

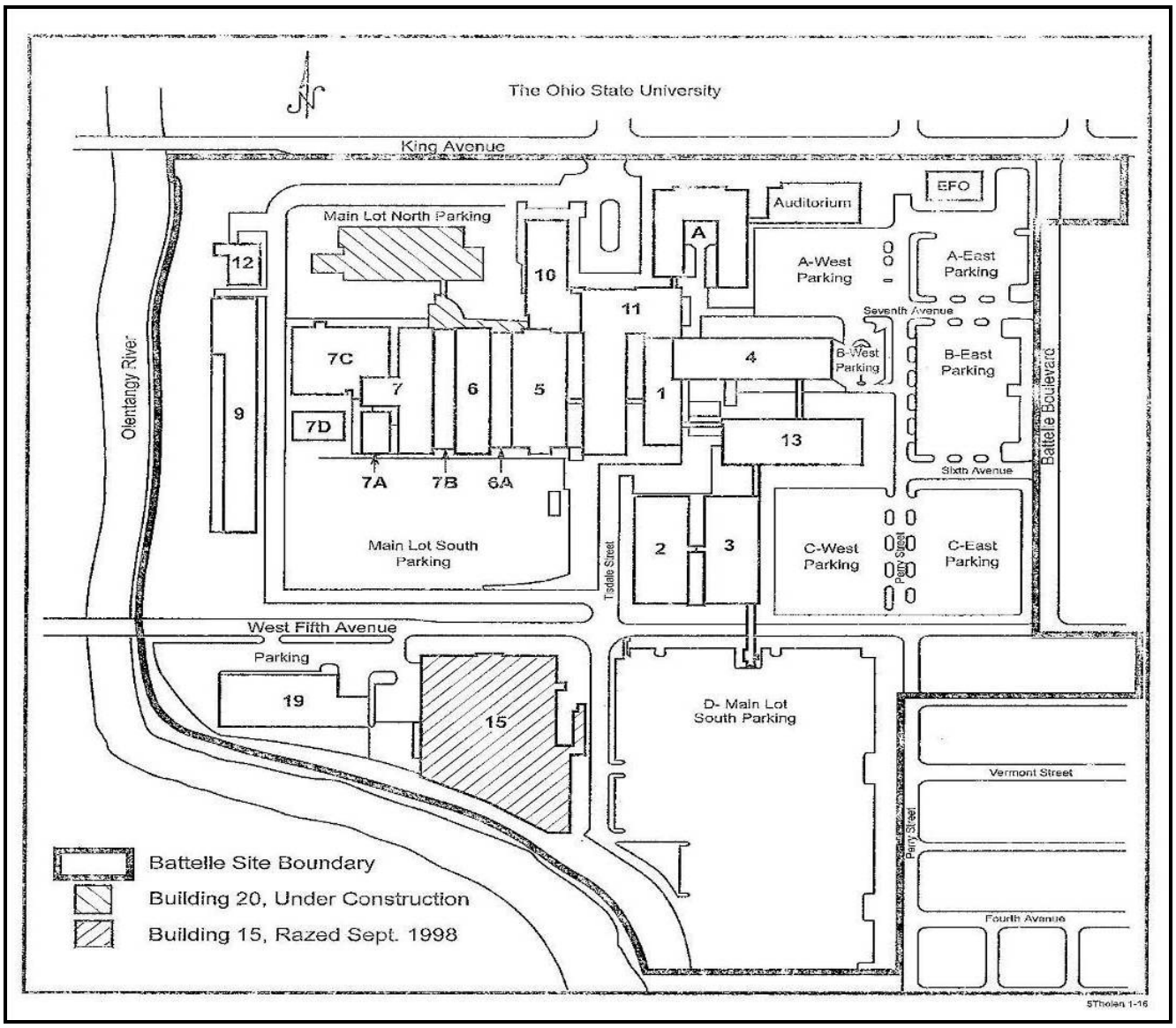

Figure 2-2. Plan view of the King Avenue site.

in a significant internal or external exposure to any worker, but at times Battelle had to do additional monitoring of one or more workers to determine this. The most notable incidents from the point of view of potential or actual exposure are those of August 8, 1956, February 10, 1959, August 9, 1961, and July 2, 1980, for external exposure and February 10, 1959, May 9, 1974, January 16, 1979, May 2, 1980, February 27, 1984, and May 1984 for internal exposure.

The abbreviations and definitions should be used as an aid in the interpretation of dosimetry records and other relevant documents.

2.2 ACCESS CONTROLS

At the Radioisotope Laboratory in Building 4, the doors from the corridor into the medium- and high-level laboratories were locked from the outside at all times. Access was otherwise through the locker room, which itself was entered through the office area (Sunderman and Dickerson 1962). These doors were used only for transporting casks and heavy equipment in and out of the laboratory. Permission of the laboratory supervisor was required before the doors could be used.

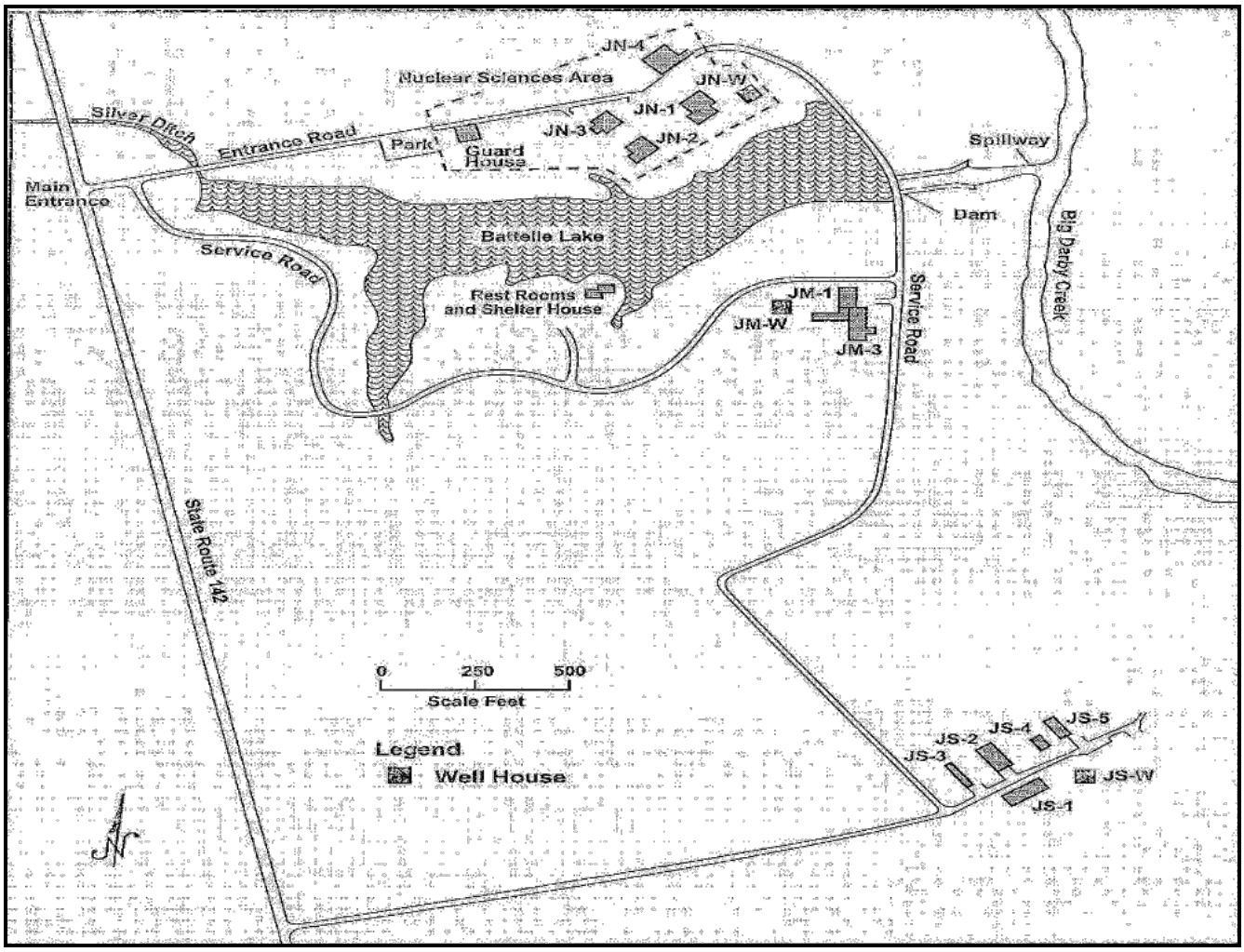

Figure 2-3. Plan view of the West Jefferson site.

At the Gamma (^{60}Co irradiation) Facility in Building 6, permission for non-staff members to enter the facility had to be obtained from the facility staff (Sunderman and Dickerson 1962). This facility was kept locked overnight, on holidays, and on weekends to prevent unauthorized personnel from entering.

The Hot Cell Laboratory (JN-1) began operations in 1955 (Wastren 2001). Access was controlled at all times and, in compliance with 10 CFR Part 20, the entire building was a restricted area (Sunderman and Dickerson 1962; Sunderman and Gates 1965). The locker rooms were divided into two areas separated by walk-through showers; one area was used by personnel not in contact with radioactive material while the other was the dressing area for entry into the contaminated areas (Sunderman and Dickerson 1962). Personnel access into the operating and contamination areas was normally through the hot locker room, but under special conditions, entry might also be made through locked doors directly into the operating area or through an equipment storage area (Sunderman and Dickerson 1962; Myers et al. 1994a). Access to the cells was only through locked doors at the rear of the cells, reached only through the Controlled Access Area (Sunderman and Dickerson 1962; Myers et al. 1994a). Access to the Alpha-Gamma Cell (AGC) operating area and receiving dock area was restricted when an AGC dry box was being moved through these areas to the repair station (Gates 1964).

At the Critical Assembly Laboratory (JN-2), before operation each day, interlocks were checked, and there was a visual check of the facility and the critical assembly room (Hogan et al. 1958, Jankowski

et al. 1957). The outer doors and doors between the control room and the critical assembly room were required to be locked during operation of the critical assembly; signs were posted before operation (Hogan et al. 1958). Only personnel engaged in activities directly connected with the current operation were allowed to be present in the control room during an experiment. There was a fence around the building to exclude personnel and trucks when necessary (Hogan et al. 1958).

At the Battelle Research Reactor (BRR or JN-3), color-coded badges were used to denote levels of access, depending on the level of training; the top level was a free access badge (Hogan et al. 1958, Plummer, Anno, and Chastain 1960). Visitors from outside Battelle, transient experimenters, maintenance staff, and Battelle non-BRR staff visitors were escorted by reactor staff or by Public Relations Office staff. In general, visitors were permitted only in areas free from experimental activity (Anno and Plummer 1962); otherwise, permission had to be obtained from the Operating Supervisor and personnel monitoring devices such as visitor badges were provided (Anno and Plummer 1962, Plummer, Anno, and Chastain 1960).

At the Plutonium Laboratory (JN-4), all outside doors and the doors between the laboratory area proper and the office area were kept locked from the inside (BCL 1977a).

3.0 OCCUPATIONAL MEDICAL DOSE

In 1943, a MED officer reported that no physical or laboratory medical examinations of Battelle employees had been done because of their low and intermittent exposures to radioactivity (Ferry 1943). It is therefore likely that there were no required medical X-ray examinations done in the early years. However, in the absence of individual information, a preemployment examination should be assumed. A posterior-anterior (PA) chest X-ray examination should be assumed from the beginning of site operations through 1951 (at least one preemployment PA chest X-ray was recorded as early as 1946). Based on a review of site records for Battelle, single chest fluoroscopy examinations were performed as part of a preemployment examination from 1952 through 1965. After 1965, radiographic PA chest X-rays were performed for preemployment examinations.

In addition to the preemployment examination, annual PA chest X-ray examinations were performed for subsequent years of employment during all periods of operations. The records also indicate that a single additional annual lateral (LAT) chest X-ray examination was performed in addition to the annual PA radiographic chest examination (Wright 2002a, b) for the period 1975 through 1980. X-ray examinations were occasionally identified as “teleo chest” X-rays, which were performed to evaluate heart size. PA chest X-ray doses should be assigned for these examinations because the same source-to-image distance and X-ray equipment would have been used for these examinations.

Table 3-1 lists the organ and skin doses for chest fluoroscopy. While ORAUT-OTIB-0006 (ORAUT 2005a) provides some default assumptions for chest fluoroscopy, new information has been found in the modern medical literature for this now obsolete procedure (Marshall 2001). The Battelle claim records indicate that the chest fluoroscopy examinations were performed in a private physician’s office. Given the era and the private office setting, the fluoroscopic equipment was most likely to have been "direct" or non-image intensified fluoroscopy equipment of the same type described by Marshall (2001). Entrance air kerma rates for this type of equipment are not commonly found in the literature. However, a study of the entrance air kerma rates, half-value layers (HVLs), and estimated fluoroscopy exposure times was conducted in Albania and described by Marshall (2001). In this study, the exposure time for chest fluoroscopy screening was estimated to be about 20 seconds, with an average entrance air kerma rate of about 4 R/min, and an average HVL of about 2.3 mm Al equivalent. Therefore, chest fluoroscopy doses for Battelle workers are calculated using the following assumptions that are favorable to claimants and based on the Marshall (2001) data: an entrance exposure rate of 5 R/min for 30 seconds of fluoroscopy time and International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982) dose conversion factors (DCFs) for a PA chest for 2.0 mm Al HVL. For chest fluoroscopy, the field is assumed to include the thoracic organs and the liver/gall bladder/spleen, but not the thyroid, gonads, bladder, or colon/rectum, because of the short source-to-skin distance (SSD) (approximately 40 cm). However, the beam size was estimated to be similar to the beam for a poorly collimated radiographic chest X-ray to account for the fact that the field in chest fluoroscopy is dynamic and could expose a larger area of the body than the short SSD would initially imply. Doses from chest fluoroscopy examinations in Table 3-1 should be assigned as the geometric mean values of a lognormal distribution with a geometric standard deviation of 2 to account for the uncertainty in the procedures.

ORAUT-OTIB-0006 (ORAUT 2005a) provides organ doses for PA and LAT radiographic chest examinations.

If individual X-ray records are available, the examination type and frequency should be assigned as identified in the records. In the absence of site or individual information, the examination types and frequencies in Table 3-2 should be assumed as default values.

Table 3-1. Organ doses from chest fluoroscopy.

PA chest fluoroscopy[a,b]	DCF mGy/Gy × 1E-3rem-Gy/cGy-mGy (HVL = 2.0 mm Al eq)	Entrance kerma (cGy)	Organ dose (rem)
Thyroid	1.50E-01[c]	2.50E+00	3.75E-01
Eye brain	2.10E-02	2.50E+00	5.25E-02
Ovaries	6.00E-04	2.50E+00	1.50E-03
Liver/gall bladder/spleen	3.55E-01	2.50E+00	8.88E-01
Urinary bladder	6.00E-04	2.50E+00	1.50E-03
Colon rectum	6.00E-04	2.50E+00	1.50E-03
Testes	1.00E-05	2.50E+00	2.50E-05
Lungs	3.55E -01	2.50E+00	8.88E-01
Thymus	3.55E -01	2.50E+00	8.88E-01
Esophagus	3.55E -01	2.50E+00	8.88E-01
Stomach	3.55E -01	2.50E+00	8.88E-01
Bone surfaces	3.55E -01	2.50E+00	8.88E-01
Remainder	3.55E -01	2.50E+00	8.88E-01
Breast	3.20E -02	2.50E+00	8.00E-02
Uterus	7.00E-04	2.50E+00	1.75E-03
Bone marrow	6.90E-02	2.50E+00	1.73E-01
Entrance skin dose (ESD) applies to skin of: back and sides of chest to iliac crest, back of shoulders, back and sides of neck, upper arms, elbows, forearms, and palms and backs of hands			3.30E+00[d]
Eye/brain dose applies to skin of face			5.25E-02
Exit skin dose applies to the skin of: front of chest, front of shoulders, front of upper abdomen (to iliac crest), front of neck			6.32E-02[e]
Outside but near entrance beam dose applies to skin of back and sides of head, ears, and buttocks.			3.30E-01[f]
Outside but near exit beam dose applies to the skin of front lower abdomen from iliac crest to pubis			6.32E-03[g]
Skin of thighs to knees			8.20E-04
Skin of knees and below			3.00E-04

a. The assumed entrance exposure rate is 5 R/min for 30 seconds.
b. For chest fluoroscopy, the field is estimated to include thoracic organs and the liver/gall bladder/spleen, but not the gonads, bladder, or colorectal organs.
c. Used DCF for AP Cervical spine and depth dose correction factor of 0.2 (ORAUT 2005a).
d. ESD is the entrance kerma rate multiplied by a backscatter factor of 1.32 from Table B-8 of National Council on Radiation Protection and Measurement (NCRP) Report 102 (NCRP 1989).
e. Exit skin dose is the ESD divided by the absorption factor for a 24-cm chest and 2.0 mm Al HVL, divided by 0.9 to account for the uncertainty in the tabulated absorption factors in Table B-7 of NCRP Report 102 (NCRP 1989).
f. Outside but near entrance beam dose is 10% of the ESD.
g. Outside but near exit beam dose is 10% of the exit skin dose.

Table 3-2. Default assumptions for X-ray procedure types and frequencies.

Period	Preemployment PA chest	Preemployment fluoroscopic chest	Annual PA chest	LAT chest
Beginning of operations–1951	X		X	
1952–1965		X	X	
1966–1974	X		X	
1975–1980	X		X	X
1981–present	X		X	

4.0 OCCUPATIONAL INTERNAL DOSE

4.1 *IN VITRO* BIOASSAY

4.1.1 Urinalysis

Routine urine samples appear nearly always to have been 24-hour samples, although the bioassay records note samples that represent longer or shorter correction periods, for which the results were corrected to 24-hour equivalents. A few spot samples were taken, probably as a check or as the result of an incident; these appear to be identified as such in the records. In the absence of specific recorded information, a urine sample should be considered to represent a 24-hour excretion period.

Table 4-1 is a summary of the primary types of routine *in vitro* bioassay samples and the associated sampling periods as observed in claimant analytical reports provided by DOE to the NIOSH project. Sampling frequencies are typically monthly, quarterly, or semiannually, depending on the activity in which the worker is involved, or driven by follow-up activities to specific incidents. The earliest urinalysis mention in records found by the NIOSH Project is of samples submitted in about September 1956 to a toxicology consultant; these samples were assayed only for uranium and the results were given in milligrams. It is unclear who performed these initial urine analyses. In about September 1957, Battelle began to send the samples to Nuclear Science and Engineering Corporation (NSEC); these samples were analyzed for either uranium or gross beta (Edelmann 1958, 1959a) through March 18, 1960, then for uranium or gross beta, as requested. By at least September 1959, NSEC was analyzing for plutonium (Edelmann 1959b) and by at least February 1962 for uranium, plutonium, gross beta, and tritium (Sunderman and Dickerson 1962). Only one type of analysis appears to have been done per sample; that is, aliquots were apparently not drawn off the same sample for different analyses by NSEC, although this might have been done by Battelle.

From at least as early as August 1963 to early 1995 (based on inspections of individual records obtained by the Project; Sunderson and Gates 1965), the samples were analyzed by the Eberline Company; after this, samples were analyzed by Thermo Nutech, of which Eberline was the predecessor company. In the first few years, these samples were analyzed for fission products, plutonium, polonium, tritium, or uranium (Geiger 1963, 1964a, 1965); from inspection of urinalysis reports, the fission products appear to have been analyzed as gross beta. Later, they were analyzed for some or all of ^{3}H, ^{14}C, ^{32}P, ^{40}K, ^{51}Cr, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{144}Ca, ^{125}I, ^{131}I, europium, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{241}Am, and/or mixed fission products. Some discussion of recovery for ^{59}Fe, ^{51}Cr, and ^{63}Ni is given in Geiger (1964b), indicating these radionuclides may also have been evaluated. Finally, a research scientist (probably a chemist) had a one-time ^{203}Hg urinalysis in 1971.

From 1957 on, the samples were collected over a nominal 24 hours (Geiger 1963), although it was often noted on records if the sample was actually over a longer period. A few spot samples were taken, probably as a check or as the result of an incident; these appear to be identified as such in the records.

It is not known on what general basis workers were selected for bioassay. Based on the dosimetry records available to the NIOSH Dose Reconstruction Project, on claimant statements, and on Battelle site documents, it appears that at King Avenue, workers in at least the following categories were included in the urinalysis program:

- Workers in the Building 4 Radioisotope Laboratory complex and in the radiotracer laboratories in Buildings A and 1, including office personnel in these facilities

Table 4-1. Summary of *in vitro* bioassay information.

Monitoring type	Radionuclide	Period
Urine, 24-hour	Gross beta	1957–1963
Urine, 24-hour	Uranium (total), RU[a]	1957–1998
Urine, 24-hour	U-234, U235, U-238 (SPU)[b]	1970–1994
Urine, 24-hour	Plutonium–total	1961–1998
Urine, 24-hour	Pu–isotopic (^{238}Pu, ^{239}Pu)	1964–1993
Urine, 24-hour	H-3	1962–1965
Urine, 24-hour	Fission products/MFP	1961–1998
Urine, 24-hour	Thorium–isotopic	1981–1994
Urine, 24-hour	Thorium–total	1993–1998
Fecal	Pu-239, FP, K-40, Ce-141-Ce/Pr-144, Ru-103-Ru/Rh-106, Z-95-Nb-95, U-234, U-235, U-38, Am-241, Sr-90	1975–1983

In addition to the information above, Eu, Am-241, Sr-90, Ce-144, Cs-134, Cs-137, Co-60, P-32, I-131, Cr-51, and I-125 were all assayed for in urinalyses at different times, as could be seen in the group reports from Eberline.

a. When RU is used in the bioassay records, it indicates "radiometric uranium", not recycled uranium.
b. When "SPU" is used in the records, it indicates the three U isotopes 234, 235, and 238, not Pu.

- Workers in areas of Buildings 2, 3, and 5 where uranium and other radioactive materials were handled

- Workers in Building 6 laboratories (except the Gamma Laboratory), but possibly only for specific projects

It appears that at West Jefferson, workers in at least the following categories were included:

- All workers at JN-1 during all years of operation and cleanup (about 1956 on)

- All workers at JN-2 during its use as a branch plutonium source testing laboratory (1964?-1970) and possibly during its use as a critical facility (1956-1963)

- All workers at JN-3 during all years of operation and cleanup (1956 on)

- All workers at JN-4 during all years of operation and cleanup (1960 on)

More details are given below. Note that workers in other buildings and facilities than those given above or discussed below may also have been included as necessary based on their job functions.

All of the Radioisotopes Laboratory (Building 4 and the two tracer laboratories in Buildings A and 1) and JN-1 personnel working with radioactive materials participated in the urinalysis program routinely; secretaries and administrative personnel at these facilities were included (Sunderman and Dickerson 1962). Staff members at JN-4 also submitted urine samples. Most of the workers in nonclerical and nonmanagement positions (above the level of supervisors), i.e., who likely were engaged in radiological work at least intermittently, were included in urinalysis program. There are urinalysis records for a metallurgical technician starting in 1957; this technician is known to have worked with uranium in Building 5. Similarly, from dosimetry records and incident reports, technicians in other areas of King Avenue and West Jefferson also appear to have had regular bioassay and also special bioassays or special attention to regular bioassays when there were incidents.

Staff members at JN-1 submitted urine samples quarterly, while personnel at the Radioisotope Laboratory submitted samples semiannually and secretaries and administrative personnel at both facilities submitted samples annually (Sunderman and Dickerson 1962). Staff members at JN-4 submitted samples quarterly and additionally as needed, e.g., in case of an incident (BCL 1977a). In

individual dosimetry files accessible to the NIOSH Project, there are multiple notices sent to workers regarding their failure to submit urine samples, which are always termed "quarterly" samples. Some of the tabulations on the company cards have the notation "To be submitted [every] 6 months" and on others the notation "3 months."

A set of urine samples analyzed in 1974 were from workers involved in a May 9, 1974, incident in which plutonium was the major airborne contaminant (Geiger 1974); the bioassay records show that urine and fecal samples were submitted approximately weekly for some months and that the urine samples were analyzed initially for ^{239}Pu, mixed fission products, and ^{90}Sr. Later samples were analyzed for ^{239}Pu and fission products. A summary of the bioassay data for the most exposed worker is shown in Toy (1975).

4.1.2 Fecal Sample Analysis

The earliest records of fecal samples date from May 1974 and go through at least March 1982, as shown in Table 4-1. Fecal sample analyses were all performed by Eberline and measured ^{40}K, ^{90}Sr, ^{95}Zr-^{95}Nb, ^{103}Ru-^{106}Rh, ^{141}Ce-^{144}Pr, ^{234}U, ^{235}U, ^{238}U, ^{239}Pu, ^{241}Am, and/or mixed fission products, depending on the year and the case. The set of samples analyzed in 1974 were from workers involved in a May 9, 1974, incident in which plutonium was the major airborne contaminant (Geiger 1974); the bioassay records show that urine and fecal samples were submitted approximately weekly for some months and that the initial fecal samples were assayed for ^{239}Pu, mixed fission products, and some specific fission products, including ^{141}Ce-^{144}Pr, ^{103}Ru-^{106}Ru-^{106}Rh, and ^{95}Zr-^{95}Nb. Later samples were analyzed for ^{239}Pu and fission products.

Fecal samples were taken as appropriate after other incidents (e.g., Langendorfer 1977; Kirsch 1978a).

4.1.3 Nose Swabs

Nose swabs were taken after suspected intakes, as shown in several incident records (e.g., Selander 1959a; Saling 1963; Kirsch 1978a). But it appears that it was routine or at least advisable to take a swab upon exiting from dusty cleanup work in JN-4 even in the absence of a known high airborne level, as indicated by an incident report showing that the workers took nose swabs on their own initiative (Hicks 1977). Although information from nose swabs typically cannot quantify intake amounts for dose reconstruction purposes, it may serve to verify whether or not a positive intake occurred after an incident.

4.2 *IN VIVO* BIOASSAY

In vivo whole-body counting is assumed to have begun in August of 1970, because there were no records found before that date, and to continue through the most recent operations (latest analysis record found was from 1998). *In vivo* counts performed by Helgeson Scientific included detailed documentation of methods, detection levels, counting parameters, and other related information. Radionuclides detected by whole body counting varied with each analysis performed, but typically included ^{40}K (naturally occurring), ^{54}Mn, ^{58}Co, ^{60}Co, ^{110}Ag, ^{131}I, ^{134}Cs, and ^{137}Cs. Batch whole body counting was performed for a group of workers at a frequency of twice per year (generally in March and again in October), although not all workers may have participated at this frequency. Before 1995, minimum sensitivities were recorded for each semi-annual batch analysis (often designated as “Appendix III” of the analytical report provided by Helgeson) and are typically included with the individual worker records. If a worker’s record indicates that a whole body count was performed but there is no associated batch record of the minimum sensitivity for a radionuclide, the highest reported value found in the records is listed in Table 4-2 for each occupationally associated radionuclide and may be used as a favorable to claimant assumption for the analysis.

Table 4-2. Whole body counting analytical sensitivity.

Radionuclide	Minimum Detectable Amount (nCi)
^{54}Mn	4.4
^{58}Co	3.0
^{60}Co	2.0
^{110}Ag	3.1
^{131}I	3.6
^{134}Cs	3.0
^{137}Cs	3.6

Beginning in 1995, details of the whole-body counts (detectors, minimum detection level for each radioisotope, etc.) are documented in the individual worker analysis reports provided by the analytical laboratory rather than for a batch of workers.

Although technical documentation included in Helgeson analytical reports described lung counting protocols, no evidence has been located in the records indicating that lung counts were performed at Battelle.

4.3 LAPEL SAMPLERS

Lapel samplers were used from at least 1975 on (e.g., Hicks 1977; Kirsch 1978a,b; Langendorfer 1977; BMI 1981).

At JN-4, lapel filters associated with routine operations were removed and analyzed daily, with results available before the start of work the next day (BCL 1977a). A new filter was used at the start of any operation with a high potential for exposure (e.g., glove changes, bagging in or out, breaches of primary containment) and the filter was counted at the end of the operation to associate the exposure with the particular operation (BCL 1977a). Lapel samplers were also used as needed at the High Energy Cell at JN-1 (i.e., spent fuel), based on data from counting a worker's personal air sampler filters from April to August 1981 given in BMI (1981). Although information from bioassay sampling should be used rather than from lapel sampling to quantify intake amounts for dose reconstruction purposes, lapel sampling information may serve to verify whether or not a positive intake occurred after an incident.

4.4 *IN VITRO* BIOASSAY DETECTION LIMITS

Table 4-3 is a table of the detection limits associated with urinalysis. It should be noted that these values are generally derived from analytical records for Battelle workers provided by DOE to the NIOSH project; no documentation could be found that specified contractual minimum detectable activities (MDAs) in effect for the analytical laboratory, except for the information provided by Waligora (2007). The detection limits discussed in this section, other than those provided in Waligora (2007), were derived from stated “less than” values as found in the worker records, or from other methods as described below.

Detection limits for urinalysis of a number of individually analyzed radionuclides found in the records (^{144}Ce, ^{134}Cs, ^{137}Cs, ^{60}Co, ^{131}I, ^{203}Hg, and ^{90}Sr) are not listed in Table 4-3 because non-positive results for these samples typically include a reported MDA or “less than” value. This is also true of fecal sample analyses and in vivo analyses. However, for fecal samples, if the report does not include this information, a detection limit of 0.1 pCi/g (ash weight) should be used for routine samples, with an optimum value of 0.03 pCi/g for special samples (Waligora 2007).

Detection limits for urinalysis were not routinely included in analytical reports before the 1990s, so the information below was derived from records available to NIOSH and information obtained from Eberline (Waligora 2007). The limits in Table 4-3 should be used when no information is available in

Table 4-3. Urinalysis detection limits data to be used in dose reconstruction.

Radionuclide	Isotope	Start	End	Routine detection limit	Units
Uranium	Total uranium (fluorometric analysis through 1995, KPA beginning 1996)	1957	1995	5	µg/L
		1996	1998	1	µg/L
	U-234, U-235, U-238	1970	1991	0.3	dpm/sample
		1992	1994	0.1	pCi/L
Plutonium	Total plutonium	1961	1991	1	dpm/24 hrs
		1992	1998	0.1	pCi/L
	Pu-238, Pu-239	1964	1991	0.2	Dpm/sample or dpm/24 hours
		1992	1993	0.06	pCi/L
Tritium		1962	1965	1	µCi/L
Americium	Am-241	1974	1980	0.03	dpm/sample
Thorium	Th-228, Th-230, Th-232	1981	1991	2	dpm/sample
		1992	1994	0.2	pCi/L
	Total thorium	1993	1998	0.5	pCi/L
Fission products		1957	1992	0.2	dpm/mL
		1993	1998	30	pCi/L

the claim records and do not take precedence over actual MDAs found in claim records. Additionally, the start and end dates should not be considered absolute if they conflict with information found in the claim records.

Detection limits lower than the routine value shown in Table 4-3 could be achieved for special sampling situations by changing analytical count times, sample aliquot volumes, and other parameters (Waligora 2007). Consequently, analytical results lower than the values listed above which are reported as positive results should be considered valid.

Detection limits for the radionuclides listed in Table 4-3 are discussed further below.

Uranium

Fluorometric analyses for total uranium were performed from the beginning of site operations through 1995. In 1996, kinetic phosphorescence analysis (KPA) became the analytical method to determine total uranium in urine. Early sampling results for uranium were reported in units of milligrams per liter (1956–1964) or micrograms per liter (1964–1998) for total uranium mass. These units have been used throughout the operation of the site. Based on claimant records from DOE that were provided to the NIOSH project, the minimum reporting level has been 5 µg/L from at least 1964 through 1995 (although not explicitly identified as a minimum detectable activity (MDA), this is an effective MDA because positive results were not reported below this value). After the change to KPA analysis in 1996, the detection level was reduced to 1 µg/L. Some early records (1956 through approximately 1969) indicate that occasional sensitivities below 5 µg/L may have been achieved, but in the absence of specific information in the records, the 5-µg/L value should be used for dose reconstruction for years before 1996, and 1 µg/L should be used for 1996 and later years. Note that these samples might have been designated as uranium (or U), fluorometric uranium (FU), total uranium (TU), or natural uranium (Nat-U).

The first records in which reporting of isotopic uranium results (^{234}U, ^{235}U, and ^{238}U) were reported were from 1970. No contractual MDA could be identified for isotopic uranium analyses, which were reported in claimant records provided by DOE to the NIOSH project in units of dpm per sample or dpm per 24 hours before 1992, and in units of pCi per liter (pCi/L) for 1992 and later results. Results for 1992 and later, although not explicitly identified in any associated documentation as MDA values, were indicated as “<1 pCi/L,” which is consistent with the isotopic MDA provided by Eberline

(Waligora 2007). This reference indicates that the later MDA provided by Eberline (Waligora 2007) was also applicable for prior periods, which would equate to approximately an MDA of 0.3 dpm per 24 hour sample. Consequently, an MDA value of 0.3 dpm per 24 hours should be applied for the period before 1992 for isotopic uranium samples in the absence of information in the record, which is consistent with reported positive values for that period. (This seems to indicate that a change in reporting units, rather than a change in analytical sensitivity, occurred in 1992, which is also supported by the information supplied by Eberline in Waligora 2007.)

Note that urinalysis results for uranium from 1976 through 1982 were sometimes designated with the abbreviation "RU," which stood for "radiometric uranium;" this designation should not be confused with recycled uranium, for which the abbreviation "RU" may be used at other sites. This designation was associated with urinalysis for uranium based on the measurement of gross radioactivity in the processed sample as opposed to the measurement of the mass of uranium in the sample by fluoroscopy. While no rationale has been identified for this method of sample analysis and no detection limits are identified for these samples, it is possible that they were used in an attempt to quantify uranium exposures from enriched uranium, for which measurement of uranium mass in urine samples would have been ineffective. Another designation, infrequently used, that was associated with uranium analysis was "SPU" or "specific uranium," (not to be confused with plutonium analyses).

If the uranium enrichment cannot be determined (e.g., from claim files or information in Attachments C, D, or F of this document), the enrichment associated with fluorometric sampling results (using units of milligrams or micrograms) should be assumed to be natural uranium; for isotopic sampling results (with units of dpm or microcuries), enriched uranium should be assumed for favorability to claimants. Note that if a worker's activities indicate a potential exposure to enriched uranium when only uranium mass measurements are found in the urinalysis records, the Battelle site lead should be consulted for further guidance.

Plutonium
Records of urine sample analyses for total plutonium content were found in the 1960s, then again beginning in 1989, with a change in reporting units found in later records. The change in detection limits and the change in units from dpm/24 hours to pCi/L are assumed to occur in 1992 and are based on a general change in reporting units for several other radionuclides (no plutonium urinalysis records were located for 1992). Positive reported values before 1992 were often lower than the routine detection limit listed in the table, which may be an indication that many of these were possibly special samples that incorporated optimum analytical techniques.

Isotopic analyses for individual plutonium isotopes (^{238}Pu and ^{239}Pu) were also performed as early as 1964. Although the reporting units changed after 1991, the actual detection capability is comparable throughout Battelle operations. Later analytical reports (1990s) are more likely to include the actual MDA for the analysis performed.

Tritium
To date, bioassay analyses for tritium have only been found in the records for 1963 and 1965. One of the samples was positive; for the remainder of the samples, the listed detection limit for tritium urinalysis was 1 µCi/L. Based on the record, it is anticipated that the detection limit will be available in the record if tritium analysis is performed for a worker.

Americium
Urine samples were infrequently analyzed for Am-241, with the earliest sample found in the records in 1977. One sample (in 1978) listed an implied detection limit of 0.03 dpm per sample, while all other samples were recorded as zero with an associated error of 0.03 dpm per sample.

Thorium
Urine samples have been infrequently analyzed for thorium at Battelle. The first sample analyzed for total thorium content found in the records was in 1993. Isotopic thorium analyses for ^{228}Th, ^{230}Th, and ^{232}Th have been performed since 1981, with an apparent change in detection limit and in reporting units from 2 dpm per sample (1981–1991) to 0.2 pCi/L (beginning in 1992). Analytical MDAs are typically included in the analytical report for the latter period.

Fission products
Gross beta analysis of urine samples has been performed for a major part of Battelle operations, with the earliest result found in the records in 1957. The earliest analyses were for both gross beta (which were usually positive due to the contribution of naturally occurring ^{40}K) and for gross beta minus ^{40}K. Because the ^{40}K contribution to the gross beta results would typically have masked any measurement of occupationally related radionuclides, only the gross beta minus ^{40}K results for the early period, assumed to represent fission products, are useful for assessing intakes. Beginning in 1961, analyses were designated as FP (fission products); beginning in 1980, they were designated as MFP (mixed fission products).

Units were initially reported as dpm/mL, then changed to pCi/L in more recent operations; the year listed in the table in which the change in units occurred, 1992, is based on a general change in reporting units for several radionuclides and should be considered approximate. (It should be noted that a few sample results for the earlier period were recorded in units of dpm/24 hr, which is likely a transcription error because the magnitudes of the reported values and associated errors is generally the same as for the results reported in dpm/mL. Consequently, units in “dpm/24 hr” for fission product or gross beta analysis results before 1992 should be interpreted as dpm/mL unless the record indicates otherwise.)

Detection capabilities for the analyses were seldom recorded in all but the most recent periods of Battelle operations. Detection capabilities appear to have been related to sample aliquot size, which made them vary from sample to sample. Complicating this were occasional sample results much lower, sometimes by an order of magnitude or more, than typical results, possibly as part of a special sampling or incident follow-up regime. In general, detection capabilities appeared to improve throughout operations. MDAs were not routinely reported until the 1990s. The MDA for the period between 1962 and 1991 was derived empirically based on counting parameters from available claimant analytical reports provided by DOE to the NIOSH project [1]. The MDA after 1991 is based on information from Eberline (Waligora 2007).

4.5 INHALATION ABSORPTION TYPES, PARTICLE SIZES, AND ACTIVITY FRACTIONS

Attachment F lists radionuclides and the most commonly encountered chemical forms by facility and building. Although the list of materials used in each building is fairly complete in Attachment F, there may be some materials or forms that are not included; however, these would represent materials or forms that were used in very limited periods and areas, such as in an alloy study in which the materials were studied only briefly. It should also be kept in mind for the reactor that the irradiated materials were encapsulated before irradiation and were put into containers as they were removed from irradiation, so that the materials that reactor workers and researchers were exposed as far as internal dose goes were the normal reactor contamination (fission products and activation products) such would be encountered in working in the pool or in removing items from the pool. Similarly, the plutonium work in JN-2 involved only encapsulated sources and thus only incidental contamination was available for intake.

Table 4-4 shows isotopic ratio data for weapons grade and fuel grade plutonium from ORAUT (2010a) and ORAUT (2005b). The data from these references are applicable to the Hanford and Savannah River sites but are appropriate for application to Battelle because these sites were the primary

producers of plutonium for the DOE complex. These ratios should be applied in the absence of specific information in the record. The activity ratios for "fresh" plutonium in Table 4-4 should be used for Battelle dose reconstruction if the work involves recently separated weapons or reactor grade material. If the age of material is unknown, the 10-year aged ratio should be used as a favorable to claimant assumption. For heat source material (as indicated by work activity or bioassay monitoring for ^{238}Pu), the activity ratios of all plutonium isotopes other than ^{238}Pu are insignificant, and the material may be assumed to be 100% ^{238}Pu (DOE 2006). The activity of ^{242}Pu in these mixtures does not contribute significantly to dose and need not be considered.

Table 4-4. Isotopic composition data for plutonium work.

Isotope	Specific activity in mixture (Ci/g)			
	Weapons grade material (fresh)[a]	Weapons grade material (10-year aged)[a]	Reactor grade material (fresh)[a]	Reactor grade material (10-year aged)[a]
Pu-238	8.56E-03	7.91E-03	1.71E-02	1.58E-02
Pu-239	5.77E-02	5.77E-02	5.26E-02	5.26E-02
Pu-240	1.36E-02	1.36E-02	2.72E-02	2.72E-02
Pu-241	8.24E-01[b]	5.09E-01[b]	3.09E+00[b]	1.91E+00[b]
Am-241	0	1.04E-02	0	3.8E-02

a. ORAUT (2005b, 2010a).
b. Pu-241 is primarily a beta emitter with insignificant associated alpha activity.

Various authors note that ^{241}Am ingrowth should be assumed for ^{239}Pu forms and contamination when the plutonium contains a few weight percent of ^{241}Pu or more and has aged and that this ^{241}Am should be assumed to have the same solubility type as the host matrix (DOE 2006). Am-241 data is included in Table 4-4 because Flynn et al. (1987) remarks that for the major research activity at JN-4, i.e., the Mixed Nitride Reactor Fuel Program, ^{241}Am was "reportedly associated" with much of the plutonium material.

If the chemical form of material involved in potential intakes for a worker can be obtained from the record, ICRP guidance (ICRP 1995) may be used to determine the appropriate choice of the inhalation absorption type. If this information cannot be discerned adequately from the claim records, favorable to claimant assumptions should be used for these parameters.

ICRP (1995) indicates that plutonium materials encountered in the workplace may be absorption Types M or S, depending on the chemical and physical form of the material. Additionally, some intakes plutonium oxides have exhibited long-term retention of plutonium in the lung exceeding that predicted by the standard Type S model. Because oxidation or high-firing temperatures are applicable to some of the plutonium processes at Battelle, Type Super-S (or Type SS) absorption, described in ORAUT (2008), must be considered as well for situations in which Type S plutonium could be encountered. The exception to this is for workers who were primarily exposed to ^{238}Pu, as identified by either work history (e.g., work with heat source material) or bioassay monitoring (e.g., specific analysis for ^{238}Pu only), for which Type Super-S is not applicable in accordance with the guidelines of ORAUT (2008).

The dose reconstructor should assume that the route of intake for radionuclides was inhalation and a particle size distribution of 5 µm activity median aerodynamic diameter (AMAD), the default ICRP Publication 66 particle size is used (ICRP 1994). If specific information is available in the record to the contrary, that information should be used.

4.6 DOSE RECONSTRUCTION CONSIDERATIONS FOR FISSION PRODUCTS

For the particular case of mixed fission products for which bioassay was performed with results as only gross beta or gamma measurements, ORAUT-OTIB-0054 (ORAUT 2007b) may be used to arrive at appropriate source terms for internal dose reconstruction.

The guidance of ORAUT (2007b) may be applied to urinalyses for workers at the reactor, JN-1 (the hot cell facility), and at any King Avenue facility where spent fuel (but not solely fission gases) was analyzed. ORAUT (2007b) states that in order to determine if radioiodine intakes need to be used, site profile and claim-specific information should be reviewed to determine if chronic iodine intakes were feasible because iodine exposures are rarely seen in operations that used adequate ventilation and some form of collection, holdup, or filtration; for the workers described above, radioiodine exposure in the course of work with spent fuel or spent fuel samples need not be considered. The spent fuel cooling (decay) times are listed in Table 4-5 for each activity.

Table 4-5. Cooling times for fission products at Battelle.

Activity (facility)	Cooling time
JN-1 (West Jefferson)	1 year
Battelle Research Reactor (West Jefferson)	10 days
Fuel dissolution (King Avenue)	1 year

ORAUT-OTIB-0054 (ORAUT 2007b) is applicable to the hot cell facility because the overwhelming bulk of its work was the examination of irradiated reactor fuel specimens and fuel assemblies; this fits into the constraints of ORAUT-OTIB-0054 because as Wastren (2001) states, the types of testing done on this material "did not involve separation of constituent elements from the fuel" and as Pasupathi and Toy (1990) state, operations at JN-1 were almost always dry except for the fuel dissolution work, the acid etching and water rinsing that might be done in the metallographic phase of the examination work, and the water used with the abrasive grinding wheel in fuel sectioning. Because of this, the HEPA filter loads for most cells would consist of particles of spent fuel and activated material (e.g., cladding bits). Irradiated fuel samples were also analyzed at King Avenue in limited ways, but these were small samples and were usually not highly irradiated, so as to limit the external dose rate. Thus a few King Avenue laboratory workers and on occasion a few machine shop workers (e.g., ORAUT 2006a) would likely have been exposed to this type of source. Finally, at King Avenue, some test dissolution of clad lightly irradiated fuel pins was done (on and off from 1958 to 1961, as different dissolution processes were tested on a small scale).

It appears that at Battelle, during the period covered by this site profile, all areas where materials containing fission products or activation products were handled had adequate ventilation. The reactor was the pool type and had exhaust over the pool in addition to the building and other exhausts; at JN-1, the spent fuel samples or whole pins or assemblies were opened in the (closed) hot cells, which had individual cell exhausts, and there was a building exhaust as well; and at King Avenue such samples appear to have been opened and examined in a glovebox (in the Radioisotope Laboratory) or a hood, which of course had an exhaust system as did the buildings. None of these facilities had iodine filters (except that JN-1 had a charcoal filter from 1978 on to which the exhaust could be diverted if an I-131 monitor so indicated). However, HEPA filters were provided for the individual cells at JN-1 and for the individual hoods and glovebox at King Avenue, while prefilters and double HEPAs were provided for the reactor and JN-1 building exhausts. From at least 1973 (and probably earlier), continuous air monitors were used for the West Jefferson building stacks and on the Building 3 exhaust stack; samples were changed and counted weekly (BCL 1974). The iodine levels were said to be well under ERDA standards. Thus it seems likely that these workers had little opportunity to be exposed to radioiodine.

The exception was when the radioiodine was part of a specific study, such as of fission gases, or when the iodine may have been used in radiotracer or similar work; in these cases, if the gas sample was taken off to a laboratory for analysis there was some potential for exposure although the sample container was likely opened in a hood or glovebox. However, the fission gases were generally collected off a sample or subassembly in a closed in-reactor sample loop or by vacuum container in a hot cell; in both of these cases the gases were counted in the loop or container or they were allowed to decay in a container so that the daughters could be trapped and counted. In the reactor, the sample or subassembly was removed underwater into a cask in an airtight condition and the gases did not escape to the pool (Basham and Rieder 1960). However, this fission gas work is not covered under ORAUT (2007b). Urinalyses done specifically for only I-131 (e.g., not also for other fission products for the same urine samples) should generally be considered to be part of fission gas, radiotracer, or similar work. (A description of the fission gas work is given in a footnote to the table in Attachment C.)

ORAUT (2007b) states that "it is generally favorable to claimants to use longer decay times because that increases the relative activities of the longer-lived radionuclides, which have higher 50-year dose conversion factors." Consequently, the cooling time is assumed to be one year for JN-1. This is consistent with Battelle's 1962 accident analysis for JN-1 (Sunderman and Dickerson 1962) that assumed a four-month cooling time for an "OMRE" element that was then sent to Battelle for analysis; the actual cooling time was usually longer than four months, although it could be as short as 10 days for Fermi assemblies taken to JN-1 (Sunderman and Gates 1965). It is also consistent with the fact that the personnel exposure would have been after the campaign of which the fuel testing was a part, i.e., during cell cleanup (when the cell might have been opened or at a minimum when waste and samples were moved out through the ports and transported for packaging or processing and for storage). The cooling time for the reactor (BRR) and other facilities handling irradiated samples should be assumed to be 10 days, consistent with the short test reactor cycle or the likely turnaround time of the sample. Finally, the cooling time for the fuel dissolution at King Avenue should be assumed to be 1 year, which seems consistent with the actual case of about 10 months for Consolidated Edison test pins irradiated at ORNL and sent to Battelle for analysis (Dayton and Tipton 1960a).

4.7 RECORDS AND REPORTS

The urinalysis and other bioassay records available for the Battelle sites are of three types. The first type is the bioassay report issued by the bioassay analytical service provider; the second type is the Battelle (company) summary card on which an individual worker's urinalysis information is tabulated, usually over a year; and the third type is the Battelle ad hoc documentation, such as incident reports that give information as to potential exposure levels and routes. The principal record to be used in dose reconstruction is the report from the bioassay analytical service provider, but the other two record types may provide information relevant to missing bioassay readings or to special bioassays sampling situations.

4.8 INTERNAL DOSE ASSESSMENT FOR UNMONITORED PERIOD (BEFORE SEPTEMBER, 1956)

[RESERVED]

5.0 OCCUPATIONAL EXTERNAL DOSE

5.1 DOSIMETRY PROCESSING SERVICES

It is not clear when badging started at Battelle. The earliest date for a film badge that has been found in the available records is June 5, 1953. Badges appear to have been worn thereafter throughout the period of operation and the period of residual radioactivity, including during decontamination and decommissioning (D&D). Table 5-1 gives summary information about badge service providers.

Table 5-1. Dosimetry processing services.

Period	Processing service
June 1953–March 1956	Unknown
April 1956–1967	Landauer
1968–1969[a]	Eberline
1969[a]–June 1994	Landauer
July 1994–1996	Siemens/ICN
1997–present	Landauer

a. Records indicate that both Landauer and Eberline provided processing service in 1969.

Badges appear always to have been processed by a film service, although it is possible that the first badges (before 1956) were read by the AEC New York Operations Office (NYOO). Landauer performed film dosimeter processing from April of 1956 through 1967. In 1968, processing was performed by Eberline. In 1969, records show that both Eberline and Landauer were used as processors. Landauer was again the sole processor beginning in 1970 and continued film processing through June 1994; TLD dosimeters were added in 1984. It should be noted that some TLD badges were in use before 1984, and film badges continued to be used well after this date for some individuals. Processing was performed by Siemens/ICN from July 1994 through 1996, then again by Landauer beginning in 1997 through the present.

5.2 DOSIMETER TYPES

Film dosimeters were used to measure whole-body dose from the start of monitoring through at least 1984, with whole-body TLD dosimeters introduced in 1985. During the film badge period, either beta, gamma, and X-ray sensitive dosimeters or beta, gamma, X-ray, and Kodak nuclear track emulsion, type A (NTA) dosimeters were issued (Author unknown undated). With the introduction of whole-body TLD dosimeters, neutron-sensitive TLD materials, and CR-39 neutron dosimeters (chemically etched plastic measuring recoil proton tracks from fast neutron interactions) were also implemented.

Ring or wrist badges were worn routinely by most laboratory, hot cell, machine shop, and similar workers who handled hot sources, equipment, or waste with their hands, even if lead gloves were also worn (e.g., Ottman 1959, 1962, 1968, 1970; Kirsch 1976; Toy 1981). Ring badges appear to have used TLDs beginning in 1970. At JN-1, each person who was temporarily or permanently assigned to the facility was issued a ring badge along with a basic film badge (Sunderman and Dickerson 1962; Sunderman and Gates 1965). At JN-4, as of at least 1977 (the year before D&D began) staff members were issued beta-gamma and X-ray TLD ring badges and beta-gamma, X-ray, and neutron wrist badges (BCL 1977a); ring badges were required to be worn by all persons who worked with gloveboxes (BCL 1977a).

The use of pencil (pocket or self-reading) dosimeters is mentioned in several individual dosimetry records. It was noted specifically for the Radioisotopes Laboratory (Building 4), the Hot Cell Laboratory (JN-4), and presumably for the Gamma Facility (Building 6) that when staff members worked in areas where they might receive an exposure that approached the maximum permissible daily dose, they wore pocket ionization chambers to keep track of their whole-body gamma dose

(Sunderman and Dickerson 1962; Sunderman and Gates 1965). This apparently included every entry into a radiation area with contamination because a pocket dosimeter was listed among the standard protective clothing and equipment set for such entries (Sunderman and Dickerson 1962; Sunderman and Gates 1965).

5.3 DOSIMETER DETECTION CAPABILITIES

Table 5-2 gives a summary of the minimum detection levels (MDLs) for evaluation of exposures that were measured by film badges and TLDs and for assessing missed dose (Landauer 1956–1997).

Table 5-2. Summary of MDLs (mR through 1958, mrem beginning 1959) for dosimeter badges.

Period	Photon	Beta	Neutron (fast)	Neutron (slow)
3/53–3/56	50	N/A	N/A	N/A
4/56–3/57	30	50[a]	60[b]	N/A
4/57–60	20	50	60	N/A
61–63	10	40	50[c]	N/A
64–84	10	40	50	10
85–6/94	10	40	50	10
7/94–96	10	40	50	N/A
97–present	10	40	20	10

a. Generally no beta doses were reported prior to April 1957, although records indicate beta measurements might have been made at times for work with uranium. If beta dose monitoring is indicated, recommend use of 50 mrem as the MDL.
b. Based on values recorded as “under 10% MPL” (MPL = maximum permissible limit); the MPL for the period was 300 mR/wk, so 10% of that value for a two-week period is assumed to be 60 mR.
c. There is inconsistency in the fast neutron MDL. In early 1964, an MDL of 15 is stated and later reports identify 20 mrem, and then 50 mrem during 1994-96. Because it is unlikely that an actual decrease in sensitivity would occur, an MDL of 50 mrem is recommended from 1961-1996.

Film badge reports from before April 1956 list only gamma and X-ray exposure components that are tabulated from shielded and unshielded dosimeter readings; units are in milliroentgens, with the MDL listed as <50 mR.

Beginning in April 1956, neutron exposure was tabulated and specified as "fast neutron" with the results in percent of the MPL; the MDL was typically recorded as "<10% of the MPL" with no other units listed. Because the MPL for the period (also listed on the reports) was 300 mR and the dosimeters were exchanged on a biweekly frequency, it is assumed that the MDL for fast neutrons was 60 mR (i.e., 10% of 300 mR/wk for a two-week monitoring period) during this period. The bottom of the dose report forms stated that a recorded gamma exposure of zero indicated less than 30 mR unless otherwise noted.

In April 1957, the minimum reported dose value was changed to 20 mR for high-energy X- and gamma rays and another category headed "Other" or “millireps if U beta” was added; this column is assumed to represent beta dose because in April 1958 this category heading was changed to "Other, Arbitrary Units," and Landauer applied this terminology in reporting later Battelle beta dose and in reports and memoranda dealing with beta dose (e.g., Selander 1961; Ottman 1959, 1961a). This usage was apparently due to the fact that the film badge readout-to-dose conversion factor (typically listed as 2.2 for <1.4 MeV energy betas) depended on the calibration for each batch of badges. Units of millirep for uranium beta exposures were also noted during this period; the heading "Beta" was not routinely included in reports until 1961. Neutron exposures continued to be listed as described for 1956.

Beginning in 1961, Landauer reports began listing dose categories of gamma- and X-ray, beta, and neutron, with MDLs of 10 mrem for gamma- and high-energy X-rays, 40 mrem for beta, and 15 mrem for neutrons. It should be noted that from 1961 through the first part of 1964, Landauer listed an MDL of 15 mrem for fast neutrons, which was changed to 20 mrem later in 1964 and for subsequent years through the present. The value of 50 mrem is used as a default value in this site profile as a more realistic estimate and because it is unlikely that a decrease in detection sensitivity occurred during the later period. The neutron doses were not categorized by energy, so it is assumed that the doses described fast neutrons, as was the case before 1961. It is also noted that neutron doses changed from percentages of the MPL to millirem in 1961.

Beginning in 1963, reports began to distinguish between thermal and fast neutron exposures, with stated MDLs of 15 mrem for fast neutrons and 10 mrem for thermal neutrons; as noted above, an MDL of 50 mrem is assumed for fast neutrons in this site profile. No changes to the Landauer MDLs were noted after 1963; therefore, the values of 10 mrem (gamma- and high-energy X-rays), 40 mrem (beta), 50 mrem (fast neutrons), and 10 mrem (thermal neutrons) were used for all periods of Landauer processing beginning in 1963 through 1996.

Landauer continued film dosimeter processing until 1967. In 1968, processing was performed by Eberline. Contract proposal documentation for Eberline indicates reporting ranges comparable to the Landauer MDLs (Eberline 1967). Because no other documentation was found for Eberline that related to MDLs, the same values were used during the period of Eberline processing. As noted above, both Eberline and Landauer were used as processing services for 1969. Landauer was again the sole processor beginning in 1970 and continued film processing through June 1994; TLD dosimeters were added to the service in 1984. As noted above, records indicate some TLD badges were in use before 1984, and film badges continued to be used well after this date for some individuals.

Processing was performed by Siemens/ICN from July 1994 through 1996, with MDLs as noted in Table 5-2, then again by Landauer beginning in 1997 through the present.

5.4 DOSIMETER EXCHANGE FREQUENCIES

Table 5-3 shows the default dosimeter frequencies that were used to monitor the primary groups of workers at Battelle (Eberline undated; BCL 1973; Author unknown undated).

External dose records, computer-assisted telephone interviews, and program documentation from Battelle indicated that badges were exchanged at 1-, 2-, and 4-week, monthly, and irregular (“special”) intervals dependent on the worker's job (Eberline undated; Yarger 1966; BCL 1973; Author unknown undated). Records from Battelle document that the primary exchange frequencies were bi-weekly and every 4 weeks, as shown in Table 5-3 (the 4-week frequency was changed to monthly in 1970). The exchange frequency was typically stated on Landauer reports that date from at least 1961. The account numbers in Table 5-3 were also listed on Landauer reports from 1969 through about 1984. If information in claimant records is insufficient to determine the worker’s dosimeter exchange frequency, then the dosimeter exchange frequency should be based on the work group that is shown in Table 5-3; if the work group cannot be determined, then a bi-weekly exchange frequency should be assumed to be favorable to the claimant.

Records show that dosimeter exchange frequencies were specified by Battelle based on work location and the type of work, and they might have been different for different work groups during the same period or for individual workers over their periods of employment. Records for one individual included weekly, biweekly, and monthly monitoring frequencies including two consecutive years where he was monitored with all frequencies. Another individual had several ”special” dosimeters that were apparently multiple dosimeters (i.e., more than one dosimeter was issued to the individual), but that

Table 5-3. Default dosimeter exchange frequency by facility or work group.

Facility or work group	Account No. (beginning with 1969 Landauer reports)	2-week exchange frequency	4-week exchange frequency (before 1970) or monthly (after 1970)
Battelle Research Reactor (BRR)	6410	X	
Critical Assembly Lab (CAL)	6412A	X	
Hot cell (HC)[a]	6408	X	
Plutonium Lab	6409	X	
Uranium Lab (25 area)	6412B	X	
Safety	--	X	
Visitor biweekly	6412Z	X	
Misc. biweekly	6412D	X	
Radioisotope Laboratory	2302		X
Analytical chemistry	2366		X
Radiography	2613C, 6412C		X
Visitor monthly	6413Y		X
Misc. monthly	6412E, 6413E		X

a. Hot cell workers might also have been on a weekly exchange frequency (Sunderman and Dickerson 1962).

were issued and retrieved at nonoverlapping periods in 1965 – these might have been in accordance with multibadging or planned special exposure procedures (Stewart 1995). Concurrent use of film and TLD dosimeters was also noted. The dose reconstructor is responsible for evaluating available records to determine the monitoring frequency that is most appropriate to support missed dose assessments.

It should be noted that dose monitoring records appear to be missing for short intervals in some individual records. This could be due to actual missing records or due to the fact that Battelle based the level of monitoring on the exposure potential of the worker and task, so that individuals with little or no potential exposure were not monitored (i.e., the lack of monitoring was intentional based on low dose potential). The dose reconstructor must evaluate available records and determine whether apparent gaps in monitoring require the assessment of unmonitored dose for those periods. Battelle records appear to be adequate to support interpolation methods outlined in OCAS-IG-001 (NIOSH 2007b, Section 3) to determine doses for gaps in records that are deemed to be due to missing reports (rather than to the intentional nonmonitoring of workers with low potential for exposure). More significant gaps in monitoring data must be evaluated on a case-by-case basis to determine if additional requests for dosimetry records should be made.

5.5 WORKPLACE RADIATION FIELDS

Attachment G summarizes site processes with radiation types and appropriate energy ranges for the King Avenue and West Jefferson sites. Note that because the West Jefferson facilities did not start up until 1955 or later, exposure to reactor neutrons or plutonium-emitted neutrons was not a possibility, except for the limited ^{239}Pu work in a laboratory in Building 6 in 1953 to 1955 and 1961. However, the possibility of neutron exposure from the alpha-neutron reaction in appropriate forms, especially for UO_2 and ThO_2, should still be considered in accordance with the guidance of ORAUT (2005c).

Attachment H summarizes the appropriate energy ranges for neutrons. For neutron doses, the measured doses should be modified by the ICRP Publication 60 correction factor for the appropriate energy range (ICRP 1991), in addition to the energy fractions in Attachment H. These factors incorporate the ratio of the Publication 60 weighting factor to the group-averaged NCRP Report 38 (NCRP 1971) quality factor. These factors are 1.86 for the 10- to 100-keV energy range), 1.91 for the 0.1- to 2-MeV energy range, and 1.32 for the 2- to 20-MeV energy range (ORAUT 2006b).

If information on the specific work processes, periods, or locations can be determined from the record, the appropriate energy range fractions in Attachments G and H should be applied. Otherwise, assumptions favorable to claimants of 100% 30- to 250-keV photons and 100% 0.1- to 2-MeV neutrons (if applicable) should be used; for shallow doses, either 100% >15-keV electrons (for nonplutonium-related work) or >30-keV photons (for plutonium-related work) should be used.

Workers at the West Jefferson site (JN-1, JN-2, JN-3 and JN-4) might have worked with gloveboxes. The presence of extremity monitoring (wrist or ring data) can be used as an indicator for glovebox work or handling radioactive material [2]. The application of the guidance in NIOSH (2005) appears to be appropriate in relation to workers who handled plutonium in gloveboxes at JN-2 (1964 to 1970) and JN-4.

5.6 ASSESSMENT OF NEUTRON DOSE MONITORED BY NTA FILM

The Battelle West Jefferson Nuclear Sciences Area contains several major buildings with the potential for workplace radiation fields (Wallace 2010) as described in Attachment I. Due to the underresponse of NTA film dosimeters to low energy neutrons, some neutron exposures may be considered unmonitored or inadequately monitored by NTA dosimeters. Consequently, except for exposures to neutrons from ^{252}Cf at JN-1 (as discussed in Attachment I), neutron doses for the film dosimeter period may be assessed based on neutron to photon exposure ratios derived from workplace radiation paired (i.e., same time and location) measurements of neutron and photon radiation dose rates that have been obtained from selected Battelle instrument survey records. These ratios should be applied to measured photon doses to obtain neutron doses for workers for the period when film dosimeters were in use (i.e., prior to 1985) and neutron exposures would not have been adequately monitored by NTA film. These ratios are not used if records indicate that TLD dosimeters were used to for monitoring. Recommended neutron to photon ratios are summarized in Table 5-4 below, based on the analysis in Attachment I.

Workplace radiation paired (i.e., same time and location) measurements of neutron and photon radiation dose rates were obtained from selected instrument survey records extending over several years for Battelle facilities as follows:

- JN-1 Hot Cell Laboratory (1955-1983). Limited survey data has been received from Battelle consisting of 49 measurements for the time period when ^{252}Cf was being processed and handled in very large quantities. Neutron to Photon dose (NP) ratio analysis based on this measured data presents an upper bound that if applied to claimants over an entire work career would result in a significant overestimate of their neutron dose. There are a few claimants who worked during other time periods where presently no survey data is available for analysis. A review of potentially impacted claims indicated that these claimants have previously been judged to be compensable because of high assigned external and internal doses.

- JN-2 Critical Assembly Laboratory (CAL) (1955-1975). Limited survey data consisting of 15 measurements has been received from Battelle and for the more recent operational time period only. No survey data has been received from Battelle for the early years of operation. Fortunately at this time, there are no claimants who worked during the early time period. Also, Battelle provided information for the plutonium laboratory in this building involved only sealed sources.

- JN-3 Battelle Research Reactor (BRR) (1960-73). Substantial survey data was received from Battelle for the period of 1960 through 1974 consisting of 2,487 paired measurements selected for analysis from 3,188 paired measurements identified in the documentation. This is considered to be substantial data to develop a robust estimate of the NP ratio for this facility.

- JN-4 Plutonium Laboratory (1968-76). Survey data was received from Battelle consisting of 67 paired measurements. This is considered to be sufficient to develop an estimate of the NP ratio for this facility.

- JS-1 Naval Reactor Research Laboratory. No paired neutron and photon dose measurements were received from Battelle apparently because there were no significant neutron radiation fields in this building. The work involved some depleted uranium historically. The building was decommissioned in 1990 and based on the type of operation would not be expected to have significant neutron radiation fields.

Results of statistical analyses of the measurement data are summarized in the following:

Table 5-4. Recommended neutron to photon ratios for dose monitored by NTA film.

Workplace location	Years	n	GM	GSD	95th%
JN-1 (Hot Cell Laboratory)					
Non-^{252}Cf Operations	1955–1983[a]	[b]			
^{252}Cf Operations	1971–1974	49	2.4	3.9	22.5
JN-2 (Critical Assembly Laboratory)					
Critical Experiments	1956–1960	[b]			
Plutonium Laboratory	1967–1975	14	1.0	1.3	1.5
JN-3 Battelle Research Reactor					
Combined Areas	1956–1974	2487	0.2	4.2	2.1
JN-4 Plutonium Laboratory					
Combined Areas	1960–1978	41	0.7	5.0	9.9
JS-1 Naval Reactor Research		[c]			

a. Neutron exposures probably very limited prior to construction and operation of alpha gamma cells in 1964.
b. Reserved—additional survey data requested
c. No paired survey data received. Depleted U-238 used in this building with essentially no potential for significant neutron radiation.

Resultant neutron dose is combined with the energy distribution appropriate for the task as shown in Attachment H, or should apply an assumed energy range of 100% 0.1 to 2 MeV if the specific task is unknown.

5.7 INCIDENT REPORTS

A form for reporting minor incidents such as overexposures, lost badges, etc., was used as early as June 1958 (e.g., Selander 1958a,b); the form was also used to document planned overexposures (e.g., Swigert 1963). While most of the copies of these forms found in records obtained by the NIOSH Project apply to occurrences at the West Jefferson site (mostly at the BRR and the hot cell facility), a few apply to occurrences at the King Avenue site (e.g., Kirsch 1976); it is likely that there were fewer such reports for King Avenue because of the lower potential for significant exposures.

5.8 EXTERNAL DOSE ASSESSMENT FOR UNMONITORED PERIOD (BEFORE JUNE, 1953)

[RESERVED]

6.0 RESIDUAL EXPOSURE

Based on information provided in the Report on Residual Radioactive and Beryllium Contamination at Atomic Weapons Employer Facilities and Beryllium Vendor Facilities (NIOSH 2006), Battelle Laboratories- West Jefferson, had the potential for residual contamination outside of the period in which weapons-related production occurred (1976-1985).

Individuals who worked at the West Jefferson site in radiological areas were monitored for internal and external radiation exposure during the period of potential residual contamination. The use of the existing monitoring records in the performance of dose reconstructions is sufficient to account for internal and external doses during this period. No additional dose assessment is necessary to complete dose reconstructions during the West Jefferson residual contamination period (1976-1985) [3].

7.0 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] King, Vincent. MJW Corporation. Dose Reconstructor. May 2007.
The fission product MDA for 1962 through 1991 was determined empirically by Thomas La Bone using information in available analytical records from Battelle.

[2] Robinson, Sallie. Dade Moeller & Associates. Dose Reconstructor. June 2007.
The conclusions in this paragraph were made based on a review of the records provided for Battelle Columbus.

[3] Robinson, Sallie. Dade Moeller & Associates. Dose Reconstructor. June 2007.
The conclusion not to add additional dose for residual contamination is based on the Battelle Columbus records that indicate the workers who had the potential for radiological dose were monitored.

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GLOSSARY

23 recovery program
The program to recover thorium from various materials, such as monazite sands, using anion exchange in a carbonate solution.

25 Area
The uranium receiving/dispensing area in Bldg 3 (Materials Bldg).

Atomic Science Center
Same as Nuclear Sciences Area.

berry bucket/can
One-gallon can used to hold an irradiation or other sample or waste in a hot cell during or after an experiment.

coffee cup
Foam coffee cup into which dissolved slugs in liquid form were poured; concrete was added to solidify the liquid in the cup.

Contractor Pool
The instrument/experiment end of the BRR pool, also called the Shielding Pool.

Davison
A predecessor or subsidiary of W. R. Grace Co.

Engineering Area
Auxiliary (south) part of West Jefferson site, including Bldgs JS-1 (Hot Isostatic Processing Facility for fabricating military reactor fuel) and JS-10 and JS-12 (studies of explosive forming/bonding techniques, ballistic studies using nuclear materials).

fissium
Simulated fission-product-containing material as a mixture of nonradioactive isotopes of those elements formed as radioactive fission products, for study of chemical and physical behavior of fission-product-bearing material.

junior cave
Medium-shielded hot-cell-type room used for handling or storage of lower level sources than a fully shielded hot cell or high-level cave or vault would be.

Lamson tube
Pneumatic tube used to move items between the Low Level Cell and Alpha-Gamma Cell 4 (JN-1).

Metmount
Fuel rod section specimen set in 1.75-in. frame to prepare it for metallurgical examination; also, the frame itself.

Myrnalloy
Thorium metal or thorium alloy.

New Plutonium Lab
(Part of) Building JN-4.

Nuclear Research Center
Same as Nuclear Sciences Area.

Nuclear Sciences Area
Main (north) part of the West Jefferson site, including Bldgs JN-1 (hot cell facility), JN-2 (criticality assembly, adjunct plutonium laboratory), JN-3 (reactor facility), and JN-4 (main plutonium laboratory).

Old Plutonium Lab
Original section of Building JN-4.

reactor pool
The core end of the BRR pool.

sheep shed
Waste Storage Shed (associated with JN-1).

slug
Burnup analysis specimen waste, after being dissolved, studied, mixed with cement, and allowed to solidify in a foam cup.

soda salt
Sodium uranate, $Na_2U_2O_7$.

target room
A target fabrication area at the King Avenue site.

test cell
Hole in the reactor core to insert test specimens (not a hot cell).

Tu-Be alloy
Uranium-beryllium alloy (Tu was synonymous with uranium).

Tubealloy, tuballoy
Uranium, uranium alloy, or U-Be alloy (Tu was synonymous with uranium).

weasel
Special type of sample capsule, or the BRR fast-flux irradiation facility in which it was used. The capsule held an aluminum container, which had ~5 g of powdered UO_2 packed into quartz tubes. The facility was hydraulically operated and could be positioned in various regions near the core.

West Jefferson North
Same as Nuclear Sciences Area.

West Jefferson South
Same as Engineering Area.

White Cross
Hospital in Columbus used by Battelle.

ATTACHMENT A
CHRONOLOGY OF EVENTS AT BATTELLE
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Event	Period/ start date	Description	Reference[a]
Initial work for US Office of Scientific Research and Development under Contract No. OEMsr-85	1942	Rolling; metallurgical studies of gas evolution; consulting on extrusion	Smith et al. 1988; BCL no date a
Experimental and pilot work for MED begins under Contract No. W-7405-ENG-92	16 April 1943–1944	Done at irregular intervals, mostly on U metal: analysis, extrusion into rods, hammering, rolling of billets, dipping, machining, plating. Some studies of uranates, U carbides	Author unknown 1992; Ferry 1943; Langsam and Carter 1986; BMI 1945a
R&D and other work with Th metal and alloys (except extraction)	1944–1954	Mostly R&D (1944–1946); forming ingots into Hanford slugs (1947); hydriding (1951); electroplating metals on Th (1948-1953); arc-welding Ames Th, alloys; iodide process (1951-1954); bomb reduction of Th halides	BMI 1945a,b; Udy and Boulger 1951; Monroe, Martin, and Voldrich 1952; Schwope, Muehlenkamp, and Marsh 1952; Veigel, Sherwood, and Campbell 1953; Beach et al. 1953; Goldhoff, Ogden, and Jaffee 1953; Berry, Pray, and Peoples 1954; Saller, Dickerson, and Foster 1955
R&D and pilot programs to extract uranium from various materials	1946–1954	Extraction from phosphate rock (Sep 1946–1950), shales (Sep 1946–1949, 1952–1954). Mech beneficiation; pyro-, electro-, and hydrometallurgical methods; shotgun assays	Beyer 1948a,b; Kelley 1948a; BCL no date a
Studies of U compounds and alloys, including alloying Be with U; start of work with UO_2	1947 on	Properties of U-Be compounds and alloys; graphite-U fuel rods, rolling techniques for Al-U alloys. In 1947, listed as "Tu-Be alloy" and "TuO2+BeO"	AEC 1947; Grenell 1947; Randall 1947; Keeler and Hare 1954; Gallagher, Blosser, and Mann 1955, Vaughan 1957; Jankowski and Chastain 1958; Cunningham, Seaver, and Edgar 1959; Egen at al. 1960
Research on graphite-U piles	1947–?	For the reactor at ORNL	Author unknown ca. 1987; AEC 1947; Boehm and Groner 1986
Process development program for extraction of uranium from various uranium ores and concentrates	Aug 1947	Carnotite ores (Aug 1947–1949); washer slimes/slurries (1950); Western ores (1952–1955); low-grade sulfide concentrate (1953); U ores (ammonium carbonate leaching) (1955–1957)	Kelley 1947a,b, 1948b; Blatz 1949; Ewing et al. 1953; Bearse et al. 1953
AEC demonstrates use of radiation detectors	Dec 1947	To check U, Th metal, surfaces, clothing, etc. Battelle did not have such instruments before this date.	Morgan 1947
AEC contract for experimental studies on U- and Th-bearing materials, including monazite sands	1947–1950	Contract AT-30-1 GEN-228; laboratory-level work started in Dec 1947	Brown 1951; Kelley 1950, 1951; Blatz 1949; Harris 1952; Kelley 1948b,c
Work for the Air Force's Aircraft Nuclear Propulsion Program	1947–1961		Wastren 2001; BCL no date a
Process development program for recovering U from phosphate materials	Jan 1948–1949(?)	Development of practical processes for leaching and recovery of U	Beyer 1948a
Active AEC-Battelle contracts for U, Th extraction from monazite sands, phosphates, shales, and carnotite ore	1949–1950	All ongoing as of Apr 1949: Contract GEN-228: extraction of U, Th from monazite sands; ENG-27: U from phosphate rock; GEN-202: U from shales; GEN-258, U from carnotite	Blatz 1949;,Calkins et al. 1950; Calkins and Filbert 1950; Wilson et al. 1954
Nuclear submarine fuel element prototype development	1948		BCL no date a
Conversion of various forms to UO_2	1950	Conversion of pitchblende to UO_2 (1950–1951); refining MgX (concentrate), V-20 soda salt to UO_2 (1950–1951)	Wesner et al. 1960; Langston, Tangel, and Richardson 1950; Ewing, Kiehl, and Bearse 1950; Ewing et al. 1950a
R&D of large-batch reduction	1950–1955	Mostly defense-related or reactor development work; some processing done for government production reactors	BMI ca. 1987

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R&D and studies of U metal, its alloys, U carbides, U nitrides, etc.	1950–1962	Included making and testing fuel forms	Schwope, Muehlenkamp, and Marsh 1952
Battelle said to have provided 10 kg of uranium to Oak Ridge firm as ingots	1951	Presumably for Aircraft Nuclear Propulsion Program because firm was a major contractor for that program	Author unknown ca. 1987
Laboratory, pilot plant study of Th extraction from mantle-grade Th nitrate tetrahydrate Th(NO3)4)	Aug 1951–Feb 1952	Solvent extraction pilot plant design by Catalytic Construction Co; pilot plant started in Jan 1952	Kelley 1951; Brown 1951; Harris 1952; Ewing at al. 1952
Completion of tracer studies for a Ce-Pr mixture	1 Nov 1951	In connection with studies of Th extraction from Th nitrate	Kelley 1951
Process support for U refining, metal production	1952–1959	For AEC, Mallinckrodt, NLO. mostly R&D, process studies	BMI ca. 1987; Author unknown no date; Ewing, Kiehl, and Bearse 1950; Schwartz and Vaughan 1953; Rengstorff and Lownie 1955
Study of fused salt mixtures as liquid fuel	1953–1954	U salts	Crooks, Snyder, and Clegg 1953; Droege, Snyder, and Filbert 1954
Studies of radioisotope tracers	1954	For industrial control	Kemp et al. 1955
Apparent first use of enriched U at Battelle	1954	Rolling experiments for the APPR	Keeler and Hare 1954; Gallagher, Blosser, and Mann 1955
King Avenue Buildings 2 through 7 and 10 through 13 constructed	Completed 1954–1955	Buildings A and 1 were already in existence	BMI 1977
Extraction of Th from Brazilian monazite sludge	1954–1955		Wallo 1981; Meeley, Snyder, and Filbert 1954
Development of APPR	1954–late 1960s		Wastren 2001; Gallagher, Blosser, and Mann 1955; Cunningham, Seaver, and Edgar 1959; Peters and Harrison 1998
Extraction of U from various ores and concentrates	1950–1957	Washer slimes/slurries (1950); Western ores (1952–1955); low-grade sulfide concentrate (1953); other U ores (ammonium carbonate leaching) (1955–1957)	Meadors et al. 1950; Ewing et al. 1950b; Bearse at al. 1953; Ewing, Kiehl, and Bearse 1955; Van Cleek, Macdonald, and Stephens 1956; Langston, Macdonald, and Stephens 1957
Start of operation of Bldg JN-1	1955		BCL ca. 1974; BCL no date a DOE 2002
Start of operation of Bldg JN-2	1955	Started as a critical assembly facility	BMI ca. 1987; DOE 2000a; Layendecker 1996; Wastren 2001; Jensen 2003; BCL no date a; Kirsch 2000a
Experiments, other work in Bldg JN-1	1955–1960	Mostly small-scale experiments on irradiated capsules	BMI ca. 1987; BCL ca. 1974
Work at the critical assembly facility (JN-2)	1955–1963	Critical assembly and vault work only	Wastren 2001; DOE 2003a; Gallagher, Blosser, and Mann 1955; BCL no date a; Kirsch 2000a
Continued work in defense	1955–1965	More Naval Reactors research; work on water-cooled reactor and the Aircraft Nuclear Propulsion Program	BMI ca. 1987; BCL 1997
Subcontract weapons research for Sandia, etc	1955–1965	Also for Los Alamos, Rocky Flats, Lawrence Livermore	BMI ca. 1987
Postirradiation examination, testing of materials in JN-1	1955–1983	Including materials from BRR, other research, defense, and commercial power reactors	
Startup of Bldg JN-3 (BRR)	Oct 1956		DOE 2002; Wastren 2001; Anno, Plummer, and Chastain 1958; Plummer, Arno, and Chastain 1958; BCL no date a; Kirsch 2000b
BRR, ETR loop program work in JN-1 and JN-3	1956–1962	Incl assay of fission gases during irradiation of fuel, other materials; BRR upgrade to 2 MW, in-pile loop in 1959	Bodnar et al. 1958; Basham and Rieder 1960

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CHRONOLOGY OF EVENTS AT BATTELLE
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Event	Period/ start date	Description	Reference[a]
Miscellaneous instrument/detector/dosimetry work	1956–1967	E.g., reactor neutron flux; leak detection; gamma, neutron effects on semiconductors; gamma, neutron dosimeters	Diethorne at al. 1959; Smith et al. 1956; Klickman et al. 1956; Moody, Kendall, and Willardson 1958; Howes, Ellerman, and Sunderman 1960; Hedden, Kircher, and King 1960; Farkas 1966; Kramer, Closser, and Mengali 1966; Kramer 1967
Evaluation and assays for recovery processes for spent fuel elements	1957–1964	Zircex, Darex, Thorex, Zirflex, fluoride volatility, Niflex processes	Ewing, Brugger, and Sunderman 1961; Peterson et al. 1959
BRR upgraded from 1 to 2 MW	1958		Anno, Plummer, and Chastain 1958
R&D on methods of measuring content in industrial materials, rates of biological/catalytic processes	1958–1963	E.g., Mg, Al, Ca, Fe in cement; investigated P-32 labeling, various radiotracers, activation analysis	Calkins and Pobereskin 1954; Dayton and Dickerson 1962; McFarling and Kircher 1963
Defense work in Bldg JN-1and JS-1 (Hot Isostatic Process Facility)	1958–1984	Naval reactors, R&D for Army and other defense programs	Wastren 2001
BRR upgraded from 1 to 2 MW	Mar 1959		Plummer, Arno, and Chastain 1958; Anno, Plummer, and Chastain 1958
BRR beam tube shut down for furnace repair	Jun–Dec 1960		
Construction of Building JN-4 (old Plutonium Lab)	1960		Wastren 2001; Flynn et al. 1987
R&D: coating of U oxide, new fuel forms and materials, containment methods	1960s		Author unknown ca. 1987; Chastain 1961
AEC license to fabricate U fuel elements	1960s		Author unknown ca. 1987
Studies involving Pu properties, processing, and fabrication; Np target rod fabrication for Pu production; fabrication of RTGs using Pu and Cm	1960–1977	U recovery process for Pu spent fuel; Ta corrosion by liquid Pu alloys; UN-PuN fuel materials, cladding for fast reactors; PuO2 and other fuel studies; Pu, Np recovery from commercially irradiated targets; Pu aerosols; fabrication of RTGs with Pu-238 (MHW) or Cm-244	Author unknown ca. 1987; FUSRAP 2000a; Swigert 1963; Taylor 1983
Addition of alpha-gamma test cells to Bldg JN-1	1964		Wastren 2001; Martin, Storhok, and Gates 1966; BCL ca. 1974
Addition to JN-4	1964		Flynn at al. 1987
RTG work with Pm sources	1964–1968		Ritzman et al. 1966
King Avenue: continued defense program work	1965–1975	Included fabrication of highly enriched fuel elements	BMI ca. 1987
West Jefferson site: materials mockup experiments, advanced fuels research	1965–1975	The advanced fuels work was done with U nitrides and oxides.	BMI ca. 1987
Further addition to JN-4	1967		Flynn at al. 1987
Addition of Mechanical Test Cell to Bldg JN-1	Apr 1967		Wastren 2001, BCL ca. 1974
Research on bioeffects of underground explosions at Amchitka Island, Alaska	1967–1974	During/after the Milrow and Cannikin tests	Kirkwood 1971, 1974; Burgner, Isakson, and Lebednik 1971; Stephan and Mercier 1972; Williamson and White 1974
JN-2 converted to a plutonium laboratory	Late 1960s–1970	Work done for Lawrence Livermore National Laboratory; handled encapsulated Pu only. Vault still used	Wastren 2001; Kirsch 2000a
Work for NLO under prime AEC contract	~1970?	Involved test quantities of radioactive metal	Author unknown no date
End of active nuclear work in Bldg JN-2	1970		Wastren 2001
Added High-Energy Cell to JN-1	1972–1973	Allowed for examination of full-sized fuel assemblies	DOE 1998; Wastren 2001; BCL ca. 1974, 1997
Neutron radiography of reactor fuel	1971–1975	Done in reactor pool and an out-of-pool facility	Ray 1972
JN-2 converted to a plutonium laboratory	Late 1960s–1970	Work done for Lawrence Livermore National Laboratory; handled encapsulated Pu only. Vault still used	Wastren 2001; Kirsch 2000a

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CHRONOLOGY OF EVENTS AT BATTELLE
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Event	Period/ start date	Description	Reference[a]
Production of Cf-252 sources	1972–1980s?	Sources made from Cf wire in two alpha-gamma cells; unclear where wire came from or for whom work was done	Wastren 2001; Scotti and Martin 1972
Final shutdown of the Battelle Research Reactor	1974		DOE 2002; Layendecker 1996; BCL no date a; Kirsch 2000b
Added fuel pool, Washdown Room to JN-1	1975	Associated with the High Energy Cell	BCL 1997
Partial decommissioning of the BRR to NRC criteria, with final survey	1975		Rubadue 2000; DOE 2002, 2003a; Layendecker 1996; Wastren 2001, BCL no date a; Kirsch 1975, 2000b; Kok 1975a
Removal of last reactor fuel elements from BRR (JN-3), shipment to Savannah River Plant	Mar 1975		Layendecker 1996; Kok 1975b
Decontam of Critical Assembly Lab/Pu Lab (JN-2)	1975		Wastren 2001; BCL no date a
Work for various defense programs, Naval Reactors, DOD (Army, Air Force), and NASA	1975–1987	Source materials processed and fabricated for DOD activities	BMI ca. 1987
Visit by AEC, ANL personnel to assess the need for a full survey and decontamination	Jan 1976		FUSRAP ca. 1987
Battelle radiological survey of King Avenue facilities used for MED projects	1977	Found to be at background levels, except for Buildings A and 1	FUSRAP ca. 1987, 2000b
Decontamination of JN-4 and Buildings A and 1	1978–1982	Battelle itself performed the JN-4 decontamination, using contractors for specialty work.	FUSRAP ca. 1987, 2000a; Wissinger 1978a; Freas and Madia 1982; Rudolph, Kirsch, and Toy 1984; Clements 1981; Stellrecht, Freas, and Dettorre 1979; Madia et al. 1979; Flynn at al. 1987; BCLDP 1982
Cask sabotage program work in Bldg JN-1	1979–1983	In the pool and the Controlled Area; Myers et al. (1994) says 1981–1983.	Wastren 2001; Author unknown 2003; Myers et al. 1994; BCL 1997
Further radiation surveys	1980–1982	Probably performed by Battelle	FUSRAP 2000a
Research on destruction of chemical agents using high-level gamma fields	1981–1982	JN-1: irradiating capsules of chemical agents using Co-60 sources, using a closed beam port (not in the hot cells)	Wastren 2001
Agreement to form the BCLDP	1984	Apparently not formally implemented until 1986	Rubadue 2000
End of nuclear research for DOE; formation of CEMP; formal start of BCLDP	1986	CEMP	DOE 1998, 2002; Langsam and Carter 1986
Removal of last reactor fuel elements from JN-1, shipment to INEL	1986	Wastren (2001) says 1987. Actual removal was apparently in 1986, license termination in 1987.	DOE 1998; Wastren 2001
Decontam of some King Ave areas by Battelle, S&M program for King Ave/West Jefferson areas with residual contamination	1986–1988	Buildings A and 1 were decontaminated under CEMP.	FUSRAP ca. 1987, 2000b; Langsam and Carter 1986; BCL 1987, 2002; Author unknown 1992
Termination of reactor license	1987	To possess and store fuel elements and similar materials	Layendecker 1996
End of use of Building JN-1, shipment of last of fuel in JN-1 pool	1987	BCL (no date) says 1988, but this appears to be in error.	DOE 1998; Peters 1998a
Preliminary characterization survey of 15 buildings at the King Avenue, West Jefferson sites	1987	By Argonne National Laboratory	Smith et al. 1988
D&D begins under the BCLDP	1989		Weaver at al. 2003; Wastren 2001
Verification surveys of Bldgs JS-1, JS-10, and JS-11 by ORAU, with release by DOE/NRC	1989–1990		DOE 2002; ORAU 2006a; Wastren 2001

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Event	Period/ start date	Description	Reference[a]
Further King Avenue D&D (by Battelle?)	1990	Done under DOE's Surplus Facilities Management Program	FUSRAP 2000b
Final verification survey of Bldg 7A	1993		ORAU 2006a
Final verification survey of Bldgs 3 and 4	1995		ORAU 2006a
Final verification survey of Bldg 5 by ORAU	1996		ORAU 2006a
Final verification survey of Bldgs 1, 6, 7 by ORAU	1997		ORAU 2006a
Completion of D&D of King Avenue site	1998	Except for Building 2? See 1999 entry below.	Wastren 2001
Beginning of D&D of Bldg JN-1	1998		Weaver at al. 2003
Final verification survey of Bldg 2 by ORAU	1999		ORAU 2006a
Emptying, removal of the JN-1 alpha-gamma cells	1999–2000		DOE 2002
Completion of remediation of King Avenue XP pad	Oct 2000	The pad was unrelated to D&D activities (BCLDP), but full RCRA closure was contingent on closure of the pad.	BCL 2002
Completion of D&D of King Avenue facilities, final verification survey of Bldg A by ORAU	2000		DOE 2002, ORAU 2006a
Removal of the BRR bioshield	FY 2001		DOE 2002
Nuclear support, surveillance/ maintenance activities; some decon conducted at West Jefferson	2001	JN-1, JN-2, and JN-3 were involved.	BCL 2002
Completion of RCRA closure requirements for the King Avenue site	25 Jul 2001?		BCL 2002
Surveys of JN-2 and JN-3 by ORAU	2004		ORAU 2006b

a. In addition to the references listed, information was obtained from site descriptions and abstracts given on the OSTI Web site for various other Battelle reports.

ATTACHMENT B
BUILDINGS AND OTHER FACILITIES AT BATTELLE

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
King Avenue site					
A		Entrance was through Bldg 4 or Bldg 11 (BMI 1977)	Thorium solvent extraction pilot plant (FUSRAP ca. 1987, Jensen 2003), ore processing (including carnotite), metallurgical studies (FUSRAP ca. 1987); encapsulation of highly enriched uranium for ATR fuel elements (pilot plant) (Jensen 2003)	First part erected in 1929 as "the King Avenue Building" (Boehm and Groner 1986); added onto before World War II (Boehm and Groner 1986); corporate offices (Langsam and Carter 1986, Jensen 2003). The Safety Office (including the health physics base of operations) was here in at least 1962 (Sunderman and Dickerson 1962)	1942–1986
	E basement, E wing	53 through 57A	Not clear that this area was involved in MED projects; Jensen (2003) lists only the 1st and 4th floors	Creep Laboratory (BMI 1977)	
	Basement, E wing, S end	58A through 58L, 67	Ore processing, monazite sand solvent extraction	After MED/AEC projects, equipment dismantled, removed (BMI 1977). Unoccupied in 1977 (BMI 1977). Was Laser Lab for several years. Residual activity found in Room 58 complex in late 1980s (FUSRAP ca. 1987)	
	1st floor		Ore processing, monazite sand solvent extraction (Jensen 2003)		
	S end of 1st floor in E wing	163 through 163F	Upper part of high bay area of 58 complex	Offices	
	NW basement of W wing	6, 6A through 6D, 7	Machine shop operations (BMI 1977)	Converted to library facility by 1977 (BMI 1977)	
	North basement, S of E-W corridor	17	Mechanical Test area (BMI 1977)	Laboratory record storage	
	2nd floor		Laboratory used for tracer work (Sunderman and Dickerson 1962)		
	N end, 2nd floor, S of E-W corridor	219, 219C, 219D	Metallography sample examination (BMI 1977), storage	Reprint and brochure distribution offices	
	4th floor		Pilot plant encapsulation of HEU for ATR fuel elements (Jensen 2003, DOE 1996), presumably in the Encapsulation Laboratory; Nuclear & Flow Systems Shop, Room A-467, supported the Encapsulation Laboratory (Browne 1974). Tracer-level lab (<100 µCi) also located on this floor (Sunderman and Dickerson 1962)	Little radioactive material handled (Browne 1974). The cafeteria was located on the 4th floor also (Boehm and Groner 1986)	
1		Foundry	Foundry (Langsam and Carter 1986, Jensen 2003); melting, cutting, grinding facilities (Jensen 2003). Natural U, Th extraction (FUSRAP ca. 1987, Jensen 2003); ore beneficiation studies (Jensen 2003)	Constructed in about 1937. Source material fabrication for DOD, 1975 on (BMI ca. 1987)	1942–1986
	1st floor	(the) Foundry	Uranium processing (BMI 1977; DOE 1996) in the tons (Jensen 2003), ore beneficiation studies (Jensen 2003)		
	High bay at S end of 2nd floor, adjacent area	1223, 1223A, 1223B	Uranium production from ore (BMI 1977, DOE 1996); beneficiation operations with ores such as carnotite (BMI 1977). Misc physical handling of materials in 1223; equipment storage in 1223A, misc lab work in 1223B	Room 1223 complex found to contain residual activity in ~1987 (FUSRAP ca. 1987), after cleanup	?–1986
	Near 2nd floor high bay area	1219 and 1219A	Ore processing	Ore lab	

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
	4th floor		Laboratory used for tracer-level (<100 µCi) work (Sunderman and Dickerson 1962)		
2		Metalworking Building (Langsam and Carter 1986, Jensen 2003); "Tisdale Building"	AEC research, incl electroplating Hanford reactor slugs (Jensen 2003, DOE 1996); heat treatment, fabrication of U, Th alloys (Jensen 2003); fabrication of U, Th slugs (DOE 1996). Also rolling studies, alloy development, and fuel element fabrication (Jensen 2003).	Metal fabricating machinery (hydraulic presses, rolling mills, furnaces) removed from the building in 1993 (Jensen 2003)	
		Metalworking Lab	Ore processing (Jensen 2003 says "tons"); metalworking (Jensen 2003)		
		Welding Lab	Natural/depleted/enriched U welding and fabrication (Jensen 2003)		
	2nd floor		Misc R&D, heat treatment, electroplating (Jensen 2003)		1954–1986
3		U-235 Processing Bldg; Materials Bldg (Langsam and Carter 1986, Jensen 2003)	Research activities using natural, depleted, enriched uranium (Jensen 2003, DOE 1996). Powder metallurgy, melting, metallographic, ceramics research facilities (Jensen 2003). Misc R&D: ceramics research; metallographic research with tons of source material (Jensen 2003)	Used as an SNM storage and handling point since early times (Carr 1993). Source material fabrication for DOD, 1975 on (BMI ca. 1987).	
	1st floor	Room 3161 complex, the "U-235 area"; "25 Area/Room"	U-235 processing facility; receiving/distribution point for unirradiated sources, SNM, incl enriched material and thorium (BCL 1975, Jensen 2003, Langsam and Carter 1986, Carr 1993); also for occasional special samples (Stickel 1993). Pickling of SNM to remove oxide for use in Bldg 3, other Battelle areas; solidification of pickling solutions by evaporation; salts stored here for later recovery (Carr 1993). U reduction by calcining for reprocessing; hydrides, carbides, nitrides also made for use elsewhere at Battelle; packaging, storing of wastes from other areas (Carr 1993). Metallography lab, ceramics research facility (DOE 1996)	Glovebox, hoods, shower, calciner, cutting wheel, prefilter, HEPA filter (Carr 1993). Decommissioning activities completed in 1994, building returned to Battelle	
	1st floor	Room 3110	Storage area (AEC 1950)		1954–1975
	2nd floor or S end of 1st floor	Melting Lab/Facil, Room 3178	Melting Lab/facility (Langsam and Carter 1986, BCL 1975, Jensen 2003, Kizer 1993). U-235 materials used, 954-1975; tons of source material (Jensen 2003). Metallographic research (Jensen 2003)	Had hoods	
	N end of basement	Powder Metallurgy Lab	Powder Metallurgy Lab (Jensen 2003, DOE 1996, BCL 1975). Natural U storage, source processing (Jensen 2003, BCL 1975)		1954–1986
4	1st floor	Radiochemistry (Radioisotope) Laboratory (Langsam and Carter 1986, Jensen 2003, Sunderman and Gates 1965)	Entrance to Bldg A was through Bldg 4 (BMI 1977). Radiochemical procedures, radiotracer studies, industrial applications of radioisotopes, neutron dosimetry, other ops with radioactive materials (Sunderman and Gates 1965). Radioisotope Laboratory main facility was divided into low-level, medium-level, and high-level rooms; had fission gas laboratory, special radiochemistry hoods, junior cave, gloveboxes, shielded operating and storage areas, vault, counting room, offices, waste disposal facility (Peters 1998a, Sunderman and Dickerson 1962, Sunderman and Gates 1965). Also had Radiography Lab with X-ray machine, Cs-137 source (Selander 1958c)	The main facilities in Building 4 and the associated facilities in Buildings A and 1 were together called the "Radioisotope Laboratory" (Sunderman and Gates 1965). Hot material transported in cask by truck between JN-1 and Building 4 (High Level Lab in the Radiochemistry Lab) (Sunderman and Dickerson 1962). Decommissioning completed in 1994	
	2nd, 4th floors		Misc labs on 2nd, 4th floors, incl encapsulation facility for highly enriched U, metallography facilities (Jensen 2003, DOE 1996). Had Tribology Shop in Rooms 4022 and 2023 during some period before 1994		1954–1986

ATTACHMENT B
BUILDINGS AND OTHER FACILITIES AT BATTELLE

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
5		Machine Shop	Work for AEC/ERDA/DOE programs: machining (Jensen 2003, DOE 1996), grinding (Jensen 2003, DOE 1996, Dosim-Serio), milling (Jensen 2003, DOE 1996). Be machining (Jensen 2003)	Source material fab for DOD, 1975 on (BMI ca. 1987). D&D completed in 1995 (DOE 1996)	
		Machine shop (Jensen 2003; DOE 1996; Langsam and Carter 1986)	Machining of depleted, natural, and enriched U and some Th (Jensen 2003)	Part of the floor of the machine shop was replaced at some point to remove contamination	
		Coating Lab	Coating (of materials) (Jensen 2003)		**Years of operation**
	Misc R&D on 1st and 2nd floors				1954–1986
6	Misc R&D on ground and 1st floors	(one) Chemistry Building (Langsam and Carter 1986, Jensen 2003)	Analytical chemistry activities in support of the DOE/Navy program, including instrumental analyses (Jensen 2003). Alloy studies, chemical analyses, and Co-60 irradiation (Jensen 2003)	Ground floor decontamination was completed in 1993 (DOE 1996)	
	1st floor	Gamma Laboratory	Gamma Facility Co-60 source was 1600 Ci in Feb 1962 (Sunderman and Dickerson 1962) or 2100 Ci in Nov 1965 (Sunderman and Gates 1965). Source located in belowground pool with 13 ft of water over source, stored in lead pig on the floor of the pool (Sunderman and Dickerson 1962, Sunderman and Gates 1965).	Source rods were in use from about November 1959 on (Sunderman and Dickerson 1962)	Ten years during 1954–1986 (?)
7	Misc R&D on 1st, 2nd, and 3rd floors	(another) Chemistry Building (Langsam and Carter 1986, Jensen 2003)	Analytical chemistry activities in support of DOE/Navy program, incl instrumental analyses (Jensen 2003), over a (unspecified) period of ten years (DOE 1996). Analytical chemistry on source materials and corrosion studies (Jensen 2003)	Annex (Building 7A) was decontaminated, released to Battelle in 1993 (DOE 1996); the significant radioactive operation in 7A was a uranium fluoridation pilot plant (Basham 1993)	1954–1986
9	Misc R&D on ground floor	Mechanical Engineering Building (Langsam and Carter 1986, Jensen 2003)	Research programs for AEC/ERDA/DOE: handling natural and depleted uranium, krypton studies (Jensen 2003)	Hoods in lab area. The building was decontaminated and released to Battelle in 1991 (DOE 1996)	1954–1986

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
West Jefferson site					1955–1986
JN-1		Hot Cell Facility/ Laboratory; JN-1A was the original bldg, added to in the 1960s; JN-1B was major addition of 1970-1971	Fuel devel research support for AEC (Jensen 2003). Spent fuel examination; postirradiation examination, studies of fuel specimens, reactor components, other mats/structures; source encapsulation; shipping container sabotage (BCL 2002, DOE 1996, Rubadue 2000, Jensen 2003); some criticality experiments (Jensen 2003); later, hot cell examination of fuel from commercial power reactors "in support of DOE programs." All cells had remote manipulation, several operating stations, each with lead-glass oil-filled viewing window (DOE 2002). Support facilities: cask handling, solid and liquid waste disposal, contam control, equipment decontamination, ventilation mezzanines (DOE 2002, 2003a; Norris 1961; Sunderman and Dickerson 1962)	Extensively modified in 1960 and 1979 (DOE 2003a). All cells in JN-1 have very high residual radiation fields (DOE 1998, 2000a). Water in the fuel transfer pool was removed in 1996 and packaged TRU waste was then stored there (DOE 2002). Main offices were on the first floor near the laboratories (Wastren 2001).	1955–1986
	Section JN-1A, 1st floor	Controlled Access Area (CAA), with small spent fuel pool	Support area for hot cell work: provided access to the cells through their doors, facilities for moving large items into cells, and space for special projects (DOE 2003a). Heat treatment furnace in CAA (Selander 1959c); ventilated cubicles for work with small shielded specimens (Sunderman and Dickerson 1962); small hot room with pit, sinks, and hot drain for equipment assembly/decon, manipulator repair bench/glovebox (Sunderman and Dickerson 1962, Myers et al. 1994b). Enclosed drum compactor (Myers et al. 1994b). Spent fuel pool used to 1972 (Wastren 2001, Myers et al. 1994b). Sabotage Program (1981–1983): apparatus bolted on top of spent fuel pool, shaped charge shot at small model cask; gases collected, analyzed (Wastren 2001, Myers et al. 1994b)		1955–1986
	Section JN-1A, ground and 1st floor (cells), basement (subcells)	Two large cells with their subcells: High Level Cell, Low Level Cell	The original two large cells (DOE 1998, 2000a, 2002, 2003a; Langsam and Carter 1986; Rubadue 2000) designed to provide shielding for 10,000 Ci and 10 million Ci of 1-MeV gamma emitter, respectively (Wastren 2001, BCL no date b, Sunderman and Dickerson 1962). High-density concrete walls (ferrophosphorus aggregate at 293 pcf) up to top of the manipulators, ordinary concrete after that (DOE 2003a). Three operating stations each (BCL 1977a, Sunderman and Dickerson 1962). Metmounts cut and ground in the LLC (Wastren 2001), which was also used for tensile tests of Co-60 samples (Author unknown 2003). LLC also used near end of operations to gamma-scan cans of waste (Myers at al. 1994c). Subcells used for creep testing (Author unknown 2003, Sunderman and Dickerson 1962)	The LLC was used to declad fuel, section Pu-containing fuel rods, and do tensile tests on irradiated cobalt specimens (Myers at al. 1994c). The High Level Cell's primary purpose was to cut irradiated fuel sections and defuel fuel rod sections (Myers at al. 1994d), i.e., the most destructive activities (BCL 1997). Irradiated Co-60 rods were also cut up here (Myers at al. 1994d, BCL 1997)	**Years of operation** 1955–1986
	Section JN-1A, 1st floor	Charpy Cell/Room; Dry/Radioactive Storage Area	Shear test area for nonfuel specimens, using Charpy apparatus (Myers, Redd, and Berchtold 1994a); 74 vertical pipe wells in floor, additional 12 capped storage holes in movable concrete block for canned specimens (Wastren 2001, DOE 2003a, Sunderman and Dickerson 1962, Myers, Berchtold, and Sands 1995, Myers, Redd, and Berchtold 1994a); rad materials stored in steel cans in wells, transported to/from other cells in portable lead shield (Sunderman and Dickerson 1962)	Charpy apparatus removed and sent to King Avenue in 1988-1989 (Myers, Redd, and Berchtold 1994a)	1955–1986

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
	Section JN-1A, 1st floor	Transuranic vault	Storage		1955–1986
	Section JN-1A, 1st floor	Evaporator Room	Open evaporator tank with exhaust hood and fill pipe coming from Evaporator Storage Tank; sludge periodically put into drums (Myers, Berchtold, and Tomlin 1994)		1961–1986
	Section JN-1A, 1st floor	Laboratories	Chemistry Laboratory: two hoods, hot sink, hot drain to sump. Counting Room: X-ray diffraction, gamma/alpha spectroscopy, radiochemistry studies; hot sinks, hood, cave, hot drain to sump. Microprobe Room: microprobe equipment, Cs-137 source; isotopic analyses of Metmount samples, using X-ray diffraction. (Wastren 2001, Myers et al. 1994e)		1964–1986
	Section JN-1A, 1st floor	East machine shop	(Wastren 2001, Myers et al. 1994e)		1964–1986
	Section JN-1A, basement	10 small segmented alpha-gamma cells (Wastren 2001, DOE 2003a, Rubadue 2000, DOE 2002)	Cells 1-9 constructed in 1964 for metallography testing of fuel rod specimens; Cell 10 added in early 1970s (Wastren 2001, BCL ca. 1974, Myers et al. 1994f). Shared working/access area (BCL no date b), individual working box in each cell (Myers et al. 1994f). Cells 1, 2, 3, 10 for metallography operations: Metmounts ground down in Cell 3; polished, washed, acid-etched in Cell 2; hardness-tested, photographed with Metallograph in Cell 1. Cell 4 used to port materials to/from CAA, other cells; never used for project work. Cells 5, 6 used only to prepare Cf-252 sources, mid-1970s on: Cf wire cut, welded into containers, leak-tested. Cell 7 used for dissolution, slug solidification of burnup fuel specimens. Cell 8: unclad fuel samples heated in furnace, exposed to laser beam/detector for analysis. Cell 9: X-ray diffraction testing of Metmounts (e.g., Myers, Berchtold, and Sands 1995, Myers et al. 1994f, Sunderman and Gates 1965, BCL 1997). Shielding added to wall between working area and evaporator room, 1964 (Gates 1964)	For handling irradiated fuel metallography specimens (BCL no date b, 1997). When Cell 10 was built, Cell 1 equipment abandoned. Cell 3 was the most contaminated alpha-gamma cell because Metmounts were ground there; two in-cell grinders were the most contaminated equipment (Wastren 2001, Myers, Berchtold, and Sands 1995). Some spills in Cell 5 (Myers et al. 1994f). Fumes from acid-fuel solutions in Cell 7 contaminated the rear of Cells 7, 8 via a faulty connection (Wastren 2001, Myers, Berchtold, and Sands 1995).	1967–1986
	Section JN-1A, 1st floor	Mechanical Test Cell	Main mechanical test cell (Rubadue 2000, DOE 1998, DOE 2003a, Myers, Redd, and Berchtold 1994b) added in 1967 (BCL ca. 1974). Three operating stations (BCL no date b). High-density concrete front wall(s) (ferro-phosphorus aggregate at 293 pcf) to the top of the manipulators, ordinary concrete above that (DOE 2003a, DeMastry, Lusk, and Gates 1967). Unspecified thickness of iron plate belatedly added to one wall for shielding reasons (DOE 2003a)	Mainly for tensile tests, but also for creep, vacuum fusion, burst, radial burnup, density, and expanding mandrel tests (Myers, Redd, and Berchtold 1994b, BCL 1997)	**Years of operation**
	Section JN-1B, 1st floor	Cask Washdown Room	For cleaning newly arrived casks, etc. (DOE 2003a, Myers et al. 1994b, Myers, Berchtold, and Stickel 1995); also entry-exit area for High-Energy Cell (DOE 2003a, Myers, Berchtold, and Stickel 1995). Walls open at top for crane access (DOE 2003a, Myers, Berchtold, and Stickel 1995). Compactor under hood (Myers, Berchtold, and Sands 1995)		1970–1986
	Section JN-1B, 1st floor	High Bay/ Operations Floor	Connected to the High Energy Cell, the Fuel Storage Pool, and associated facilities; designed for handling large casks (DOE 2003a)		1970–1986

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BUILDINGS AND OTHER FACILITIES AT BATTELLE

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
	Section JN-1B, 1st floor	Fuel Storage Pool	Storage of fuel assemblies, rod bundles, rod holders, tools (DOE 2003a, Myers, Berchtold, and Stickel 1995). Inside and outside sumps to collect any pool leakage (Myers, Berchtold, and Stickel 1995). Cask brought in, lowered into pool; fuel assemblies or bundles taken out, transferred to High Energy Cell through fuel channel running from pool to under the High Energy Cell floor (Jensen 2003)		
	Section JN-1B, 1st floor	Pump Room	Held wastewater storage tank, deionized water tank, and ion exchange tanks used to process the liquid radwaste (Myers, Berchtold, and Sands 1995, Myers, Berchtold, and Stickel 1995)		1972–1986
	Section JN-1B, 1st floor	High Energy Cell	Largest hot cell (DOE 2003a, DOE 1998, DOE 2002), five operating stations (BCL no date b). Power plant fuel element testing, eval (DOE 1998). Access via door, ceiling plugs, or floor trap door to transfer canal (DOE 2003a), then to fuel transfer pool (Rubadue 2000, DOE 2002). 7 storage holes in floor (DOE 2003a). Two walls barytes (at 220 pcf), two ordinary concrete (DOE 2003a). Cask washdown room at entryway (BCL no date b, Myers et al. 1994b). Had beam port for Co-60 source inside the cell to irradiate test instruments (Myers et al. 1994b), some storage holes in floor (Myers et al. 1994b)	Designed to handle entire high-burnup fuel assembly (BCL no date b, 1997); nondestructive inspection and testing (BCL 1997); sectioning of rods (BCL 1997); fission gas measuring tests done here (Myers et al. 1994b, BCL 1997); studies and characterization of TMI resins (BCL 1997); effects of Co-60 on instrumentation (BCL 1997)	
	Section JN-1B, 1st floor	Old Back Dock, Waste Control Area	In early years, used to collect and package waste and as the original JN-1 dock; later, used for storage of a large number of highly contaminated items (Myers at al. 1994g)		1970–1986
	Attached to the JN-1B section	Waste Storage Shed, Sheep Shed, Equipment Storage Room	Storage of low-level contaminated containerized waste, equipment, other material (DOE 2003a,b; Myers and Berchtold 1995). Two internal rooms/areas were heavily shielded (Myers and Berchtold 1995)		
	With JN-1, but not attached	Waste Management Shed	Storage of highly contaminated containerized waste, equipment, other material (DOE 2003a,b)		JN-2: 1955–1963; 1964–1970. Vault to at least 1996

ATTACHMENT B
BUILDINGS AND OTHER FACILITIES AT BATTELLE

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
JN-2		Critical Assembly Laboratory, Critical Assembly Facility, Critical Assembly Building; later also a Plutonium Laboratory	Started operation in 1955 (Wastren 2001). 1956–1963: critical assembly studies (DOE 2003a, DOE 2000a, Chamberlain ca. 2003, Jankowski et al. 1957, Jankowski and Chastain 1958, Egen at al. 1960); zero-power organic-moderated critical assembly and other experiments (Jensen 2003). 1964(?)–1970, used for other nuclear projects, including direct conversion concepts/plutonium laboratory (DOE 2000a, 2002, 2003a; Jensen 2003; Chamberlain ca. 2003; Kirsch 2000a), irradiation experiment assembly (DOE 2003a, Chamberlain ca. 2003), special laboratory (Jensen 2003). Had Pu, enriched U storage vault (DOE 2000a, 2002, 2003a; Jensen 2003; Rubadue 2000; Freas et al. 1971; Evans and Woodward 1979; BCL 1977a); control room (Jankowski et al. 1957, Hogan et al. 1958, Jankowski and Chastain 1958); attached high-bay area (DOE 2000a, 2002; Rubadue 2000), machine shop (Hogan et al. 1958), offices, labs. Also a fence around the building (separate from the site fence) (Hogan et al. 1958)	Built to accommodate zero/low-power mockups of prototype reactors (Kirsch 2000a). Later, a lab installed for work with encapsulated Pu for Lawrence Livermore Laboratory. 1970: end of active nuclear work (Chamberlain ca. 2003, Wastren 2001). 1975: first decontamination (Wastren 2001). Was Admin Bldg, had Accountability Lab to ~1987 (Langsam and Carter 1986). RAL in decontaminated former Pu Lab, 1978 to ~2003 (FUSRAP 2000a; Rubadue 2000; DOE 1996,2000a, 2002, 2003a; Chamberlain ca. 2003; Wastren 2001; Jensen 2003); carpenter shop in bay moved from JN-3, from ~1987 on (Langsam and Carter 1986). Vault still used in 1996 or later (DOE 1996). "Minimally contaminated" at final decontamination (DOE 1996, 2000a; Jensen 2003)	Years of operation 1956–1974
JN-3		BRR Building	Pool-type research reactor (Jensen 2003); operation began in October 1956 at 1 MW (Anno, Plummer, and Chastain 1958), was increased to 2 MW in March 1959 (Plummer, Arno, and Chastain 1958), ended in December 1974 (DOE 1996). Shielding facility located at end of thermal column (Morgan et al. 1958, Plummer, Arno, and Chastain 1958, Myers and Stickel 1995); gas loop facility added 1958 (Bodnar et al. 1958; Plummer, Anno, and Chastain 1958, Basham and Rieder 1960, Anno and Plummer 1962); fast neutron activation facility added ~1960 (Jung et al. 1960). Carpenter shop (Langsam and Carter 1986); health physics office and instrument laboratory (Langsam and Carter 1986). JN-3 addition: well/hole storage in 144 wells/holes, primarily for spent fuel assemblies (Myers and Stickel 1995)	Partly decommissioned in 1975 (Rubadue 2000, DOE 2002, Jensen 2003, DOE 1996). Carpenter shop, Health Physics and Instrument Laboratory to ~1987 (Langsam and Carter 1986). 1987 on: temporary storage of TRU wastes (DOE 2002, Jensen 2003), for which a special waste storage area was built in the basement (Myers and Stickel 1995)	1960–1977 (FUSRAP 2000a, Rudolph, Kirsch, and Toy 1984)

ATTACHMENT B
BUILDINGS AND OTHER FACILITIES AT BATTELLE

Bldg ID	Location or subarea	Room, area, or alternate name	Description and MED/AEC use	Later uses and status	Years of operation
JN-4		Main Plutonium Laboratory ("old" laboratory section and its "new" additions)	Facility used in part for production of U-Pu nitride pellets, which were packed into fuel pins (Peters and Smith 2000). Development of actinide fabrication and joining techniques (Smith 2000). Had Metallography Laboratory (BCL 1977a). Room 4118 was used for fabrication of Pu-238 heat sources (FUSRAP 2000a, Smith 2000). Backup fac for LLL weapons assembly (Author unknown 2003, Peters and Smith 2000). Some wet chemistry in a glovebox for Allied Chemical Nuclear Services project (Smith 2000); some nuclear weapons, test shot (cask sabotage) projects (Author unknown 2003). Pu shipped to Battelle was handled here (Author unknown 2003, BCL 1977a), initially in the Downdraft Room (BCL 1977a).	Support of Pu research, processing (Wastren 2001, Freas et al. 1971, Rudolph, Kirsch, and Toy 1984, BCL 1977a); added to in 1964, 1967 (Freas et al. 1971, Rudolph, Kirsch, and Toy 1984, BCL 1977a). ~50% of work was Pu alloy R&D to support weapons development for Lawrence Livermore, Rocky Flats, Army reactors (Author unknown 2003, Smith 2000). Two fume hoods; 43 gloveboxes in 1971, 28 in 1978 (Wastren 2001, Freas and Madia 1982, Rudolph, Kirsch, and Toy 1984). Presses, furnaces, grinders, lathes (Clements 1981). Old section removed by 1982 (BCLDP 1982)	1976–present
JN-6		(New) Guardhouse	Security operations (guardhouse)(Rubadue 2000, DOE 2003a)		1965–1975?
JS-1			Used to fabricate military reactor fuel by hot isostatic pressure bonding technique (DOE 1996, Boehm and Groner 1986). Hot Isostatic Processing Facility (BMI ca. 1987, Langsam and Carter 1986); explosive containment (Langsam and Carter 1986); Ballistics Facility (Langsam and Carter 1986)	Decommissioned in 1990 (DOE 1996); D&D was complete by 2003 ()	?–1988
JS-10			Fabrication of uranium components using explosive forming techniques and ballistic experiments with depleted uranium (DOE 1996, Boehm and Groner 1986)	Facility characterization in 1998 showed that no D&D was necessary (DOE 1996)	?–1989
JS-12			Operations with radioactive materials in the ballistic tunnel, ductwork, and hardware using depleted uranium (DOE 1996, Boehm and Groner 1986)	Decommissioned in 1989 (DOE 1996)	

a. An old guardhouse building (with no number) built in 1956 was apparently abandoned when JN-6 was built (DOE 2003b).

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL

Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
King Avenue Site					
A			U, Th, daughters	DU, NU, EU, Th	6.4 MT (Author unknown 1992) (apparently the total ever worked with in this building)
	1943 1956	1944; 1956	U, daughters	Uranate; U_3O_8; $U_2O_2(NH_4)_2$	Metallurgical R&D, studies of uranates
	1943 1950 1958 1972	1944; 1952; 1961; 1975	U, daughters	U carbides, mainly UC (nat; enriched 9-93%)	R&D, studies of U carbides and their alloys
	1943 1979	1962; 1979	U, daughters	U metal, alloys	R&D, studies of work on U metal and its alloys
	1946	1957	U, daughters	U_3O_8, UO_2, $(NH_4)_2U_2O_7$, $Na_2U_2O_7$, other forms (UO_3?)	U chemical extraction: phosphate rock (1946-1950); shales (1946-1949, 1952-1954); washer slimes/slurries (1950); carnotite ores (1947-1949); Western ores (1952-1955); low-grade sulfide concentrate (1953); U ores (ammonium carbonate leaching) (1955-1957). Converting pitchblende to UO_2; refining MgX (concentrate), V-20 soda salt to UO_2 (1950-1951)
	1950	1971	U, daughters	UO_2 (nat, depl)	R&D on UO_2 used in fuel of various types (powder, pellet, plate-type, etc.) (a few plates: depleted U)
	1953	1954	U, daughters	U salt solutions (see at right)	Study of fused salt mixtures as liquid fuel: U fluorides, phosphates, sulfates, hydrosulfides; solubility of U in fused salts, O_2 in uranyl sulfate solutions
	1953	1959	U, daughters	U metal, UO_2, UO_3, UNH	Process support for U metal production for Mallinckrodt, NLO
	1953	1959	U, daughters	UF_4	Process support for U metal production (some work involved UF_4); study of UF_4 as fused salt mixture for liquid fuel (1953-1954)
	1956	1959	U, daughters	U compounds (see at right)	Study of U compounds: U beryllides, borides, silicides, sulfides
	1957	1958	U, daughters	UCl	Study of UCl dispersions (short period only)
	1957	1961	U, daughters	U nitrides, mainly UN (depl; nat; enr 5-93%)	R&D, studies of U nitrides and their alloys
	1958	1960	U, daughters	UO_2 (enr, mostly 93%)	R&D on UO_2 for fuel of various types (powder, pellet, plate-type, etc.); enrichment from few percent to full; bulk of work apparently with 93% enr
	1944	1961	Th, daughters	Th metal, Th alloys	Work with Th compounds, alloys (except extraction): R&D with Th metal (1944-1946); forging, rolling, machining Th ingots into Hanford slugs (1947)
	1951	1955	Th, daughters	$Th(NO_3)_4$, other forms	Th extraction from monazite sands (1949-1950). Solvent extraction to purify $Th(NO_3)_4$ (1951-1952). Extraction from Brazilian monazite sludge (1954-1955)
1			U, Th	DU, NU, EU, Th	11.6 MT (Author unknown 1992)
	1943 1950 1956	1944; 1952; 1962	U, daughters	U carbides, mainly UC (nat; enr 9-93%)	R&D, studies of U carbides and their alloys
	1943 1956	1944; 1956	U, daughters	Uranate; U_3O_8; $U_2O_2(NH_4)_2$	Metallurgical R&D, studies of uranates
	1943	1962	U, daughters	U metal, alloys	R&D, studies of work on U metal and its alloys
	1946	1957	U, daughters	U_3O_8, UO_2, $(NH_4)_2U_2O_7$, $Na_2U_2O_7$, other forms (UO_3?)	U chemical extraction from phosphate rock (1946-1950); shales (1946-1949, 1952-1954); washer slimes/slurries (1950); carnotite ores (1948-1949); Western ores (1952-1955); low-grade sulfide concentrate (1953); U ores (ammonium carbonate leaching) (1955-1957). Converting pitchblende to UO_2 (1950-1951); refining MgX (concentrate), V-20 soda salt to UO_2 (1950-1951)
	1950	1965	U, daughters	UO_2 (nat, depl)	R&D on UO_2 used in fuel of various types (powder, pellet, plate-type, etc.) (a few plates: depleted U)
	1952	1958	U, daughters	U metal, UO_2, UO_3, UNH	Process support for U metal production for MED/AEC, Mallinckrodt, NLO
	1952	1958	U, daughters	UF_4	Process support for U metal production (some work involved UF_4); study of fused salt mixtures as liquid fuel (1953-1954)

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL

Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
	1953	1954	U, daughters	U salt solutions (see at right)	Study of fused salt mixtures as liquid fuel: U fluorides, phosphates, sulfates, hydrosulfides; solubility of U in fused salts, O_2 in uranyl sulfate solutions
	1956	1959	U, daughters	U compounds (see at right)	Study of U compounds: U beryllides, borides, silicides, sulfides
	1956	1962	U, daughters	UO_2 (enr, mostly at 93%)	R&D on UO_2 for fuel of various types (powder, pellet, plate-type, etc.); enrichment from few percent to full; bulk of work apparently with 93% enrichment
	1957	1961	U, daughters	U nitrides, mainly UN (depl; nat; enr 5-93%)	R&D, studies of U nitrides and their alloys
	1944	1961	Th, daughters; minor U	Th metal, Th alloys; Th phosphate, halide, fluorides, carbides; ThN	Th compounds, alloys (except extraction): R&D with Th metal (1944-1946); forming Th ingots into Hanford slugs (1947); Th hydriding (1951); electroplating metals on Th (with Th phosphate) (1948-1953); arc-welding Ames Th, Th alloys; metallurg/mech study of Th; Th prep by iodide process (1951-1954); bomb reduction of Th halides; Th ingot prod by arc melting, casting (with Th fluorides) (e.g., 1955); Th-5, -10, -15, -20 w/o U alloys; Th-U alloy made with thorium iodide; ingots cast by vacuum induction melting to Th buttons, casting Th-U carbides by arc-melting; ThN prep (1956-1961). Dissolution of Al-canned Th (1955)
	1951	1955	Th, daughters	$Th(NO_3)_4$, other forms	Th extraction from monazite sands (1949-1950). Solvent extraction to purify $Th(NO_3)_4$ (1951-1952). Th extraction from Brazilian monazite sludge (1954-1955)
2			U, Th	DU, NU, EU, Th	32.6 MT (Author unknown 1992)
	1954	1959	U, daughters	U metal, UO_2, UO_3, UNH	Process support for U metal production for Mallinckrodt, NLO
	1954	1962	U, daughters	UF_4	Process support for U metal production (some work involved UF_4) (1954-1958); prep of UO_2 crystals from UF_4 by vapor deposition (1959-1962)
	1954	1962	U, daughters	U metal, alloys	R&D, studies of work on U metal and its alloys
	1954	1971	U, daughters	UO_2 (nat, depl)	R&D on UO_2 used in fuel of various types (powder, pellet, plate-type, etc.) (a few plates: depleted U)
	1955	1957	U, daughters	U_3O_8, $(NH_4)_2U_2O_7$, other forms(?)	U extraction from U ores (ammonium carbonate leaching) (1955-1957)
	1956	1956	U, daughters	$U_2O_2(NH_4)_2$	Study of prep of ammonium uranate
	1956	1959	U, daughters	U compounds (see at right)	Study of U compounds: U beryllides, borides, silicides, sulfides
	1956	1962	U, daughters	UO_2 (enr, mostly at 93%)	R&D on UO_2 for fuel of various types (powder, pellet, plate-type, etc.); enrichment from few percent to full; bulk of work apparently with 93% enr
	1956	1962	U, daughters	U carbides, mainly UC (nat; enr 9-93%)	R&D, studies of U carbides and their alloys
	1957 1961	1958; 1961	U, daughters	UCl (enr; nat?); U_3O_8 (nat?)	Study of UCl dispersions (enr, short period only, 1957-1958); making UCl from U_3O_8 (1961)
	1957	1961	U, daughters	U nitrides, mainly UN (depl; nat; enr 5-93%)	R&D, studies of U nitrides and their alloys
	1961	1961	U, daughters	HEU_3O_8, HEU	Prep of Al-U (HEU) fueled glass fiber fuel plates for irrad
	1955 1971	1965; 1972	Th, daughters; minor U	Th metal, alloys; iodide, phosphate, halide, nitride, fluoride, carbide;ThO_2 alloys	Th compounds, alloys (except extraction): bomb reduction of Th halides; prod Th ingots by arc melting, casting (with Th fluorides); Th-5, -10, -15, -20 w/o U alloys; Th-U alloy made with Th iodide; ingots cast by vacuum induction melting as Th buttons, casting Th-U carbides by arc-melting; ThN prep (1956-1961); Ta alloy buttons (trace Th) (1959-1960); Th carbide powder prep by vapor deposition (1960); corrosion of Th under storage, Th compounds in NaK (1960-1961); additives to Th-U (1960-1965); ThO_2 alloys with other mats (1971-1972)
	1956	1956	U content	Fissium	Fissium ("synthetic fissium alloy"): specimen fab, annealed; X-ray diffrac
3			U, Th	DU, NU, EU, Th	39.5 MT (Author unknown 1992)
	1954	1959	U, daughters	U metal, UO_2, UO_3, UNH	Process support for U metal production for Mallinckrodt, NLO

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL

Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
	1954 1979	1960; 1979	U, daughters	U metal, alloys	R&D, studies of work on U metal; its alloys, incl electroplating; vapor deposition of metals on U
	1954	1962	U, daughters	UF_4	Process support for U metal production (some work involved UF_4) (1954-1958); prep of UO_2 crystals from UF_4 by vapor deposition (1959-1962)
	1954	1971	U, daughters	UO_2 (nat, depl)	R&D on UO_2 used in fuel of various types (powder, pellet, plate-type, etc.) (a few plates: depleted U)
	1956	1959	U, daughters	U compounds (see next column)	Study of U compounds: U beryllides, borides, silicides, sulfides
	1956	1962	U, daughters	UO_2 (enr, mostly at 93%)	R&D on UO_2 for fuel of various types (powder, pellet, plate-type, etc.); enrichment from few percent to full; bulk of work apparently with 93% enrichment
	1956	1962	U, daughters	U carbides, mainly UC (nat; enr 9-93%)	R&D, studies of U carbides and their alloys
	1957	1961	U, daughters	U nitrides, mainly UN (depl; nat; enr 5-93%)	R&D, studies of U nitrides and their alloys
	1957 1961	1958; 1961	U, daughters	UCl (enr; nat?); U_3O_8 (nat?)	Study of UCl dispersions (enr, short period only, 1957-1958); making UCl from U_3O_8 (1961)
	1955 1971	1965; 1972	Th, daughters; minor U	Th metal, alloys; iodide, phosphate, halide, nitride, fluoride, carbide;ThO_2 alloys	Th compounds, alloys (except extraction): Th ingot prod by arc melting, casting (Th fluorides); Th-5, -10, -15, -20 w/o U alloys; Th-U alloy with Th iodide; ingots cast by vacuum induction melting as Th buttons, casting Th-U carbides by arc-melting; ThN prep (1956-1961); Ta alloy buttons (trace Th) (1959-1960); Th carbide powder prep by vapor deposition (1960); corrosion of Th under storage, Th compounds in NaK (1960-1961); Th-U additives (1960-1965); ThO_2 alloys with other mats (1971-1972)
	1956	1956	U content	Fissium	Fissium ("synthetic fissium alloy"): specimen fab, annealed; X-ray diffrac
4			U, Th	DU, NU, EU, Th	12.0 MT (Author unknown 1992)
	1954	1959	U, daughters	U metal, UO_2, UO_3, UNH	Process support for U metal production for Mallinckrodt, NLO
	1954 1979	1961; 1979	U, daughters	U metal, alloys (nat, 10% enr)	R&D, studies of work on U metal and its alloys (nat, 10% enr)
	1954	1962	U, daughters	UF_4	Process support for U metal production (some work involved UF_4) (1954-1958); for preparation of UO_2 crystals from UF_4 by vapor deposition (1959-1962)
	1954	1971	U, daughters	UO_2 (nat, depl)	R&D on UO_2 used in fuel of various types (powder, pellet, plate-type, etc.) (a few plates: depleted U)
	1955	1957	U, daughters	U_3O_8, $(NH_4)_2U_2O_7$, other forms(?)	U extraction from U ores (ammonium carbonate leaching) (1955-1957)
	1955?	1965?	Fission gases[e]		Fission gas analysis in fission gas laboratory (in Radioisotope Laboratory)
	1956	1962	U, daughters	UO_2 (enr, mostly at 93%)	R&D on UO_2 for fuel of various types (powder, pellet, plate-type, etc.); enrichment from few percent to full; bulk of work apparently with 93% enrichment
	1956	1956	U, daughters	$U_2O_2(NH_4)_2$	Study of preparation of ammonium uranates, including X-ray diffraction
	1956	1959	U, daughters	U compounds (see next column)	Study of U compounds: U beryllides, borides, silicides, sulfides
	1956	1962	U, daughters	U carbides, mainly UC (nat; enr 9-93%)	R&D, studies of U carbides and their alloys
	1957 1961	1958; 1961	U, daughters	UCl (enr; nat?); U_3O_8 (nat?)	Study of UCl dispersions (enr, short period only, 1957-1958); making UCl from U_3O_8 (1961)
	1957	1961	U, daughters	U nitrides, mainly UN (depl; nat; enr 5-93%)	R&D, studies of U nitrides and their alloys
	1961	1961	U, daughters	HEU_3O_8, HEU	Preparation of Al-U (HEU) fueled glass fiber fuel plates for irradiation
	1955	1955	Th, daughters	?	Support for Th extraction activities?

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL
Page 4 of 9

Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
	1955 1971	1965; 1971	Th, daughters; minor U	Th metal, alloys; iodide, phosphate, halide, nitride, fluoride, carbide;ThO_2 alloys	Th compounds, alloys (except extraction): bomb reduction of Th halides; Th ingot prod by arc melting, casting (with Th fluorides); Th-5, -10, -15, -20 w/o U alloys; Th-U alloy made with Th iodide; ingots cast by vacuum induction melting as Th buttons, casting Th-U carbides by arc-melting; ThN prep (1956-1961); Ta alloy buttons (trace Th) (1959-1960); Th carbide powder prep by vapor deposition (1960); corrosion of Th under storage conditions, Th compounds in NaK (1960-1961); additives to Th-U (1960-1965); ThO_2 alloys (1971-1972)
	1956	1956	U content	Fissium	Fissium ("synthetic fissium alloy"): specimen fab, annealed; X-ray diffrac
	1954				Radioisotopes in industrial control (tracer methods)
	1958	1960			Rad chemistry of inclusion compounds: nitration of hydrocarbons, urea compounds
	1967	1974			Research on bioeffects of underground explosions at Amchitka Island, Alaska during/after Milrow, Cannikin tests (samples counted at Battelle?)
	1982	1982?			Rad surveillance for Piqua Nuclear Power Facility: annual rad survey, soil sampling. Apparently done by Battelle (samples counted at Battelle?)
5			U, Th	DU, NU, EU, Th	14.7 MT (Author unknown 1992)
	1954	1959	U, daughters	Only U metal?	Process support for U metal production for Mallinckrodt, NLO, including dingot metal
	1954 1979	1960; 1979	U, daughters	U metal, alloys	R&D, studies of work on U metal and its alloys, including extrusion cladding, roll-bonding, fuel element fabrication
	1954	1971	U, daughters	UO_2 (nat, depl)	R&D on UO_2 used in fuel of various types (powder, pellet, plate-type, etc.) (a few plates: depleted U)
	1956	1962	U, daughters	UO_2 (enr, mostly at 93%)	R&D on UO_2 for fuel of various types (powder, pellet, plate-type, etc.); enrichment from few percent to full; bulk of work apparently with 93% enrichment
	1956	1962	U, daughters	U carbides, mainly UC (nat; enr 9-93%)	R&D, studies of U carbides and their alloys, including fuel element fab and coating
	1957	1961	U, daughters	U nitrides, mainly UN (depl; nat; enr 5-93%)	R&D, studies of U nitrides and their alloys, including bonding, welding
	1956	1959	U, daughters	U compounds (see at right)	Study of U compounds: U beryllides, borides, silicides, sulfides. Included ball-milling, fabrication
	1955 1971	1965; 1972	Th, daughters; minor U	Th metal, alloys; iodide, phosphate, halide, nitride, fluoride, carbide;ThO_2 alloys	Th compounds, alloys (except extraction work): production of Th ingots; Th-5, -10, -15, -20 w/o U alloys; Th-U alloy made with Th iodide; Th, Th-U carbides; ThN prep (1956-1961); Ta alloy buttons (trace Th) (1959-1960); prep Th carbide powders (1960); additives to Th-U (1960-1965); ThO_2 alloys with other mats (1971-1972)
	1958	1960	P-32, Ba-140, La-140, Y-91	Tracers in cement	Develop activation analysis, other methods to measure Mg, Ca, Al, Fe in cement; e.g., P-32 labeling, EDTA titration to precipitate tagged Ag*IO
6/7			U, Th	DU, NU, EU, Th	7.9 MT in Bldg 6, 8.7 MT in Bldg 7 (Author unknown 1992)
	1954	1959	U, daughters	U metal, UO_2, UO_3, UNH	Process support for U metal production for Mallinckrodt, NLO
	1954 1979	1961; 1979	U, daughters	U metal, alloys	R&D, studies of work on U metal and its alloys, including corrosion studies
	1954	1962	U, daughters	UF_4	Process support for U metal production (some work involved UF_4) (1954-1958); for preparation of UO_2 crystals from UF_4 by vapor deposition (1959-1962)
	1954	1971	U, daughters	UO_2 (nat, depl)	R&D on UO_2 used in fuel of various types (powder, pellet, plate-type, etc.) (a few plates: depleted U)
	1955	1957	U, daughters	U_3O_8, $(NH_4)_2U_2O_7$, other forms(?)	Chemical extraction of U from U ores (by ammonium carbonate leaching, as feed to Grand Junction pilot plant) (1955-1957)
	1956	1956	U, daughters	$U_2O_2(NH_4)_2$	Study of preparation of ammonium uranates
	1956	1959	U, daughters	U compounds (see at right)	Study of U compounds: U beryllides, borides, silicides, sulfides
	1956	1962	U, daughters	UO_2 (enr, mostly at 93%)	R&D on UO_2 for fuel of various types (powder, pellet, plate-type, etc.); enrichment from few percent to full; bulk of work apparently with 93% enrichment

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL

Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
	1956	1962	U, daughters	U carbides, mainly UC (nat; enr 9-93%)	R&D, studies of U carbides and their alloys
	1957	1961	U, daughters	U nitrides, mainly UN (depl; nat; enr 5-93%)	R&D, studies of U nitrides and their alloys
	1957 1961	1958; 1961	U, daughters	UCl (enr, nat); U_3O_8 (nat?)	Study of UCl dispersions (enr, short period only, 1957-1958); making UCl from U_3O_8 (1961)
	1961	1961	U, daughters	U_3O_8	Preparation of single U_3O_8 crystals, examination
	1955	1955	Th, daughters		Support for Th extraction activities?
	1955 1971	1965; 1972	Th, daughters; minor U	Th metal, ThO_2 alloys; iodide, phosphate, halide, nitride, fluoride, carbide	Th compounds, alloys (except extraction): Th-5, -10, -15, -20 w/o U alloys; Th-U alloy made with Th iodide; ThN prep (1956-1961); solubility of U in Th, corrosion of Th under storage, Th compounds in NaK (1960-1961); Th-U additives (1960-1965); ThO_2 alloys (1971-1972). Dissolution of Al-canned Th (1955)
	1960?	1972?	Pu, U	Spent fuel (small quantities?); Pu alloys, UN-PuN	Study of Pu in pyrometallurgical process for U recovery from spent fuel elements, with Al-10 w/o U-5 w/o Pu; corrosion of Ta, Ta alloys by liquid Pu alloys (1960?). Study of UN-PuN fuel mat, cladding for fast reactors
	1956	1956	U content	Fissium	Fissium (synthetic fissium alloy): specimen fab, annealed; X-ray diffraction
		1954 1958	1954; 1962	Fe-59, Mn-54	
	1956	1961		$HEUO_2$, depl UO_2; other?	Miscellaneous neutron dosimetry/monitor work, including wire-activation method for reactor flux profile data; fast neut effects on semiconductors;
					neut activation of ion chamber walls; ceramic tubes of Al_2O_3-Mo-Si_2-UO_2 with enriched U for fission-power elements, depleted U for heating elements (1959-60)
	1958	1960			Rad chemistry of inclusion compounds by nitration of hydrocarbons and their urea (nitration) compounds
	1958	1960	P-32, Ba-140, La-140, Y-91	Tracers in cement	Develop activation analysis, other methods to measure Mg, Ca, Al, Fe in cement; radiometry of samples. P-32 labeling, EDTA titration with tagged Ag*IO
	1959	1960	Fission gases?[e]		Isotopic exchange leak detection system (an Ag-Br column in conjunction with delayed-neutron monitor)
	1960	1962	H-3	Triated cytidine, trace levels	Miscellaneous biological effects studies, including nucleic acid metabolism in HeLa S3 cells after X-ray-induced mitotic delay (using tritiated cytidine)
	1962	1963	MFP; UO_2	UO_2 particles	Internal rad effects on catalyst activity: 5 w/o ceramic-coated UO_2 particles added to catalyst; catalyst efficiency tested; neut irradiation
	1967	1974			Research on bioeffects of underground explosions at Amchitka Island, Alaska during/after Milrow, Cannikin tests (samples counted at Battelle?)
	1982	1982?			Rad surveillance for Piqua Nuclear Power Facility: annual rad survey, including soil sampling, by Battelle (samples counted at Battelle?)
9			U, Th	DU	0.06 MT (Author unknown 1992)
	1958	1962?	Krypton[e]	Krypton, UO_2	Analysis of gas from SME, OMRE, and OMR fuel specimens; limited laboratory-level work with depleted and natural U
West Jefferson site					
JN-1 (Hot cells)			U, Th, AP, FP, Pu	DU, NU, EU, Th, AP, FP, Pu	8.9 MT (Author unknown 1992)
	1954	1962	U, MFP, AP	U metal, alloys (nat, 10% enr)	Postirradiation studies/examinations of clad nat U element; fuel elements, specimens irradiated elsewhere; U alloys (nat or 10% enr); U-Nb alloys
	1954	1972	U, MFP, AP[e]	UO_2 (nat)	Postirradiation studies of corrosion of clad U metal, alloys and elements irradiated elsewhere; uncoated, coated fuel particles; fission gas release from UO_2 crystals, UO_2 in cladding; sweep capsules; cleavage faces for recoils, tracks; cladding contacted with UO_2 foil (MFP penetration analysis). Fission product diffusion and recoil studies, including sectioning; rad damage studies in ceramics, Al by contact with UO_2; iodine-retaining coatings

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL

Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
	1962	1972	U, MFP, AP	UO_2 (nat)	Study of Cr foils impregnated with fission product conc of 2 x 10^9 recoils/cm^2 to measure Xe-133 release and Ce-141, Ru-103, and Nb-95 distribution
	1956	1961	Th, U, MFP, Cs-137[e]	U-Th alloys	Studies of U-Th alloys: fission gas retention study, other postirradiation analyses and tests, including burnup disk sectioning, Cs-137 release
	1956	1962	U, MFP, AP[e]	UO_2 (enr 25-93%)	BRR, ETR loop programs (25-50% enrichment); postirradiation examination of $HEUO_2$ dispersed in SS; UO_2-SS fuel (mostly at 93%); spherical fueled elements (93% enrichment); high burnup fuel (some at 30% enrichment, some at 93%); encapsulated UO_2-SS fuel (at 93% enrichment), UO_2 pin-type fuel (at 35%); pellets (at 25-50% enrichment) and compacts for ML-1. Miscellaneous studies of fuel; UO_2 dispersions in various matrices, claddings (20% enrichment); coated particles, including crushing to release fission gases; high-burnup irradiation stability study of Zr_2O_2-UO_2, similar fuels
	1957 1965	1961; 1971	U, MFP	U nitrides, mainly UN (depl; nat; enr 5-93%)	Postirradiation testing of UN dispersion, cermet forms; fission bubble growth kinetics, migration; irradiation behavior of UN fuel elements
	1958	1962	U, MFP[e]	U carbides, mainly UC (nat; enr 10-93%)	Postirradiation examination of UC (some natural, some enriched) capsules; dispersed UC, UC_2 (nat); other UC, UC_2 specimens (at 30% enrichment, some at 93%), further specimens (at 10% enrichment) to high burnup; included section/seal/heat in tubes for fission gas examination, postirradiation heat/capture fission gases on charcoal traps or by freezing, e.g., coated nat UC_2 particles; fission product deposition in out-of-pile loop system (UC_2); fission bubble growth kinetics, migration; irradiation behavior of UC elements
	1962 1965	1962; 1966	U, MFP[e]	U silicides, hydrides	Postirradiation studies of U_2Si_2; deposition behavior of fission products in an out-of-pile gas loop system, with U hydride as fuel
	1957	1964	U, Th; MFP[f], AP	Spent fuel in solid, liquid form (mostly non-rad)	Recovery (dissolution) of spent fuel: Zircex, Darex, Thorex, Zirflex, fluoride volatility, Niflex processes; mostly non-rad Zirflex: U fuel elements; Thorex: Th forms. Examine ORNL Fluoride Volatility Pilot Plant vessels, Hanford Purex evap steam coil sections. 1961 on: mostly fluoride volatility process studies
	1958	1966	AP, some incidental MFP	Al plate; Nb, Zr, SS as cladding, matrix, or alloy component	Postirradiation examination of GCRE Mark 1 fuel plate Al; elements with Nb, Zr cladding or alloys; irradiation surveillance program on SS; seals, gaskets, etc.; non-rad core, structural materials, especially cladding (SS, Inconel, Zircaloy-2, etc.), sintered Al particles, often with postirradiation heating; Ta alloy damage, high-burnup boron compound dispersions; materials, electrical components for SNAP-8
	1964	1983	MFP, AP	Al plate; Nb, Zr, SS as cladding, matrix, or alloy component	Postirradiation examination of items from power and defense reactors: Shippingport Atomic Power 1B generator (1964-65); Fermi Reactor failed fuel (1967?); PM-3A Type I, Serial 2 (defective) core and Serial 3 core (1967-68); Vermont Yankee 304 SS Sch 80 reducer (1974); Arkansas Nuclear Plant 1 reactor bldg spray system SS 304 recirc piping (≤1975); H. B. Robinson, Point Beach Zircaloy (1975-1976); fuel rods (unspecified, 1977); Point Beach 1, Dresden 3 fuel rods, Oskarshamn 1 fuel rod sections (1978); Connecticut Yankee failed fuel assemblies (1981); oxide thickness on spent fuel rods (unspecified, 1983); support of TMI cleanup: characterization of highly loaded EPICOR II prefilter liners #3 and #16 by sampling, analyzing liner contents, examining liner (1981-1983)
	1979	1983?	MFP	Spent fuel	Shipping cask sabotage source term investigation; used five irradiated fuel rods from the H. B. Robinson reactor (1979)
	1964	1968	Pm-147	Pm oxide	RTG work: hot cell examination of SD-4 thermionic diode (1964-1968)
	1964	1977	Pu-238, U, Th, MFP; Nd-150, N-15 as tracers	PuO_2, UO_2, UO_2-PuO_2, UN-PuN	Rad effects on irradiated PuO_2 (1967); in-pile creep of PuO_2, UO_2-PuO_2 (1970-1972). UN-PuN capsule postirradiation examination (1970?-1971); PuN-UN burnup with Nd-150 tracer, UN-PuN burnup with N-15 tracer (1970). After Pu-238 prod in commercial power reactor: postirradiation examination, Pu recovery (1974?-1975). Experiments, irradiation effects on fuel mat aerosols (UO_2, PuO_2) (1975?-1977)
	1974?	1975	Np, Pu	Pu fuel?	After production of Pu-238 in commercial power reactor: postirradiation examination, Np recovery (1974?-1975)

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Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
	1972	1980s ?	Cf-252	Cf-252 wire	Processing and encapsulating Cf-252 (produced elsewhere)
	1956 1966	1961; 1967		HEUO_2, depl UO_2; other?	Miscellaneous neutron dosim/monitor work, including fast neut effects on semiconductors; neut activation of ion chamber walls; proportional flow counter for neut activation studies of MGCR specimen fission gas release (including in-op degassing) (1959). Ceramic tubes of Al_2O_3-Mo-Si_2-UO_2 with enrichment U, depl U (1959-1960)
	1958	1960			Develop activation analysis, other methods to measure Ca, Al, Fe in cement
	1961	1962			Evaluation of stresses, other test parameters on sealed radiation sources
	1962	1963	MFP; U	UO_2	Internal radiation effects on catalyst activity: 5 without ceramic-coated UO_2 particles added to catalyst; catalyst efficiency measured after neut irradiation. Postirradiation beta-gamma activity followed as function of decay time. Catalysts with up to 65 mCi/g of fission product beta activity used in dehydration of cyclohexanol
JN-2 (Critical Assem-bly Lab, Pu Lab)			U, Pu	NU, EU, Pu	1.7 MT (Author unknown 1992)
	1955	1961		U metal foil (nat, depl); UO_2 (2-93% enr)	APPR criticality experiment (1955, enriched U foil). Evaluation reflected heterog BWR, including critical assembly experiments (U foil) (1957-1958). Crit experiment with movable water reflector; core: Al-polyethylene-U core (1957-?). Crit assembly experiment for GCRE-1 (UO_2) (1958). Plastic-moderated crit assembly: polyethylene, polystyrene (1958-1961). Mockup ML-1-1B reactor, GCRE crit assembly elements rewrapped to average 303 g U-235 per element, 61 element positions; 19 pins/element, with 7 at 35 vol%, 12 at 70 vol% UO_2 (1959-1960). Ditto, but 48 elements with total of 31.1 kg U-235 (1961). Crit assembly experiments with UO_2 pellets, pins (1.8% enrichment); depleted U foil (0.04 w/o U-235), natural U foil to calibrate Battelle counting facilities in activity per fission in U-235, U-238 (1959-1960)
	1964	1968	Pm-147	Pm oxide	RTGs: purify multicurie quantities of Pm-147 (oxide) (1964-1966). Fab, test SD-4 thermionic diode (1964-1968), segmented thermoelectric modules (1966)
	1964 1974	1968; 1978	Pu-238, Pu, U, Th, MFP; Nd-150, N-15 (as tracers)	Pu and U-Pu forms (see at right)	Study PuN as fuel; Pu-Al, Pu-Fe, U-Pu-fissium, U-Pu-Mo, PuO_2-UO_2; solid-solution alloys (Th-Pu, U-Pu-Nb, etc.); liquid-metal fuels (Pu alloys); ceramic fuels (PuC, PuC-UC mixtures, PuN, Pu_2Si_3, $PuSi_2$); cermet fuels (PuC, PuO_2); cast dispersion alloys (Pu-Fe alloys); PuB; fab, casting, etc. (1964-1968). Prepare U, Pu microspheres as intrinsic thermocouple flux probes (PuO_2) (1966-1968). Study UN-PuN fuel mat, cladding for fast reactors: prepare UCN-PuCN by arc melting, casting; vaporization of Pu nitride, carbide fuels; UN-PuN with liquid Na or with SS, Nb-Zr, Inconel,
					Incaloy cladding (1966-1968?). Fab, examine UN-PuN pellets, EBR II pellet-type fuel, UN-PuN pin-type elements, irrad capsules (1968-1971). 1970: Study of PuN-UN burnup using Nd-150 tracer, N diffusion in PuN, UN-PuN with N-15 as tracer (1970). Devel Na-bonded SS-clad PuN, capsule (1972?). Design, fab RTGs with Pu-238 (PuO2) (1974-1978)
	1966	1974?	Np, Pu	NpO_2	Prepare Np microspheres as thermocouple flux probes (Np oxide) (1966-1967?); fab NpO_2-ZrO_2, NpO_2-CaO-ZrO_2 target rods for Pu prod (1971?-1974?)
	1974	1978	Cm-244	Cm oxide?	Design, fab RTGs with Cm-244 (1974-1978)
JN-3 (BRR)			U	NU, EU	0.1 MT (Author unknown 1992)
	1955	1965	U, MFP, AP[e]	UO_2 (nat)	Irradiation/damage study of: graphite; UO_2 rods in graphite; uncoated, coated fuel particles; ceramics. Foils in recoil studies. Irradiate to study fission gas diffusion/release from foils, coated powders, clad forms; releases from sweep capsules, fueled graphite in in-pile loop. UO_2-contacted Al damage study

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL
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Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
	1956	1962	U, MFP, AP[e]	UO_2 (enr 25-93%)	BRR, ETR loop programs (25-50% enrichment); evaluate spherical fueled elements (93% enrichment); fission gas release from high-burnup irrad (some at 30% enrichment, some at 93%); irradiation of UO_2-SS capsules, other fuels (at 93% enrichment), including gas loop measurements; irrad coated particles
	1957	1957	U, MFP, AP	U metal (nat), alloys (nat, 10% enr)	Irradiation of Zr-clad natural U element; irradiation study of U alloys (natural or 10% enrichment)
	1958	1962	U, MFP, AP[e]	U carbides, mainly UC (nat; enr 10-93%)	Irradiation of UC (natural, enriched) capsules; PyC-coated UC_2 particles (natural); UC, UC_2 (natural) dispersion specimens, other UC, UC_2 specimens (at 30% enrichment, some at 93%); high-burnup specimens (at 10% enrichment); coated spheres in sweep capsules, including in-pile fission gas analysis. Fission product deposition in out-of-pile loop system (UC_2); fission bubble growth kinetics, migration; UC fuel irrad behavior
	1958	1972	AP	See at right	Irradiation effects on seals, gaskets, etc.; non-rad core, structural mats, especially cladding, sintered Al particles. Irradiation of SNAP-8 mats, electrical components
	1965	1971	U, MFP	U nitrides, mainly UN (depl; nat; enr 5-93%)	Postirradiation testing of UN dispersion, cermet forms; fission bubble growth kinetics, migration; irradiation behavior of UN fuel elements
	1956	1961	U, Th, MFP	U-Th alloys	U-Th alloy studies: irradiation to measure fission gas retention, other postirradiation data
	1964	1971	Pu, U, MFP; Nd-150, N-15 (tracers)	PuO_2, PuN, UN-PuN; Nd-150, N-15 (as tracers)	Rad effects on PuO_2 (1967); PuO_2, UO_2-PuO_2 in-pile creep studies (1970-1972). Study of UN-PuN fuel mats: irradiation of capsule(s) (1970-1971). PuN-UN burnup study with Nd-150 tracer; UN-PuN with N-15 tracer (1970). Irradiation, experiments re fuel material aerosol properties (UO_2, PuO_2) (1975?-1977)
	1964	1968	Pm-147	Pm oxide	RTG work: irradiation, in-pile testing of SD-4 thermionic diode (1964-1968)
	1956 1966	1961; 1967	U, MFP, AP	UO_2 (enr, depl), other forms?	Miscellaneous neutron dosimetry/monitor work, including the following. Wire-activation for reactor flux profile data; fast neut effects on semiconductors; thermal neut flux meter, sensor; "tactical" neut dosim; fast neut dosim system; neut activation of ion chamber walls. Proportional flow counter for neut activation studies of MGCR specimen fission gas release (1959). Thermal neut flux monitoring system for Hanford; ceramic tubes of $Al2O_3$-Mo-Si_2-UO_2 with enriched U, depleted U (1959-60). Study of 1-50K rad semiconductor fast-neut dosimeter (1966-1967)
	1956	1961			Miscellaneous gamma dosimetry/monitor work, including the following. Gamma effects on semiconductors, tin oxide films; effects of high-intensity rad bursts on electrometer-type ion chambers; gamma testing of photovoltaic gamma dosimeter; high-level gamma dosimetry research, including glasses for high-level gamma dosimeters
	1958	1960	Ba-140, La-140, Y-91	Tracers in cement	Develop activation analysis to measure Mg, Ca, Al, Fe in cement
	1958	1961	Fission gases[e]		Installation, use of in-pile apparatus (loop) to study fission gas release (in beam tube facility) (1958-1960). Beam tube furnace for coated particle fuel irradiation, including collection, analysis of released fiss products; develop methods to study fission gases with gamma spec analysis, charcoal traps (1961)
	1959	1960	Fission gases?[e]		Develop fuel element leak detector
	1960		AP?		Facility to study fast neutron activation using the BRR spectrum
	1962	1963	U, daughters	UO_2	Internal rad effects on catalyst activity: 5 w/o ceramic-coated UO_2 particles added to catalyst, irradiation
	1964		N-17/O-17		Develop N-17 (O-17) decay neutron monitor to track reactor power
	1971	1975	AP?	Likely $HEUO_2$	Neut radiography of reactor fuel: done in reactor pool and in out-of-pool facility

ATTACHMENT C
HISTORY OF WORK DONE AT BATTELLE, BY BUILDING AND MATERIAL

Bldg[a]	Start	End	Isotopes[b]	Form[c]	Type(s) of work[d]
JN-4 (part of this was called the "Old" Pu Lab)	1960?	1968	Pu, Th, U	Pu, PuO_2, PuO_3, Th-Pu and U-Pu alloys	Study Pu in pyromet process for U recovery from spent fuel, with Al-10 w/o U-5 w/o Pu; corrosion of Ta, Ta alloys by liquid Pu alloys (1960). Study PuO_2 pellets in SS, Inconel, etc.: 10-15 vol% Pu_2O_3 presintering to PuO_2 (1960-1962). Pu alloys, 5-28 w/o Pu; Th-Pu; heat, hot roll, metallog examination (1960-1962). Evaluate PuN fuel; Pu-Al, Pu-Fe, U-Pu-fissium, U-Pu-Mo, PuO_2-UO_2; solid-solution alloys (Th-Pu, U-Pu-Nb); liquid-metal fuels (Pu alloys); ceramics (PuC, PuC-UC mixtures, PuN, Pu silicides); cermets (PuC, PuO_2); dispersion Pu-Fe alloys; PuB; fab, cast (1962-1968). Prep U, Pu microspheres (PuO_2) (1967-1968). Study UN-PuN fuel mat: prep UCN-PuCN by arc melting, casting; vaporize Pu nitride, carbide fuels; UN-PuN with liquid Na or with SS, Inconel cladding; Na wetting of UN-PuN fuels (1966-1968?). Fabricate, examine UN-PuN pellets, EBR II pellet fuel, UN-PuN pin-type elements, irradiated capsules (1968-1971)
	1964	1968	Pm-147	Pm oxide	RTG: purify multicurie quantities of Pm-147 (oxide) (1964-1966)? Fabricate, test SD-4 thermionic diode (1964-1968). Develop segmented thermoelectric modules (1966)
	1966	1967?	Np		Prepare Np microspheres as thermocouple flux probes (Np oxide)
	1978	1980	Pu, Th, U, daughters	Residual radioactivity	Decontamination of JN-4
JS-1	1960s ?	Early 1980s ?	U, Th	DU, NU, EU, Th	0.9 MT (Author unknown 1992)
JS-10, JS-12	1960s ?	Early 1980s ?	U	DU, EU	0.3 MT for JS-10, 0.002 MT for JS-12 (Author unknown 1992)
INEL	1958	1960	U, MFP, fission gases	UC (nat, enr)	Irradiate UC (natural, enriched) fission product release; in-pile irradiation, postirradiation examination of UC (SRE specimens): at MTR(?), Xe-133 assay during postirradiation heating with charcoal traps, gamma spec; also Kr-85. Battelle representative observed data-taking at MTR (INEL)
Hanford	1961	1962			Research at Hanford (HAPO) on reactor materials in NPR; on PRTR operation
Power plants, ANL, INEL	1970	1981			Work at commercial nuclear power plants, etc. The 1970 work at Connecticut Yankee might have been part of program to use commercial reactors to make Pu-238 from Np target rods.

a. Bldgs 4, 6, and 7 might have been used for some work even where not listed, because it is not always clear what associated laboratory-type tests might have been done; also, X-ray diffraction of most samples and specimens should be assumed to have been performed (usually in Building 4 if the specimen was not hot; however, plutonium was not handled at Building 4).
b. MFP: mixed fission products; FP: fission products; AP: activation products (for the materials in question).
c. The U form was probably natural uranium when not specified; enriched uranium appears not to have been used before 1954. Sometimes only the final form was indicated by the relevant reference, so the possibility of a different initial or intermediate form than listed above must be kept in mind.
d. X-ray diffraction was said always to have been on a powder sample, so diffraction samples or specimens of a solid material had to be ground or milled before the test could be performed. Thus, at least small amounts of the material should be assumed to have been ground to powder form.
e. Fission gases could be generated in samples or rods irradiated elsewhere or in the Battelle reactor. Fission gases could be counted in the in-reactor loop at the Battelle reactor, in a JN-1 hot cell when a rod or sample was opened, or (if the total fission product content was less than 1 Ci) at the fission gas laboratory in the Building 4 Radioisotope Laboratory at King Avenue (Sunderman and Dickerson 1962). If chemical separations or special counting had to be done, the sample was opened in the hot cell or at the fission gas laboratory. In both such cases, the sample could be heated in a quartz tube to drive off the gases, which were then collected. Townley et al. (1960) indicate that in the analysis of fission gases from samples irradiated at the Battelle reactor, some or all of the Kr-89, Xe-137, Xe-140, and Xe-141 fission product chains were studied, with the respective down-the-chain daughters S-89, Cs-137, Ba-140, and Ce-141 being analyzed in some studies by being trapped on stainless steel mesh and with I-131 and I-133 also being analyzed when they deposited on the traps; the traps were dissolved in acid and the various daughters and radioiodine were then chemically separated and counted.
f. One report stated that the principal radioisotope after a 10-month cooling of the fuel was Co-60 (~100% of gamma activity in the eluted fraction) (Dayton and Tipton 1960a). However, another report stated that at high burnup, Co-60 was a minor contributor to the total activity of decladding solutions and that the MFPs were in the same proportion as in the fuel dissolved except for cesium (Ewing, Brugger, and Sunderman 1961).

ATTACHMENT D
TYPES AND QUANTITIES OF MATERIAL PRODUCED OR USED IN BATTELLE WORK

Material	Process or operation	Content and form notes[a]	Period and amount[b]	References
Source and production materials				
U metal, natural	Production from phosphate, etc. (see other entries below); metal refining process support; development of fuel rods as metal in a matrix; e.g., U in graphite; studies, fabrication of U metal, U alloys		1943-1979 overall. 1946-1957 (extraction). 1952-1958 (metal refining process support, e.g., casting large ingots); largest ingot melt ~1,200 lb, 170 lb typical (Rengstorff and Lownie 1955)]. 1951 [10 kg of U ingots to ORNL (Author unknown ca. 1987)]	Author unknown ca. 1987; FUSRAP 2000b, Ferry 1943, DOE 2000a, Dayton and Tipton 1959a, Rengstorff and Lownie 1955
U metal, depleted	Used as foil in critical assembly work; machined, rolled		1957-1960, possibly other years also	FUSRAP 2000b, DOE 2000a
U metal, enriched	R&D on fuel elements; processing and machining	10-93% enrichment	1954-1962; 1979. One critical experiment: critical mass of HEU foil was 4.935 kg (Dayton and Tipton 1957).	Author unknown ca. 1987, FUSRAP 2000b, DOE 2000a, Dayton and Tipton 1957
U as recycle uranium	Apparently used for testing of recovery methods, assay	Depleted, normal, or enriched	1962-1980, sent by Battelle to FEMP or RFI: 168 kg depleted U, 5,135 kg normal U, and 29 kg enriched U (including 1.45 kg U-235 for enriched). 1962-1982, received by Battelle: 1,616 kg depleted U, 2846 kg normal U, and 0.06 kg enriched U (including 1 g U-235 in the enriched). More than half of the total kg U transfers were in 1964	DOE 2000b
UO_3	Small amount in metal refining process support; some made from UNH (1957)	Natural	1954-1959	Vaughan 1957
UO_2	Extensive research, testing: production from pitchblende, MgX, soda salt; metallurgical, fab operations, including fuel element production; metal refining process support; other uses, e.g., in instruments	Depleted, nat, enr; much as $HEUO_2$; apparently all natural for refining process support. As powder, pellets, or plates. For 1.7 g UO_2 powder, standard capsule: activation to 1.5 Ci at 10 s postirradiation, 0.23 Ci at 2 d	1946-1972 overall. 1952-1958 (metal refining process support). 1956-1961 (instrument work). Neutron radiography of $HEUO_2$ reactor fuel in the BRR in 1971-1975. Not enriched before about 1956	Author unknown ca. 1987, FUSRAP 2000b, Chastain 1961
U carbides	R&D, study of U carbides and alloys, mainly for fuel apps	Natural and enriched, up to 93%	1943-1944; 1950-1952; 1956-1961; 1972-1975	Litton 1960, Hanson 1961
U nitrides	R&D, study of U nitrides and alloys, mainly for fuel apps	Depleted, natural, and enriched, up to 93%	1945; 1957-1961	BMI 1945b
Uranate, UNH forms	Uranate studies; metal refining support; extraction products, byproducts; producing fueled glass fiber plates; producing UCl from U_3O_8	U_3O_8; HEU_3O_8 (fueled glass); $U_2O_2(NH_4)_2$; $Na_2U_2O_7$. Possibly some enriched forms	1943-1944, 1956 (uranate studies). 1952-1959 (metal refining process support: UNH, uranates). 1946-1957 (U extraction from various forms). 1961 (fueled glass, UCl prod)	
U salts, including UF_4	Study fused salt mixtures as liquid fuel; refining process support (UF_4); vapor deposition conversion of UO_2 to UF_4	U fluorides, hydrosulfides, phosphates, sulfates	1953-1954 (fused salt study). 1952-1959 (metal refining process support). 1959-1962 (conversion of UO_2 to UF_4)	

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Material	Process or operation	Content and form notes[a]	Period and amount[b]	References
Other U compounds	Studies of miscellaneous U compounds; postirradiation studies of some; study, production of UCl	Natural and enriched, up to 93%. U beryllides, borides, UCl (dispersion), silicides	1945: Al with 1-30% U, 10-15-lb melts forming ingots ~6 in. × 10 in. × 1.5 in. (BMI 1945b). Feb 1947: 14 lb "TU-Be alloy" at 90% Be; 13 lb at 30% Be; 72 lb Tu-Be dross at 2% Be; 59 lb TuO_2 +BeO at 33% Be (Grenall 1947). 1956-1959 (misc compds). 1962, 1965-1966 (postirradiation studies). 1957-1958 (UCl study); 1961 (UCl production)	BMI 1945b, Grenell 1947
Thorium metal and alloys	R&D with Th metal; forging, rolling, machining ingots into slugs for Hanford; arc-welding Ames Th, Th alloys; mech/metallurg study of Th; making Th-U alloy with Th iodide; casting Th buttons; casting Th-U carbides by arc-melting		1944-1961 overall. 1944-1946 (R&D). 1947 (slugs for Hanford)	BMI 1945a,b; Author unknown ca. 1987
Th nitrate and other Th salts; Th-containing materials	Production of Th nitrate from various feed materials (see below); Th solvent extraction pilot plant, to purify $Th(NO_3)_4$ and produce Th metal	November 1949: Th product with 33 parts U_3O_8 per million of ThO_2 produced from carbonate solution initially having 38,000 parts U_3O_8 per million of ThO_2	1949-1950 (extraction from monazite sands). 1951-1952 (R&D, pilot plant). 1954-1955 (extraction from Brazilian monazite sludge)	FUSRAP ca. 1987, 2000b; Author unknown ca. 1987; Brown 1951; Hunter 1949, Kelley 1949, 1951; DOE 2000a
Other Th compounds	Th hydriding; electroplating metals on Th (Th phosphate); Th prep by iodide process; bomb reduction of Th halides; Th ingot prod by arc melting, casting (with Th fluorides); making Th-U alloy with Th iodide; ThN prep; Th carbide powder prep by vapor deposition; prep of Th-U, ThO_2 with various additives	Th carbides, fluorides, halides, iodide, nitride, phosphate; ThO_2. Most often to produce Th metal or a Th alloy. Th-U alloys: 5-10 without U	1951 (hydriding). 1948-1953 (electroplating metals on Th). 1951-1954 (Th prep by iodide process). 1954-1955 (electrodeposition of Th to form ingots). 1956-1961 (ThN prep).	Gallagher, Blosser, and Mann 1955

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TYPES AND QUANTITIES OF MATERIAL PRODUCED OR USED IN BATTELLE WORK

Material	Process or operation	Content and form notes[a]	Period and amount[b]	References
Plutonium and other transuranics	Study of Pu in U spent fuel recovery; Ta corrosion by Pu alloys; studies of UN-PuN fuel, PuO_2 pellets, Th-Pu and U-Pu alloys, liquid metal fuels, ceramic/cermet fuels; R&D on Pu processing, fabrication; fabrication of Pu-238 heat sources; breeder experiments; Pu production from Np targets fabricated at Battelle (irradiated elsewhere), Np/Pu recovery; Pu microspheres; aerosol experiments	Some transuranics as a result of breeder experiments. Usually Pu-238 (e.g., for RTGs: powder transferred, coated, pressed, sintered to pellets, welded into capsules), but Pu-239/240 also handled; Np-237 in microspheres. U-Pu spent fuel: 10 without U, 5 without Pu. Ceramic, cermet, and alloy fuels included Pu carbides, nitrides, oxide, and silicides and various U-Pu compounds. Some vaporization was done for fuel production. RTGs, aerosols: as PuO_2	Work apparently began in 1960 (recovery, corrosion studies). 1960-1962 (PuO2 pellets; e.g., ~1 kg UO2-PuO2 fuel pellets fabricated into test fuel in one campaign); nitride fuel studies. 1962-1968 (various fuel studies; >20 kg of Pu metal fabricated into classified shapes). 1964-1971 (test fuel irradiations). 1966-1968 (Pu microspheres as probes). 1968-1971 (fabrication of UN-PuN pellets, EBR II pellet fuel, UN-PuN pins, irradiation specimens; ~20 kg of Pu metal powder processed into PuN or PuN-UN pellets/test fuel)). 1974-1975 (Pu recovery from targets). 1974-1978 (RTG work: ~4 kg of Pu-238-O2 handled in fuel development studies, heat source fabrication. 1975-1977 (aerosol experiments). Some Pu sent from INEL in 1969-70 (form unknown).	FUSRAP 2000a, Toy 1986, DOE 2000a, Freas and Madia 1982, BCL (circa 1980)
Phosphate rock, superphosphate material	Extraction of U via leaching and other chemical processes	Florida phosphate rock, 0.009% U, extracted at 87-94% efficiency; superphosphate, 0.006% U, at 55% efficiency	1946-1950	Beyer 1948a, Blatz 1949
Shales	Extraction of U via leaching and other chemical processes	Tennessee shales: 0.005-0.009 % U	1946-1949, 1952-1954	Beyer 1948b, Blatz 1949, Bearse et al. 1948c
Monazite sands	Extraction of U via leaching, other chemical processes; extraction of Th via solvent extraction, with production of ThO_2 or Th metal	5-7% ThO_2 for Brazilian, Indian sand concentrates, 3-4% for Idaho sand concentrates. 1949: 6 lb U + 100 lb Th from each ton of sand, i.e., 5-6% Th and 0.3% U. 5-10 mR/hr contact with sack	1948-1950. In 1949, expected to process 30-40 lb of sand per week eventually (Blatz 1949)	Hunter 1949, Wallo 1981, Blatz 1949
Colorado carnotite ore; "Western" ores; other ores	Carnotite ore: ground to minus 10 mesh; sep of minus 325 mesh fraction; mixing with 10% salt; roasting. No details: Colorado, Western ores. Other ores: ammonium carb leaching	Colorado carnotite: 0.25-0.3% U as ore; after grinding, the 5% that was the minus 325 fraction assayed at 0.7-1% U	1948-1949 (carnotite). 1952-1955 (Western ores). 1955-1957 (other ores)	Willigman 1949, Author unknown ca. 1987, FUSRAP 2000b, Blatz 1949

ATTACHMENT D
TYPES AND QUANTITIES OF MATERIAL PRODUCED OR USED IN BATTELLE WORK

Material	Process or operation	Content and form notes[a]	Period and amount[b]	References
Pitchblende ore	Probably same as Mallinckrodt process, including grinding; converted to UO_2	Pitchblende ore, July 1944 on, at 300 mg Ra per ton (Mason 1977); to 65% (DOE 1997, AEC 1949) or 70% (Dupree-Ellis et al. 2000) U_3O_8 by wt; to 100 mg Ra/ton (Dupree-Ellis et al. 2000); average 135 mg Ra/ton (AEC 1949); 0.185 ppm equil Ra for Q-11 (60%) ores (AEC 1949); 0.1 Ci/ton, to 70% U, avg U conc >25%, ~100 mg Ra/ton ore for 25% U (Eisenbud 1975)	1950-1951	Wesner et al. 1950, Langston, Tangel, and Richardson 1950, Mason 1977, DOE 1997, AEC 1949, Dupree-Ellis et al. 2000, Eisenbud 1975
MgX, other sludge forms	MgX concentrate (Mg uranate prepared in Africa from low-grade ore tailings) converted to UO_2. Other forms: washer slimes/slurries, low-grade sulfide concentrate	Pitchblende ore tailings, from which MgX was made, were 30-50% U_3O_8 (AEC 1951).	1950 (washer slimes). 1950-1951 (MgX). 1953 (sulfide concentrate)	Meaders et al. 1950; Ewing, Kiehl, and Bearse 1950; Ewing et al. 1950a, 1951; AEC 1951; Wheeler, Langston, and Stephens 1955; Van Kleeck, Macdonald, and Stephens 1956; Langston, Macdonald, and Stephens 1957
V-20 soda salt	Converted to UO_2	Probably sodium uranate ($Na_2U_2O_7$). 1952: Vitro soda salt assayed at 75% U_3O_8, Colorado soda salt at 60-72% U_3O_8 (Termini 1952)	1950-1951	Termini 1952
Intact fuel elements, assemblies; fuel samples	Unirradiated, irradiated, or spent fuel material: postirradiation studies, including fission gases (assayed in an in-pile loop)	Irradiated/spent fuel specimens (usually enriched), mixed fission products; when cladding/additives present, could also have substantial level of activation products. Fission progeny on one loop filter: Ba-140, Ce-141, Cs-137, Sr-89 (I already decayed)	1955-~1983	DOE 2000a
Fuel elements and dissolution products (Th, U, activation products, fission products)	Dissolution of simulated and actual spent fuel elements to test recovery processes: Sulfex, Zircex, Darex, Thorex, Zirflex, fluoride volatility, Niflex processes. Con Ed pins were dissolved one at a time, with the solids from previous dissolutions added to each new dissolution.	Co-60 was principal isotope after 10-month fuel cooling (~100% of gamma activity in eluted fraction) (Dayton and Tipton 1960a); pin core had 44 g of 95.5% ThO_2-UO_2 by weight, cladding had 25 g of Type 304 SS (Ewing, Brugger, and Sunderman 1961). But: at high burnup, Co-60 a minor contributor to total activity of decladding solutions, MFPs in same proportion as in fuel, except for Cs (Ewing, Brugger, and Sunderman 1961).	1957-1964 overall. 1955 (dissolution of Al-canned Th); 1959 (dissolution of 25 ThO_2-UO_2 Con Ed pins, each 7.4 in. long by 0.31 in. in diameter; dissolution products were returned to ORNL for analysis)	Ewing, Brugger, and Sunderman 1961, Peterson et al. 1959
Miscellaneous activated material	Material irradiated at BRR or elsewhere, studied in hot cells during and after irradiation	Typically Al, SS, Nb, Zr. Often highly activated	1955-~1983	

Material	Process or operation	Content and form notes[a]	Period and amount[b]	References
Fission plate	Used in the BRR shielding facility for fission spectrum/energy studies, etc.	Plate: 3.5 kg U-235 (as HEU), clad with ~25 mils 2S Al (Anno and Plummer 1962, Morgan et al. 1958). Ratio of thermal to epithermal neutrons at plate was 67; average gamma 2 MeV; thermal neutron/gamma flux ratio 16 (Morgan et al. 1958)	Plate was 28 in. in diameter (Morgan et al. 1958)	Morgan et al. 1958
Fission product-containing material	Used to dope catalysts to test efficacy of catalysts	Up to 65 mCi per gram of catalyst	At least 1962	Dayton and Dickerson 1962
Pm oxide	Purification of multicurie quantities of Pm-147; fabrication of diodes, RTGs	Pm-147	1964-1966 (purification). 1964-1968 (diodes). 1966-1968 (RTGs)	Ritzman et al. 1966
Np	Production of Pu from Np targets fabricated at Battelle (irrad elsewhere), Np recovery; study, preparation of U, Pu, Np microspheres as flux probes	Np-237 in microspheres as Np oxide	1960-1974 overall? 1960 (recovery, corrosion studies). 1966-1967 (microsphere work). 1974-1975 (Np recovery from irradiated targets)	FUSRAP 2000a
Cm	RTG work	Cm-244 (Cm oxides?)	1974-1978	
Cf-252 material	Cf wire ported into alpha-gamma cell, cut, weighed, put into containers. These were sealed by welding, leak-tested, washed. In second cell, welded into larger container, leak-tested, washed	Cf-252	Started in the mid-1970s	Wastren 2001, Scotti and Martin 1972
Miscellaneous radioisotopes	Studies using radiotracers or labeled compounds; hydrocarbon rad chemistry studies; study using Cr foil impregnated with fission products to study Xe-133 release, other fission product distribution; alpha cell direct-conversion generator develop	P-32, Ag-?, H-3, I-125 as labels; Nd-150, N-15 as tracers for burnup. Cr foil impregnated with 2E9 recoils/cm^2 of unspecified fission products (to see Ce-141, Ru-103, and Nb-95 distribution). Po-210 layer as cathode in alpha cell direct conversion generator	1954 (tracers for industrial process controls). 1958-1960 (P-32, Ag used for labeling). 1958-1960 (rad chemistry of hydrocarbons). 1960-1962 (tritiated cytidine for bio studies). 1962-1970 (Cr foil during small part of this period). 1963-1964 (alpha cell generator devel). 1970 (burnup study). 1976 (at least) (I-125 labeling)	Calkins and Pobereskin 1954; McFarling et al. 1962; Plummer et al. 1964
"Fissium" (faux irradiated fuel material)	Used to study dissolution, interactions of fuel materials	Radioactive content unclear: faux fission product mix, but might have had actual U content	1956	Dayton and Tipton 1956
Sealed sources				
Gamma sources	Used in nondestructive testing laboratory for radiography; used in Co-60 facility for irradiation effects research, destruction of chemical agents. Some sources stress-tested for standards development	Radiog: Co-60, Cs-137; at hot cells, 100 mCi Co-60 source in well, other large sealed Co-60 sources, 100 mCi Ra-226 source; Ir-192 (to 30 Rhm), Tm-170 (to 8 Rhm) studied at King Ave (Rhoten 1958)	All of operating period (radiog). 1961-1962 (stress eval). 1981-1982 (chemical agent destruction). Large Co-60, Ra-226 sources: instrument calibration. ~1982: Co-60 pellets put in spent fuel cask to make 10K-Ci source for calibrating high-level detectors for Three Mile Island	BMI 1977, Rhoten 1958, DeArmond 2006

ATTACHMENT D
TYPES AND QUANTITIES OF MATERIAL PRODUCED OR USED IN BATTELLE WORK

Material	Process or operation	Content and form notes[a]	Period and amount[b]	References
Beta sources	Studies of reactor coolant channel voids; U penetration into Al cladding; Po-210 alpha cell generators	Sr-90 source for uranium penetration into Al cladding (backscattering method); Ce-Pr source for alpha cell generator voltage checks	1960 (reactor coolant channel voids, U penetration into cladding); 1964 (Ce-Pr source)	Dayton and Tipton 1960b, 1961a; Plummer et al. 1964
Neutron sources	Radiographic source(s) in testing laboratory; startup source in critical assembly facility (JN-2); activation source for production of short-lived isotopes (unspecified location	Critical assembly: Po-Be source ("small") (Hogan et al. 1958, Jankowski and Chastain 1958). Activation source: 10-Ci Po-Be source (Sunderman 1962, Dayton and Tipton 1961)	All of operating period for radiography (?); 1956-1970 for the startup source; Sept 1961 on for the activation source	Hogan et al. 1958, Jankowski and Chastain 1958, Ray 1972, Dayton and Tipton 1961, Sunderman 1962
U_3O_8	Small amount present with the metal in most processes			Ferry 1943
Residue, scrap from carnotite ore processing		70-200 mg U per L of liquid residue; 0.34% U in cake residue; some scrap at 0.2% U		Blatz 1949
Wastes and remainders				
Leftover samples, specimens		Some were highly irradiated and activated		
Activated parts, mats		Activation products		DOE 2000a

a. X-ray diffraction was done on samples of many and probably most specimens. For this test, the material had to be in powdered form; therefore even larger solid specimens would have a small amount of powder associated with them, probably produced by grinding of the specimen or a specimen from the same lot. The age of forms obtained from elsewhere (e.g., metal from a refinery) is generally not available, so the material might have had significant progeny.

b. Information on quantities is not available in most cases. However, except for fuel production contracts and fuel handled in the BRR and the hot cells, the amounts handled at any given time appear to have been relatively small (laboratory or pilot-plant scale).

ATTACHMENT E
INCIDENTS REPORTED AS OCCURRING AT THE KING AVENUE AND WEST JEFFERSON SITES

Description of incident	Location	Date	Reference
When Co-60 wires were being cut and cast in the High Level Cell, the dose rates were so high that two windows cracked. (The dust level was high, so it is not clear if the dose rate was from the sources themselves or from surface dust on the windows.)	JN-1	Between 1955 and 1987	BCL 1997
A worker was preparing to expose a solution using a 5-Ci Cs-137 source. The arm of the camera (which locks the source in place when the top plug is screwed into its lowest position) was placed in backwards; this released the source and allowed it to fall out of the camera and into the solution when she opened the lower plug to create the beam. She tried to recover the source and replace in the camera using a threaded rod, but she was unable to do so after several attempts. She left the laboratory and sat in the office (where films in a drawer registered the dose rate there from the loose source) until a coworker came in from lunch. He helped replace the source in the camera. The source was later transferred from the defective camera to another camera by the assistant division chief. The first worker's film badge registered 9,600 mR; the second worker forgot to put on his film badge before attending to the source, so his dose was estimated to be 3,200 mR; the assistant chief also forgot to put on a badge, but no estimate of his dose is available. The workers were allowed to continue to work in the lab, but were restricted to non-rad work.	Building 4, Radiography Lab	8/8/1956	Selander 1956, Petersheim 1956
Minor corrosion of the heat exchanger tube bundle resulted in contamination of the primary demineralized-water system by the undemineralized secondary-system water. Activation of the dissolved salts in the pool water caused radioactive contamination of the water. The tube bundle and the primary water were replaced. No exposures noted.	BRR	Late October 1957	Anno and Plummer 1962
In studies of the thermal conductivity of U and UO_2, a leak developed in the hot cell measuring apparatus during analysis of hot uranium.	JN-1	Mar 1958	
During SRE fuel materials program postirradiation studies, for one capsule, there was a significant air leak at the capsule-punch seal, so the capsule puncturing apparatus had to be modified. No exposures noted.	JN-1	Jun 1958	Dayton and Tipton 1958
Irradiated capsule containing graphite-coated UO_2 spheres was opened with power hacksaw (at ends) and a remote milling machine (lengthwise split). "During milling, the capsule slipped in the vise, allowing the middle tool to penetrate the middle can containing the two spheres fabricated at Battelle. The halves of the capsule pulled apart, freeing the inner cans ..., invalidating the fission gas measurements." After the canister gases were sampled, the canisters were opened by slitting the sides and ends with a milling machine. The spheres were recovered along with the graphite "flour" used to fill the annulus around the spheres and neutron dosimeter wires.	JN-1	~12/1/1958	Dayton and Tipton 1959b
A worker punctured his finger with contaminated tweezers while cleaning the low-level cell. After he removed his outer clothing, he tried to clean the wound, but after several attempts, the dose rate at the wound was 0.4 mR/hr. He was taken to the emergency room at White Cross Hospital, where the doctor was not able to clean the contamination out of the wound. The surface of the skin around the wound was excised, which reduced the reading to background level. The HP accompanied him to the hospital and performed the radiation monitoring; the HP checked all surgical equipment and saw that all materials used in the decontamination were properly disposed of. (Fission products)	JN-1	2/10/1959	Selander 1959b

ATTACHMENT E
INCIDENTS REPORTED AS OCCURRING AT THE KING AVENUE AND WEST JEFFERSON SITES

Description of incident	Location	Date	Reference
A worker punctured his finger with a piece of metal containing radioactive dust, while cutting up the pan from beneath the cutoff wheel in the high-level cell at the Hot Cell Building. This operation also caused a dust cloud that highly contaminated his face and clothing. After he removed his outer clothing, the radiation reading at 6 inches in front of his face was > 5 mR/hr. After decontamination, a survey showed that he had contamination in his nose and around his eyes. Contamination in his nose was 6,000 cpm beta-gamma on a Q-Tip. Readings around his eyes were about 0.5 mR/hr. Readings at the puncture location on the back of his fourth finger, right hand, were 5 mR/hr. (Fission products)	JN-1	2/12/1959	Selander 1959a
A worker technician was overexposed (greater than 3 rem in a quarter) while removing a Weasel capsule from the reactor pool. It was shipped from Bldg 4, Room 4005, via the Battelle mail car to the BRR. It had ~1 g of alumina powder and 1.7 g of UO_2 powder packed into three quartz tubes, which in turn were in a sealed hollow aluminum container inside the Weasel capsule. The capsule was being irradiated in the pool at the end of a long wire. The technician was raising the wire when the CAM alarmed. He and a researcher left the area. Fission product activity was calculated to be 1.5 Ci at 10 s after exposure of the capsule, 0.23 Ci 2 d later. The capsule was placed in a cask. See Table 5-5 for dose rates related to this. The technician's dose to the lens of the eye was 7.75 rem (beta plus gamma); to the gonads, 13.55 rem; to the extremities, "within tolerance limits," and the whole-body dose, 13.2 rem gamma. (Probably the same incident as the entry immediately above.)	BRR	8/9/1961	Chastain 1961
A worker got a hand overexposure in cleaning highly contaminated equipment in a hot cell. He did not wear leaded gloves during many parts of the operation because they were too cumbersome and he thought he would not go over the limit.	JN-1	1Q62	Saling 1962
A worker opened each of four small lead containers, removed the X-ray diffraction mounts from the lead plugs, and placed each mount on a length of angle iron. A second worker pushed the angle iron with the mount through a port into the hot cell, removed the mount, and extracted the angle iron for the next mount. After all four mounts had been transferred into the cell, the first worker discovered that he was contaminated. The insides of both his lead gloves were contaminated, indicating that the contamination was on the outside of the lead containers because these had been handled with bare hands and all the work after the small containers were opened were done with the lead gloves on. The second worker checked himself and found that he too was contaminated; some contamination appeared to be inside his nose.	JN-1	11/14/1963	Saling 1963
A technician was overexposed (greater than 3 rem in a quarter). The overexposure was discovered when the film badge reports came back from Landauer. The cause was said to be the failure of a supervisor to keep proper track of radiation exposure.	JN-1	1Q64	Saling 1964
A worker's film badge for March 14-27, 1966, read 1,800 mrem. This was thought to have resulted from maintenance work in the stall area of the reactor pool on March 19. Although the dose rate in that general area, where he spent 5 minutes, was 2.5 R/hr before the reactor flanges were removed, the radiation level immediately in front of the beam tube was 10-20 times higher and he might have passed close to the tube. The worker also handled a beam tube plug reading 10 R/hr for about half a minute. His pocket dosimeter had been dropped before this and had been thought to be in working order, but on March 21 it was discovered to be malfunctioning, so it did not register the exposure.	BRR	3/19/1966	

ATTACHMENT E
INCIDENTS REPORTED AS OCCURRING AT THE KING AVENUE AND WEST JEFFERSON SITES
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Description of incident	Location	Date	Reference
An unspecified spill occurred in the plutonium laboratory. During the cleanup, coveralls, rubber gloves, booties, paper suits, masks, and both body and ring film badges were worn. Nevertheless, one worker's badges were contaminated and his dose had to be estimated from past experience.	JN-4	9/9/1968	Ottman 1968
A worker exceeded 3 rem for 2Q73 by the 6/3/1973 film badge report. The exposure was primarily associated with control area and cell entries that involved cask unloading operations and experiment setups. (Typical of various such reports from 1960 on.)	JN-1	2Q73	Lowry and Kirsch 1973
Over many years, about 55 gal annually of hydraulic fluid leaked from the glands/ seals of the rams onto the Hydraulic Door Room floor to a depth of ~5 in. The fluid was pumped out and the seal gaskets were replaced in about 1974, but the leakage continued. At one time, the walls of the room were sandblasted and some sand was left in the room, so it was suspected that the rams were scarred and that was why leakage continued even after the seal gasket replacement. Washwater from many CAA cleanings was also thought to have drained into the opening between the door and the CAA floor, adding 1-3 in. of washwater. There was also an opening between the door and the floor of the cell interior. Fuel/cladding dust and fragments, etc., and even small items fell through the opening between the door and the HLC, producing a layer of sludge.	JN-1	Before 1974	Myers and Berchtold 1994a
A worker was exposed to Pu-239 via inhalation. Urine samples collected during the first week after exposure indicated excretion rates from 0.09 to 0.21 dpm/24 hr. Urine samples collected during the fifth and sixth weeks after exposure indicated excretion rates below 0.03 dpm/24 hr. A sample collected July 20-21 with an unusually high 4,000 mL of urine showed a rate of 0.25 ±0.11 dpm/24 hr; however, this was considered a dubious result because of the volume. Urine, fecal, and whole-body counting data are also available for September-October 1974 for this worker, who was involved in another unspecified potential intake incident during the week of September 9-13, 1974. Fecal samples indicated that the lung burden of Pu-239 was unlikely to be more than a few percent of the MPBB. Two other workers exposed in the same incident showed some positive Pu-239 results, but the urine and feces indicated an even lower intake for them, likely less than 1-2% of the MPBB.	JN-4	5/9/1974	Geiger 1974
A worker was exposed to an average airborne concentration of 1.0E-11 µCi/mL of Pu-239, 7.17E-10 µCi/mL of Sr-90, and 7.37E-12 µCi/mL of U-238 while engaged in operations associated with transfer operations in the control area.	JN-1	9/9-13/74	Kirsch 1974a
One worker was exposed to an airborne concentration of 3.60E-10 µCi/mL of soluble Pu-239 and 4.31E-10 µCi/mL of soluble Sr-90 for a 90-min period while engaged in transferring waste containers from the low-level cell to a shipping hopper in the control area at the Hot Lab Facility. Data were obtained from a lapel BZ sample. This was a planned operation: airborne contamination was anticipated and the worker was wearing protective apparel, including a full-face respirator. The respirator smears were taken immediately and the results indicated that contamination did not enter the respirator. Urine and fecal samples were also negative. It was concluded that the worker "did not inhale any of the contaminant."	JN-1	Week of 10/27/75-11/2/75	Toy 1975

ATTACHMENT E
INCIDENTS REPORTED AS OCCURRING AT THE KING AVENUE AND WEST JEFFERSON SITES

Description of incident	Location	Date	Reference
Two electricians were tearing out electrical wiring connected to the ducting in the old part of the building. One apparently thought that airborne levels were high, so they both took nose swabs. The swabs were negative, but the second worker's lapel air filter read positive (80 dpm of mostly Pu-239, 0.13% soluble). His gloves had been found to be contaminated and had been changed several times during the work, but his coveralls read clean. He submitted 24-hour urine and fecal specimens over the next 2 days and a smear survey of his work area was done.	JN-4	2/25/1977	Hicks 1977; Langendorfer 1977; BCL 1977b (air sample report), 1977c (smear survey report); Farmelo and Helwagen 1977 (lapel sampler report)
Core samples taken around the holding tanks and autoclave during the 1978-1982 decontamination showed that contamination had occurred "sometime during the 16-year use."	JN-4	Between 1960 and 1977	Rudolph, Kirsch, and Toy 1984
Several minor spills occurred in the Plutonium Laboratory.	JN-4	Between 1960 and 1977	Rudolph, Kirsch, and Toy 1984
At the end of the working day on February 25, 1977, it was found that during the removal of electrical wiring from the Old Laboratory area, the lapel sampler filter of a technician exceeded the 40-hr MPC for soluble Pu-239, 2.0E-12 µCi/mL. The concentration of February 25 was calculated at 3.51E-12 µCi/mL; after a 64-hr decay it showed 2.84E-12. The technician was removed from laboratory activities and placed on a bioassay program. His nasal swabs indicated no activity. A smear survey of the areas in which he had been working indicated activity; it was cleaned up.	JN-4	2/25/1977	Langendorfer 1977, Farmelo and Helwagen 1977, Hicks 1977, BCL 1977a,b
A release took place during a manipulator removal operation. The highest measurable contamination was 138 dpm/100 cm^2 beta-gamma; no airborne contamination was detected.	JN-1	4/7/1977	Peters and Harrison 1998
A worker was repairing a contaminated transient tube burst apparatus, wearing what was later found to be a contaminated lead apron. The alpha air concentration inferred from his lapel air sampler was found to be 10% percent greater than the 40-hr control guide for soluble Pu-239 (the soluble control guide was applied until a solubility analysis was done). Subsequent analyses of the air filter showed that the material was insoluble Pu-239, giving a concentration of 5.5% of the insoluble Pu-239 control guide . Nasal swabs results were negative, as were bioassays for Pu, U, and Sr-90 in the urine and feces. Gamma isotopic analyses were also performed on the bioassay specimens.	JN-1	3/16/1978	Kirsch 1978a (includes most of the bioassay data)
A worker entered the Pu-238 laboratory with two other workers; they wore lapel samplers but he did not because he intended to stay only a minute or two. However, he became involved in moving gloveboxes (#33 and #44) with them over a 2-hr work period. His involvement became known only several days later. Because of the elevated readings from the lapel samplers, urine and fecal specimens were collected from him starting October 26. Because of the delay, the readings were essentially negative and he was assigned the same dose as that to another of the workers, 196 mrem as the 50-yr accumulated lung dose.	JN-4	10/17/1978	Kirsch 1978b

ATTACHMENT E
INCIDENTS REPORTED AS OCCURRING AT THE KING AVENUE AND WEST JEFFERSON SITES
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Description of incident	Location	Date	Reference
A routine count of a nasal swab for a worker after a control area entry prompted follow-up bioassay sampling. Counts for both a follow-up nasal swab and a smear of the worker's respirator interior were negative. Fecal samples were collected 1, 2, and 3 days later to assess the early clearance phase; a urine sample was collected. Results for all samples were negative for Pu, Am, and fission products, while the feces also showed normal concentrations of uranium. It was concluded that an inhalation intake had not occurred and that the original nasal swab probably was contaminated by contact with a contaminated surface in the hot change room.	JN-1	11/9/1978	Kirsch 1978c (includes most bioassay data)
The Hot Lab received an empty NAC shipping cask under the HEDL program. Workers were not aware that the cask was pressurized when the lid was removed in the JN-1N High Bay area in preparation for loading an HEDL fuel element. Airborne radioactivity was released. Workers involved in the cask operation were wearing respiratory equipment, but another worker not involved but in the area was not. All workers evacuated immediately. There were no CAM alarms. The immediate surrounding area was contaminated by airborne radioactive debris. Bioassay data was normal for the worker not wearing a respirator. Calculations indicated that DOE and NRC airborne concentration guides were not exceeded; concentrations measured in the area were an alpha max of 3.14E-14 µCi/mL and a beta-gamma max of 1.36E-11 µCi/mL. The floor was contaminated to 5-10 dpm/100 cm^2 alpha and 153,000 dpm/100 cm^2 beta-gamma; equipment surfaces were contaminated to <5 dpm/100 cm^2 alpha and 42.3K dpm/100 cm^2 beta-gamma. [Timeline given in Author unknown 1979; air sampling results in BCL 1979]	JN-1	1/16/1979	Author unknown 1979, BCL 1979 (a timeline is given in Author unknown 1979, air sampling results in BCL 1979), Peters and Harrison 1998, Ray 1990
A depleted uranium fire occurred in an autoclave in Building JS-1, where military fuel was fabricated. The fire was brought under control and moved to another part of the building where a controlled burn continued until it self-extinguished. Then removable contamination was cleaned up. Personnel were not exposed to airborne contaminations above [NRC?] guidelines.	JS-1	9/22/1979	Smith et al. 1988, Peters and Harrison 1998, Ray 1990
In the Hot Cell Facility (JN-1), during unloading operations of a failed spent fuel assembly from the Connecticut Yankee Atomic Power Company, there was a release of airborne radioactivity and subsequent surface contamination from what one source described as an explosion when unloading a “superheated” fuel element. Exposure was said to be for from one to several minutes. At least one worker was not wearing a respirator. This was reported to NRC. Bioassay procedures, including *in vivo* counting, showed that exposures were below 10 CFR 20 limits and that pulmonary depositions were <1% of the permissible body burden. [Probably same incident as entry below]	JN-1	5/2/1980 or 5/3/1980	Jensen 2003, DOE 2003a, Ray 1990, Kirsch 1987
In a second NAC cask incident, a cask was opened above the storage pool, which resulted in the release of widespread radioactive contamination within the high bay area up to the ceiling. There was no release from the building; personnel exposures were well below 10 CFR 20 limits. The cleanup and disposal of radioactive waste were completed.	JN-1	5/2/1980	Peters and Harrison 1998, Pasupathi and Toy 1990, Kirsch 2000b

ATTACHMENT E
INCIDENTS REPORTED AS OCCURRING AT THE KING AVENUE AND WEST JEFFERSON SITES

Description of incident	Location	Date	Reference
A worker received a hand dose of 22.48 rem in 2Q80. Of this, 20.560 rem were received during an operation that involved the collection of scrapings from the interior wall of a spent fuel cask. The personnel monitoring device was a finger ring TLD. The operation involved two tasks: the collection of the sample and the manipulation of a plastic shroud attached between the cask lid and the cask as the lid was lowered onto the top of the cask. The shroud was used to minimize the migration of airborne particulate radioactive material from the cask interior. A small opening was made in the shroud and a scoop attached to a 3-ft rod was inserted through the opening to collect the sample. The sample was then removed and transferred to a container held by the employee in the right hand. There was a deviation [unspecified] in how this was done from how it was planned to be done. [Apparently it was flashed, unknown to HP.]	JN-1	7/2/1980	Toy 1981
A worker was cut in an unspecified fashion. The wound was smeared at the exit from the contaminated area and again several times after decontamination of the wound; all smears were negative. The Battelle wound monitor (detector) was also used to check the cut, again with negative results. It was concluded that no uptake had likely occurred. (Fission products)	JN-1	3/17/1981	BCL 1981a
A fire that resulted in $100,000 of damage occurred at Building 7. It is not clear if any radioactive material was involved.	Building 7	7/15/1982	ORAUT 2006a
A worker was burned in an unspecified fashion at Building 10 [sic]. The material was depleted uranium. Special urine monitoring was done every 2 weeks (see undated entry below) in May 1984 due to what was said to be a potential inhalation in Building 2 and that could be related to this burn incident. (Note that Building 10 was not found to be contaminated in characterization surveys (e.g., Jensen 2003) and was not listed in any document as being the site of radioactive work. Because Building 10 adjoined Building 5, it is likely that the incident actually occurred in Building 5.)	"Building 10"	27 Feb 1984	BCL 1984 (includes wound survey results); dosimetry records
A worker was subject to special biweekly urine monitoring in May 1984 due to a potential inhalation of uranium in Building 2. At this time, it was recommended that he discontinue rad work. When he was found still to be excreting low levels of uranium in October 1984, it was recommended that filtered exhaust ventilation be used if he were needed to perform work rolling uranium or the like.	Building 2	May 1984	McKown 1984a,b; dosimetry records
Co-60 wires were cut and cast into slugs in the High Level Cell, creating radioactive Co-60 dust. The radiation levels in the cell were so high that two windows cracked.	JN-1	Not stated	Sunderman and Gates 1965
Air currents from a heating fan in the ceiling of the HEC fuel pool (high bay) disturbed the surface currents in the Washdown Room and caused a release into the pool area.	JN-1	Not stated	Myers et al. 1994b

ATTACHMENT F
RADIONUCLIDES AND CHEMICAL FORMS BY BUILDING

Bldg	Compound or alloy[a]	Large amounts handled?	RN[b]
A	U metal	Yes	U, daughters
	U alloys	Yes	U, daughters
	U_3O_8	Yes	U, daughters
	UO_3 (part of production support R&D from UNH)		U, daughters
	UO_2 (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	UNH		U, daughters
	$UO_2CO_3 \cdot 2(NH_4)2CO_3$ (uranyl ammonium carbonate)		U, daughters
	$U_2O_7(NH_4)_2$ (ammonium diuranate)		U, daughters
	$U_2O_7Na_2$ (soda salt)	Yes	U, daughters
	U beryllides		U, daughters
	U borides		U, daughters
	U carbides, mainly UC (natural; enriched 9-93%)	Yes	NU/EU, daughters
	UCl (enriched)		EU, daughters
	UF_4		U, daughters
	U fluorides (except UF_4) (salt solution)		U, daughters
	U hydrosulfides (salt solution)		U, daughters
	U nitrides, mainly UN (natural; depleted; enriched 5-93%)	Yes	U, daughters
	U phosphates (salt solution)	Yes	U, daughters
	U silicides		U, daughters
	U sulfates (salt solution)		U, daughters
	U sulfides		U, daughters
	Th metal (including casting by vacuum induction)	Yes	Th, daughters
	Th alloys (except with U)	Yes	Th, daughters
	$Th(NO_3)_4$	Yes	Th, daughters
	Th phosphate	Yes	Th, daughters
	Tracers in cement		Ba-140, La-140
	Tracers in cement		Y-91
	Tracers in cement: tagged $Ag*IO_3$		Ag-110
1	U metal	Yes	U, daughters
	U alloys	Yes	U, daughters
	U_3O_8	Yes	U, daughters
	UO_3 (part of production support R&D from UNH)		U, daughters
	UO_2 (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	UNH		U, daughters
	$UO_2CO_3 \cdot 2(NH_4)2CO_3$ (uranyl ammonium carbonate)	Yes	U, daughters
	$U_2O_7(NH_4)_2$ (ammonium diuranate)		U, daughters
	$U_2O_7Na_2$ (soda salt)	Yes	U, daughters
	U beryllides		U, daughters
	U borides		U, daughters
	U carbides, mainly UC (natural; enriched 9-93%)	Yes	NU/EU, daughters
	UF_4		U, daughters
	U fluorides (except UF_4) (salt solution)		U, daughters
	U hydrosulfides (salt solution)		U, daughters
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	U phosphates (salt solution)		U, daughters
	U silicides		U, daughters
	U sulfates (salt solution)		U, daughters
	U sulfides		U, daughters
	Th metal (including casting by vacuum melting)	Yes	Th, daughters
	Th alloys (except with U)	Yes	Th, daughters
	Th carbides		Th, daughters
	Th fluorides		Th, daughters
	Th halide		Th, daughters
	Th iodide (used to make Th-U alloy)	Yes	Th, daughters

ATTACHMENT F
RADIONUCLIDES AND CHEMICAL FORMS BY BUILDING

Bldg	Compound or alloy[a]	Large amounts handled?	RN[b]
	ThN	Yes	Th, daughters
	$Th(NO_3)_4$	Yes	Th, daughters
	Th phosphate	Yes	Th, daughters
	Th-U alloys (5, 10, 15, 20 weight percent U)	Yes	Th, some U, daughters
	Th-U carbides (casting by arc melting)		Th, some U, daughters
	Tracers in cement		P-32
	Tracers in cement		Ba-140, La-140
	Tracers in cement		Y-91
	Tracers in cement: tagged $Ag*IO_3$		Ag-110
2	U metal	Yes	U, daughters
	U alloys	Yes	U, daughters
	U_3O_8 (depleted; natural; enriched, including HEU)	Yes	DU/NU/EU, daughters
	UO_3 (part of production support R&D from UNH)		U, daughters
	UO_2 (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	UNH		U, daughters
	$UO_2CO_3 \cdot 2(NH_4)2CO_3$ (uranyl ammonium carbonate)	Yes	U, daughters
	$U_2O_7(NH_4)_2$ (ammonium diuranate)		U, daughters
	$U_2O_7Na_2$ (soda salt)	Yes	U, daughters
	U beryllides		U, daughters
	U borides		U, daughters
	U carbides, mainly UC (natural; enriched 9-93%)	Yes	NU/EU, daughters
	UCl (enriched)		U, daughters
	UF_4		U, daughters
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	U silicides		U, daughters
	U sulfides		U, daughters
	Th metal	Yes	Th, daughters
	Th alloys (except with U)	Yes	Th, daughters
	ThO_2 alloys (except with U)	Yes	Th, daughters
	Th carbides		Th, daughters
	Th fluorides		Th, daughters
	Th halide		Th, daughters
	Th iodide (used to make Th-U alloy)	Yes	Th, daughters
	ThN	Yes	Th, daughters
	Th phosphate	Yes	Th, daughters
	Th-U alloys (5, 10, 15, 20 weight percent U)	Yes	Th, minor U, daughters
	Th-U carbides (casting by arc melting)	Yes	Th, some U, daughters
	Fissium ("synthetic fissium alloy") (unirrad'd U)		EU, daughters
3	U metal	Yes	U, daughters
	U alloys	Yes	U, daughters
	U_3O_8 (depleted; natural; enriched, including HEU)	Yes	DU/NU/EU, daughters
	UO_3 (part of production support R&D from UNH)		U, daughters
	UO_2 (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	UNH		U, daughters
	U beryllides		U, daughters
	U borides		U, daughters
	U carbides, mainly UC (natural; enriched 9-93%)	Yes	NU/EU, daughters
	UCl (enriched)		U, daughters
	UF_4		U, daughters
	U hydrides	Yes	U, daughters
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	U silicides		U, daughters
	U sulfides		U, daughters
	Th metal	Yes	Th, daughters
	Th alloys (except with U)	Yes	Th, daughters
	ThO_2 alloys (except with U)		Th, daughters

ATTACHMENT F
RADIONUCLIDES AND CHEMICAL FORMS BY BUILDING

Bldg	Compound or alloy[a]	Large amounts handled?	RN[b]
	Th carbides		Th, daughters
	Th fluorides		Th, daughters
	Th halide		Th, daughters
	Th iodide (used to make Th-U alloy)	Yes	Th, daughters
	ThN	Yes	Th, daughters
	Th phosphate	Yes	Th, daughters
	Th-U alloys (5, 10, 15, 20 weight percent U)	Yes	Th, minor U, daughters
	Th-U carbides (casting by arc melting)	Yes	Th, some U, daughters
	Fissium ("synthetic fissium alloy") (unirrad'd U)		EU, daughters
4	U metal		U, daughters
	U alloys (natural; enriched 10%)		NU/EU, daughters
	U_3O_8 (depleted; natural; enriched, including HEU)		DU/NU/EU, daughters
	UO_3 (part of production support R&D from UNH)		U, daughters
	UO_2 depleted; (natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	U fuel specimens, irradiated (usually EU, probably usually UO_2)	Yes	NU/EU, daughters, some MFP
	UNH		U, daughters
	$U_2O_7(NH_4)_2$ (ammonium diuranate)		U, daughters
	U beryllides		U, daughters
	U borides		U, daughters
	U carbides, mainly UC (natural; enriched 9-93%)	Yes	NU/EU, daughters
	UCl (enriched)		EU, daughters
	UF_4		U, daughters
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	U silicides		U, daughters
	U sulfides		U, daughters
	Gaseous fission product, daughter counting		Kr, Xe, I, daughters
	Th metal		Th, daughters
	Th alloys (except with U)		Th, daughters
	ThO_2 alloys (except with U)		Th, daughters
	Th carbides		Th, daughters
	Th fluorides		Th, daughters
	Th halide		Th, daughters
	Th iodide (used to make Th-U alloy)		Th, daughters
	ThN		Th, daughters
	$Th(NO_3)_4$		Th, daughters
	Th phosphate		Th, daughters
	Th-U alloys (5, 10, 15, 20 weight percent U)		Th, minor U, daughters
	Th-U carbides (casting by arc melting)		Th, some U, daughters
	Fissium ("synthetic fissium alloy") (unirrad'd U)		DU, daughters
5	U metal	Yes	U, daughters
	U alloys (natural; enriched 10%)	Yes	NU/EU, daughters
	UO_2 (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	U fuel, irradiated (usually EU, probably usually UO_2)	Yes	NU/EU, daughters, some MFP
	U beryllides		U, daughters
	U borides		U, daughters
	U carbides, mainly UC (natural; enriched 9-93%)	Yes	NU/EU, daughters
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, daughters
	U silicides		U, daughters
	U sulfides		U, daughters
	Th metal	Yes	Th, daughters
	Th alloys (except with U)	Yes	Th, daughters
	ThO_2 alloys (except with U)	Yes	Th, daughters
	Th carbides	Yes	Th, daughters
	Th fluorides		Th, daughters
	Th halide		Th, daughters
	Th iodide (used to make Th-U alloy)		Th, daughters
	ThN	Yes	Th, daughters

ATTACHMENT F
RADIONUCLIDES AND CHEMICAL FORMS BY BUILDING
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Bldg	Compound or alloy[a]	Large amounts handled?	RN[b]
	Th phosphate		Th, daughters
	Th-U alloys (5, 10, 15, 20 weight percent U)	Yes	Th, minor U, daughters
	Th-U carbides (casting by arc melting)	Yes	Th, some U, daughters
6, 7	U metal	Yes	U, daughters
	U alloys (natural; enriched 10%)	Yes	NU/EU, daughters
	U_3O_8 (depleted; natural; enriched, including HEU)		DU/NU/EU, daughters
	UO_3 (part of production support R&D from UNH)		U, daughters
	UO_2 (enriched, mostly at 93%)	Yes	EU, daughters
	UO_2 particles, irradiated (enriched?)	Yes	EU; MFP
	$U_2O_7(NH_4)_2$ (ammonium diuranate)		U, daughters
	U beryllides		U, daughters
	U borides		U, daughters
	U carbides, mainly UC (natural; enriched 9-93%)		NU/EU, daughters
	UCl (enriched)		EU, daughters
	UF_4 (probably only Building 7)	Yes	U, daughters
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)		DU/NU/EU, daughters
	U silicides		U, daughters
	U sulfides		U, daughters
	Th metal	Yes	Th, daughters
	Th alloys (except with U)	Yes	Th, daughters
	ThO_2 alloys (except with U)	Yes	Th, daughters
	Th carbides		Th, daughters
	Th fluorides	Yes	Th, daughters
	Th halide		Th, daughters
	Th iodide (used to make Th-U alloy)		Th, daughters
	ThN	Yes	Th, daughters
	$Th(NO_3)_4$		Th, daughters
	Th phosphate		Th, daughters
	Th-U alloys (5, 10, 15, 20 weight percent U)	Yes	Th, minor U, daughters
	Th-U carbides (casting by arc melting)		Th, some U, daughters
	Spent fuel in solid or liquid form (recovery studies; mostly unirradiated)	Yes	U, Th; MFP[6], AP
	Pu alloys, UN-PuN (Building 6 only)	Yes	Pu-239, HEU
	Pu recovery from U spent fuel	Yes	Pu-239, HEU
	PuO_2 volatility (very limited benchtop study)		Pu-239
	Fissium ("synthetic fissium alloy") (unirrad'd U)		
	Tracers: CePr (rare-earth study)	Yes	Probably Ce/Pr-144
	Radiotracer study of activation (Mg sulfate solution)		Fe-59, Mn-54
	Radiotracer study of activation (Fe56(n,p)Mn56)		Mn-56
	Tracers in cement		P-32
	Tracers in cement		Ba-140, La-140
	Tracers in cement		Y-91
	Tracers in cement: tagged Ag^*IO_3		Ag-110
	Triated cytidine, trace levels in biological studies		H-3
	Unspecified labeling (Building 7)		I-125
9	U, form unknown (depleted; natural)		DU/NU, daughters
	Th, form unknown (minor amounts found in D&D)		Th, daughters
	Krypton gas studies (lab-level amounts)		Kr-85
West Jefferson site			
JN-1	U metal (natural; enriched)	Yes	NU/EU, MFP
	U alloys (natural; enriched 10%)	Yes	NU/EU, MFP
	U_3O_8 (depleted; natural; enriched, including HEU)		DU/NU/EU, MFP
	UO_2 (enriched 25-93%, mostly at 93%)	Yes	EU, MFP
	UO_2 (one specific project)	Yes	U; MFP up to 6 mCi/g
	U carbides, mainly UC (natural; enriched 10-93%)	Yes	NU/EU, MFP
	U hydrides		U, MFP
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)	Yes	U, MFP
	U silicides		U, MFP

ATTACHMENT F
RADIONUCLIDES AND CHEMICAL FORMS BY BUILDING

Bldg	Compound or alloy[a]	Large amounts handled?	RN[b]
	U sulfides		U, MFP
	Spent U fuel in solid or liquid form in recovery studies	Yes	U; MFP, AP
	U-Th alloys	Yes	Th, U, MFP, Cs-137
	Spent U-Th fuel in solid or liquid form in recovery studies	Yes	U, Th; MFP, AP
	Al, Nb, Zr, SS as cladding, matrix, or alloy component	Yes	AP, incidental MFP
	Miscellaneous spent fuel forms	Yes	U, MFP
	PuO_2, UO_2-PuO_2		Pu-239, U, MFP
	UN-PuN		Pu-239, U, MFP
	Pu, Np recovery from Np rods irradiated in commercial reactor		Np, Pu-238, MFP
	Pm oxide (RTG work)		Pm-147
	Cf-252 wire	Yes	Cf-252
	Co-60 research (probably as the metal and/or in activation materials)	Yes	Co-60
JN-2	U metal foil (depleted; natural) (used in zero power experiments)	Yes	DU/NU, MFP
	UO_2 (2-93% enrichment) (used in zero power experiments)	Yes	EUO2, MFP
JN-2	Pu source study (encapsulated form only, probably as PuO_2)	Yes	Pu-239
JN-3	U metal (natural)	Yes	U, MFP, AP
	U alloys (natural; enriched 10%)	Yes	NU/EU, MFP, AP
	UO_2 (natural; enriched 25-93%)	Yes	NU/EU, MFP, AP
	U carbides, mainly UC (natural; enriched 10-93%)	Yes	NU/EU, MFP, AP
	U nitrides, mainly UN (depleted; natural; enriched 5-93%)	Yes	DU/NU/EU, MFP, AP
	Encapsulated U fuel (probably enriched; in in-pile gas loop facility)	Yes	Fission gases
	Nonfuel reactor structural and associated components (radiation effects studies)	Yes	AP (steel, Al, etc.)
	Th-U alloys		U, Th, MFP
	PuO_2 (encapsulated form only)		Pu, U, MFP
	PuN, UN-PuN (all encapsulated form only; probably all U was enriched)		Pu, EU, MFP
	Pm oxide (encapsulated only, as irradiation test of RTG)		Pm-147
JN-4	Pu metal (e.g., >20 kg of Pu metal fabricated into various shapes for classified work)	Yes	Mostly Pu-239
	PuO_2 (e.g., 1 kg of UO2-PuO2 fabricated into fuel pellets)	Yes	Mostly Pu-239
	PuO_2 (~4 kg of PuO_2 made into pellets, sintered, welded into capsules for use as heat sources)	Yes	80% Pu-238; probably 16% Pu-239, 1.2 ppm Pu-236
	PuO_3		Mostly Pu-239
	Pu hydride (mostly formed as intermediate product, but some scrap formed)		Pu-239
	PuN, PuUN (e.g., ~20 kg of Pu metal powder processed into fuel pins: Pu or U crushed, hydrated, nitrated, and reducing to nitride; PuN/UN pressed into pellets, loaded into fuel pins)	Yes	90% w/o Pu-239; 93% w/o U-235
	U-Pu alloys (probably enriched U)	Yes	Pu-239, EU, daughters
	Th-Pu alloys		Pu-239, Th, daughters
	Pu reprocessing study : Pu as 1 kg of Pu nitrate solution	Yes	Pu-239, Pu-238
	Pm oxide	Yes	Pm-147
	Np microsphere preparation	Yes	Np
	>1 kg of NpO_2 fabricated into NpO_2-ZrO_2 and NpO_2-CaO-ZrO_2 target rods	Yes	Np
JS-1	DU, NU, EU (assumed as UO_2)	Yes	DU/NU/EU daughters
	Th (assume as ThO_2)		Th, daughters
JS-10	DU, EU (assume as UO_2)	Yes	DU/EU
JS-12	DU, EU (assume as UO_2)		DU/EU

a. The U form was probably natural U when not specified; enriched U appears not to have been used before 1954. Sometimes only the final form was indicated by the relevant reference; thus, the possibility of a different initial or intermediate form than listed above must be kept in mind.

b. MFP: mixed fission products; FP: fission products; AP: activation products (for the materials in question).

ATTACHMENT G
PHOTON AND ELECTRON ENERGY RANGES

Bldg[a]	Description[b]	Operations		Photon		Electron		Reference	Location in Ref
		Begin	End	Energy, keV	%	Energy, keV	%		
A	Metallurgical R&D on U, including alloying[c]	1943	[1962]	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
A	R&D, fabrication of nat/depl U as pellets, powder, or plates	1950	1971	30-250	100	>15	100	ORAUT 2006b	p. 23
A	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	30-250	100	>15	100	ORAUT 2006b	p. 23
A	Extracting U from phosphates, slimes, slurries (except 1951)	1946	1954	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
A	Extracting U from carnotite ores	1947	1949	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
A	Extracting U from Western ores	1952	1955	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
A	Extracting U by ammonium carbonate leaching	1955	1957	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
A	Converting pitchblende to UO_2	1950	1951	30-250 >250	50 50	>15	100	ORAUT 2004	Table 6-9
A	Refining MgX (concentrate), V-20 soda salt to UO_2	1950	1951	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
A	Process support for U metal production (including casting)	1953	1959	30-250 >250	70 30	>15	100	ORAUT 2006b	p. 23
A	Metallurgical R&D on Th, including alloying	1944	1961	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
A	Extracting Th from monazite sands, etc. (except 1953)	1949	1955	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
A	Radiotracer work - industrial (certain labs) (e.g., P-32, Ba-140, La-140, Y-91, and Ca-45 in cement; Fe-59, Mn-54 in industrial control; tagged AgIO)	1953	1960	30-250	100	>15	100		
1	Rolling, machining, fabrication of U metal, other forms	1943	1980	30-250	100	>15	100	ORAUT 2009b; 2006b	p. 37; 23
1	Casting and other heating and melting operations on U metal	1943; 1979	1962; 1979	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
1	Metallurgical R&D on U, including alloying	1943	[1962]	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
1	Extracting U from phosphates, slimes, slurries (except 1951)	1946	1954	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
1	Extracting U from carnotite ores	1947	1949	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
1	Extracting U from Western ores	1952	1955	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
1	Extracting U by ammonium carbonate leaching	1955	1957	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
1	Refining MgX (concentrate), V-20 soda salt to UO_2	1950	1951	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
1	Process support for U metal production (including casting)	1953	1959	30-250 >250	70 30	>15	100	ORAUT 2006b	p. 23
1	Rolling, machining, casting, fabrication of Th metal, other forms	1944	1980	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
1	Metallurgical R&D, including alloying Th	1944	1961	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
1	Radiotracer work - industrial (certain labs) (e.g., P-32, Ba-140, La-140, Y-91, and Ca-45 in cement; Fe-59, Mn-54 in industrial control; tagged AgIO)	1953	1960	30-250	100	>15	100		
2	Rolling, machining, fabrication of U metal, other forms	1950	1980	30-250	100	>15	100	ORAUT 2009a, 2009b	p. 23; 37
2	Casting and other heating and melting operations on U	1950	1980	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10

ATTACHMENT G
PHOTON AND ELECTRON ENERGY RANGES

Bldg[a]	Description[b]	Operations		Photon		Electron		Reference	Location in Ref
		Begin	End	Energy, keV	%	Energy, keV	%		
2	Metallurgical R&D on U, including alloying	1950	[1962]	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
2	Metallurgical R&D on U, including alloying	1979	1979	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
2	R&D, fabrication of nat/depl U as pellets, powder, or plates	1950	1971	30-250	100	>15	100	ORAUT 2006b	p. 23
2	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	30-250	100	>15	100	ORAUT 2006b	p. 23
2	Extracting U from phosphates, slimes, slurries (except 1951)	1950	1954	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
2	Extracting U from Western ores	1952	1955	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
2	Extracting U by ammonium carbonate leaching	1955	1957	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
2	Refining MgX (concentrate), V-20 soda salt to UO_2	1950	1951	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
2	Process support for U metal production	1953	1959	30-250 >250	70 30	>15	100	ORAUT 2006b	p. 23
2	Rolling, machining, casting, fabrication of Th metal, other forms	1950	1980	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
2	Metallurgical R&D on Th, including alloying	1950	1961	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
2	Metallurgical R&D on Th, including alloying	1971	1972	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
2	Preparing Th in Th iodide process	1951	1954	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
2	R&D on Th-U alloys	1960	1965	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
3	Metallurgical R&D on U, including alloying	1950	[1962]	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
3	Metallurgical R&D on U, including alloying	1979	1979	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
3	Production of U forms for other facilities, including melting and powder formation	1954	1975	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
3	R&D, fabrication of nat/depl U as pellets, powder, or plates	1950	1971	30-250	100	>15	100	ORAUT 2006b	p. 23
3	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	30-250	100	>15	100	ORAUT 2006b	p. 23
3	Calcining of U samples and waste for recovery	1954	1975?	30-250 >250	70 30	>15	100	ORAUT 2006b	p. 23
3	R&D on Th-U alloys	1960	1965	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
3	Storage and dispensing of SNM, incl EU and Th[d,e]	1950	1975	30-250	100	>15	100	ORAUT 2009b; 2006b	p. 37; 23
4	R&D, fabrication with enriched UO_2 in pellet, powder, and plate forms (not the Radioisotope Lab)	1954	1962	30-250	100	>15	100	ORAUT 2006b	p. 23
4	High-level radiochemistry (mostly fission products)	1953	1975	30-250 >250	75 25	>15	100		
4	Low-level radiochemistry (mostly fission products)	1953	1975	30-250 >250	75 25	>15	100		
4	Gaseous fission product counting, radiochemistry[f]	1956	1966	30-250	100	>15	100		
4	Radiotracer work - industrial	1953	1960	30-250	100	>15	100		
4	Radiography of material samples (Cs-137, Co-60)	1953	1975	30-250 >250	25 75	>15	100	ORAUT 2004	Table 6-9
4	Activation using Po-Be source	1953?	1975	30-250 >250	25 75	>15	100	ORAUT 2004	Table 6-9

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PHOTON AND ELECTRON ENERGY RANGES
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Bldg[a]	Description[b]	Operations		Photon		Electron		Reference	Location in Ref
		Begin	End	Energy, keV	%	Energy, keV	%		
5	Rolling, machining, fabrication of U metal, other forms	1953	1980[b]	30-250	70	>15	100	ORAUT 2009b; 2006b	p. 37; 23
5	Casting and other heating and melting operations on U	1953	1980[b]	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
5	R&D, fabrication of nat/depl U as pellets, powder, or plates	1953	1971	30-250	100	>15	100	ORAUT 2006b	p. 23
5	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	30-250	100	>15	100	ORAUT 2006b	p. 23
5	Process support for U metal production (including casting)	1953	1959	30-250 >250	70 30	>15	100	ORAUT 2006b	p. 23
5	Rolling, machining, casting, fabrication of Th metal, other forms	1953	1980	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
5	R&D on Th-U alloys	1960	1965	30-250 >250	25 75	>15	100		
6	Metallurgical R&D on U, including alloying	1954	1962	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
6	Metallurgical R&D on Th, including alloying	1954	1961	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
6	Metallurgical R&D on Th, including alloying	1971	1972	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
6	R&D on Th-U alloys	1960	1965	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
6	Low-level radiochemistry (mostly fission products)	1954	1975	30-250 >250	75 25	>15	100		
6	Co-60 irradiations[g]	1959	1975	30-250 >250	25 75	---	---	ORAUT 2010b	Table 6-2
6	R&D on Pu-239 alloys and other Pu forms	1954	1955	<30 30-250	65 35	>15 keV electron or <30 keV photon	100	ORAUT 2009b	p. 37
7	Metallurgical R&D on U, including alloying	1954	1962	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
7 (7A)	Research, pilot U fluoridation	1954	1954	30-250 >250	50 50	>15	100	ORAUT 2005d	Table 6-10
7	Metallurgical R&D on Th, including alloying	1954	1961	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
7	Low-level radiochemistry (mostly fission products)	1954	1975	30-250 >250	75 25	>15	100		
7	Radiotracer work - biological/chemical (H-3, tritiated cytidine), C-14, P-32, I-125)	1954?	1975?	30-250	100	>15	100		
9	Examination of krypton from test fuel rods (gases extracted at JN-1) or other samples[f]	1958	1962?	30-250	100	>15	100		
JN-1	Cell preparation, cleaning, maintenance: irradiated U fuel specimens	1956	1971	30-250 >250	75 25	>15	100	ORAUT 2010b	Table 6-2
JN-1	Cell preparation, cleaning, maintenance: spent fuel sectioning	1956?	1980?	30-250 >250	75 25	>15	100	ORAUT 2010b	Table 6-2
JN-1	Cell preparation, cleaning, maintenance: examination of irradiated reactor non-fuel parts	1958	1975	30-250	100	>15	100		
JN-1	Cell preparation, cleaning, maintenance: irradiated U-Th fuel specimens (>90% Th)	1956	1961	30-250 >250	25 75	>15	100	ORAUT 2005d	Table 6-10
JN-1	Cell preparation, cleaning, maintenance: sectioning of Co-60 rods	1971	1982?	30-250 >250	25 75	>15	100	ORAUT 2010b	Table 6-2

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PHOTON AND ELECTRON ENERGY RANGES
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Bldg[a]	Description[b]	Operations		Photon		Electron		Reference	Location in Ref
		Begin	End	Energy, keV	%	Energy, keV	%		
JN-1	Cell preparation, cleaning, maintenance: fabrication of Cf-252 sources (two AGC cells)	1972	1974?	<30	100	>15	100		
JN-1	Co-60 irradiations (HEC)	1972?	1982	30-250 >250	25 75	---	---	ORAUT 2010b	Table 6-2
JN-1	Cask movements	1955	1983	30-250 >250	25 75	---	---		
JN-1	Cleaning/maintenance in non-Cf cells	1956	1983	30-250 >250	75 25	>15	100	ORAUT 2010b	Table 6-2
JN-1	Cell preparation, cleaning, maintenance: irradiated Pu, U-Pu forms (except 1968-1969)	1967	1972	<30 30-250	65 35	>15 keV electron or <30 keV photon	100	ORAUT 2009b	p. 37
JN-1	Cell prep, cleaning, maintenance: irradiated Pu fuel rods, recovery of Pu-238, Np-237 (Low Level Cell)	1974?	1975	<30 30-250	65 35	>15 keV electron or <30 keV photon	100		
JN-1	Study of irradiated U, Pu fuel aerosols (Pu-239?)	1975	1977	<30 30-250	65 35	>15 keV electron or <30 keV photon	100	ORAUT 2009b	p. 37
JN-1	Sabotage project work in HEC, pool (spent fuel)	1979	1983	30-250 >250	75 25	>15	100	ORAUT 2010b	Table 6-2
JN-1	Waste handling (mostly MFPs)	1955	1983	<30 30-250	25 75	>15	100	ORAUT 2010b; 2007a	Table 6-2; 6-9
JN-2	Critical assembly (zero power facility) operations	1955	1963	30-250 >250	50 50	>15	100	ORAUT 2010b	Table 6-2
JN-2	Research, fabrication with encapsulated Pu-239 (direct conversion devices) for LLNL	1964	1970	<30 30-250	65 35	>15 keV electron or <30 keV photon[f]	100[f]	ORAUT 2009b	p. 37
JN-2	Storage and dispensing of SNM, incl EU, Th[e]	1955?	1959	30-250	100	>15	100	ORAUT 2009b; 2006b	p. 37; 23
JN-2	Storage and dispensing of SNM, incl EU, Pu, Th[d]	1960	1996	<30 30-250	65 35	>15 keV electron or <30 keV photon	100	ORAUT 2009b; 2006b	p. 37; 23
JN-3	Routine/typical reactor operator activities	1956	1974	30-250 >250	25 75	>15	100	ORAUT 2009b, 2010b, 2007a	
JN-3	Reactor maintenance activities (reactor down)	1956	1974	30-250 >250	25 75	>15	100		
JN-3	Reactor irradiation/activation work	1956	1974	30-250 >250	25 75	---	---		
JN-3	Reactor beam area work	1956	1974	30-250 >250	25 75	---	---		
JN-3	Reactor thermal column/shielding plate work	1956	1974	30-250 >250	25 75	---	---		
JN-3	Reactor shielding pool, maintenance work in	1956	1974	30-250 >250	25 75	>15	100		
JN-4	Alloying/mixing Pu with various materials, incl U, Th	1960	1977	<30 30-250	65 35	>15 keV electron or <30 keV photon[g]	100[g]	ORAUT 2009b	p. 37

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PHOTON AND ELECTRON ENERGY RANGES
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Bldg[a]	Description[b]	Operations		Photon		Electron		Reference	Location in Ref
		Begin	End	Energy, keV	%	Energy, keV	%		
JN-4	Other research with Pu-239 (corrosion, etc.)	1960	1977	<30 30-250	65 35	>15 keV electron or <30 keV photon[g]	100[g]	ORAUT 2009b	p. 37
JN-4	Preparation of UCN-PuCN by arc melting, casting	1967	1967	<30 30-250	65 35	>15 keV electron or <30 keV photon[g]	100[g]	ORAUT 2009b	p. 37
JN-4	Fabrication of UN-PuN (Pu-239) pellets and pins, including heat treatment and rolling	1968	1971	<30 30-250	65 35	>15 keV electron or <30 keV photon[g]	100[g]	ORAUT 2009b	p. 37
JN-4	Research, fabrication of RTGs with Pu-238	1974	1977	<30 30-250	65 35	>15[g]	100[g]		
JN-4	R&D on Po-210 alpha-cell direct conversion generator	1963?	1964	<30 30-250	50 50	>15[g]	100[g]	ORAUT 2004	Table 6-9
JN-4	Purification of multicuries of Pm-147 for RTGs	1964	1966	---	---	>15[g]	100[g]		
JN-4	Research, fabrication of RTGs with Cm-244	1964	1968	<30 30-250 >250	25 50 25	>15[g]	100[g]	ORAUT 2010b	Table 6-2
JN-4	Preparation of Np oxide microspheres	1966	1967?	<30 30-250	80 20	>15[g]	100[g]		
JN-4	Fabricating NpO_2 targets for Pu-238 production (Np-237)	1971?	1974?	<30 30-250	80 20	>15[g]	100[g]		
JN-4	Pu waste handling (mostly Pu-239)	1960	1977	<30 30-250	65 35	>15 keV electron or <30 keV photon	100	ORAUT 2009b	p. 37
JS-1	Production of fuel using the hot isostatic pressure bonding process (HEU plates)	1965?	1980	30-250	100	>15	100	ORAUT 2006b,e	p. 23; Table 6-13
JS-10, JS-12	Explosive forming, ballistic studies (mostly DU, some EU)	1979?	1988?	<30 30-250	90 10	>15	100	ORAUT 2007a	Table 6-9

a. Only Buildings A and 1 existed before the 1950s, when Buildings 2 through 9 were built. It is known that Buildings 2 and 3 were in use in 1950. Thus, Buildings 2 and 3 should not be assumed to have been in use before 1950, Buildings 4 and 5 before about 1953, and Buildings 6, 7, and 9 before about 1954. It is not clear when JS-1 was built, but it likely was not in operation before 1965.

b. Where it is stated that a year or period is excepted, it means that no work of this type was done during that year or period.

c. Per ORAUT (2006b p. 23), during casting, any U-238 decay products float to the top surface of the molten metal and condense as surface residues. The Pa-234 has high beta and photon energies; Pa-234 has 93% of its photons at >250 keV, while U-238 in equilibrium with Th-234m, Pa-234m, and Pa-234 has 18% of its photons at >250 keV. Thus, in processing that involves melting, a higher percentage of photons with energies greater than 250 keV should be assumed.

d. Some parts of Building 3, probably the vault, were in use until 1991; some intermittent machining of uranium forms was done from 1981 to 1991 in the Building 5 machine shop.

e. The vault in Building 3 probably contained more EU than anything else, as probably did the vault in JN-2 until the critical assembly facility shut down in 1963; after that, the JN-2 vault likely contained more Pu than any other material.

f. See footnote to table in Attachment C for a description of the fission gas analysis work.

g. These figures are assumed to be applicable to a bare or wall-shielded source. However, at Battelle, these Co-60 rods were actually covered by water during irradiations, producing a minimal dose rate at the worker position. It is assumed that most of the Battelle dose resulted from movements or changes of the rods, in which less water covered the sources, but some adjustments might still need to be made for the water shielding.

g. This was glovebox work, hence betas should not be included except for periods when the glovebox was assumed to be opened, gloves were changed, or wastes were removed. Such periods should be assumed to total <10% of work time.

ATTACHMENT H
NEUTRON ENERGY RANGES

Bldg	Description[a]	Operations		Neutron		Reference	Location in Ref
		Begin	End[b]	Energy	%		
A	Metallurgical R&D on U, including alloying	1943	[1962]	For alpha-neutron reactions, UO_2 may be taken to be typical			
A	R&D, fabrication of nat/depl U as pellets, powder, or plates	1950	1971	---	---		
A	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	---	---		
A	Extracting U from phosphates, slimes, slurries (except 1951)	1946	1954	---	---		
A	Extracting U from carnotite ores	1947	1949	---	---		
A	Extracting U from Western ores	1952	1955	---	---		
A	Extracting U by ammonium carbonate leaching	1955	1957	---	---		
A	Converting pitchblende to UO_2	1950	1951	0.1-2.0 MeV 2-20 MeV	50 50	ORAUT 2004	Table 6-9
A	Refining MgX (concentrate), V-20 soda salt to UO_2	1950	1951	---	---		
A	Process support for U metal production (including casting)	1953	1959	---	---		
A	Metallurgical R&D on Th, including alloying	1944	1961	---	---		
A	Extracting Th from monazite sands, etc. (exc 1953)	1949	1955	---	---		
A	Radiotracer work - industrial (certain labs only)	1953	1960	---	---		
1	Rolling, machining, fabrication of U metal, other forms	1943	1980	---	---		
1	Casting and other heating and melting operations on U			---	---		
1	Metallurgical R&D on U, including alloying	1943	[1962]				
1	Extracting U from phosphates, slimes, slurries (exc 1951)	1946	1954	---	---		
1	Extracting U from carnotite ores	1947	1949	---	---		
1	Extracting U from Western ores	1952	1955	---	---		
1	Extracting U by ammonium carbonate leaching	1955	1957	---	---		
1	Refining MgX (concentrate), V-20 soda salt to UO_2	1950	1951	---	---		
1	Process support for U metal production (including casting)	1953	1959	---	---		
1	Rolling, machining, casting, fabrication of Th metal, other forms	1944	1980	---	---		
1	Metallurgical R&D, including alloying Th	1944	1961	---	---		
1	Radiotracer work - industrial (certain labs)	1953	1960	---	---		
2	Rolling, machining, fabrication of U metal, other forms	1950	1980	---	---		
2	Casting and other heating and melting operations on U	1950	1980	---	---		
2	Metallurgical R&D on U, including alloying	1950	[1962]	For alpha-neutron reactions, UO_2 may be taken to be typical			
2	Metallurgical R&D on U, including alloying	1979	1979	For alpha-neutron reactions, UO_2 may be taken to be typical			
2	R&D, fabrication of nat/depl U as pellets, powder, or plates	1950	1971	---	---		
2	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	---	---		
2	Extracting U from phosphates, slimes, slurries (except 1951)	1950	1954	---	---		
2	Extracting U from Western ores	1952	1955	---	---		
2	Extracting U by ammonium carbonate leaching	1955	1957	---	---		
2	Refining MgX (concentrate), V-20 soda salt to UO_2	1950	1951	---	---		
2	Process support for U metal production	1953	1959	---	---		
2	Rolling, machining, casting, fabrication of Th metal, other forms	1950	1980	---	---		

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NEUTRON ENERGY RANGES

Bldg	Description[a]	Operations		Neutron		Reference	Location in Ref
		Begin	End[b]	Energy	%		
2	Metallurgical R&D on Th, including alloying	1950	1961	---	---		
2	Metallurgical R&D on Th, including alloying	1971	1972	---	---		
2	Preparing Th in Th iodide process	1951	1954	---	---		
2	R&D on Th-U alloys	1960	1965				
3	Metallurgical R&D on U, including alloying	1950	[1962]	For alpha-neutron reactions, UO_2 may be taken to be typical			
3	Metallurgical R&D on U, including alloying	1979	1979	For alpha-neutron reactions, UO_2 may be taken to be typical			
3	Production of U forms for other facilities, including melting and powder formation	1954	1975	---	---		
3	R&D, fabrication of nat/depl U as pellets, powder, or plates	1950	1971	---	---		
3	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	---	---		
3	Calcining of U samples and waste for recovery	1954	1975?	---	---		
3	R&D on Th-U alloys	1960	1965				
3	Storage and dispensing of SNM, incl EU and Th[b,d]	1950	1975	0.1-2 MeV 2-14 MeV	79 21	ORAUT 2006b	p. 27
4	R&D, fabrication with enriched UO2 in pellet, powder, and plate forms (not the Radioisotope Lab)	1954	1962	---	---		
4	High-level radiochemistry (mostly fission products)	1953	1975	---	---		
4	Low-level radiochemistry (mostly fission products)	1953	1975	---	---		
4	Gaseous fission product counting, radiochemistry[e]	1956	1966	---	---		
4	Radiotracer work - industrial	1953	1960	---	---		
4	Radiography of material samples (Cs-137, Co-60)	1953	1975	---	---		
4	Activation using Po-Be source	1953?	1975	0.1-2.0 MeV 2-20 MeV	25 75	ORAUT 2004; 2007a	Table 6-9; 6-16
5	Rolling, machining, fabrication of U metal, other forms	1953	1980[c]	---	---		
5	Casting and other heating and melting operations on U	1953	1980[c]	---	---		
5	R&D, fabrication of nat/depl U as pellets, powder, or plates	1953	1971	---	---		
5	R&D, fabrication of enriched U as pellets, powder, or plates	1954	1962	---	---		
5	Process support for U metal production (including casting)	1953	1959	---	---		
5	Rolling, machining, casting, fabrication of Th metal, other forms	1953	1980	---	---		
5	R&D on Th-U alloys	1960	1965				
6	Metallurgical R&D on U, including alloying	1954	1962	For alpha-neutron reactions, UO_2 may be taken to be typical			
6	Metallurgical R&D on Th, including alloying	1954	1961	---	---		
6	Metallurgical R&D on Th, including alloying	1971	1972	---	---		
6	R&D on Th-U alloys	1960	1965	---	---		
6	Low-level radiochemistry (mostly fission products)	1954	1975	---	---		
6	Co-60 irradiations	1959	1975	---	---		
6	R&D on Pu-239 alloys and other Pu forms (taken to be Pu processing not in a glovebox	1954	1955	10-100 keV 0.1-2 MeV 2-20 MeV	11 56 33		
7	Metallurgical R&D on U, including alloying	1954	1962	For alpha-neutron reactions, UO_2 may be taken to be typical			
7 (7A)	Research, pilot U fluoridation (consider to be as for UF_4 (green salt))	1954	1954	0.1-2 MeV	100	ORAUT 2005d	Table 6-10
7	Metallurgical R&D on Th, including alloying	1954	1961	---	---		

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NEUTRON ENERGY RANGES
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Bldg	Description[a]	Operations		Neutron		Reference	Location in Ref
		Begin	End[b]	Energy	%		
7	Low-level radiochemistry (mostly fission products)	1954	1975	---	---		
7	Radiotracer work - biological/chemical (assume H-3, C-14, P-32, I-125)	1954?	1975?	---	---		
9	Examination of krypton) from test fuel rods (gases extracted at JN-1) and other samples[e]	1958	1962?	---	---		
JN-1	Cell preparation, cleaning, maintenance: irradiated U fuel specimens	1956	1971	0.1-2 MeV	100		
JN-1	Cell preparation, cleaning, maintenance: spent fuel sectioning (nondestructive examinations performed on the assemblies, bundles, rods; rods (encased in cladding) were removed; fission gases were collected and analyzed from a hole drilled in the cladding. These examinations: ~ 90 percent of the work performed in the HEC)	1956?	1980?	0.1-2 MeV	100	Wastren 2001	
JN-1	Cell preparation, cleaning, maintenance: examination of irradiated reactor non-fuel parts	1958	1975	---	---		
JN-1	Cell preparation, cleaning, maintenance: irradiated U-Th fuel specimens (>90% Th) (93.5 w/o ThO_2-6.5 w/o UO_2 (U was 92.7% enriched); core had 44 g of 95.5 w/o ThO_2-4.5 w/o UO_2)	1956	1961	0.1-2 MeV	100	Dayton and Tipton 1959; Peterson et al. 1959	
JN-1	Cell preparation, cleaning, maintenance: sectioning of Co-60 rods	1971	1982?	---	---		
JN-1	Cell preparation, cleaning, maintenance: fabrication of Cf-252 sources (two AGC cells)	1972	1974?	0.1-2 MeV 2-14 MeV	23 77	ORAUT 2006b; 2007a	p. 29; Table 6-16
JN-1	Co-60 irradiations (HEC)	1972?	1982	---	---		
JN-1	Cask movements	1955	1983	---	---		
JN-1	Cleaning/maintenance in non-Cf cells	1956	1983	0.1-2 MeV	100		
JN-1	Cell preparation, cleaning, maintenance: irradiated Pu, U-Pu forms (except 1968-1969)	1967	1972	10-100 keV 0.1-2 MeV 2-20 MeV	11 56 33		
JN-1	Cell preparation, cleaning, maintenance: irradiated Pu fuel rods, recovery of Pu-238 and Np-237 (Low Level Cell)	1974?	1975	10-100 keV 0.1-2 MeV 2-20 MeV	11 56 33		
JN-1	Study of irradiated U, Pu fuel aerosols (Pu-239?)	1975	1977	10-100 keV 0.1-2 MeV 2-20 MeV	11 56 33		
JN-1	Sabotage project work in HEC, pool (spent fuel)	1979	1983	---	---		
JN-1	Waste handling (mostly MFPs)	1955	1983	0.1-2 MeV 2-20 MeV	90 10	ORAUT 2007	Table 6-3
JN-2	Critical assembly (zero power facility) operations	1955	1963	10-100 keV 0.1-2 MeV 2-20 MeV	3.2 59 38	ORAUT 2009b	Table 6-21
JN-2	Research, fabrication with encapsulated Pu-239 (direct conversion devices) for LLNL	1964	1970	10-100 keV 0.1-2 MeV 2-20 MeV	11 56 33		
JN-2	Storage and dispensing of SNM, incl EU, Th[d]	1955?	1959	0.1-2 MeV 2-14 MeV	79 21	ORAUT 2006b	Table F-3
JN-2	Storage and dispensing of SNM, incl EU, Pu, Th[d]	1960	1996	0.1-2 MeV 2-20 MeV	80 20	ORAUT 2010c	Table 6-25
JN-3	Routine/typical reactor operator activities	1956	1974	0.1-2 MeV	100	ORAUT 2009b; 2006c	Table 6-21; 6-3
JN-3	Reactor maintenance activities (reactor down)	1956	1974	---	---		
JN-3	Reactor irradiation/activation work	1956	1974	0.1-2 MeV	100	ORAUT 2009b; 2006c	Table 6-21; 6-3
JN-3	Reactor beam area work	1956	1974	0.1-2 MeV	100	ORAUT 2009b; 2006c	Table 6-21; 6-3
JN-3	Reactor thermal column/shielding plate work	1956	1974	0.1-2 MeV	100	ORAUT 2009b; 2006c	Table 6-21; 6-3
JN-3	Reactor shielding pool, maintenance work in	1956	1974	---	---		

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NEUTRON ENERGY RANGES
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Bldg	Description[a]	Operations		Neutron		Reference	Location in Ref
		Begin	End[b]	Energy	%		
JN-4	Alloying/mixing Pu with various materials, incl U, Th (taken to be Pu processing (not machining, etc.)[f]	1960	1977	10-100 keV 0.1-2 MeV 2-20 MeV	10 50 40	ORAUT 2009b	Table 6-21
JN-4	Other research with Pu-239 (corrosion, etc.) (taken to be Pu processing (not machining, etc.)[f]	1960	1977	10-100 keV 0.1-2 MeV 2-20 MeV	10 50 40	ORAUT 2009b	Table 6-21
JN-4	Preparation of UCN-PuCN by arc melting, casting (taken to be Pu processing (not machining, etc.)[f]	1967	1967	10-100 keV 0.1-2 MeV 2-20 MeV	10 50 40	ORAUT 2009b	Table 6-21
JN-4	Fabrication of UN-PuN (Pu-239) pellets and pins, including heat treatment and rolling (taken to be Pu processing (not machining, etc.)[f]	1968	1971	10-100 keV 0.1-2 MeV 2-20 MeV	11 56 33	ORAUT 2009b	Table 6-21
JN-4	Research, fabrication of RTGs with Pu-238[f]	1974	1977				
JN-4	R&D on Po-210 alpha-cell direct conversion generator[f]	1963?	1964	0.1-2 MeV 2-20 MeV	25 75	ORAUT 2004	Table 6-9
JN-4	Purification of multicuries of Pm-147 for RTGs[f]	1964	1966	---	---		
JN-4	Research, fabrication of RTGs with Cm-244[f]	1964	1968	0.1-2.0	100	ORAUT 2010b	Table 6-3
JN-4	Preparation of Np oxide microspheres[f]	1966	1967?	10-100 keV 0.1-2 MeV 2-20 MeV	10 50 40	ORAUT 2009b	Table 6-21
JN-4	Fabricating NpO2 target rods for Pu-238 production[f]	1971?	1974?	10-100 keV 0.1-2 MeV 2-20 MeV	10 50 40	ORAUT 2009b	Table 6-21
JN-4	Pu waste handling (mostly Pu-239) (taken to be manual)	1960	1977	10-100 keV 0.1-2 MeV 2-20 MeV	11 56 33	ORAUT 2009b	Table 6-21
JS-1	Production of fuel using the hot isostatic pressure bonding process (HEU plates)	1965?	1980	---	---		
JS-10, JS-12	Explosive forming, ballistic studies (mostly DU, some EU)	1979?	1988?	---	---		

a. Only Buildings A and 1 existed before the 1950s, when Buildings 2 through 9 were built. It is known that Buildings 2 and 3 were in use in 1950. Thus, Buildings 2 and 3 should not be assumed to have been in use before 1950, Buildings 4 and 5 before about 1953, and Buildings 6, 7, and 9 before about 1954. It is not clear when JS-1 was built, but it probably was not in operation before 1965.
b. Where it is stated that a year or period is excepted, it means that no work of this type was done during that year or period.
c. Some parts of Building 3, probably the vault, were in use until 1991; some intermittent machining of uranium forms was done from 1981-1991 in the Building 5 machine shop.
d. The vault in Building 3 probably contained more EU than anything else, as probably did the vault in JN-2 until the critical assembly facility shut down in 1963; after that, the JN-2 vault likely contained more Pu than any other material.
e. See footnote to table in Attachment C for a description of the fission gas analysis work.
f. Glovebox work (hence betas are not included).

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ANALYSIS OF BATTELLE MEASURED NEUTRON AND PHOTON DOSE RADIATION SURVEY DATA

1.0 INTRODUCTION

On April 16, 1943, Battelle Memorial Institute entered into contract with the Manhattan Engineering District to perform atomic energy research and development activities (Battelle 2002). Since that time, Battelle has continuously performed research and developmental work at its facilities for the Department of Energy (DOE) and its predecessor agencies. Work was done at Battelle King Avenue and West Jefferson facilities. The Battelle West Jefferson Nuclear Sciences Area contains several major buildings with the potential for workplace radiation fields (Wallace 2010) as follows:

- **Building JN-1 Hot Cell Building** contains hot cells that were used to provide research and technical assistance in the areas of power reactor fuel performance evaluations, post-irradiation examination of nuclear materials and components, radiation source encapsulation, and physical and mechanical property studies on irradiated materials and structures.

  The original section of this facility, referred to as JN-1A since 1973, was built in 1955. JN-1A contained offices, lab space, hot cells, and subterranean alpha gamma cells. In 1973, JN-1B was added to the building as a high-bay structure containing a large hot cell, adjacent fuel storage pool, and truck bay designed to off-load casks containing irradiated fuel assemblies into the pool for subsequent transfer underwater in to the cell. Both JN-1A and JN-1B were in operation until 1983. In 1983 both JN-1A and JN-1B were shutdown and put under a surveillance and maintenance program prior to initiation of decontamination and decommissioning activities.

  The primary purpose of the entire facility was for destructive and non-destructive examination of irradiated reactor fuel, cladding materials and associated reactor components. The facility was never a source of routine neutron radiation exposures. Occasionally, over the years, several ad-hoc research experiments using sealed neutron sources (e.g., usually ^{252}Cf) were performed for relatively short periods. This facility was used for these experiments because of its inherent shielding and radiation source handling capabilities. The only other neutron exposure potential is associated with storage of these sealed sources and also a small number of instrument-calibration-type neutron sources stored periodically for subsequent transfer offsite.

- **Building JN-2 CAL Building** was designed and constructed for use as a critical assembly laboratory and was used for critical experiments. This building was constructed in 1955 and housed a vault used to store special nuclear materials, a radio-analytical laboratory used to assay routine health physics samples, and capabilities to perform low-level radioactivity and environmental sample analyses. From inception of use, the building housed administrative offices and a radiation detection instrument calibration laboratory that used various radiation sources including at least one or more sealed neutron calibration sources. The high bay of the building housed a facility for reactor related-critical assembly experiments. The experiments were conducted from ~ 1956 through ~ 1960 and involved the use of very low-levels of uranium foils. After the cessation of critical assembly experiments, the building was used for several nuclear-related projects, including direct conversion concepts, irradiation experiment assemblies, and special nuclear materials storage and dispensing. The storage area contained a thick-walled vault located on the ground floor.

  A small plutonium laboratory constructed in 1966 (noted in survey records as JN-2 Pu Lab, Amstein 2010) was used for research conducted for what became known as the “Lawrence

Livermore National Laboratory" involving only sealed sources of plutonium contained in glove boxes. This lab was decommissioned in 1975. After decommissioning, this small plutonium lab was converted into a radioanalytical laboratory (RAL) dedicated to analyses of low-level radiological samples associated with onsite facilities, including analyses of various health physics samples and environmental media.

- **Building JN-3, Battelle Research Reactor** (BRR) operations began in October 1956 and ended December 1974. Based on Battelle licensing submittals to the Nuclear Regulatory Commission (Dingee and Chastain, Jr., 1961) several critical assembly systems have been studied including a beryllium-moderated, a plastic-moderated, two gas-cooled, water –moderated, and a uranium dioxide-fueled, organic-and-water moderated. This facility was selected because the shielding-research area was equipped with instruments to measure fast-neutron, thermal-neutron, and gamma radiation dose rates and spectra (Klingensmith, Epstein, and Chastain, Jr., 1959). BRR defueling and partial dismantlement was completed in 1975.

- **Building JN-4, Plutonium Laboratory** was built in 1960, with additions constructed in 1964 and 1967, to house activities for plutonium research and processing. The facility was operated from 1960 to 1978 when it was shut down for decontamination and decommissioning (D&D). The facility contained a neutron exposure-potential area in one small lab within the building known as the Pu-238 laboratory. This laboratory contained several glove boxes for research studies involving the use of ^{238}Pu. The laboratory portion of the facility was dismantled in 1985. Thereafter a hazardous materials research facility was located in Building JN-4 that involved only nonradioactive hazardous materials.

- **Building JS-1** was used to develop alloy and fabrication processes, for corrosion Chemistry studies, and to conduct engineering analyses for the Naval Reactor Program. Records indicate that uranium (depleted in U-235) was used in this Facility (Cotten and Payne 1990). The building was decommissioned in 1990.

Data collections from Battelle were received as follows:

- **December 3, 2009.** ORAUT staff uploaded 25 documents to the NIOSH database. These documents contained results of radiological surveys during the period of 1957-1977, primarily associated with operation of the Battelle Research Reactor (BRR) in Building JN-3. The pre-1970 neutron dose survey data were in units of neutron flux (i.e., neutrons/cm^2/sec). Often survey results were provided for thermal and fast neutrons. The instruments used in the surveys were typically listed on the respective documents. A memorandum (Selander 1957) identified the maximum permissible limit (i.e., assumed to be 5 rem per year) for fast neutrons as being 50n/cm^2/sec for 40 hrs for the JN-2 critical assembly. The primary focus of this effort was to collect and analyze paired photon and neutron radiation measurements for use in analyzing the neutron-to-photon dose (NP) ratio. Twenty of the files were identified as containing useful survey data to analyze the neutron to photon dose ratio and these were selected for data entry. The respective files along with the Site Research Database (SRDB) reference are listed in Table I-1.

- **February 15, 2010.** ORAUT staff uploaded 16 documents of supplemental information requested (1/7/10), approved by DOE (1/20/10) and received (Wallace 2010) from Battelle to the NIOSH database. These documents contained results of radiological surveys during the period of 1971-1974, primarily associated with operation of the JN-2 and JN-4 facilities. Fourteen of the files

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Table I-1. Battelle reference files uploaded December 3, 2009 containing neutron and photon radiation survey data.

SRDB*	File	SRDB	File
76975	1960 JN-3 redacted	76986	1968 JN-4 redacted
76976	1961 JN-3 redacted	76987	1969 JN-3 redacted
76977	1962 JN-3 redacted	76988	1969 JN-4 redacted
76978	1963 JN-3 redacted	76989	1970 JN-3 redacted
76979	1964 JN-3 redacted	76990	1970 JN-4 redacted
76980	1965 JN-3 redacted	76991	1971 JN-3 redacted
76982	1966 JN-3 redacted	76993	1973 JN-3 redacted
76983	1967 JN-2 redacted	76994	1974 JN-4 redacted
76984	1967 JN-3 redacted	76995	1975 JN-4 redacted
76985	1968 JN-3 redacted	76996	1976 JN-4 redacted

*Site Research Database (SRDB) Reference identification.

were identified as containing useful survey data to analyze the neutron to photon dose ratio and these were selected for data entry. As noted in Wallace (2010) The Battelle Monthly Health Physics Program Reports for Plutonium Facilities contain a section for "Neutron Flux Surveys" on page 2 of the report. The reference to the "Old Lab" refers to the original section of the JN-4 plutonium facility. The "New Lab" refers to the plutonium facility located in the section of JN-4 constructed in 1967. The "Office Area" refers the office area in JN-4. The JN-2 "Pu Lab" refers to the small plutonium laboratory located in JN-2. Also note that the reference to the "238 lab" under the same section was the plutonium-238 laboratory located in the JN-4 "New Lab." The New Lab was also referred to periodically as the "Large Lab." The respective files are listed in Table I-2 with the associated SRDB reference.

Table I-2. Battelle reference files uploaded February 15, 2010 containing neutron and photon radiation survey data.

SRDB*	File	SRDB	File
79055	1971 JN-3 Reactor	79057	1974
79067	1972 (Apr) JN-4	79069	1974 (Apr) JN-4
79071	1972 (Aug) JN-4	79074	1974 (Feb) JN-4
79076	1974 (Jan) JN-4	79078	1972 (Jul) JN-4
79079	1972 (Jun) JN-4	79080	1972 (Mar) JN-4
79081	1974 (Mar) JN-4	79082	1972 (May) JN-4
79083	1972 (Oct) JN-4	79084	1972 (Sep) JN-4

*Site Research Database (SRDB) Reference identification.

- **February 28, 2010.** ORAUT staff received from OCAS (2/26/10) documents provided by OSTI for scanning and data entry. Although significant information was found describing the operations at several facilities at the West Jefferson location, no survey data was found. Two hazard summary reports were found that described the relative neutron and photon hazards at the JN-2 facility (Table I-3).

2.0 METHODS

The respective records of photon and neutron dose measurement data were categorized according to the general workplace or type of exposure radiation per information in the survey documentation. The

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Table I-3. SRDB reference files for Battelle information received from OSTI uploaded February 26, 2010.

SRDB*	Title	Document Number	Year
79448	Hazards Summary Report for the PWAR-3 Critical Assembly Experiments	BMI-ACRS-611	1956
79450	Hazards Summary Report for the APB Reflector-Control Critical-Assembly Experiments	BMI-ACRS-615	1956

*Site Research Database (SRDB) Reference identification.

data were analyzed to eliminate incomplete data with respect to dates, missing photon or missing neutron measured doses, less-than photon doses and those results with a calculated NP ratio of zero. Beta/gamma survey instrument data were typically recorded in units of mR/hr. The results were typically for photon radiation only but when it was clear that beta radiation significantly contributed to the reading, the gamma component only was obtained if available for use in the analysis. Neutron survey results were recorded during earlier years in terms of flux (n/cm^2-sec) and beginning in 1970 as a measured dose rate (mrem/hr) depending upon the instrument. Thermal and fast neutron components were identified although most data results used in the analysis were identified as fast neutron doses only. The thermal and fast neutron flux was converted to a neutron dose rate using equation 1 as follows:

Neutron dose = 2.5 (Fast Neutron Flux/20 + Thermal neutron flux/680) mrem/hr (Eq 1)

This equation is based on NCRP Report 38 guidance regarding values to use to convert neutron flux to dose rate for identified neutron energies as shown in Table I-4. The selection of 20 (i.e., neutron energy of approximately 1 MeV) to convert the workplace measured fast neutron flux to dose equivalent tends to increase the measured neutron dose rate and will tend to result in a higher NP ratio which is favorable to claimants.

Table I-4. Mean neutron quality factor and flux corresponding to maximum dose equivalent of 1 mSv (100 mrem) per 40-hour week (NCRP 1971).

Neutron Energy, MeV	QF	Neutron Flux Density, $cm^{-2}sec^{-1}$
2.5×10^{-3} (thermal)	2	680
1×10^{-7}	2	680
1×10^{-6}	2	560
1×10^{-5}	2	560
1×10^{-4}	2	580
1×10^{-3}	2	680
1×10^{-2}	2.5	700
1×10^{-1}	7.5	115
5×10^{-1}	11	27
1	11	19
2.5	9	20
5	8	16
7	7	17
10	6.5	17
14	7.5	12
20	8	11

3.0 RESULTS

The available data for each Battelle Building have been analyzed and presented in the following sections.

Building JN-1, Hot Cell Laboratory
The primary mission of the JN-1 Hot Cell facility was non-destructive and destructive testing of irradiated reactor fuels. Most of the cells appear to have been used for these testing operations. There was one area that contained alpha-gamma cells that were specifically designed for work with transuranium materials which have a potential for neutron exposure. These cells were added to the basement of the JN-1 facility in 1964 (Wastren 2001). Some of these cells contained water windows for neutron shielding. Cells 5 and 6 were primarily used beginning in 1971 for work with ^{252}Cf. During the time period 1971 through 1974, potential for neutron exposure was quite large as the quantities of ^{252}Cf being worked with were in the mg range. Other operations involving transuranium isotopes appear to have occurred periodically from startup in 1955 through 1988; however, the potential for neutron exposure would be much lower than during the ^{252}Cf operations.

For the development of an NP ratio, several radiological surveys during the ^{252}Cf operations from 1971 through 1974 were collected from a small sampling of records boxes. In total, 49 paired neutron and photon dose rate measurements were evaluated. The neutron to photon ratio can be described as a log normal distribution with a geometric mean of 2.4 (2.42) and a geometric standard deviation of 3.9 (3.93) as shown in Figure I-1. The r^2 value of the fitted distribution was 0.97 indicating a robust fit to the dataset. The paired neutron and photon measurements also exhibited a reasonable degree of correlation with the Pearson correlation coefficient of 0.54 and the Spearman Rank correlation coefficient of 0.56.

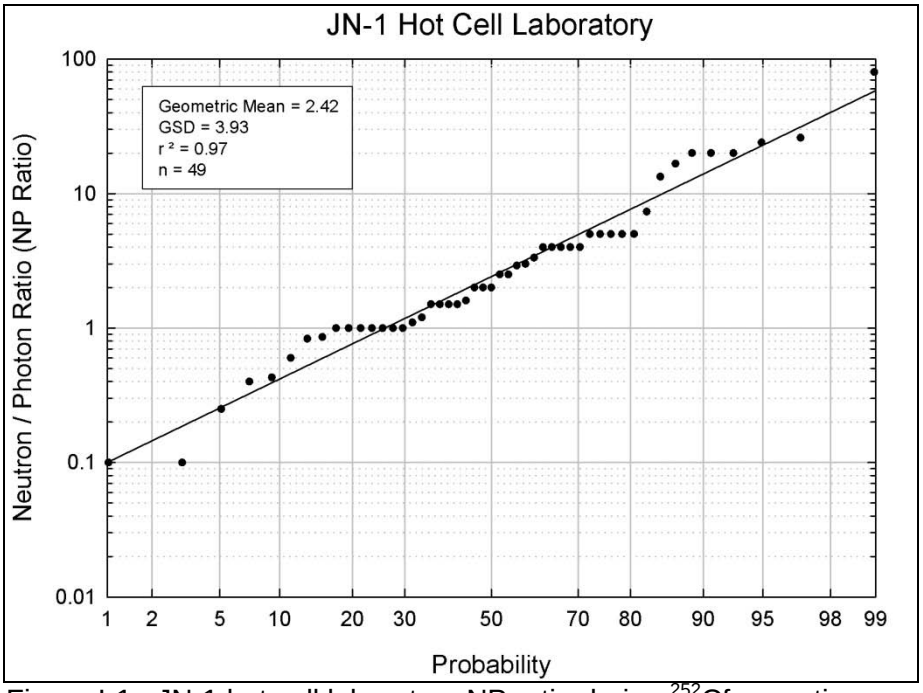

Figure I-1. JN-1 hot cell laboratory NP ratio during ^{252}Cf operations.

Because NTA film would have adequately monitored neutron energies associated with ^{252}Cf, for dose reconstruction if the worker was monitored for neutron exposure and worked in the JN-1 facility, the recorded neutron doses should be used for dose reconstruction with the appropriate adjustments (OCAS 2007) for missed dose. If the worker worked in the JN-1 facility and was not monitored for neutron exposure, consideration should be given as to the potential for neutron exposure prior to assigning a neutron dose based on the NP ratio listed in Table I-5 and illustrated in Figure I-1. The data presented in Figure I-1 are considered the upper bound of the NP ratio, since the NP ratio for ^{252}Cf is likely higher than other possible exposure scenarios. However, it is likely not appropriate to assign this ratio for a best estimate case for a long term employee who was not monitored for neutron exposure. For example, assigning 95th percentile ratio of 20:1, as listed in Table I-5, is certainly bounding however the worker could not have worked with ^{252}Cf until at least 1971. Additional survey data for exposure scenarios for earlier years has been requested in order to provide a more accurate estimate of potential neutron dose.

Table I-5. Recommended lognormal parameters of NP ratios for Building JN-1.

Workplace location	Years	n	GM	GSD	95th%
JN-1 (Hot Cell Laboratory)					
Non-^{252}Cf Operations	1955–1983[a]	[b]			
^{252}Cf Operations	1971–1974	49	2.4	3.9	22.5

a. Neutron exposures probably very limited prior to construction and operation of alpha gamma cells in 1964.
b. Reserved—additional survey data requested

Building JN-2, Critical Assembly Laboratory

According to Battelle (BCL 2010), the JN-2 Critical Assembly Laboratory was built in 1955. From 1956 through the early 1960s, the facility conducted various critical experiments using enriched uranium. Hazard summary reports were written documenting the radiological controls in place to prevent high level exposures (Jankowski et al., 1956a and 1956b). Neutron survey results presented in Selandar (1957) show significant neutron dose rates associated with operation of a critical assembly. These reports indicated that radiation surveys through the building would be conducted during the early stages of operations. During the small sampling of radiological survey boxes (<50 boxes of over 700 boxes), Battelle has not yet located these early surveys.

In the interim without these surveys, a neutron to photon ratio is developed based upon the Hazard Summary Reports. According to Jankowski et al. (1956a) the calculated maximum neutron dose rate in the hallway outside the critical assembly during operations with power levels in the 1 to 10 watt range would result in a photon dose that was 1/8 the tolerance dose of 300 mR/wk. This corresponds to a photon dose rate of approximately 0.94 mR/hr. In addition, the calculated fast neutron dose would be on the order of ¼ the weekly tolerance dose of 300mrem/week or 75 mrem/week. This fast neutron dose corresponds to a dose rate of approximately 1.88 mrem/hr. Based on the information the expected neutron to photon ratio for the JN-2 facility is approximately 2:1.

Based on a review of the radiological records provided by Battelle for claimants, multiple workers at the West Jefferson facility were monitored for neutron exposure as early as 1956. Unfortunately to date all of the claimant data is for individuals who worked in the JN-1 (Hot Cell Facility) and the JN-3 (Research Reactor). The dosimetry reports have been redacted for other workers at the facility however at least 30 workers per 2 week cycle were monitored for neutron exposure. Most of the fast neutron results were below the 30 mrem detection limit, however, occasionally the dose would be

positive but usually less than 50 mrem. Assuming that some of the neutron badges were issued workers in the JN-2 facility the measured neutron dose rates are well below the conservative dose estimates used in the Hazard Summary Report. As a result the dose rates in the Hazard summary report are considered reasonable and bounding.

According to Amstein (2010) in the late 1960's a small plutonium laboratory was constructed at the JN-2 facility where the former radioanalytical laboratory was located. Radiological surveys for this laboratory have been obtained. The earliest survey obtained to date was conducted in September 1967. Additional surveys conducted from 1972 through 1974 have been added to the analysis for the development of a NP ratio for the facility during the plutonium laboratory operations starting around 1967. The neutron to photon ratio can be described as a log normal distribution with a geometric mean of 1.0 (0.97) and a geometric standard deviation of 1.3 (1.28) (Figure I-2). The arithmetic mean of the distribution was 1.01. Although the r^2 value for the regression was only 0.73, this ratio is considered reasonable given the limited data and the relatively low GSD. The Pearson correlation coefficient for the 14 paired neutron and photon dose rate measurements was 0.94 and the Spearman Rank correlation coefficient was 0.91 indicating a very high degree of correlation between the measurements.

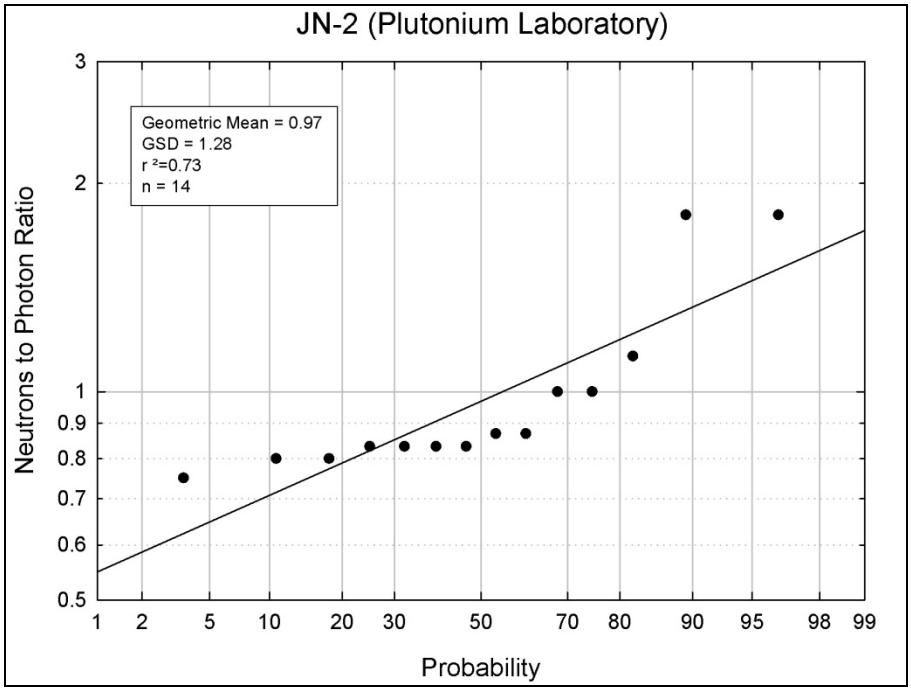

Figure I-2. JN-2 plutonium laboratory NP ratio.

The NP ratio for the vault area of the JN-2 facility was significantly lower than the plutonium laboratory. The arithmetic mean of the NP ratio for the vault area was calculated from 9 data points to be 0.29 or approximately on third of the NP ratio for the plutonium laboratory.

Since it is virtually impossible to place individual workers within the JN-2 facility (i.e. vault or Pu laboratory), the favorable to claimant approach is to use the higher of the two NP ratios for the JN-2 Facility. Therefore for the early period during the critical assembly experiments from 1956 through 1966, a NP ratio of 2:1 should be used. For the later years when the JN-2 plutonium laboratory was

in use a NP ratio of 1:1 should be used. Analysis results of the JN-2 survey data were best described by a lognormal distribution with a geometric mean of 1.0 (0.97) and a GSD of 1.3 (1.28) as shown in Table I-6.

Table I-6. Recommended lognormal parameters of NP ratios for Building JN-2.

Workplace location	Years	n	GM	GSD	95th%
JN-2 (Critical Assembly Laboratory)					
Critical Experiments	1956–1960	(a)			
Plutonium Laboratory	1967–1975	14	1.0	1.3	1.5

a. Reserved–additional survey data requested

Building JN-3, Battelle Research Reactor

A total of 3,188 NP ratios were obtained from the Battelle documents. These were categorized according to general work location or type of exposure per information in the respective survey documentation. For example, all of the vacuum cleaner samples whether for dust or sludge were combined. Similarly, all survey data associated with evaporator were combined. Following categorization, data associated with ^{252}Cf was eliminated based on the understanding that the ^{252}Cf source was present in the reactor for about one year. The neutron dose rates associated with ^{252}Cf were all less than detectable (i.e., 1 mrem/hr). The data with less-than photon doses were also eliminated. This reduced the data set to 2,487 values. A scatter plot of the neutron and photon dose rate paired measurements is presented in Figure I-3. The data illustrate a higher relative measured photon dose compared to the measured neutron dose rate.

A lognormal probability plot of the data shown in Figure I-3 is presented in Figure I-4. The data are best represented by a lognormal distribution with a geometric mean of 0.2, a geometric standard deviation of 3.3 (3.34) and a 95th percentile of 1.4 (1.383).

Each of the workplace categories were analyzed individually and the results are listed in Table I-7 illustrating the variation in the NP ratio and the variability. The recommended option is to utilize the lognormal parameters for all of these work areas collectively as shown in the last line of Table I-7 as exposed workers would be expected to move throughout the reactor facility.

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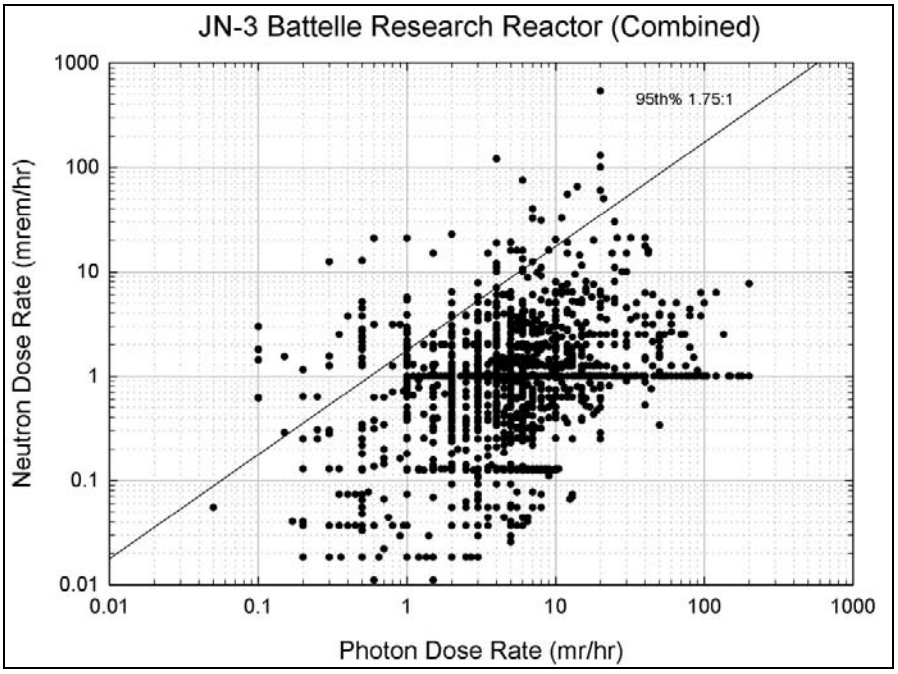

Figure I-3. JN-3 paired neutron and photon dose rate measurements.

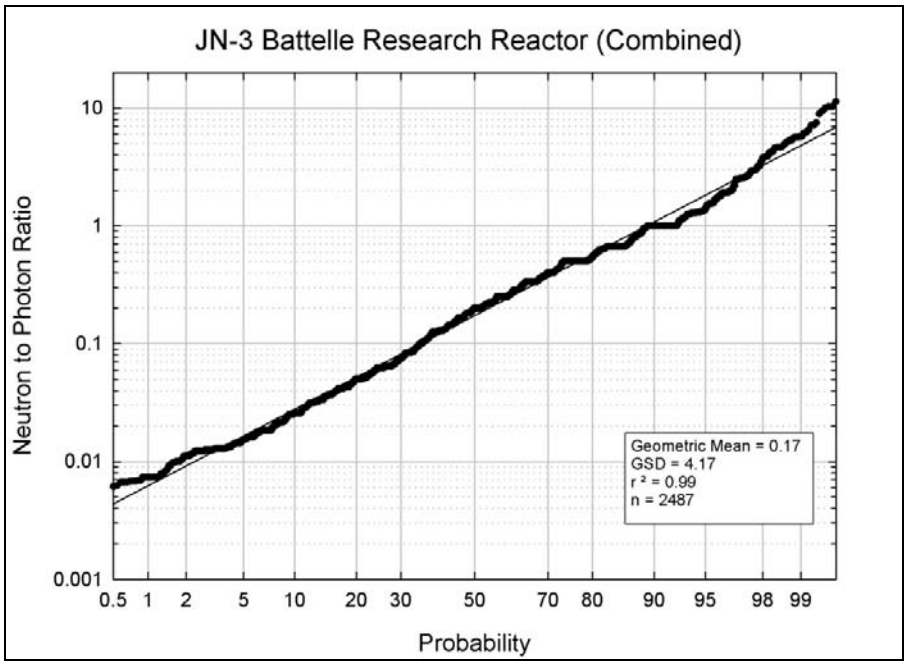

Figure I-4. JN-3 lognormal probability plot of the measured NP ratio.

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Table I-7. Statistical parameters of JN-3 survey record analysis.

General location	No.	NP ratio			
		Median	84th %	GSD	95th %
Radioactive dust and sludge	251	0.125	0.050	4.00	1.000
Evaporator	290	0.050	0.167	3.34	0.500
Hot area (3rd floor)	174	0.250	0.667	2.67	1.000
Hot area (basement)	144	0.153	0.667	4.36	1.000
Reactor (beam tubes)	1,116	0.250	0.876	3.50	2.527
Reactor (thermal column)	366	0.222	0.667	3.00	1.028
Shielding tank	146	0.250	0.501	2.00	4.717
Combination of all areas	**2,487**	**0.2**	**0.8**	**4.2**	**2.1**

Building JN-4, Plutonium Laboratory

The JN-4 facility (Plutonium Laboratory) began operations in the early 1960s. According to Battelle (BCL 2010), the facility was modified in 1964 and 1967. A sampling of radiological survey records for the entire West Jefferson plant resulted in a total of 93 records of paired neutron and photon dose rate measurements from 1968 through 1976 for the JN-4 facility. These were obtained from less-than 50 boxes of records. It is understood from Battelle that as many as 700 boxes of similar type records are available. Of the 93 records of paired measurements, the neutron measurements were greater than the detection limit in 41 records. The neutron dose rate detection limit varied somewhat from 1968 through 1976 but was generally in the range of 0.2 to 0.3 mrem/hr. The neutron to photon ratio by year in Figure I-5 illustrates that the NP ratio remained relatively constant over the operational time period.

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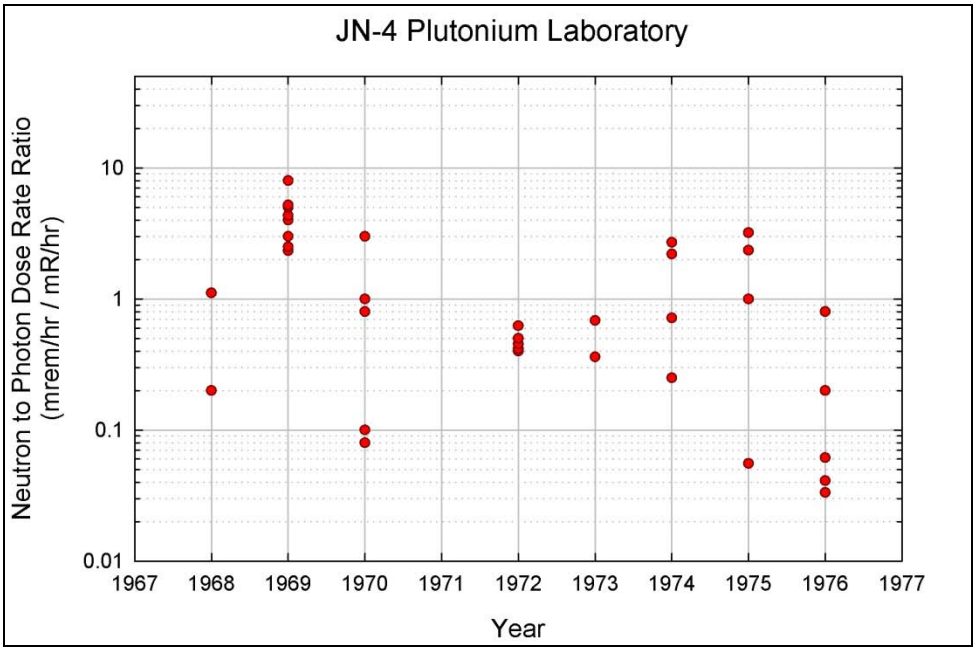

Figure I-5. JN-4 historical trend in NP ratio.

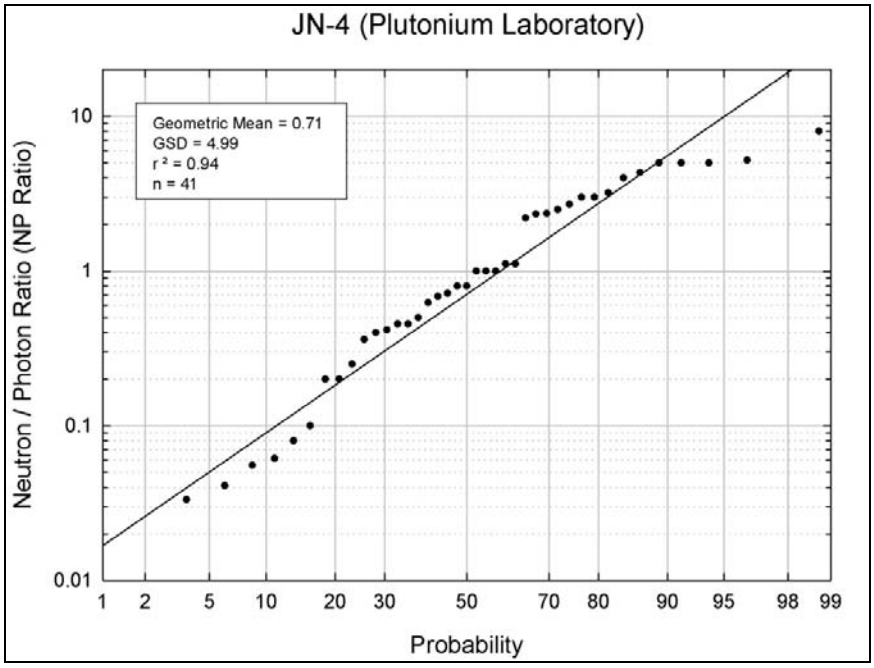

Figure I-6. JN-4 plutonium laboratory NP ratio.

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Table I-8. Lognormal parameters of NP ratios for Building JN-4.

Workplace location	Years	n	GM	GSD	95th%
JN-4 Plutonium Laboratory					
Combined areas	1960–1978	41	0.7	5.0	9.9

The 41 records of paired measurements were analyzed and are best described by a lognormal distribution with a geometric mean of 0.7 (0.71) and a GSD of 5.0 (4.99) (Figure I-6). The 95th percentile of the fitted distribution was 5.0 (5.1) and the r^2 value was 0.94 indicating a strong lognormal distribution. The arithmetic mean of the distribution was 1.71 and the Pearson Correlation Coefficient was 0.68 while the Spearman Rank correlation coefficient was 0.73. The NP ratio is summarized in Table I-8.

The relatively large geometric standard deviation is attributed to the different operations within the facility. Many of the paired NP ratio measurements greater than 1 were from the Pu-238 laboratory. This is likely due to the moderately high neutron production rates due to the high specific activity and the alpha interactions with light materials including oxygen. Due to the relatively large GSD, uncertainty should be considered in most dose reconstructions. A scatter plot of the paired measurements illustrates that the measured neutron and photon dose rates are highly correlated (Figure I-7). The NP ratio 95th percentile of 9.9 is shown on the graph and illustrates that this bounds the majority of the measured data as would be expected.

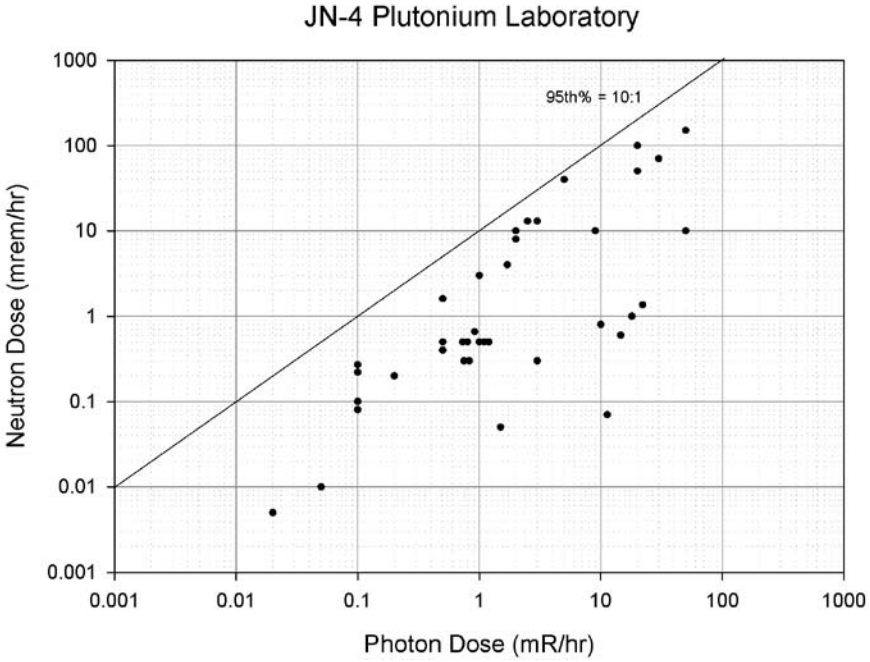

Figure I-7. JN-4 paired neutron and photon dose rate measurements.

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