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Site Profile for Grand Junction Facilities

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ACRONYMS AND ABBREVIATIONS

ac	acre
AEC	U.S. Atomic Energy Commission
AmBe	americium-beryllium (alloy)
ARA	Airborne Radioactivity Area
AWE	atomic weapons employer
CEP	Controls for Environmental Pollution
cm	centimeter
DAC	derived air concentration
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
D&D	decontamination and decommissioning
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
GJF	Grand Junction Facilities
GJPORAP	Grand Junction Project Office Remedial Action Project
GJRAP	Grand Junction Remedial Action Project
hr	hour
INL	Idaho National Laboratory
kg	kilogram
L	liter
LOD	limit of detection
MDA	minimum detectable amount
mg	milligram
mL	milliliter
MPC	maximum permissible concentration
mR	milliroentgen
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NTS	Nevada Test Site
NURE	National Uranium Resource Evaluation
NYOO	New York Operations Office
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
pCi	picocurie
REECo	Reynolds Electrical & Engineering Company
REMS	Radiation Exposure Monitoring System
SEC	Special Exposure Cohort
SNL	Sandia National Laboratories
SRDB Ref ID	Site Research Database Reference Identification (number)

t	ton
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
UMTRA	Uranium Mill Tailings Remedial Action Project
WL	working level
WLM	working level month
yd	yard
yr	year
µCi	microcurie
µR	microroentgen
§	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 historical background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean nor should it be equated to an "AWE facility" or a "DOE facility." The terms AWE and DOE facility are defined in sections 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively. An AWE facility means "a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling." 42 U.S.C. § 7384l(5). On the other hand, a DOE facility is defined as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program);" and with regard to which DOE has or had a proprietary interest, or "entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services." 42 U.S.C. § 7384l(12). The Department of Energy (DOE) determines whether a site meets the statutory definition of an AWE facility and the Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Accordingly, a Part B claim for benefits must be based on an energy employee's eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility's designated time period and location (i.e., covered employee). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility. Unlike the abovementioned statutory provisions on DOE facility definitions that contain specific descriptions or exclusions on facility designation, the statutory provision governing types of exposure to be included in dose reconstructions for DOE covered employees only requires that such exposures be incurred in the performance of duty. As such, NIOSH broadly construes radiation exposures incurred in the performance of duty to include all radiation exposures received as a condition of employment at covered DOE facilities in its dose reconstructions for covered employees. For covered employees at DOE facilities, individual dose reconstructions may also include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

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

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

1.1 PURPOSE

This site profile provides methods for dose reconstruction for the Grand Junction Facilities (GJF) in Grand Junction, Colorado.

1.2 SCOPE

Section 1.3 provides information on classes of GJF workers that have been added to the SEC. Section 2.0 describes facilities and operations at the site. Sections 3.0 through 6.0 discuss occupational medical, environmental, internal, and external dose, respectively. 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.

GJF personnel performed a lot of offsite work. Exposures incurred while performing work at locations other than GJF are not discussed in this site profile.

1.3 SPECIAL EXPOSURE COHORT

January 1, 1943, to January 31, 1975
The Secretary of the U.S. Department of Health and Human Services has added the following class of employees at GJF, formerly known as Grand Junction Operations Office, to the SEC (Sebelius 2011):

> *All employees of the Department of Energy, its predecessor agencies, and its contractors and subcontractors who worked at the Grand Junction Operations Office from January 1, 1943 through January 31, 1975, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees in the SEC.*

NIOSH has determined that it lacks sufficient information to reconstruct doses associated with radon and internal exposures from January 1, 1943, to January 31, 1975, to unmonitored GJF workers during these periods (NIOSH 2011a). In addition, NIOSH has determined that it lacks sufficient information to reconstruct doses associated with external exposures from 1943 through 1959 to unmonitored GJF workers (NIOSH 2011a).

February 1, 1975, to December 31, 1985
The Secretary has also added the following class (Burwell 2015):

> *All employees of the Department of Energy, its predecessor agencies, and its contractors and subcontractors who worked at the Grand Junction Facilities site in Grand Junction, Colorado, during the period from February 1, 1975, through December 31, 1985, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort.*

NIOSH has determined that it lacks sufficient information to reconstruct doses from nonradon internal exposures from February 1, 1975, to December 31, 1985, to unmonitored GJF workers (NIOSH 2015).

Dose reconstruction guidance in this site profile for periods before January 1, 1986, is presented to provide a technical basis for partial dose reconstructions for nonpresumptive cancers not covered in the SEC classes. Although NIOSH found that it is not possible to bound the total dose for the classes, it intends to use internal and external monitoring data that might become available for an individual

claim (and that can be interpreted using its existing dose reconstruction processes or procedures). Therefore, partial dose reconstructions for individuals who were employed at GJF before January 1, 1986, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

2.0 SITE DESCRIPTION

In 1943, the Manhattan Engineer District purchased the GJF. Figure 2-1 shows a timeline of major projects and operations.

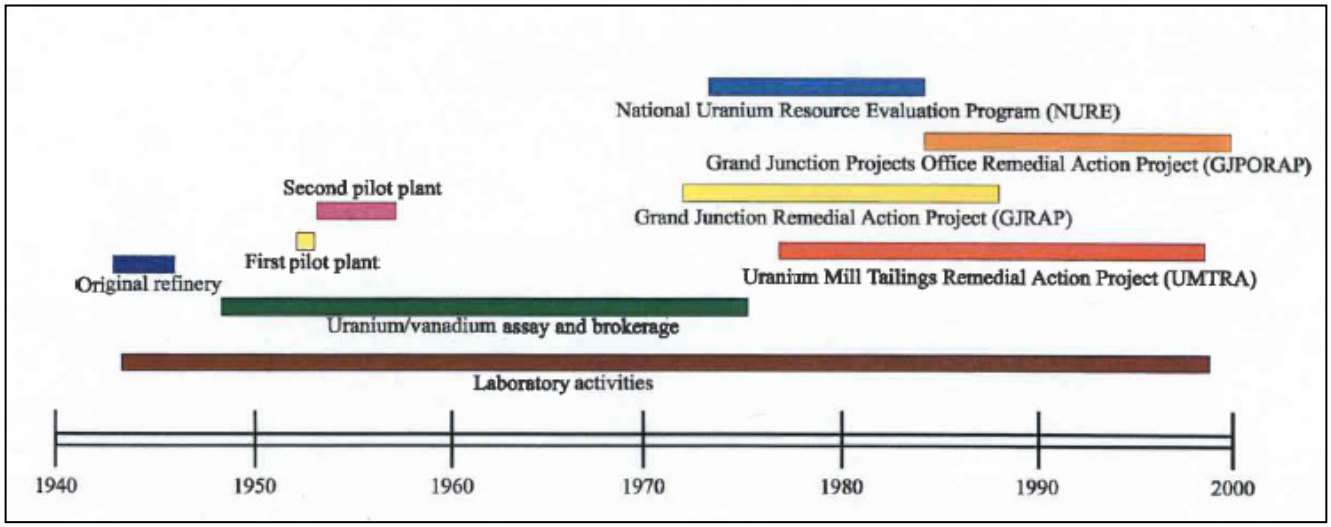

Figure 2-1. Timeline of major projects and operations (Forbes and Egidi 1997).

A refinery was operated on site from 1943 to 1946 to treat and concentrate uranium oxide from "green sludge," a byproduct of vanadium production in the area. Approximately 1,180 t of uranium oxide and a comparable amount of vanadium concentrate were produced and shipped off site for further refining. Wastes from this refinery included dust losses, a few hundred tons of alumina cake, and liquid discharges (Wastren 2001a, p. 15).

In late 1947, the U.S. Atomic Energy Commission (AEC) established the Colorado Raw Materials Office on site to manage the domestic uranium procurement program. This office was responsible for the receipt, sampling, and analysis of uranium and vanadium concentrates AEC purchased from ore processing operations in the western United States. AEC operated a uranium concentrate Sample Plant and assay laboratory on site until 2003. Between 1948 and 1971, a total of approximately 172,500 t of uranium oxide and 14,500 t of vanadium oxide passed through the facility in steel drums. The remaining stockpiled vanadium and uranium concentrates were shipped off site in 1965 and 1975, respectively (Wastren 2001a, p. 15).

A research program was conducted to test experimental uranium ore milling techniques in a small pilot mill from 1953 to 1954 near the present location of Building 46 and in a larger pilot mill on the southern end of the facility from 1954 to 1958. At the end of the program, some of the mill buildings and their support facilities were converted to other uses. The mill operations were the primary source of contaminated materials. Approximately 17,000 yd^3 of mill tailings and other residue remained on site. Significantly greater quantities of soil were contaminated due to windblown erosion and runoff and because tailings were used in the reconstruction of the dike along the Gunnison River and other site construction activities. Some contaminated equipment was buried on site, and some contaminated lumber and steel was reused in construction. Smaller amounts of contamination

resulted from the sampling and stockpiling uranium concentrate (yellowcake, U_3O_8) in the years after milling operations.

Tailings from the nearby commercially operated Climax Mill had been used for construction and as fill in the Grand Junction area. The Grand Junction Remedial Action Program (GJRAP) was funded to address this issue. GJF assisted in the cleanup of 600 vicinity properties in the Grand Junction area from 1972 to September 30, 1988. While this work was off site, soil samples were prepared and analyzed in onsite facilities. Exposures associated with the offsite cleanup and collection of these samples are not discussed in this site profile. However, exposures associated with the onsite analysis of these samples are discussed in this site profile.

From 1974 to 1984, GJF supported the National Uranium Resource Evaluation (NURE) Program, which was a nationwide uranium modeling effort. During this program mainly non-ore samples (drilling cores, etc.) were collected from offsite locations. The samples were returned to the site for processing. Some of the samples were crushed to the proper size, blended, etc. in the sample preparation area, Building 7A, before analysis in the Analytical Chemistry Laboratory, Building 20. The sample preparation activities presented the greatest potential for internal exposures after the end of concentrate sampling and storage in January 1975.

Instrument calibration models to support the NURE program as well as remediation programs, consisting of concrete mixed with radioactive materials, were constructed at GJF over its history. The models were in the form of pads and boreholes. Although ^{232}Th would have been present as a contaminant in tailings and, to a lesser extent, in the yellowcake processed and stored there, it was not routinely processed at GJF. In the 1975 to 1987 timeframe, ^{232}Th was handled sporadically in relatively small quantities to develop field calibration sources for uranium ore exploration and environmental remediation. The amount of ^{232}Th present in the calibration models was orders of magnitude less than the tons of uranium ore, concentrate, and tailings that were handled on site.

Starting in 1978, GJF participated in the Uranium Mill Tailings Remedial Action (UMTRA) program to cleanup commercial mill sites and vicinity properties. Again, the work was off site with onsite analysis and support. In addition, GJF supported the remediation work at the Monticello site in Utah, which was a government-owned mill that was technically not part of the UMTRA program. Though these projects would have included GJF employees that may have monitoring data specifically associated with these projects, any exposures that are directly attributed to these projects are not discussed in this site profile.

At the start of the Grand Junction Project Office Remedial Action Project (GJPORAP) remediation of the site in 1986, there were approximately 33.3 ac of open land and 24 ac where over time, approximately 61 buildings and smaller structures have resided (Wastren 2001a, p. 22). Most of the buildings were constructed in the 1940s and 1950s, but some prefabricated buildings were added more recently. Most of the buildings and structures that are known to have been contaminated (as shown in Table 2-1) have been either remediated or demolished (DOE 2006).

DOE transferred ownership of the site to Riverview Technology Corporation on September 30, 2001. However, DOE continues to lease portions of the site, provides some ongoing remediation services, and continues to conduct the Long-Term Surveillance and Maintenance Program. In December 2001, the remaining 8 ac were transferred ownership to the U.S. Army Reserve (DOE 2016). As of 2001, only Building 20 remained contaminated. In April of 2006, DOE demolished Building 20 and remediated the contamination beneath it (DOE 2006).

In June of 2006, DOE issued a report indicating the rest of the site was released with some institutional controls in place to deal with ground water and surface water that contain contaminants in concentrations exceeding regulatory limits. In addition, portions of the subgrade structures and soil

beneath Building 12 still contain uranium and radium contamination. The contamination beneath Building 12 was left in place to preserve the structural integrity of the building. Surveys indicate that the contamination associated with Building 12 does not pose any increased health risk to occupants. All of the exterior land areas have been remediated and are released for unrestricted use. Lastly, the borehole containing radium foil used for calibrating down-hole logging instrumentation was decommissioned, but was not removed. A metal plaque marks the borehole's location and provides a warning not to disturb (DOE 2006).

Table 2-1. History of GJF contaminated buildings/structures.[a]

Building	Constructed	History	Remediated	Demolished
1	1943	Originally a boiler house for the refinery. Later housed the steam boilers and a back-up generator for the facility.	N/A	1996
2	1944	Originally a shower facility and warehouse. Later used for telecommunications and offices. Currently DOE offices.	1997	N/A
6	1953	Originally a bench-scale pilot mill. Subsequently used as a laboratory building and office space.	N/A	1992
7	1952, Remodeled 1956, 1978 1984	Originally a sampling plant and materials staging area. Later used as offices, laboratories, and storage areas. Remediated in two phases and transferred to U.S. Army Reserve.	1999	N/A
7A	1956	Sample plant and sample preparation area from 1956 until March 2001. Demolished in June 2001 during phase III of Bldg 7 remediation.	N/A	2001
12/12A	1953	Built as an engineering office building. Used as an office building and training facility. Approved for deferred remediation of a contaminated former mill slab present under the south wing until Bldg is no longer required. Currently DOE offices.	2000	N/A
18	1975	Training facility. Also used for office space and for the storage of supplies and equipment.	N/A	2001
20	1951, Expanded 1956	Analytical chemistry laboratory. Operations ended December 2003. GJF tried to find a commercial tenant for the facility, but eventually abandoned the idea. It had been released for unrestricted use prior to demolition.	2000	2006
28	1954	Originally built as maintenance and repair facility for vehicles, heavy equipment, and electrical equipment. Also used as site support building with offices and maintenance shops. Remediated and transferred to Riverview Technology Corporation (RTC) business Incubator.	1999	N/A
31	1954	Former large pilot plant building built to house the acid-leach circuit. Subsequently used for storage, including uranium and vanadium concentrates.	N/A	1992
31A	1954	Built as an analytical chemistry laboratory and office building. Later used as a physics and radon laboratory with associated offices.	N/A	1998

Building	Constructed	History	Remediated	Demolished
32	1954	Constructed as a chemical storage area and warehouse. Later used, for seed storage, core preparation and viewing, and radon research. Currently used as a DOE environmental laboratory. A final release survey will be required in affected areas after laboratory operations cease.	2000	N/A
33	1954	Former large pilot plant building. Built as a mill operations building. After mill operations ceased, it was used for storage.	N/A	1998
34	1954	Former large pilot plant building. Built as the boiler house. Later used for storage.	N/A	1996
35	1954	Former large pilot plant building. Built as the uranium ore and yellowcake feed preparation and sample plant.	N/A	1998
36	1945	Originally a paint shop for the small pilot plant. Relocated in 1954 and used as a uranium concentrate drying area for the large pilot plant. Subsequently used for concentrate storage and, later for general storage.	N/A	1996
37	Unknown	Former scale house for truck scale.	N/A	1992
39	Unknown	Metal shed that housed pumps and valves that controlled the supply of fuel from the emergency reserve tanks to the facility back-up generator and boiler plant.	N/A	1992
42	1955	Former hazardous and mixed waste storage building. Assembled and expanded on three occasions from structures located elsewhere on site. Waste was transferred to Bldg 61C in June 2000.	N/A	2000
44	1956	Former storage shed for gas cylinders.	N/A	1994
46	1977	Former cafeteria reconfigured with a sample preparation area for Building 20 after Bldg 7A was closed (March 2001). Activities ended September 2004. Transferred to RTC after final survey.	1999 Final survey 2005	N/A
52	1956	Former radioactive source storage shed.	N/A	1994
62	Unknown	Bag house for Bldg 7A sampling plant	N/A	2001
938	1954-1955, 1981	Former Bldgs 9, 9A, and 38. Office space for exploration geologists and mill support personnel. Later used as offices and conference rooms for DOE contractor personnel. Presently DOE offices.	2000	N/A
3022	1953	Former Bldgs 30, 22, and 22A. Formerly sedimentation and electronics laboratories, warehouse, and storage space. After buildings were joined in 1982, it was used for core storage and logging vehicle support. Later, it was converted to facility maintenance, supply, and procurement warehouse. Building 30 portion of remediation was complete 1/28/99. Transferred to RTC.	1999, 2000	N/A

a. Source: DOE 2006.
b. N/A = not applicable.

3.0 OCCUPATIONAL MEDICAL DOSE

From 1943 through 1946, annual chest and pelvic X-rays were taken of all employees (Ruhoff 1943). For 1947 through 1992, X-rays were taken off site at a doctor's office or the Community Hospital in Grand Junction (DOE undated). However, for a short period between 1962 through 1969, an office of the U.S. Public Health Service brought a portable X-ray unit to GJF three or four times a year and stayed for about a week to X-ray employees (DOE undated).

Dose reconstructors should assume the following:

- Preemployment, annual, and postemployment posterior-anterior (PA) chest and anterior-posterior (AP) pelvis X-rays for each year during the operations period before 1947.

- Preemployment, annual, and postemployment chest X-rays between 1962 and 1969. Because the view geometry is not known and the X-rays were from a portable X-ray machine, assign the more favorable to the claimant view between PA and photofluorographic.

  Note: When assigning post-1962 photofluorographic doses, assume that the photofluorographic doses given in ORAUT-OTIB-0006 for the 1943 to 1962 timeframe to remain unchanged for the post-1962 timeframe (ORAUT 2011a).

- For all other years, X-ray dose is not applicable because they were performed off site at a noncovered facility (ORAUT 2017a).

X-ray doses should be assigned in accordance with ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (ORAUT 2011a).

4.0 OCCUPATIONAL ONSITE AMBIENT AND ENVIRONMENTAL DOSE

There is no need to account for onsite ambient and environmental exposures separately. This is because they are already accounted for in the assessment of unmonitored internal and external worker dose. Unmonitored doses are discussed in Sections 5.0 and 6.0.

In addition, there is no evidence that ambient was subtracted from the monitored dose, therefore no adjustment need to be made to account for ambient dose.

5.0 OCCUPATIONAL INTERNAL DOSE

5.1 INTERNAL SOURCES OF EXPOSURE

Per the SEC determinations, unmonitored intakes cannot be reconstructed prior to 1986 and unmonitored radon exposures cannot be reconstructed prior to February 1975. Limited monitoring data is available during this period. Starting in 1986, available monitoring data is sufficient to perform dose reconstruction for unmonitored workers. During this period, the GJF performed support work for other DOE programs and performed remediation of the GJF buildings and grounds. The principle exposures during this period were to uranium and associated decay products; there was also some limited exposure to thorium during this period.

Based on the methodology described in this site profile, there are only two potential intake rates that will be applied to unmonitored workers after the end of the SEC in 1985 and until 1989. Unmonitored worker exposures will be based either on work performed at the Sampling Plant or on work associated with D&D activities for the years of 1988 and 1989. After 1990, all unmonitored workers exposures

will be limited based on requirements in 5480.11. Therefore, workers' job location is not used in this dose reconstruction approach.

5.1.1 Uranium

Uranium and associated decay products were the principal radiological source of concern at the GJF during operation of the mills in the 1940s and 1950s. Uranium was also the principle concern during the 1948 through 1971 period when the site received and sampled 347 million pounds of uranium. The last of those materials was shipped off-site by January 1975. After 1975, uranium continued to be a source of exposure due to contamination from previous operations and support work for other programs, including remediation of the GJF buildings and grounds.

5.1.2 Thorium

Thorium-232 is not a major contaminant of concern for the overall GJF (DOE 1996c, p. 24). However, ^{232}Th was handled as part of the development of the instrument calibration sources or models. This work was performed in the Sample Preparation Laboratory. The main source of exposure was during the crushing and grinding operations.

Thorium-230 was present as a contaminant of the uranium ore. Most of the radionuclides (other than uranium) remained insoluble during leaching and left the mill (pilot plant) with the solid tailings (Sears 1976). As this implies, ^{230}Th would have been depleted in the concentrates and enhanced in the mill tailings (in relation to uranium).

5.1.3 Radium

Radium-226 was present as a contaminant of the uranium ore and assumed to be in equilibrium with ^{234}U. Most of the radionuclides (other than uranium) remained insoluble during leaching and left the mill (pilot plant) with the solid tailings (Sears 1976). As this implies, ^{226}Ra was depleted in the concentrates and enhanced in the mill tailings relative to uranium.

5.1.4 Radon

Radon would have been present in areas and buildings that processed or handled uranium or in buildings built on tailings piles. As such, radon and its progeny could have presented an inhalation hazard to workers. In addition, GJF operated a radon calibration chamber.

5.1.5 Thoron

Thoron would have been present in the Sample Preparation Laboratory that processed and handled thorium. As such, thoron and its progeny could have presented an inhalation hazard to workers.

5.1.6 Assessment of Source Terms

Tables 5-1 and 5-2 list the isotopic ratios for various source materials that were processed at the GJF Sample Plant after 1985, and apply to all GJF workers. Before 1986, only the radionuclide that was monitored for via bioassay can be assessed because there is not enough information to determine source term isotopic ratios.

Table 5-1. Alpha intake fraction for each radionuclide for uranium ore and tailings, after 1985.[a]

Source	U-238	U-234	Th-230	Ra-226	Po-210
East tailings	0.0884	0.0884	0.2753	0.2839	0.2639
Vanadium tailings	0.0623	0.0661	0.2964	0.3077	0.2675
Climax ore	0.2084	0.2072	0.2046	0.1991	0.1808

a. Source: Donivan and Chessmore (1987).

Table 5-2. Alpha intake fraction for each radionuclide for thorium ore, after 1985.

Th-232	Ra-228[a]	Ac-228[a]	Th-228	Ra-224
0.333	0.333	0.333	0.333	0.333

a. These beta emitters are included because they provide a measurable contribution to the overall dose.

The main use of the thorium ore was the creation of the calibration pads. Table 5-3 provides a list of pads GJF constructed after 1985 with the approximate construction period.

Table 5-3. Thorium ore use, 1986-1988.[a]

Designation	Description	Year
Relocatable pad TL1	Portable spectrometer and scintillation surface pad	1986–1987
Relocatable pad TL2	Portable spectrometer and scintillation surface pad	1986–1987
Relocatable pad TL3	Portable spectrometer and scintillation surface pad	1986–1987
Relocatable pad TL4	Portable spectrometer and scintillation surface pad	1986–1987
Relocatable pad TH1	Portable spectrometer and scintillation surface pad	1986–1987
Relocatable pad TH2	Portable spectrometer and scintillation surface pad	1986–1987
Relocatable pad TH3	Portable spectrometer and scintillation surface pad	1986–1987
Relocatable pad TH4	Portable spectrometer and scintillation surface pad	1986–1987
Soil-based U disequilibrium & mixed U-Th	Reference materials	1986–1988

a. The estimated exposure time for each item listed in the table is 1 month. This exact month of exposure during the years listed is unknown.

Based on interviews (ORAUT 2014a to 2014c), the grinding, crushing, and blending operations for a pad were normally completed within 30 calendar days. The grinding and crushing of the ore, which were the main sources of exposure, would be completed in much less time than a full month. However, the assumption of a full month of exposure to thorium ore for each pad is considered a bounding assumption. The exact construction dates for the pads are unknown, other than they occurred sometime between 1986 and 1988. Therefore, during the period from 1986 to 1988, the source term to be applied to any gross alpha intake rate should be assumed to be to thorium for the first potential 9 months of exposure, but not to exceed 1 month in 1988. After then, only the uranium ore source term should be assumed. This results in the exposure assessment most favorable to the claimant.

In 2001, the demolition of the Sample Plant occurred (GJPORAP 2001), in which the isotopic ratios for thorium ore should also be considered and the exposure more favorable to the claimant between uranium and thorium ore should be assigned.

All radionuclides should be assessed using the solubility that is most favorable to claimants in accordance with ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014d).

5.2 IN VITRO BIOASSAY

There is no comprehensive database of bioassay results for the Grand Junction site.

When the Grand Junction site was established, it was recognized that bioassay might be required for personnel “directly exposed to special materials” (Ruhoff 1943). Urine samples appear to have been analyzed for total uranium by fluorometric methods and reported in mg/L.

In 1971, the Sample Plant was shut down (Author unknown undated a), and by January 1975 the remaining drums of uranium concentrate on the site were shipped out. While analytical laboratory operations continued, the source term for most workers was then reduced to residual building and environmental contamination. The onsite analytical laboratory did not accept high-activity samples, and the workers were not required to be in a bioassay program (ORAUT 2010a).

The samples collected after 1975 were for both on- and offsite work. Therefore, for a given worker, these samples might have been collected for the purpose of monitoring exposures that are not discussed in this site profile. Regardless, exposures should be assumed to be on-site covered exposures unless off-site exposures can be differentiated. Urine and fecal samples collected in 1984, 1986 and from 1990 to 1998, were generally analyzed by alpha spectroscopy. The samples were typically analyzed for $^{234/235/238}$U, but often included ^{230}Th and ^{226}Ra.

For part of this period, there was a prejob sampling program, and many of the samples were collected for this purpose. In the early 1990s, the collected prejob/baseline sample were discarded after a period (about 1 year) if the worker had not been exposed to greater than 10% of the derived air concentration (DAC) (ORAUT 2017c).

Before 1986, source term information on radionuclides associated to uranium could not be determined. These radionuclides are covered under the SEC. Therefore, when assessing bioassay results before 1986, only the intake associated with the bioassay results can be assessed. For 1986 and beyond, the source term information in Section 5.1.6 should be used.

The site revised its *Internal Radiation Dosimetry Program* procedure in 1990 to comply with DOE Order 5480.11 (DOE 1988). A baseline (or pre-job), routine, and a termination (or post-job) bioassay samples were required for all radiation workers that would be working in an Airborne Radioactivity Area (ARA). For workers assigned to areas where mill tailings were present, a routine frequency of monthly sampling was required. In addition, no subcontractors or visitors were allowed to enter an ARA if they were not participating in the Internal Radiation Dosimetry Program (UNC Geotech 1991).

During the 1993 to 1994 period, several GJF employees were involved in nonintrusive radiological field assessment activities at Sandia National Laboratories (SNL). These employees submitted samples for bioassay analysis to the SNL Internal Radiological Dosimetry Program while working at SNL. Some of these samples were analyzed by Controls for Environmental Pollution (CEP) (Renberger 1995). In cases where CEP analyzed bioassay samples, these samples should not be used and the worker should be considered unmonitored. The only other samples sent to CEP were some waste characterization samples, but the results failed quality assurance and were determined to be unusable (Rodinella 1994).

5.2.1 Detection Limits

During the early years, the uranium urinalysis procedure used the fluorometric fusion process, which fused uranium from raw urine with sodium fluoride and measured the fluorescence created by ultraviolet light. This method provided a measure of the total amount of elemental uranium in the sample. The minimum detectable amount (MDA) was not formally established in the early periods (as evidenced by a records search). However, the values in the bioassay data sheets are reported at levels as low as 0.001 mg/L in urine. Guidance from other sites (e.g., the Feed Materials Production Center) that also used the fluorometric fusion process indicates an effective MDA as being near 0.014 mg/L (ORAUT 2017b).

By the early 1980s, personal dosimetry records indicate that isotopic analysis was being performed. Little information has been identified on the procedure for the analyses. However, footnotes in the bioassay reports from UNC Geotech (GJOO 1985–1987) and Lockheed-Martin Idaho Technologies

Center (GJOO 1998–1999) state that results greater than 3 times the total or overall error indicate detection. Therefore, if no MDA is provided, then the MDA is assumed to be 3 times the reported total or overall error.

5.2.2 Uranium Enrichment

There is limited information on the enrichment level of uranium over time throughout the site. Therefore, a generic enrichment level is difficult to determine. If bioassay data is provided in mass units and no information can be identified on the enrichment levels the employee worked with, then the bioassay data should be assessed as natural uranium with activity of 684 pCi/mg (NIOSH 2011b) based on the large amount of natural uranium processed over the history of the plant.

5.3 UNMONITORED INTERNAL EXPOSURE APPROACH

5.3.1 Air Monitoring

Early on, air samples were taken during visits or inspections by AEC. Eventually, the GJF organizations acquired their own sampling and analytical capabilities. Commonly, gross alpha counts were made by scintillation detectors and interpreted as uranium activity. In a few cases, an additional analysis was made for radium. In 1967 and 1968, 16 measurements of ^{222}Rn were made within the Grand Junction compound as a part of a large study of radon from tailings (Sill 1968, p. 14; PHS 1969). In December 1985, three high-volume air samplers were installed to collect environmental onsite air data. The air concentrations of uranium, ^{230}Th, and ^{226}Ra were then reported in the annual environmental reports (UNC Geotech 1987, 1989, 1990a; DOE 1991 to 1994). Radon measurements are available in these reports. The annual atmospheric releases of radioactive materials are available for most years from 1992 through 2001. These reports indicated that very low levels were released; therefore, the on- and offsite environmental concentrations would have been relatively low.

Air sample data from before the start of the D&D work in 1989 are scarce. Before 1989, the most radiologically hazardous onsite work appears to have taken place in the Sample Plant. A 1980 environmental monitoring report stated that the Sample Plant prepared approximately 1,000 samples per month, but that the majority of the samples were exploration samples of low radioactivity rather than of uranium ores. It indicated that the principal environmental problem was the dust generated from grinding and crushing. The report also mentions air sampling in the Sample Plant during July 1980 while ore samples were being prepared. The most concentrated sample contained 0.0046 mg/m^3 of uranium (Korte and Thul 1981). The report indicates that the relevant American Conference of Governmental Industrial Hygienists standard at the time was 0.2 mg/m^3 of uranium. The report also states that very high-grade uranium or thorium ore (5% to 10% U_3O_8 or ThO_2) was handled occasionally in the preparation of calibration models. This operation could produce dust that exceeded the uranium-in-dust standard.

A 1986 memorandum, “Summary of MPC-Time Weighted Exposure for the First Quarter,” provides air monitoring results for three individuals performing grinding of uranium mill tailings (Rothman 1986). The results from these samples are in units of maximum permissible concentration-hours (MPC-hr) per quarter. These data are also supported by bioassay data taken during the work (GJOO 1985–1987).

In March 1990, *Technical Basis for Bioassay Sampling for Sample Preparation Plant and Grand Junction Vicinity Property Workers*, provided a set of air monitoring data for the Sample Preparation Laboratory (UNC Geotech 1990b, p. 9). The data consist of isotopic air concentration measurements for ^{210}Po, ^{226}Ra, ^{230}Th, ^{210}Pb, ^{238}U, and ^{210}Bi.

For the D&D period from 1989 to 2001, numerous air monitoring results are available including breathing-zone samples. For example, the remediation of Building 7, which was contaminated during use for sample preparation, was divided into three phases (areas). There were 60 area measurements and 15 personnel measurements made in Building 7 during Phase III (GJPO 1991–2001a). Most of these measurements were made after a 1994 contamination incident caused by a water leak and during removal of contaminated concrete in 1999. Five hundred and sixty-nine air sample measurement results are available for onsite D&D work after 1988 including both general area and breathing-zone samples (GJPO 1980–1998, 1986–2000, 1990–1991, 1990–1992, 1990–2000, 1991–2000, 1991–2001b, 1992–1996, 1993–1997, 1997). These samples indicate that air concentrations were well controlled during these activities (generally less than 10% of the DAC or action level in use).

5.3.2 Sample Preparation and Analytical Chemistry Operations

After the end of the SEC period (i.e. starting in January of 1986), the sample preparation is considered the highest onsite exposure scenario. The grinding, crushing, and preparation of these samples occurred in the Sample Plant, Building 7A. In March 2001, the sample preparation operations were moved to Building 46. Analytical chemistry operations ended in late 2003. Analytical Chemistry Operations in Building 20 were related to, but less hazardous than, sample grinding, crushing, mixing, etc. in a ventilated, unenclosed area. The chemical digestions of rock and soil samples in Building 20 were carried out in hoods that were necessary because of the strong acids in use.

When samples that potentially contained ore and/or tailings were prepared for the NURE and GJRAP programs, intake rates were calculated by the site based on the GJF quarterly limit of 520 MPC-hr. Rothman (1986) is an example of MPC time-weighted exposures for the first quarter of 1986 for three Sample Preparation Laboratory workers performing grinding of uranium mill tailings. Based on a review of the available limited air and bioassay data, there is no indication that a worker had the potential to exceed the quarterly limit of 520 MPC-hr. The maximally exposed [REDACTED] received [REDACTED] MPC-hr of exposure to soluble ^{230}Th uncorrected for respiratory protection. The results from these samples were compared to the allowable number of MPC-hr (Rothman 1986). Because they were collected over an entire quarter, NIOSH considers these data to be representative of grinding and crushing tailings in the Sample Preparation Laboratory. Therefore, GJF quarterly limit of 520 MPC-hr is considered a bounding limit for exposure. In addition, workers in the Sample Preparation Laboratory were routinely issued respirators. However, no credit should be taken for the protection factor associated with respirators. This assumption is favorable to claimants as it results in maximizing the assigned potential exposure.

Daily intake rates (Table 5-4) were calculated assuming a worker received the MPC-hr limit every quarter. Thorium-230 was used as the limiting radionuclide (which is consistent with the calculation in Rothman 1986). The limiting MPC for ^{230}Th was 2.00×10^{-12} µCi/mL (DOE 1981), which is what would have been used to control exposures.

5.3.3 Decontamination and Decommissioning

GJF officially began D&D in 1984, but before 1988 or 1989 the initial activities were surveys and so forth with minimal work that actually disturbed surfaces. Most of the D&D projects were short term, occurring over a few months. All available D&D air sample data were used to determine the 95th-percentile air concentration (2.66×10^{-12} µCi/mL) of the lognormal distribution for the entire D&D period (GJPO 1972-1999; 1980-2000a; 1980-2000b; 1985-1999; 1986-2000; 1990; 1990-1992; 1990-2000; 1991-2000; 1991-2001a; 1991-2001b; 1991-2001c; 1992-1996; 1993-1999; 2001). This resulted in an estimate of the workforce's exposure, that is favorable to claimants, as provided in Table 5-5.

5.3.4 Implementation of DOE Order 5480.11

The 1990 technical basis for bioassay sampling (UNC Geotech 1990b) lays out the implementation of DOE Order 5480.11 (DOE 1988) for monitoring workers. The 1990 technical basis for bioassay sampling specifies that bioassay would be collected if exposure indicated that a worker could be exposed to inhalation intakes during the year that exceeded 0.1 ALI. This is implemented in the GJF Procedure 3.8, *Internal Radiation Dosimetry Program*, which indicates that any worker working in any area posted as an ARA (area with the potential to exceed 10% of a DAC) should be routinely monitored. The 10% of a DAC requirement in Procedure 3.8 is analogous with the 1990 GJF technical basis requirement of 0.1 ALI = 200 DAC-hr = 2000 hr @ 10% DAC. The GJF used its workplace monitoring program in the 1990s to identify any potential source of airborne radioactivity.

Any radiation workers that would be then be tasked to work in an ARA would have been required to provide a baseline (or pre-job), routine, and termination (or post-job) bioassay sample. For workers entering an ARA, a routine frequency of monthly sampling was required. In addition, no subcontractors or visitors were allowed to enter an ARA if they were not participating in the Internal Radiation Dosimetry Program (UNC Geotech 1991). Special bioassays may also be required if an exposure event occurred (e.g., facial contamination) or if air sampling revealed unexpectedly high airborne concentrations (UNC Geotech 1991).

Based on interviews with health and safety personnel (ORAUT 2017c), this process was implemented by the start of 1991. Therefore, starting in 1991, it is assumed that any unmonitored (no bioassay monitoring) routine radiation worker would not have exceeded 0.1 ALI in a given year. Job categories that fall into routine radiation workers are Operator and Laborer workers. These are workers that would routinely work in contamination areas.

All other workers that would not routinely work in in a contamination area should be considered a non-radiation worker. These included Administrative worker job categories. According to the 1990 technical basis for bioassay sampling (UNC Geotech 1990b), if the results of the workplace monitoring program indicate that there was a potential for an intakes greater than 0.02 ALI to have occurred, individual worker monitoring (i.e., follow-up bioassay samples) should be initiated. Therefore, 0.02 ALI should be considered bounding for an unmonitored non-radiation worker, such as Supervisors and Administrative worker job categories. This was confirmed by health and safety personnel (ORAUT 2017c), that ambient airborne radioactivity levels were low and are bounded by the assignment of 0.02 ALI per year.

The 1990 technical basis for bioassay sampling reiterates that the controlling radionuclide was ^{230}Th. The limiting DAC for ^{230}Th is 3.00×10^{-12} µCi/mL (DOE 1988). Table 5-6 provides the calculated intake rates for unmonitored workers based on these limits.

5.3.5 Radon and Thoron

By February 1975, the last of the drums containing uranium concentrate had been shipped off site, but the ^{226}Ra in surface contamination, in soils, and under and around the buildings remained relatively constant until remediation of the outdoor areas. Radon in buildings was studied extensively during D&D (1989 to 2001). There were indoor radon progeny measurements for most of the buildings, including 300 measurements in 1985 in some of the former Pilot Plant buildings. Only Building 34 (Henwood and Ridolfi 1986, p. 36), the former Boiler building for the large Pilot Plant, exceeded 0.02 working level (WL) (averaged over 100 hours). This building had been used to store ore and yellowcake and was not routinely occupied (GJAO 1984, p. 2).

In 1990, the site implemented and participated in the DOE radon study that included all occupied buildings on site at that time. The study's measurements were representative of the highest radon

levels in those portions of the buildings that were fit for occupancy (DOE 1990, p. 19). Analysis of these data indicates that the median concentration was 2.2 pCi/L or 0.011 WL, assuming a typical indoor equilibrium factor of 0.5. Only three buildings had activity levels greater than EPA's recommended action level of 4 pCi/L or 0.020 WL (UNC Geotech 1990d): Building 26 (4.5 pCi/L), Building 30B (5.7 pCi/L), and Building 32 (4.9 pCi/L) (DOE 1990). These three buildings were reassessed in 1997 and 1998 after remediation, and all measured less than 1.6 pCi/L or 0.008 WL (Wastren 1997; Egidi and Green 1999; Various 1980–2000). These remediated radon levels are lower than the average indoor radon levels in Mesa County (Author unknown undated b). Therefore, no radon exposure should be assigned for the postremediation period.

GJF made routine calibrations on thoron instruments (George 1992; Pearson 1990), which indicates the site was capable of detecting routine thoron levels. However, no direct thoron measurement could be identified. Therefore, thoron levels were assumed to be equivalent to radon. This is considered bounding because the thoron source term (thorium) would be much less than that of the radon source term (radium from uranium). Therefore, it is unlikely that the thoron air concentration would have exceeded the radon air concentration. Radon and thoron exposure rates are provided in Table 5-7, and apply to all GJF workers.

In addition, GJF operated a radon calibration chamber. The radon calibration chamber was used for calibrating, testing, and evaluating both radon and radon-daughter measuring instruments. The chamber was an environmentally controlled cylindrical vessel through which air containing radon was circulated (GJPO 1985). Based on interviews with health and safety personnel (ORAUT 2017c), "when in use," the chamber was posted as an ARA. During use, access to the chamber was controlled with double entry locking doors and no personnel where allowed in the chamber. GJF Procedure 3.8, *Internal Radiation Dosimetry Program*, indicates that for radon worker entry logs shall be maintained. These logs shall indicate the date, time, concentration, and stay time (UNC Geotech 1991). Any exposure from radon while working around the radon calibration chamber were calculated as WLM and should be provided in a workers exposure file (ORAUT 2017c).

5.3.6 Summary of Unmonitored Internal Exposure Rates

Before 1986 for particulates, and before 1975 for radon and thoron, no unmonitored internal exposures should be assessed in accordance with SEC-00175 (NIOSH 2011a, 2015). Only exposures associated with bioassay data for the individual should be assessed.

Gross alpha inhalation and ingestion intake rates by job category for all GJF workers are provided in Tables 5-4 through 5-6 for the period after 1985. These are default intakes for workers who have no bioassay data. Dose reconstructions also need to consider any available bioassay data for a worker. Section 5.1.6 provides the isotopic source terms to apply to these gross intake rates. In addition, all workers should be assigned the radon and thoron exposures from the rates in Table 5-7 for the period after February 1975 through 1998.

During certain years, the unmonitored approach periods overlap for various job categories. Therefore, where there is little or no information available to determine the appropriate exposure scenario, the more favorable to the claimant assumption should be used. All radionuclides should be assessed using the solubility that is most favorable to claimants in accordance with ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014d).

Table 5-4. Sample Plant gross alpha inhalation and ingestion intake rates by job category (pCi/calendar day), 1986 to 1990.[a]

Job category[b]	Inhalation	Ingestion
Operator/Laborer	13.68	0.274
Supervisor[c]	6.84	0.137
Administrative[d]	0.68	0.014

a. All intakes assigned as a constant distribution.
b. All job categories are used as generic titles and the merits of each individual claim should be considered when determining which exposure potential category that individual claims falls into.
c. Supervisor dose is assumed to be one-half of the Operator/Laborer dose (NIOSH 2011b).
d. Administrative dose is assumed to be one-tenth of the Supervisor dose (NIOSH 2011b).

Table 5-5. D&D gross alpha inhalation and ingestion intake rates (pCi/calendar day), 1988 to 1990.[a]

Job category[b]	Inhalation	Ingestion
Operator/Laborer	17.5	0.350
Supervisor[c]	8.75	0.175
Administrative[d]	0.87	0.017

a. All intakes assigned as a constant distribution.
b. All job categories are used as generic titles and the merits of each individual claim should be considered when determining which exposure potential category that individual claims falls into.
c. Supervisor dose is assumed to be one-half of the Operator/Laborer dose (NIOSH 2011b).
d. Administrative dose is assumed to be one-tenth of the Supervisor dose (NIOSH 2011b).

Table 5-6. Gross alpha inhalation and ingestion intake rates (pCi/calendar day), after 1990.[a,b]

Job category[c]	Inhalation	Ingestion
Operator/Labor worker[d]	1.97	0.039
Supervisor/Administrative worker[e]	0.39	0.008

a. All intakes assigned as a constant distribution.
b. Intakes are assumed to be uranium ore or tailings for all years other than 2001. In 2001, the demolition of the Sample Plant occurred (GJPORAP 2001), in which the isotopic ratios for thorium ore should also be considered and the exposure more favorable to the claimant between uranium and thorium ore should be assigned.
c. All job categories are used as generic titles and the merits of each individual claim should be considered when determining which exposure potential category that individual claims falls into.
d. Based on 10% of a DAC for 2000 hours resulting in 200 DAC-hr or 0.1 ALI per year.
e. Based on 2% of a DAC for 2000 hours resulting in 40 DAC-hr or 0.02 ALI per year.

Table 5-7. Radon and thoron exposure rates, February 1975 through 1998.[a]

Source	Year	Concentration (pCi/L)	WL	WLM/yr[b]
Radon	1975–1998	5.7	2.85E-02	0.340
Thoron[c]	1975–1998	5.7	7.60E-01	8.941

a. Rates not applicable after 1998 as buildings were reassessed after remediation and released.
b. WLM = working level month; assigned as a constant distribution.
c. Thoron WLM exposures should be assessed based on guidance in DCAS-TIB-0011.

5.4 INCIDENTS

After January 1975, the number of documented incidents that could have resulted in internal doses was relatively small. There are two reports of interest. In 1992, there was a spill of yellowcake during disposal of what was thought to be UMTRA Project soil samples. [REDACTED] individuals were involved, and initial 24-hour urine samples and follow-up samples were collected. A formal investigation indicated that one of the samples (from [REDACTED] who was involved but not contaminated), had been contaminated with material that was not involved in the spill (Chem-Nuclear Geotech 1993, Appendices E through K). The identities of the individuals involved are not given in the report, but can be determined from a 1992 report of internal doses to DOE.

In a second incident in 1994, a water leak occurred during work involving conversion of old yellowcake processing areas into office space that contaminated the spaces below. Fecal samples were collected. There was "no significant activity in the samples." (King 1994). The names of the individuals involved are given.

In general, the GJF should be providing incident reports from a workers exposure history file.

6.0 OCCUPATIONAL EXTERNAL DOSE

Per the SEC determinations, unmonitored external exposures cannot be reconstructed prior to 1960. If monitoring data prior to 1960 exists then it should be included in the assessment, if it is determined that there is sufficient information available to assess it.

6.1 EXTERNAL SOURCES OF EXPOSURE

The radiation source (other than X-ray procedures) for external exposure at Grand Junction was primarily uranium. External exposures were (1) the result of direct radiation exposure from handling and working with uranium ore and tailings and (2) submersion in the contaminated dust cloud (NIOSH 2011a, p. 32).

The photons were from uranium, ^{226}Ra, and uranium progeny. There were high-energy beta radiation exposures for workers in close proximity to the ore that contributed to shallow dose. Neutron radiation was also present from ^{252}Cf and AmBe sources and neutron generators such as a linear accelerator in some periods. Well-logging involved a low potential photon and neutron exposure (NIOSH 2011a, p. 38; ORAUT 2010b, p. 6).

6.2 EXTERNAL MONITORING PROGRAM

Early in GJF history, some workers were provided with film badges (GJPO 1952; GJEB 1952–1953). The New York Operations Office (NYOO) Fiscal Year 1953 Film Badge Summary (AEC 1953, pp. 28–31) showed the beta/gamma results for 757 individuals.

Film badge use restarted in 1957 (GJEB 1957; GJOO 1957). Memoranda from January 3 and 8, 1957, address the concern that radioactive dust can accumulate on film badges, and wrapping the dosimeters in thin film was offered as solution to the surface contamination problem (Harris 1957). Fourteen film badges were initially sent from the NYOO to GJF for use for a 2-week period. The first set indicated exposure to gamma radiation, and GJF was advised to continue the use of film dosimeters.

In a March 1958 letter to NYOO, GJF requested discontinuation of the film badge program until further notice due to the lack measured exposure (GJEB 1958, p. 2). There is a note on top of the NYOO Film Badge Report for the period from March 31 and April 7, 1958, that it is the last batch (GJEB 1958, p. 3). The film badge service then appears to have been restored and more film badge results are available through 1959 (GJOO 1959).

In the 1960 "Summary of Whole Body Radiation Exposures to External Penetrating Radiation Accumulated During the Year" report from the Chicago Operations Office, [REDACTED] Lucius Pitkin workers were monitored. The remaining 389 workers (138 Lucius Pitkin and 251 AEC) were not monitored (AEC 1960–1961, p. 30).

In the 1961 "Summary of Whole Body Radiation Exposures to External Penetrating Radiation Accumulated During the Year" report from the Chicago Operations Office (AEC 1961–1962, p. 40), 47 workers (29 Lucius Pitkin and 18 AEC) were reported to have been monitored with film badges and

Cambridge self-reading dosimeters. The remaining 304 workers (114 Lucius Pitkin and 190 AEC) were not monitored. The footnotes indicate that the film badges were worn by Lucius Pitken workers at the Sample Plant and in the Electronics Laboratory and by AEC employees working with a neutron source.

The Grand Junction Project Summary report from Reynolds Electrical & Engineering Company (REECo) indicates that the GJF dosimetry service was provided by REECo from 1967 through 1981 (REECo 1991, p. 5). No GJF dosimeter specifications are available during this time period, therefore a surrogate site is required. Because REECo operated the Nevada Test Site (NTS), it is reasonable to assume that the dosimeter technical information from NTS is an applicable surrogate for the GJF dosimeter. At NTS, REECo used a DuPont 301-4 Packet from 1960 to 1965. From 1966 to February 1971, the NTS dosimeter was a DuPont Type 556 Packet. From March 1971 through 1986, NTS switched to a Kodak Type III film dosimeter (ORAUT 2012).

The neutron dosimeter NTS used from 1961 through part of 1979 was Kodak nuclear track emulsion, type A, with a monthly exchange frequency. Starting in 1979 and through 1986, REECo switched to Hankin-type albedo thermoluminescent dosimeters (TLDs) with four pairs of TLD-600 and TLD-700 (^{6}LiF and ^{7}LiF) chips in cadmium pillboxes for thermal neutron suppression. Hankin-type albedo dosimeters have high sensitivity to low-energy neutrons, with decreasing response as energy increases. The exchange frequency was monthly (ORAUT 2012).

The 1980 beta/gamma dosimeter results for all the monitored workers at the Sample Plant and Chemistry Laboratory showed zero dose, and again a proposal was made to discontinue badging for those personnel unless a change in duties was anticipated (Thul 1981).

In June 1980, GJF received a REECo proposal to change the personnel dosimeters from Kodak Type III film badges to albedo TLD badges for neutron monitoring (Schiager 1980). The Hankin-type albedo TLD badge (in use at NTS from 1979 to 1986) used ^{6}LiF and ^{7}LiF TLD chips to respond to neutron plus beta/gamma and beta/gamma-only exposures.

Neutron doses of 10 mrem were expected to be detected routinely even though REECo did not claim a sensitivity below 30 mrem. The REECo proposal to change from Type III film dosimeters to albedo TLDs was accepted with the plan to make the change in 1980. However, film dosimeters were still in use at GJF as of September 1980 (Bendix 1980, p. 41). It has not been possible to determine when, or if, GJF actually started to use the Type III albedo TLD.

By the fourth quarter of 1981, the dosimetry service for GJF was being provided by the Idaho Operations Office and so can be assumed to be similar to that at Idaho National Laboratory (INL) (Gesell 1982). The dosimeter used by INL in 1981 was a commercial Harshaw system with two LiF TLDs that were 240 mg/cm^2 thick. One chip was covered by 540 mg/cm^2 (initially 350 mg/cm^2) of aluminum, and the other was under 4 mg/cm^2 of Mylar. The aluminum-covered chip provided penetrating dose at a nominal tissue depth of 1 cm.

The beta dose was calculated from the difference between the two TLD chips. Because of the thickness of the Mylar-covered chip, the beta dose was accurate only for the beta energy used in calibration. Field calibrations were used to reduce the problem of beta energy dependence (ORAUT 2011b). The reporting level of the Harshaw dosimeter for penetrating and nonpenetrating radiation was 15 mrem (Gesell 1996; ORAUT 2011b).

In 1986 with the advent of the DOE Laboratory Accreditation Program (DOELAP), INL changed to the four-element Panasonic 814 AS4 TLD system (ORAUT 2011a). Elements 1 and 2 with lithium borate ($Li_2B_4O_7$) phosphor elements had plastic and aluminum filtration to provide an improved measurement of deep dose equivalent and, with a thinner filter, an improved measurement of the shallow dose

equivalent. Calcium sulfate ($CaSO_4$) phosphor in elements 3 and 4 provided a strong low-energy photon response (INEEL 2001).

Each Panasonic element was 15 mg/cm^2 thick. Element 1 had filtration of 16 mg/cm^2, element 2 had 58 mg/cm^2 of plastic, element 3 had 550 mg/cm^2 of plastic, and element 4 had 50 mg/cm^2 of aluminum (INEEL 2001).

The minimum reporting level of 15 mrem was retained in the INL Panasonic Dosimetry System, but their experience indicated that, for penetrating radiation, the detection limit of 10 mrem was not expected to result in false positive readings. For nonpenetrating radiation, the reporting level of 30 mrem was expected to eliminate false positive readings (Gesell 1996).

The GJF badge exchange frequency in the 1990s was quarterly. The Hankin albedo neutron dosimeter was added to the badge for the workers involved with well-logging and for Radiological Assistance Program team members. Only the radiation workers were monitored, not the office workers (ORAUT 2010b; UNC Geotech 1990c).

The initial SEC evaluation report states that interviews indicate TLDs were used during the NURE Program and GJRAP. A small number of employees who worked with neutron-generating equipment had neutron dosimetry, but the results were not available to review and the specific type of dosimetry is unknown (NIOSH 2011a, p. 47). However, the technical basis for the INL personal neutron dosimeter (Gesell et al.1996) describes a Hankin-type two-chip dosimeter. The reporting level of the INL Hankin albedo dosimeter was 15 mrem (Gesell et al. 1996, p. 19). The technical basis for the INL personal photon/beta dosimeter states that, for those employees at INL who had the potential for exposure to neutrons, a special Panasonic dosimeter with an attached albedo dosimeter was provided (Gesell, Hall, and Anderson 1992, p. 16).

6.3 EXTERNAL MONITORING DATA

Exposure records are maintained at the Grand Junction office and in a database maintained by INL. A data report was provided by INL that includes personnel believed to be associated with Grand Junction through the use of INL location codes (SRDB Ref. ID: 107374). This report has data between the years 1982 and 1998 and contains over 15,000 records, each with a gamma and beta result. There are also occasional neutron results in this spreadsheet. The persons listed in this report may include individuals involved in off-site remediation work. As claimant-favorable assumption, all exposures listed in this report would be assumed to have occurred on-site.

A series of twenty-five files (SRDB Ref. ID: 102151-102158, 102195, 102208, 102229, 102231-102233, 102242-102343, 102391, 102393, 102410, 102415-102416, 102450, 102469, 102472, and 102506) have been added to the SRDB from Grand Junction that comprises dosimetry files. Each file contains documents for persons whose last names begin with an A, B, C, etc.

Although NIOSH found that it is not possible to bound the external dose prior to 1960, any external monitoring data that might become available for an individual claim during this time period can be included if the information below allows for it to be interpreted.

6.4 EXTERNAL DOSIMETRY LIMITS OF DETECTION AND RADIATION FIELDS

6.4.1 Photon

Exposure to photons was possible during all phases of handling and processing the natural uranium ore. Radium-226 was also a source of external exposure to the workers. Other gamma-emitting uranium progeny from the ^{238}U and ^{235}U decay chains were present and contributed to the photon

exposure, although the ^{235}U concentration represents a small part (0.0072% by weight) of the isotopic composition of natural uranium while ^{238}U represents 99.27% by weight. Penetrating doses should be assessed as 100% 30- to 250-keV photons using an acute exposure rate. Table 6-1 shows the LODs and exchange frequencies for photon exposures.

Table 6-1. Gamma LODs and exchange frequencies.

Period	Type	LOD	Exchange frequency	Source
1960–02/1971	Film	40 mR	Monthly	ORAUT 2012, p. 19
03/1971–1981[a]	Film	30 mR	Monthly	ORAUT 2012, p. 20
1981–1985	TLD	15 mrem	Quarterly	ORAUT 2011b, pp. 21, 40
01/1986–07/1986	TLD	15 mrem	Quarterly	ORAUT 2011b, pp. 21, 40
08/1986–09/1989	TLD	10 mrem	Quarterly	ORAUT 2011b, pp. 21, 40
10/1989–1993	TLD	15 mrem	Quarterly	ORAUT 2011b, pp. 21, 40
1994–present	TLD	10 mrem	Quarterly	ORAUT 2011b, pp. 21, 40

a. For 1981, there is no documentation on when the site switched from film to TLDs. Therefore, if the type cannot be determined from the records, then the more favorable assumption should be made.

For dose conversion factors (DCFs) for 1960 to 1985, before DOELAP, dose reconstructors should apply the exposure (R) dose equivalent DCF values in accordance with the OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (NIOSH 2007). After that (1986 to 2006), doses should be considered deep dose equivalent [*Hp(10)*], and dose reconstructors should apply those DCF values in accordance with OCAS-IG-001.

6.4.2 Beta

Shallow dose should be assigned as an acute dose of 100% >15-keV electrons. Shallow measured and missed doses should be based on the dosimetry records in accordance with ORAUT-OTIB-0017, *Interpretation of Dosimetry Data for Assignment of Shallow Dose* (ORAUT 2005). Table 6-2 shows the LODs and exchange frequencies for beta exposures.

Table 6-2. Beta LODs and exchange frequencies.

Period	Type	LOD (mrem)	Exchange frequency	Source
1960–02/1971	Film	40	Monthly	ORAUT 2012, p. 19
03/1971–1981[a]	Film	30	Monthly	ORAUT 2012, p. 20
1981–1985	TLD	15	Quarterly	ORAUT 2011b, p. 40
01/1986–07/1986	TLD	15	Quarterly	ORAUT 2011b, pp. 21, 40
08/1986–09/1989	TLD	30	Quarterly	ORAUT 2011b, pp. 21, 40
10/1989–1993	TLD	30	Quarterly	ORAUT 2011b, pp. 21, 40
1994–present	TLD	30	Quarterly	ORAUT 2011b, pp. 21, 40

a. For 1981, there is no documentation on when the site switched from film to TLDs. Therefore, if the type cannot be determined from the records, then the more favorable assumption should be made.

6.4.3 Neutron

Neutron sources such as ^{252}Cf and neutron generators with deuterium and tritium targets were used on site by one contractor (ORAUT 2010c). There is a reference to Grand Junction purchasing a "small quantity" of zetatrons (a neutron-producing device that uses a tritium target) sometime between 1991 and 1995. The same reference indicates no zetatrons at Grand Junction from 1980 to 1990 (Lutz 1995). Neutron doses should be assessed as 100% 0.1- to 2-MeV neutrons with International Commission on Radiological Protection Publication 60 weighting factors (ICRP 1991) using a chronic exposure rate.

TLD badge doses should be assessed using deep dose equivalent [$Hp_{slab}(10)$] for all years, in accordance with OCAS-IG-001 (NIOSH 2007). Table 6-3 shows the LODs and exchange frequencies for neutron exposures.

Table 6-3. Neutron LODs and exchange frequencies.

Period	Type	LOD (mrem)	Exchange frequency	Source
1960–1981[a]	Film	50	Monthly	ORAUT 2012, p. 21
1981–present	TLD	15	Quarterly	ORAUT 2011b, p. 41

a. For 1981, there is no documentation on when the site switched from film to TLDs. Therefore, if the type cannot be determined from the records, then the more favorable assumption should be made.

6.5 UNMONITORED EXTERNAL EXPOSURE APPROACH

No unmonitored external exposures should be assessed for periods before 1960 (NIOSH 2011a, 2015). Only exposures associated with dosimetry data for the individual should be assessed.

All unmonitored external doses should be assigned as a constant distribution.

6.5.1 Photon

The maximum values from the DOE Annual Report Summary, or the 95th-percentile value from the Radiation Exposure Monitoring System (REMS) database (DOE 2010) were applied as a single exchange. Missed dose was applied to all other exchanges. These values were used to determine annual doses for the unmonitored Operator/Laborer category, as shown in Table 6-4. Supervisor and Administrative category doses were determined by scaling as explained in the footnotes.

Table 6-4. Unmonitored gamma dose (rem).

Year	Operator/Laborer[a]	Supervisor[b]	Administrative[c]
1960	1.220	0.610	0.240
1961	1.220	0.610	0.240
1962	1.220	0.610	0.240
1963	1.220	0.610	0.240
1964	1.220	0.610	0.240
1965	1.220	0.610	0.240
1966	1.220	0.610	0.240
1967	1.220	0.610	0.240
1969	1.220	0.610	0.240
1970	1.220	0.610	0.240
1971	1.175	0.588	0.190
1972	1.165	0.583	0.180
1973	1.165	0.583	0.180
1974	1.165	0.583	0.180
1975	0.915	0.458	0.180
1976	0.180	0.180	0.180
1977	0.665	0.333	0.180
1978	0.665	0.333	0.180
1979	0.915	0.458	0.180
1980	1.165	0.583	0.180
1981[d]	1.165	0.583	0.180
1982[d]	1.023	0.511	0.051
1983[d]	1.023	0.511	0.051
1984[d]	1.023	0.511	0.051
1985	0.080	0.040	0.030
1986	0.054	0.027	0.025

Year	Operator/Laborer[a]	Supervisor[b]	Administrative[c]
1987	0.077	0.038	0.020
1988	0.045	0.040	0.040
1989	0.067	0.034	0.023
1990	0.067	0.033	0.030
1991	0.043	0.030	0.030
1992	0.074	0.037	0.030
1993	0.036	0.030	0.030
1994	0.033	0.020	0.020
1995	0.026	0.020	0.020
1996	0.038	0.020	0.020
1997	0.025	0.020	0.020
1998	0.087	0.043	0.020
1999	0.025	0.020	0.020
2000	0.025	0.020	0.020
2001	0.022	0.020	0.020
2002	0.031	0.020	0.020
2003	0.039	0.020	0.020
2004	0.025	0.020	0.020
2005	0.025	0.020	0.020
2006	0.022	0.020	0.020
2007	0.022	0.020	0.020
2008	0.024	0.020	0.020
2009–present	0.042	0.021	0.020

a. Doses through 1980 are based on a maximum value from the DOE annual summaries. Doses after 1984 were based on the 95th percentile of the REMS data (DOE 2010) for badges with end dates in that year. Values were applied as a single exchange, and missed dose was applied to all other exchanges.
b. Supervisor dose is assumed to be one-half of the Operator/Laborer dose or missed dose for all exchange frequencies (NIOSH 2011b).
c. Administrative dose is assumed to be one-tenth of the Supervisor dose or missed dose for all exchange frequencies (NIOSH 2011b).
d. Based on a maximum recorded dose for adjacent years plus missed dose based on that year's dosimetry requirements and LOD.

6.5.2 Beta

No beta dose data were found for the early years (before 1950). A beta/gamma ratio for the 1950s era data was calculated to be 1.2. Using data from REMS (DOE 2010) for 1985 and later, an average beta/gamma ratio was calculated to be 1.5. Because this data from after 1985 include exposure from offsite remediation activities, the beta component could be expected to be high in comparison with onsite activities. To be favorable to claimants, dose reconstructors should use the higher ratio of 1.5 to bound unmonitored shallow dose.

6.5.3 Neutron

There is limited data for neutron exposures from before 1985 in individual claimant files. However, there is exposure data from REMS (DOE 2010) from 1985 through 2009, and there is no indication that the source term was different before then. This data was analyzed to obtain the 95th and 50th percentiles, which are considered bounding estimates for unmonitored neutron exposures to geologists and all other workers, respectively. Table 6-5 lists those percentiles.

Table 6-5. Unmonitored neutron dose (rem/yr).

Job category	Period	Measured dose	Missed dose	Total dose
Geologist[a]	Before 1981	0.123	0.275[c]	0.398
Geologist[a]	1981–1985	0.123	0.0225[d]	0.1455

Job category	Period	Measured dose	Missed dose	Total dose
All other[b]	Before 1981	0.0315	0.275[c]	0.3065
All other[b]	1981–1985	0.0315	0.0225[d]	0.054

a. Based on 95th percentile.
b. Based on 50th percentile.
c. 0.275 rem = (12 – 1) × (0.050/2).
d. 0.0225 rem = (4 – 1) × (0.015/2).

The number of workers that had potential for neutron exposure was small due to the limited role of neutron sources at GJF (Duray 1981a; Various 1979–1981; Bendix 1981). Therefore, the 95th percentile applies only to the Geologist job category, and the 50th percentile applies to all other job categories. After 1985, based on a review of GJF records, neutron dosimetry records are assumed to be complete. Therefore, no unmonitored dose should be assigned after 1985.

7.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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GLOSSARY

acute exposure
Radiation exposure to the body delivered in a short period. See *chronic exposure*.

annual limit on intake
Historical dose limit that represents the activity of a radionuclide which, taken alone, would irradiate a person, represented by Reference Man, to the limit set by the International Commission on Radiological Protection for each year of occupational exposure.

bioassay
Measurement of amount or concentration of radionuclide material in the body (in vivo measurement) or in biological material excreted or removed from the body (in vitro measurement) and analyzed for purposes of estimating the quantity of radioactive material in the body. Also called radiobioassay.

chronic exposure
Radiation dose to the body delivered in small amounts over a long period (e.g., days or years). See *acute exposure*.

decommissioning
Removal of a facility from service, usually involving decontamination of radioactivity to specified levels and often involving demolition of the facility.

decontamination
Reduction or removal of radioactive material from a structure, area, object, or person. Decontamination can occur through (1) treating the surface to remove or decrease the contamination or (2) allowing natural radioactive decay to occur over a period of time.

derived air concentration (DAC)
Annual limit on intake of a radionuclide divided by the volume of air inhaled by Reference Man in a working year (2.4×10^3 cubic meters). A DAC-hour is the exposure to a person breathing the DAC for 1 hour. See *working level*.

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

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

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

internal dose
Dose received from radioactive material in the body.

in vitro bioassay

Measurements to determine the presence of or to estimate the amount of radioactive material in the excreta or in other biological materials removed from the body.

Manhattan Engineer District

Subdivision of the U.S. Army Corps of Engineers that administered the World War II Manhattan Project to develop the first nuclear bomb. The word *Manhattan* was chosen to divert attention from the Project's real purpose. The U.S. Atomic Energy Commission assumed control of District facilities and activities in 1946.

occupational dose

Internal and external ionizing radiation dose from exposure during employment. Occupational dose does not include that from background radiation or medical diagnostics, research, or treatment, but does include dose from occupationally required radiographic examinations that were part of medical screening.

occupational environmental dose

Dose received while on the grounds of a site but not inside a building or other facility.

occupational medical dose

Dose from X-ray procedures performed for medical screening of workers as part of an occupational health program. Doses from X-rays used to diagnose diseases or injuries, even if incurred on the job, are not considered occupational and are therefore not eligible to be included in dose reconstruction under the Energy Employees Occupational Illness Compensation Program Act of 2000.

site profile

Oak Ridge Associated Universities Team document that describes a U.S. Department of Energy or atomic weapons employer site. U.S. Department of Energy site profiles usually consist of six technical basis documents: Introduction, Site Description, Occupational Medical Dose, Occupational Environmental Dose, Occupational Internal Dosimetry, and Occupational External Dosimetry. Site profiles for atomic weapons employers generally incorporate the relevant portions of those topics into a single.

source term

Description of the types and quantities of radioactive materials. The source term is usually specified as a rate of exposure or an amount of radioactivity (i.e., becquerels or curies), sometimes by specific radionuclide. Often includes distinctions in chemical and physical forms and history of the material.

Special Exposure Cohort (SEC) [42 U.S.C. § 7384l(14)]

… "member of the Special Exposure Cohort" means a Department of Energy employee, Department of Energy contractor employee, or atomic weapons employee who meets any of the following requirements:

(A) The employee was so employed for a number of work days aggregating at least 250 work days before February 1, 1992, at a gaseous diffusion plant located in Paducah, Kentucky, Portsmouth, Ohio, or Oak Ridge, Tennessee, and, during such employment—

(i) was monitored through the use of dosimetry badges for exposure at the plant of the external parts of employee's body to radiation; or

(ii) worked in a job that had exposures comparable to a job that is or was monitored through the use of dosimetry badges.

(B) The employee was so employed before January 1, 1974, by the Department of Energy or a Department of Energy contractor or subcontractor on Amchitka Island, Alaska, and was exposed to ionizing radiation in the performance of duty related to the Long Shot, Milrow, or Cannikin underground nuclear tests.

(C) (i) Subject to clause (ii), the employee is an individual designated as a member of the Special Exposure Cohort by the President for purposes of the compensation program under section 7384q of this title.

(ii) A designation under clause (i) shall, unless Congress otherwise provides, take effect on the date that is 180 days after the date on which the President submits to Congress a report identifying the individuals covered by the designation and describing the criteria used in designating those individuals.

thermoluminescent dosimeter (TLD)

Device for measuring radiation dose that consists of a holder containing solid chips of material that, when heated, release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

U.S. Atomic Energy Commission (AEC)

Federal agency created in 1946 to assume the responsibilities of the Manhattan Engineer District (nuclear weapons) and to manage the development, use, and control of nuclear energy for military and civilian applications. The U.S. Energy Research and Development Administration and the U.S. Nuclear Regulatory Commission assumed separate duties from the AEC in 1974. The U.S. Department of Energy succeeded the U.S. Energy Research and Development Administration in 1979.

U.S. Department of Energy (DOE)

Federal agency created in 1979 that assumed, from the U.S. Energy and Research Development Administration, the responsibility for development of new reactors, production and use of nuclear materials, and production of nuclear weapons by the Federal government.

U.S. Department of Labor (DOL)

Agency that oversees compliance with Federal labor laws and collects labor-related information. DOL is responsible for compensation decisions under the Energy Employees Occupational Illness Compensation Program Act of 2000.

working level (WL)

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

working level month (WLM)

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