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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/01/2006	00	New document to establish the technical basis for the development of a radiation exposure matrix for Allied Chemical Corporation Plant. First approved issue. Training required: As determined by the Task Manager. Initiated by Cindy W. Bloom.
10/01/2007	01	Approved Revision 01 initiated to add text in Section 2.0 and remove information regarding nonuranium radionuclides in Sections 3.0 and 5.0 to incorporate SEC evaluation report recommendation to not reconstruct nonuranium internal dose. Moved Figure 2-1. Incorporates formal internal and NIOSH review comments. Added reference for employee statement regarding X-rays. Constitutes a total rewrite of the document. The recently designated residual period is identified. Section 5.0, Estimating Exposures From Residual Radioactivity, expanded to address dose reconstruction methodologies for exposures received during the residual period. Added Attributions and Annotations section and additional references. Training required: As determined by the Task Manager. Initiated by Bernard M. Olsen.
05/05/2014	02	Revision initiated to add text in Section 5.0 and to incorporate changes to Table 5-2 based on ORAUT-OTIB-0070, Revision 01. Revised Sections 2.3, 2.4, 2.5, 2.7, 3.0, 3.2, 4.0, and 5.0, including Tables 5-1 and 5-3, as indicated pursuant to recommendations in Report-SCA-TR-SP2011-0012-PA. Replaced text in Section 1.0 and conformed to standard presentation. Includes editorial changes. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Estella L. Keefer.

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ACRONYMS AND ABBREVIATIONS

ACCP	Allied Chemical Corporation Plant
AEC	U.S. Atomic Energy Commission
AP	anterior-posterior
AWE	atomic weapons employer
Ci	curie
cm	centimeter
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ft	feet
hr	hour
IMBA	Integrated Modules for Bioassay Analysis
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
kg	kilogram
KPA	kinetic phosphorescence analysis
L	liter
lb	pound
m	meter
mCi	millicurie
MDL	minimum detection level
MeV	megaelectron-volt, 1 million electron-volts
MPLB	maximum permissible lung burden
mrem	millirem
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NRC	U.S. Nuclear Regulatory Commission
NU	natural uranium
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
pCi	picocurie
RFP	Rocky Flats Plant
RMC	Radiation Management Corporation
SEC	Special Exposure Cohort
t	ton

U.S.C.	United States Code
wk	week
yr	year
µCi	microcurie
µg	microgram
§	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 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 2010a):

- 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 2010a). 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.

1.1 PURPOSE

This document provides information that may be used for dose reconstructions for AWE workers at the Allied Chemical Corporation Plant (ACCP) in Metropolis, Illinois. The Metropolis facility was also known as General Chemical Division and the Allied-Signal (later AlliedSignal) Metropolis Plant or Metropolis Works. AlliedSignal purchased Honeywell in 1999 and assumed that company's name.

1.2 SCOPE

Section 2.0 of this document describes the ACCP site and its history including information about the radiological processes and source terms as well as the radiological controls and monitoring practices. Sections 3.0 and 4.0 discuss internal and external dose assessment, respectively. Section 5.0 provides information for assigning dose during the residual radiation period beginning in 1977 after the cessation of Atomic Energy Agency (AEC)-related operations.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 6.0.

1.3 SPECIAL EXPOSURE COHORT INFORMATION

The Secretary of the U.S. Department of Health and Human Services has designated a class of employees from ACCP for inclusion in the Special Exposure Cohort (SEC) (Leavitt 2007). The class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy includes all employees who were monitored or should have been monitored for exposure to ionizing radiation while working at the ACCP in Metropolis, Illinois, for a number of workdays aggregating at least 250 workdays from January 1, 1959, through December 31, 1976, or in combination with workdays within the parameters established for one or more other classes of employees in the SEC.

A decision has been made that internal dose from nonuranium radionuclides cannot be reconstructed with sufficient accuracy for employees of ACCP during the period 1959 through 1976 (NIOSH 2006); therefore only internal dose from uranium is considered in Section 3 of this site profile.

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

The information that follows applies to the period of AEC operations at ACCP in Metropolis, Illinois, from January 1, 1959, to December 31, 1976, which involved AEC-contracted conversion of uranium ore concentrates to uranium hexafluoride (UF_6). Opening ceremonies for the ACCP fluorine plant occurred in October 1958 (Sloop 1978). The original license issue date was December 17, 1958 (NRC 2003, p. 37). Four claims (claim Numbers redacted) include bioassay results in December 1958; and one of these from December 15, 1958, has a positive result that indicates that uranium exposures might have occurred in late 1958, before the covered AWE period as established by the Office of Worker Screening and Compensation Support, which does not begin until January 1, 1959. The plant was closed temporarily on June 30, 1964, and AEC (1966) reported that it might reopen in 1966. A review of available worker dosimetry records indicated that some workers might have been laid off or transferred around this period, but that other workers were still on the site. The reviewed documentation indicates that weapons-related residual contamination exists outside the listed operational period (NIOSH 2011). Residual contamination from previous weapons-related activities is indistinguishable from contamination produced during later operations. This facility is still operational, and the residual contamination period has been established as being from January 1, 1977, through March 1, 2011 (DOE 2013).

Detailed information about buildings and processes is provided in Sections 2.1, 2.2, and 2.3 based on descriptions written after the period of operations that is covered by this document. Individuals who worked at ACCP indicated that there was little variation in the processes over time. Because individual dosimetry results are available for the vast majority of workers at ACCP, reconstructed doses should be based on specific individual dosimetry.

The ACCP radiological source term started with the receipt of uranium ore concentrates. Some long-lived uranium progeny were included in the concentrates (e.g., ^{230}Th and ^{226}Ra). Uranium chemical

forms included oxides, fluorides, and hexafluorides, which meant that exposures could have been to uranium solubility types F, M, S, or a combination.

The ACCP was also known as General Chemical Division, Allied Signal Metropolis Plant, and was later purchased by Honeywell.

2.1 SITE DESCRIPTION

"On February 4, 1957, the Allied Chemical and Dye Corp. announced selection of Metropolis, Illinois, as the site of its plant to process 5,000 tons of U_3O_8 a year under contract with the [Atomic Energy] Commission[AEC]" (AEC 1957). The official plant startup date appears to be January 1, 1959, but there are indications that uranium and uranium workers might have been on the site in late 1958. One individual reported participating in opening ceremonies at the fluorine plant outside Metropolis in October 1958 (Sloop 1978), which indicates that uranium exposure could have occurred as early as October 1958.

ACCP operated its UF_6 production facility using a dry conversion process (versus a wet solvent extraction process) to supply UF_6 feed for the Paducah Gaseous Diffusion Plant through June 30, 1964, under an AEC contract (Perkins 1982). In addition, ACCP was sampling uranium concentrates for other entities as of 1982.

On June 30, 1964, the plant was temporarily closed. AEC (1966) reported that the plant "may be reopened in 1966 for uranium hexafluoride production." Perkins (1982) noted that ACCP resumed operations in February 1968, but the available dosimetry records indicate that radiological exposures were still occurring at the plant between June 30, 1964, and February 1, 1968. Some of the claimant interviews and external dosimetry records show that a number of workers were on the site during the shutdown and that hiring was occurring in 1967, although these records also indicate that a number of workers were laid off in July 1964. The available records do not indicate what activities might have been ongoing in the plant during the shutdown period. However, based on U.S. Department of Labor job descriptions associated with one claim (claim number redacted), some processing operations might have continued at least on a sporadic basis.

The ACCP U.S. Nuclear Regulatory Commission (NRC) license (NRC 2003, p.4) stated:

> *The Allied Signal Metropolis Plant is located on approximately 1,000 acres of land in Massac County at the southern tip of Illinois, along the north bank of the Ohio River. The site perimeter is formed by US Highway 45 to the north, the Ohio River to the south, an industrial coal blending plant to the west and privately owned, developed land to the east. Plant operations are conducted in a single fenced-in, restricted area covering 59 acres in the north-central portion of the site.*

The plant is now owned by Honeywell and is still providing UF_6 to gaseous diffusion plants for use in the commercial sector. The 1982 building locations are shown in Figure 2-1.

The following description of the buildings is from ACCP licensing documentation (NRC 2003, pp. 36–37). The list was originally numbered 8.5.1 through 8.5.8, but has been simplified to 1 through 8 below.

> *Most of the uranium processing equipment is housed in a six-story structure termed the Feed Materials Building where essentially all of the steps in the UF_6 manufacturing process are conducted. Other areas and buildings in which operations are conducted*

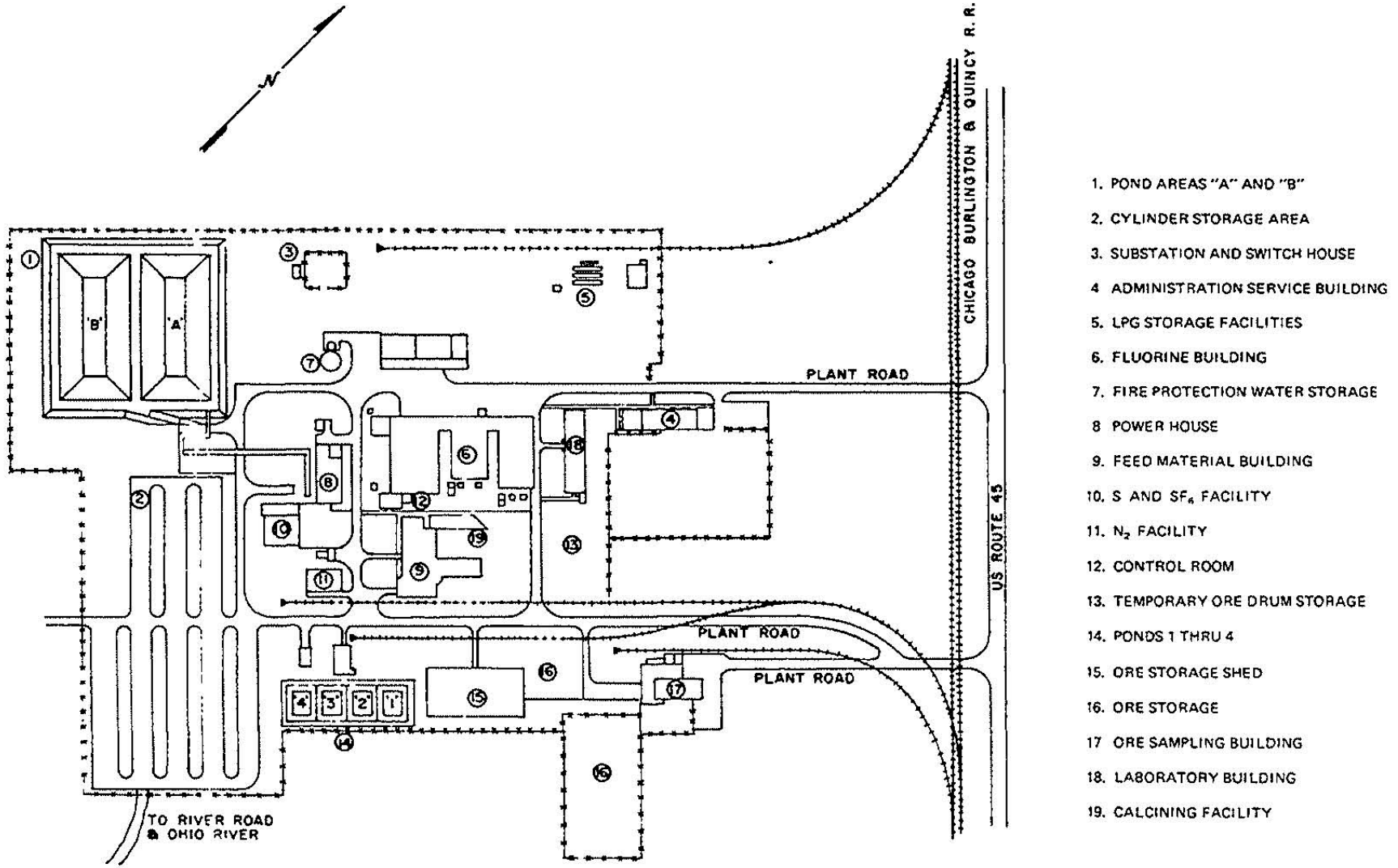

Figure 2-1. Plot plan of ACCP Metropolis, Illinois (Perkins 1982, p. 7).

involving the handling or processing of significant quantities of source material include the following:

1. *A Sampling Plant which receives samples or concentrates for uranium assay and moisture content.*

2. *The Sodium Removal (pretreatment) and Uranium Recovery Facilities which are housed in buildings where high sodium content ore concentrates are treated to remove sodium impurity, and where materials are reprocessed to recover additional uranium.*

3. *The KOH* [potassium hydroxide] *muds washing facility which removes fluorides and KOH from the potassium diuranate muds generated in the fluorination scrubber system. The washed potassium diuranate is then processed through Sodium Removal. The wash liquors are neutralized at EPF* [environmental protection facility, this facility probably did not exist during the early years].

4. *The Calcining Facility which dries the incoming feed material and recovered uranium as the first step in ore preparation.*

5. *The Pond Mud Calciner Drier where hard/wet ore concentrates and KOH muds are processed prior to packaging for blending with additional ore concentrates at the Feed Materials Building for conversion to UF_6.*

6. *The Laboratory Building which houses facilities for conducting process control, product, and radiological control analyses.*

7. *The Cylinder Wash Building where UF_6 product cylinders are periodically washed and hydrostatically tested prior to reuse.*

8. *Outdoor pads for storage of drums of ore concentrates and other uranium bearing materials, as well as UF_6 product cylinders.*

Additional plant facilities which are involved directly in the UF_6 manufacturing process but do not involve the handling of any significant quantities of source material include a fluorine manufacturing building, a fluoride waste treatment facility with four large CaF_2 settling tanks, a powerhouse, a reductor off-gas incinerator, and two small uranium settling ponds to collect any uranium spills.

ACCP was also involved in the manufacture of 30,000 lb/wk of liquid fluorine, 1,200 t/yr of sulfur hexafluoride, 2,500 lb/wk of antimony pentafluoride, and 10,000 lb/wk of iodine pentafluoride (Perkins 1982). These materials were not radioactive.

2.2 PROCESS DESCRIPTION

The conversion process from ore concentrates (yellowcake) to UF_6 is described below, and a process flow diagram is presented in Figure 2-2. As of 1982, the processing capacity was 14,000 t of uranium per year and the plant had processed more than 100,000 t of uranium from domestic and foreign uranium concentrates (Perkins 1982).

As part of an evaluation of environmental control technologies for (UF_6) nuclear material conversion facilities, Perkins (1982) described the conversion of yellowcake to UF_6 at ACCP. Although some changes in the process might have occurred since the first days of operation, it is likely that these

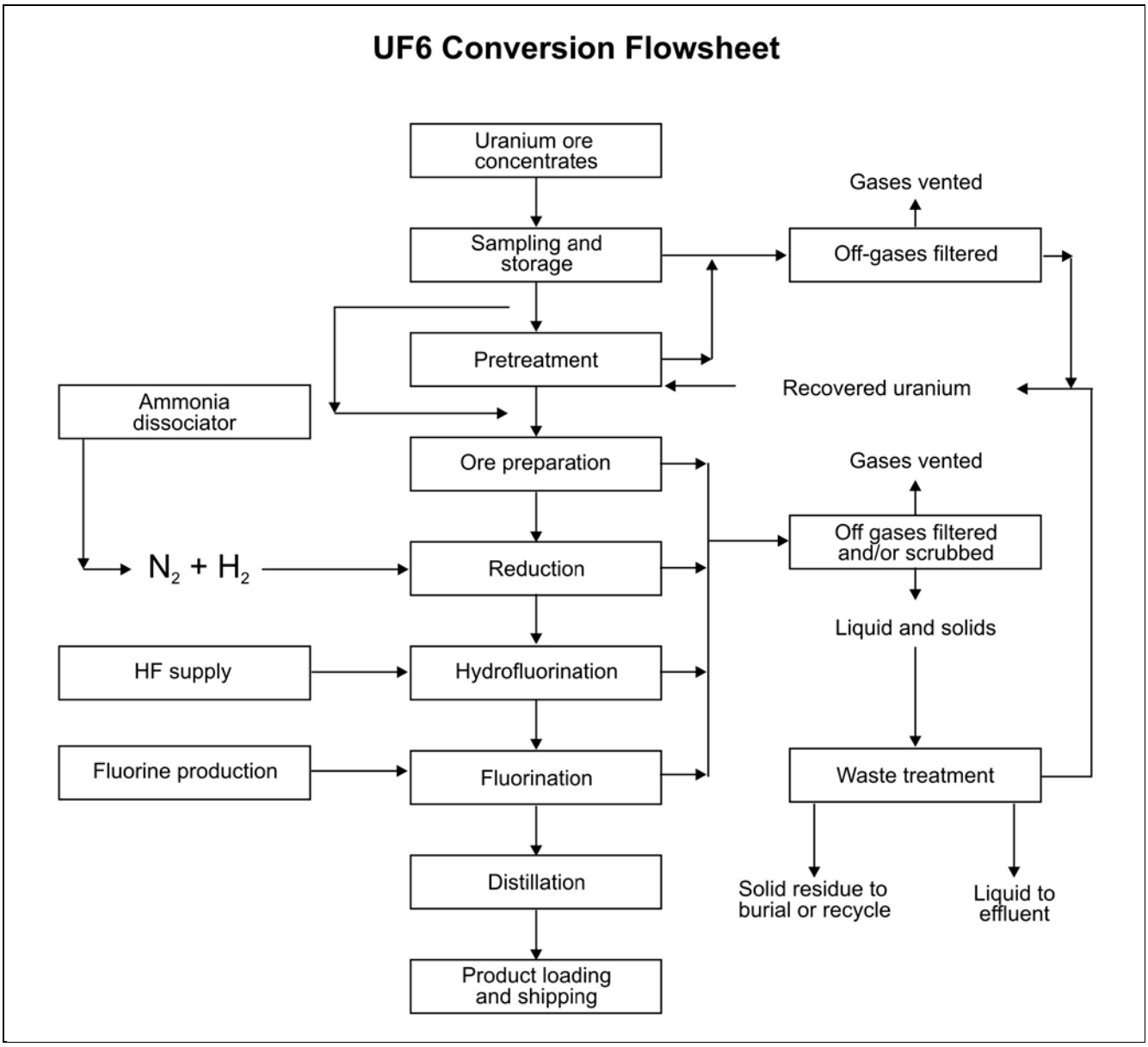

Figure 2-2. Process steps for conversion from ore concentrates (yellowcake) to UF_6 (NRC 2003, p. 66).

changes would have related to ore sampling techniques, ventilation and filtration controls, and waste disposal practices, and that the general process was similar throughout the plant's history. Process descriptions from Perkins (1982) follow.

> *Drums are weighed, and a falling stream method is used to obtain a representative sample. The airborne dusts generated in the sampling process are removed through the use of two baghouses in series, which discharge through a stack. Empty drums are air cleaned and the discharge runs through two baghouses before being discharged to a stack.*
>
> *Concentrates that are found to contain a high percentage of sodium are pretreated in the sodium-removal facility.*

Sodium Removal (Pretreatment)

Because sodium forms a compound that causes caking and sintering in the fluorination fluid beds, any incoming uranium concentrates containing sodium and all the uranium concentrates produced by the uranium recovery sections of the UF_6 facility must first have the sodium or potassium removed before they can be processed. These concentrates are treated by reaction with a solution of ammonium sulfate in four counter current vessels to make $(NH_4)_2U_2O_7$ for further processing. The chemical reaction is

$$Na_2U_2O_7 + (NH_4)_2SO_4 \rightarrow (NH_4)_2U_2O_7 + Na_2SO_4$$

The liquid effluent contains the excess $(NH_4)_2SO_4$, Na_2SO_4, K_2SO_4, and uranium and small quantities of ^{226}Ra and ^{230}Th, selenium, molybdenum, and other trace impurities. The effluent is sent to the two uranium spill control ponds. Uranium contaminated storm water is also discharged to these ponds. The sludges are allowed to settle, and the decantate is discharged to the main discharge outfall for the plant…. When the minimum freeboard is reached (approximately 2 ft) on a pond, the pond is dredged and the sludge is sent to the pond sludge calciner…. Pond liners are inspected and repaired at this time. In addition, all pond liners are underlain by a gravel layer that allows any seepage to drain to a leak detection sump….

The $(NH_4)_2U_2O_7$ (ADU) [ammonium diuranate] is removed from solution in the last reaction vessel and is sent to the main feed preparation section of the plant.

Feed Preparation

In the feed preparation circuit, sodium-free uranium concentrate, either from the pretreatment section or from the sampling section, is first fed into a calciner where water and ammonia are removed. The off-gases containing ammonium, sulfur dioxide, uranium, and contaminant particles pass through two baghouses in series. Particulates recovered by blowback of the baghouses are collected and sent back into the blending feed stream….

The calcined material is blended and then agglomerated, dried, crushed, and sized before being sent to the reduction circuit. Wet off-gas streams join the off-gases from the calciner, whereas dried off-gases pass through two baghouses in series before discharge…. Material collected by the dry stream baghouse is fed into the blending feed stream.

Reduction

In the reduction circuit, Allied operates two trains in parallel, both having the same basic design. The U_3O_8 from the feed preparation circuit is fed into the reductor vessel where hot cracked ammonia (N_2 and H_2) and additional nitrogen mix with the feed to form a fluidized bed. The U_3O_8 is reduced to UO_2, which is withdrawn from the bottom of the bed. Off-gases from the reactor include H_2, N_2, H_2S, AsH_3, vaporized S, SeH_2, and particulates composed of UO_2, unreacted U_3O_8 and reduced compounds of impurities originally in the concentrate….

The off-gases pass through two porous metal filters in series, a sulfur condenser, and incinerator….

Particulates collected by cleaning the filters are sent to the uranium recovery section.

Off-gases from the oxide vacuum cleaner are sent through cyclone and two baghouses in series before discharge…. Residues from these collection devices are sent to the uranium recovery section.

Hydrofluorination

Again in the hydrofluorination circuit, two trains in parallel are in use. The UO_2 from reduction is fed into two reactor vessels in series, which use vaporized hydrofluoric acid and N_2 to fluidize the UO_2 and permit HF to react with the material to form UF_4. The off-gases contain the excess HF needed to give good conversion to UF_4 (10% excess or more), volatile SiF_4, BF_3, and some of the molybdenum and vanadium (which were present as impurities in the concentrate) as volatile fluorides and oxyfluorides, and any remaining sulfur as H_2S_4. These gases first pass through two sets of porous carbon filters per set, where the unreacted UO_2 particles, entrained UF_4 particles, and any other particulate matter are removed. The gases then pass through two venturi water scrubbers where the H_2O in the off-gases condenses, and finally through a venturi KOH scrubber and a packed tower using KOH scrubbing liquid.

The residue from the clean carbon filters is sent to uranium recovery. Liquid coming from the venturi water scrubbers contains hydrofluoric acid and is sent to the acid neutralization treatment plant, where lime is added to precipitate the fluorine as CaF_2. The uranium content of this stream is reported to average less than 5 ppm [parts per million]. Silicon, boron, and some molybdenum, and vanadium, which were originally in the concentrate, are expected to be in the sludge. The liquid from the KOH venturi and packed tower is sent to the liquid treatment systems.

The vacuum cleaning off-gases from the cleaning activities necessary in the hydrofluorination section are routed through a cyclone and two baghouses before discharge…. Residues from the dust collectors are sent to the uranium recovery section.

Fluorination

The green salt, UF_4, produced in the hydrofluorination process is fed into one of two fluid bed reactors used in parallel. Again, Allied uses two trains at the works. The bed material is CaF_2, and unreacted UF_4. The vessels are operated at temperatures of approximately 1000° F, and good temperature control is required. Fluorine, F_2, from an on-site fluorine production facility is introduced into the reactor vessels to convert UF_4 into gaseous UF_6.

The off-gasses, including uranium UF_6, F_2, HF, unreacted UF_4, and other particulates, and volatilized impurities … are first cooled before passing through two sets of sintered nickel filters, each containing two filters. The material recovered as the filters are cleaned is stored, and then sent to the uranium recovery section.

The stream exiting from the filters has the UF_6 removed by condensation in a set of three cold traps used in series. Any uncondensed UF_6, F_2, HF and other volatiles passing from the cold wraps are removed from the gas stream by a KOH spray tower, a KOH pack tower, and finally a KOH coke box.

Carbon dioxide in the spent scrubber liquor reacts with the uranium and potassium as follows.

$$2(UO_3)^{4-} + 6CO_2 + 6OH^- + 2K^+ \rightarrow K_2U_2O_7 + 6CO_3^{2-} + 3O_2 + 3H_2O$$

The $K_2U_2O_7$ is settled from the KOH solution and sent to the pretreatment facility.

Decantate from the uranium settling section is sent to the KOH regeneration system as indicated previously…. The KOH is then sent back to the scrubbing system. In addition to CaF_2 compounds of uranium, vanadium, and molybdenum, trace quantities of compound of silica, carbon sulfur, and other trace contaminants are expected to be in the sludge….

The condensed material in the three cold traps in series is melted and drained to the still feed tanks. Entrained hydrogen fluoride is vaporized during melting and passes to the off-gas system.

From the still feed tanks, the liquid is fed to a low-temperature boiler bubble cap column in which the impurities are volatilized and exit from the top of the column….

The liquid uranium hexafluoride passes from the low boiler column into the bubble cap, high boiler column. In this column, the UF_6 is volatilized and exits from the top of the column. Non-volatilized impurities are removed from the bottom of the column and stored.

The gaseous UF_6 from the column is condensed into two cold traps operated in series. The UF_6 is transferred to the shipping cylinders by melting the UF_6 and allowing the material to drain into the cylinders.

Because impurities build up on the recycled CaF_2 bed material used in the fluorination reactors, part of the bed material must be withdrawn periodically. This "ash" [also referred to as spar or bed material] along with the fluorination-cleaned filter residue, is drummed and stored for a minimum of 6 months to permit the uranium daughters ^{234}Th and ^{234}Pa to decay. The ash is then sent to the uranium recovery section. A total quantity of about 0.1 ton of ash per ton of uranium processed is produced, and it contains approximately 1.8% of the total uranium processed and most of the uranium daughters originally present in the concentrate.

The dusts produced by withdrawing bed material from the reactors are passed through a cyclone and two baghouses in series before discharge…. The ash vacuum cleaner systems also discharge from this stack. Residue from cleaning these particulate removal devices is treated similarly to the spent bed material….

The feed preparation, reduction, hydrofluorination, and fluorination circuits are all located in the feed material building. This building has a complete air changeout approximately once every 5 minutes….

Washdown of the feed materials building is pumped from collection sumps into the uranium recovery ponds.

The transfer lock to fluorination discharges through two baghouses…. Again, dust collection residue is sent to uranium recovery.

Uranium Recovery
There are several sources of uranium-containing wastes produced by the facility, and it is desirable to recover the uranium from these wastes. Thus, uranium-containing dried sludges, spent bed material, filter residue, and various scraps and dust are sent to the uranium recovery circuit.

Off-gases from storage before processing vent through the 3-1 stack. The main contaminants in the stack off-gases should be radon and radon daughters, if the radium originally in the concentrate feed goes into the ash (as was assumed in the previous section).

The material from storage is first dumped and ground. Dusts from this operation are recovered in a baghouse….

The finely ground material is leached using a sodium carbonate solution to solubilize the uranium as the tricarbonate complex….

After leaching, the pregnant solution is filtered. Lime is used to aid in precipitation of any fluoride, and the solution is again filtered. Sludge from the filters is dried. Off-gases from the dryer pass through the dumping and grinding off–gas baghouse.

The dried sludge probably contains all nondecayed uranium daughters, some residual uranium, and some fluoride compounds. This sludge is drummed and sent to a licensed radioactive waste disposal facility. Approximately 1500 tons of this waste, containing a maximum of 46.9 Ci is produced yearly.

The uranium is precipitated from the solution using NaOH. The uranium is filtered and washed and then sent to the sodium removal section.

Cylinder Wash

Cylinders are returned to Allied from the enrichment facilities. These cylinders contain residual UF_6 and the daughters of uranium that have "grown in" while the cylinders containing UF_6 were in storage. The daughters in general are found plated out on the cylinder walls.

After any residual UF_6 is removed from the cylinder, the cylinder is washed, using a solution of Na_2CO_3 to remove any impurities from the walls and to solubilize the uranium. The wash solution is filtered to remove the unleached solids, and the pregnant solution is pumped to join the pregnant solution in the uranium treatment section.

The solid residue from the filters contains daughter products of uranium, principally ^{234}Th and ^{234}Pa, and is stored on-site in drums until disposal in a licensed waste disposal facility.

Sludge Dryer

As previously described, the process generates several sludges that contain uranium. Before being sent for uranium recovery, these sludges are dried in a calciner. Off-gases containing SO_2, HF and particulates from the calcining operation pass through a baghouse and a water spray tower before discharge….

The spent scrubber water, which contains uranium, fluoride compounds, and some sulfur compounds, is sent to the uranium recovery ponds.

The calcined sludges are drummed and stored until they can be processed in the uranium recovery section.

2.3 SOURCE TERM

The plant produced UF_6 from uranium ore concentrates initially for gaseous diffusion facilities and later also for commercial fuel fabrication facilities. The uranium conversion process at the plant has remained essentially unchanged since its inception. In 1982, Perkins (1982) reported that the concentrates initially contained 70% to 75% uranium by mass, and these concentrates included impurities that were dependent on the mines and mills from which the yellowcake came.

Uranium chemical forms at ACCP included all solubility types (i.e., F, M, and S). The initial design processing capacity was 5,000 t of uranium in a year, and by 1982 the throughput capacity had been increased to 14,000 t per year in what was essentially a continuous chemical process. As of 1982, more than 100,000 t of uranium had been processed (Perkins 1982).

The initial milling of the uranium before arrival at ACCP resulted in disequilibrium of uranium progeny in the concentrate. Exposure to the nonuranium radionuclides occurred at the front end of the processing, beginning with receipt. Increased concentrations of other radionuclides in relation to uranium were found in the fluorination bed ash and other solid waste streams, such as the sludge. Environmental air measurements in the late 1970s showed ratios of ^{226}Ra and ^{230}Th in relation to uranium that were larger than the concentrate ratios but lower than complete equilibrium ratios.

Radon concentrations would probably have been elevated during the initial opening of the drums of concentrate, in the feed area, and in work areas where radium would have concentrated. No measurements of radon concentrations have been found at this time.

Perkins (1982) summarized uranium, thorium, and ^{226}Ra activities in ACCP effluents and wastes from the 1970s. These results were used to estimate ratios of the activity of other radionuclides to uranium in the effluent (activity ratios are listed in Table 2-1) and to reconstruct internal doses for nonuranium nuclides during the residual period. The ratio listed below for ^{230}Th to NU in the concentrate was based on an average of yellowcake feed ratios from 33 mills (Perkins 1982, Table II-8). The equilibrium activity ratio of ^{230}Th to uranium in uranium ore was about 0.4886; the milling of the ore usually reduced this ratio by almost a factor of 100 by removing the ^{230}Th from the concentrate.

It should be noted that ^{232}Th comprised a portion of the radioactivity in the uranium concentrates, and although ^{232}Th was not specifically reported for most effluents at ACCP, the water effluents for 1975 and 1976 showed annual average activity ratios for ^{232}Th to ^{234}Th of 0.076 and 0.017, respectively (Perkins 1982, Table II-13). Assuming that ^{234}Th is in equilibrium with ^{238}U, and the activity fraction for ^{238}U to NU from Table 3-1, the ratio of ^{232}Th to NU based on the 1975 and 1976 water effluent results is 0.037 and 0.008.

Table 2-1. Radionuclide activity ratios in relation to uranium based on reported activities in ore concentrates, and in ACCP wastes, air, and effluents[a] (ORAUT 2014a).

	Average			Largest		
Source	**Th-nat: NU**	**Th-230: NU**	**Ra-226: NU**	**Th-nat: NU**	**Th-230: NU**	**Ra-226: NU**
Concentrate (yellowcake feed average for 33 mills)	ND	5.20E-03	ND	ND	ND	ND
Uranium recovery solid waste (dried sludge)	3.58E+00	1.90E+01	1.11E+00	ND	ND	ND
Solid nonsludge waste	ND	5.27E-03	2.75E-04	ND	ND	ND
Outdoor air	ND	6.70E-02	1.97E-03	ND	1.67E-01	8.46E-03
Air effluent	ND	1.70E-02	2.70E-04	ND	4.75E-02	3.38E-04
Water effluent	ND	3.99E-03	2.04E-02	ND	1.58E-02	5.79E-02

a. From Perkins (1982).
ND = no data provided in Perkins (1982).

Processing at ACCP resulted in further separation of uranium and its progeny, and this could have resulted in increased activity ratios of nonuranium radionuclides in some areas in the plant. The largest disequilibrium ratios during the operational period were associated with the solid waste (dried sludge) from the uranium recovery facility. As stated above, these materials were barreled and shipped off the site as radioactive waste.

AEC and DOE recycled uranium inventory reports use the designation "JSA" to identify Allied Chemical Corporation (as a whole). DOE reported that the Rocky Flats Plant (RFP) shipped 71 kg (160 lb) of depleted recycled uranium to site designation JSA (the corporation) in 1975 (RFETS 2000, Appendix A, p. 74). Appendix B of the same document provides the site address as being in Idaho Falls, Idaho (RFETS 2000, Appendix B, p.115). Another reference that appears to summarize some parts of the same RFP report notes a shipment of 22,060 kg from RFP to Allied between 1955 and 1964 (DOE ca. 2000), but this appears to be an error due to the misidentification of the next site designation in the RFP report, "LAB," with "JSA." In addition, Appendix A (RFETS 2000, Appendix A, p. 74) shows that this was a shipment from "LAB" to RFP. Therefore, it is assumed that contaminants in recycled uranium were not a significant contributor to ACCP worker radiation doses.

ACCP was licensed by the NRC to have sealed ^{137}Cs sources up to 100 mCi each. These were used as level control devices and are unlikely to have contributed to internal dose.

2.4 SAFETY

Specific radiological safety measures implemented in the beginning of ACCP operations are not available but, as of 1958, radiological control programs in general had become more sophisticated. Dosimetry is available from the earliest days of covered operations for all employees who worked in the controlled area. The following information is based primarily on reference material from after 1972, and it should be noted that the criteria to prompt radiological control activities could have differed in the early years.

Engineered confinement was and is the primary source of contamination control at ACCP. Drums, process vessels, lines, etc., are used to confine the materials. When unconfined uranium was handled, procedures called for ventilation controls to reduce exposures (Allied-Signal 1985a, p. 27).

An exception was requested from the NRC requirement to post and label individual radioactive material areas and containers, which was replaced by a requirement to train workers (NRC 2003, p. 75). Signs stated that any area or container in the plant could contain radioactive materials.

As of 1985, and probably from the earliest days of operations, protective clothing and shoes or shoe covers were provided to employees and visitors to ACCP to ensure that personnel were not inadvertently contaminated with uranium compounds (Allied-Signal 1985b, p. 49). This did not apply to administrative areas where contamination would not be expected. A review of claim records supports the use of personal protective equipment during the operational period and indicates increased personal protective equipment requirements depending on job, which included full-face masks, Scott Air Paks, rubber suits, plastic or rubber coveralls, and gray suit with supplied air.

Additional information indicates that at least before April 1975, all new hires at the ACCP Metropolis site received an introductory safety and health physics indoctrination and were issued a film badge and personal safety gear including hardhat, glasses, shoes, coveralls, and towels for their shower at the end of the workday, and employees entering the Feed Materials Building were provided with half-face respirators to carry with them for emergency use (Freeman 1975, p. 178).

Current ACCP procedures, discussed below, include four contamination measurement and control parameters:

- Visual observation of contamination,
- Air concentration measurements,
- Surface contamination measurements, and
- Decontamination procedures.

2.4.1 Visual Observation of Contamination

ACCP noted that NU compounds had a low specific activity characterized by a high ratio of mass to activity. The ACCP uranium compounds were highly colored, which provides an immediate method for detecting gross surface and air contamination. For instance, yellowcake was yellow and UF_6 releases appeared as white smoke due to the decomposition products, UO_2F_2 and HF. Procedures from 1985 stated that if employees detected small spills, they were responsible for cleanup (Allied-Signal 1985a). Larger leaks or spills that resulted in visible accumulation of uranium on equipment or on the floor required immediate decontamination, activation of the respirator lights, and possibly shutdown of the unit. The foremen were to prepare a health physics incident report and notify the health physics shift technician to initiate special air sampling and investigation as appropriate. Health physics personnel made a daily inspection of uranium operating areas to ensure proper decontamination and contamination control. These procedures were consistent with contemporary industrial health practices for uranium facilities (DOE 1988).

2.4.2 Air Activity Measurement of Contamination

As of 1985, stationary breathing-zone samples were collected daily from 57 stations in the UF_6 building, 10 stations in the sampling plant, 2 stations in the drum dumper, 3 stations in sodium removal, and 2 stations in the uranium recovery unit. Summaries of some of these measurements can be found in the available references. As of 1985, respirators were required when either the average gross alpha air concentration on a floor exceeded 4×10^{-11} µCi/cm^3 or when any four air samples on the floor exceeded that concentration. In addition, as of 1985, any single air sample result that exceeded 1×10^{-10} µCi/cm^3 required investigation and preparation of a health physics incident report (Allied-Signal 1985a, p. 29).

Although some air concentration data are available for the 1970s and later, these data were not used to estimate worker intakes because of the abundance of bioassay data.

2.4.3 Surface Contamination Measurements

Surface contamination measurements in uranium and nonuranium areas were made routinely. Removable contamination was determined by taking a wipe or smear of 100 cm² on a surface. Each smear was counted for alpha radioactivity and reported in dpm/100 cm² removable alpha contamination. The plant lunchroom and offices or control rooms were surveyed weekly, as were the locker rooms and personnel exit areas. Uranium processing areas such as the Feed Materials Building, Sodium Removal, Uranium-Recovery Building, and Sampling Plant were surveyed monthly. Other nonuranium processing areas were surveyed quarterly (Allied-Signal 1985a; Honeywell 1999, Section 3).

As of 1985, decontamination was to be initiated when removable alpha contamination exceeded 5,000 dpm/100 cm² in the uranium processing areas. All other areas were to be decontaminated when removable alpha contamination exceeded 200 dpm/100 cm² (Allied-Signal 1985a).

One summary of health physics data for the last half of 1991 (Wilkins 1992) noted that 1.7% of the 2,002 weekly smears exceeded the weekly limit of 200 dpm/100 cm^2 and that the highest result was 923 dpm/100 cm^2 in the lunchroom on a table. One of the 570 monthly smears and none of the 163 quarterly smears exceeded the limit.

2.4.4 Decontamination

ACCP had detailed procedures for decontaminating spills or leaks found in the plant. These procedures generally included roping off the area, sweeping or vacuuming the contaminated material, and then washing the contaminated surface. During these procedures protective clothing was to be used and monitoring was to be performed (Allied-Signal 1985a; Honeywell 1999, Section 4).

2.5 INCIDENTS

The claim records include some information about incidents, but details are few and there are no dates or references to particular incident reports. Claim information describes spills of ore, dusty conditions (yellow dust), occasional leaking valves and line ruptures resulting in releases of UF_4 and UF_6, and inadequate packing that resulted in material releases, the evacuation of buildings, and environmental releases.

A partial history of incidents is provided in Attachment C (ORAUT 2013a). The listed events occurred primarily during the residual period and therefore provide a general summary of the frequency and types of releases and incidents for the period. This includes a release of 43 kg of UF_6 due to a valve failure on November 12, 1968, at the ACCP (ORAUT 2013a; NRC 2010). Because all workers participated in a routine bioassay program (generally biweekly for plant workers and monthly for administration workers and more frequently if an intake was suspected), these bioassay results can be used for internal dose reconstructions. The direct deposition of uranium on exposed skin was possible, and an evaluation of the impact on skin dose is evaluated on a case-by-case basis. In such cases, any specific information about an incident or contamination event from claimant records should be considered and whether the deposition is co-located with the cancer site. A dose reconstructor should apply the guidance in ORAUT-OTIB-0017, *Technical Information Bulletin: Interpretation of Dosimetry Data for Assignment of Shallow Dose,* for the assignment of skin dose (ORAUT 2005).

2.6 PHYSICAL EXAMINATIONS – X-RAYS

No documented ACCP requirement for occupationally required medical X-ray examinations has been found, but, more than half of the claimant interviews indicate that chest X-ray examinations were routine and a number of the interviews indicate the frequency was annual. Information indicates that at least before April 1975, all new hires at the ACCP Metropolis site received a pre-employment physical exam which included a chest X-ray, and that repeat annual physical exams were given with chest X-rays included on alternate years (Freeman 1975, p. 178). Anecdotal information indicates that the examinations were offered annually, but were optional by 1980, and would have been done at Massac Memorial Hospital or perhaps a local doctor's office according to one employee, who began work at ACCP in the 1970s.

2.7 SUMMARY OPERATIONAL PERIOD ASSUMPTIONS, WORKDAYS, WORK HOURS, WORK CATEGORIES

Because bioassay and film badge data were used to estimate internal and external exposures during AEC uranium operations, an estimate of the number of workdays or work hours per year is not necessary.

Workers who might have had a higher external exposure potential or workers who might have handled radioactive materials and had a higher extremity dose potential are listed by job title in Attachment B. Individual dosimetry appears to be available for most workers. Therefore, the reconstructed external dose should be based on specific individual dosimetry.

2.8 RESIDUAL CONTAMINATION

Uranium concentrate processing continued at ACCP after 1976, and differentiation between residual contamination from the AWE period and contamination due to later and/or ongoing operations is not feasible.

3.0 ESTIMATING INTERNAL EXPOSURE

As stated in Section 1.3 above, a decision has been made that internal dose from nonuranium radionuclides cannot be reconstructed with sufficient accuracy for employees of ACCP during the AEC operations period from 1959 through 1976. The primary source of internal radiation exposure at ACCP was uranium dust produced from the processing of uranium concentrates to produce UF_6. It is assumed that the uranium was of natural enrichment before 1977. Although the uranium ore concentrate contained uranium progeny of dosimetric interest as well as thorium (assumed to be ^{232}Th and ^{228}Th), only uranium dose can be estimated for ACCP claims for the period from January 1, 1959, through December 31, 1976.

3.1 URANIUM

During the processing of uranium concentrates at ACCP, workers might have been exposed to a variety of uranium chemical forms that encompass all lung absorption types: F, M, and S. Although some process steps might have had more or less exposure to a given lung absorption type, it is not clear how well separated these areas were. In addition, workers might have worked in multiple uranium process areas. The selection of absorption type should depend on the organ of interest. The specific activity of the NU and the isotopic mass and activity fractions are listed in Table 3-1 [1]. For organ dose estimates, the uranium activity can be assumed to be from ^{234}U [2]. A conversion factor is provided to adjust results reported as micrograms of ^{235}U to total uranium activity in picocuries.

Table 3-1. NU specific activity and isotopic fractions.

Isotope	Activity fraction	Mass fraction	Activity ratio to U-235	Mass ratio to U-235
U-234	0.4886	5.37E-05	21.4	0.00745
U-235	0.0228	7.20E-03	1	1
U-238	0.4886	9.93E-01	21.4	138
Useful factors				
NU pCi/µg	0.683			
U (pCi):U-235 (µg)	94.8			

3.1.1 Uranium Urinalysis Data

Individual uranium urinalysis began as early as December 1958 and was done in house. It appears there are bioassay data for all workers. The worker records show that bioassays were typically collected at hire and periodically thereafter. ACCP notes that fluorimetry was used for analyses until 2002, when kinetic phosphorescence analysis (KPA) began (Rogers 2006). Some urinalysis data between 1989 to 1992 are missing, and ACCP reported that it was assumed that the missing records might have been water-damaged beyond recovery.

In the early years, uranium urinalysis results that were reported in microcuries per milliliter (µCi/mL) are misstated; the units were actually micrograms per liter (µg/L). The recording limit of 10 µg/L is

from the early records and is consistent with the default detection threshold for uranium urinalysis assumed to be 10 µg/L based on a reported sensitivity of 5 to 10 µg/L for uranium fluorimetry urinalysis in the early years (Wilson 1958). Beginning in late 1974, a recording limit of 5 µg/L appears to have been in use. ACCP reported that its minimum detection level (MDL) was 2 µg/L in the early 1980s, but no records of MDL are available before that. In 1985, ACCP noted that routine urinalysis samples were to be left after 24 to 96 hours of absence from the workplace, but it is unknown when this procedure was implemented. In addition, as of 1985, ACCP employees were encouraged to leave special urine samples before their next work shift in response to known or suspected airborne exposures (NRC 1993, p. 50). In later years, it was noted that a result equal to 30 µg/L was cause for investigation.

On the computer printouts, results are sometimes noted in the comments section rather than the bioassay measurement section.

3.1.2 Uranium In Vivo Data

Lung counts are available for many workers beginning in late 1978, which is after the covered operational period. Lung counts appear to have been performed on an annual or biannual frequency until the mid-1980s. They appear to be less frequent in later years, but this could indicate that only some workers were required to have annual lung counts in later years.

ACCP claims include a letter that reports use of a uranium lung-counting system from Radiation Management Corporation (RMC) and analysis of the spectra using a software package called RMCWBC, which was based on the Oak Ridge National Laboratory program ALPHA-M (Rogers 2006). The counting system includes an RMC-designed shadow shield and four detectors, which appears to have consisted of thin NaI(Tl) and thicker CsI(Na) crystals. The diameter was reported as 5 ft but was probably 5 in. Before analysis of the spectra, the background was automatically subtracted. A REMCAL standard man equivalent phantom was used to calibrate the system. Radionuclides included ^{235}U, ^{234}Th, ^{137}Cs, and ^{40}K.

Specific ACCP criteria were given for judging the data and can be used for considering the relative validity of a result (Rogers 2006):

- Fit should be less than 3.0 and usually ranges between 0.5 and 1.5. An ideal fit would be 0.
- The shift value should range between +2.0 and -2.0; values outside the range of ±3.0 are carefully reviewed before they are accepted. MCA zero level and/or gain adjustments are warranted when the shift value exceeds ±2.0.
- The gain should ideally be 1.0 and a gain of 0.90 to 1.10 is considered acceptable. Adjustment to the gain and/or zero might be needed if the value is outside this range.
- Results with errors greater than 100% (results less than 2 times their counting standard deviation) were considered questionable.

The analysis program reportedly printed a table showing all identified radionuclides and their estimated activities and relative 2-standard-deviation counting error in terms of a percent error. ACCP reported that results of ^{235}U were given in micrograms and results for other radionuclides were given in nanocuries. However, some records show ^{234}Th results in micrograms. The maximum permissible lung burden (MPLB) was noted as 194.3 µg of ^{235}U, or summed as 26,974 µg of total uranium (Allied-Signal 1986, p. 10). The reported ^{235}U minimum detection level was noted as 63 µg, which was equated to 32% of the MPLB (NRC 1993, p. 51; Allied-Signal 1986, p. 16). In later years, it was noted that a result equal to 50% of the MPLB was cause for investigation.

Unless there was a prominent low-energy peak or the detector ratios varied by more than 0.025, the detected uranium was assumed to be in the lung.

In general, the urinalysis results should be used to estimate intakes and the lung counts can be used as supporting data. The lung counts did not directly measure total uranium and, although height and weight were recorded and could have been used to estimate chest wall thickness, there is no indication that chest wall thicknesses were measured directly.

To convert ^{235}U mass to total uranium activity, it was assumed that the uranium was of natural enrichment and so the ^{235}U mass in µg should be multiplied by 2.16 pCi/µg (the specific activity of ^{235}U) and divided by 0.0228 (the activity fraction of ^{235}U) (a combined factor of 94.8 [U pCi / ^{235}U µg]) to obtain the total uranium activity in picocuries [3].

To convert ^{234}Th to total uranium activity, it was assumed that the ^{234}Th was in equilibrium with both ^{238}U and ^{234}U, and so the mass of ^{234}Th in micrograms should be multiplied by 2.32×10^{10} pCi/µg (the specific activity of ^{234}Th) and divided by 0.4886 to obtain the total uranium activity in picocuries [4]. If the ^{234}Th was given in nanocuries, it can be converted to picocuries of uranium by dividing by 4.886×10^{-4}. Note that with a 24.1-day half-life, ^{234}Th might not have been in equilibrium with its uranium parent depending on when and where an exposure occurred.

The ^{40}K and ^{137}Cs that were reported in lung counts are not likely to be associated with workplace exposures; ^{40}K should be ignored. On occasion, in vivo measurement results included ^{137}Cs. However, those workers could have had body burdens of ^{137}Cs from nonoccupational sources (e.g., fallout and consumption of specific foodstuffs). There is no evidence of occupational intakes of ^{137}Cs at ACCP, so no dose of record should be associated with these measurement results [5].

A handwritten note (Allied-Signal 1996) indicates that other whole-body counting systems might have been in use as of 1996, but there were no differences in reported sensitivity.

3.2 NOTATIONS ON BIOASSAY RECORDS

Some of the bioassay records include brief comments on the job assignment, time away from the site, reasons for a resample such as a release, and other notations and abbreviations. These include:

- Laid off,
- Rehired,
- Trnfd [transferred],
- MTO [Morristown Office, corporate headquarters in New Jersey],
- MPLB,
- Sample type R,routine (Honeywell 2013b), and
- Sample type S, all nonroutine bioassay samples including initial samples, exit samples, and samples after a suspected exposure (Honeywell 2013b).

3.3 OCCUPATIONAL INTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

The AEC operational exposure period was from January 1, 1959, to December 31, 1976. As stated in Section 1.3 above, a decision has been made that internal dose from nonuranium radionuclides cannot be reconstructed with sufficient accuracy for employees of ACCP during this period, so only internal dose from uranium is considered in this section.

In general, the urinalysis results should be used to estimate uranium intakes, and the lung counts can be used as supporting data using the guidance in ORAUT-OTIB-0060, *Internal Dose Reconstruction*

(ORAUT 2007b). The uranium photofluorimetry urinalysis reporting limit in the early years at ACCP was 10 µg/L [6]. The less-than results, when available in the individual dosimetry records, can be assumed to be uranium urinalysis detection thresholds. The uranium could have been absorption type F, M, or S. For activity-based dose calculations, uranium intakes can be assumed to be ^{234}U.

To estimate uranium intakes from the lung counts, the intake of ^{235}U should be determined and then adjusted to total uranium intake activity using the conversion in Table 3-1. The lung detection threshold was 63 µg for ^{235}U and 5,970 pCi for total uranium.

Based on the current information, all workers were monitored for uranium intakes, so at this time no assumptions have been provided for unmonitored workers or unmonitored periods. This section will be developed further, if necessary.

4.0 ESTIMATING EXTERNAL EXPOSURE

4.1 PENETRATING AND NONPENETRATING DOSES

External dosimetry results are available for ACCP workers beginning on January 1, 1959, and include results for gamma, beta, and neutron exposures. ACCP reports that the data before 1970 are handwritten and the records do not include the company or method of measurement. Beginning in 1969, R.S. Landauer Jr. & Company provided film badge dosimetry services and measured gamma and beta radiation. From about April 1976 through 1999, Eberline Instrument Company and its' successors provided thermoluminescent dosimeter services. ICN Worldwide Dosimetry began providing thermoluminescent dosimeter services in 2000 and Landauer Dosimetry beginning in 2007. Neither Landauer nor Eberline reported doses below 10 mrem (Landauer report code M). Table 4-1 lists the types of dosimeter in use and the reported dose quantities.

Table 4-1. ACCP dosimeter type and reported dose quantity.

Year	Dosimeter Type	Dosimeter Measured Quantity
1959–1969	Film	Gamma, beta, neutron
1970–1973	Film	Gamma, beta
1974–March 1976	Film	Gamma, beta, period total (gamma+beta)
April 1976–1993	TLD	Gamma, beta, whole body, skin total
1994–1996	TLD	Deep, eye, shallow
1997–1999[a]	TLD	Deep, lens, shallow, total period extremities
2000–present	TLD	Deep, lens

a. Starting in 1997, the record is notated that all blank dose entries are values less than the lower limit of detection.

The earliest available ACCP external dosimetry results are from January 1, 1959. Badge exchange frequencies at ACCP were typically monthly in the available records. In the 1980s, hourly employees exchanged badges monthly and salaried employees changed badges quarterly.

A detection threshold of 40 mrem has been recommended for this Project (ORAUT 2006).

The majority of photons from NU have energies in the range of 30 to 250 keV, so this analysis assumed workers were exposed to photon energies in the 30- to 250-keV range, which is consistent with NIOSH (2007). Measured penetrating doses from photon radiation should be reasonably correct. It is possible to read a photon dose of 100 mrem to within ±15 mrem if the exposure involved photons with energies between several keV and several MeV (Morgan 1961, p. 13). The estimated standard error in recorded film badge doses from photons of any energy is ±30% (ORAUT 2006). The estimated error for thermoluminescent dosimeter (TLD) doses from photons is likely lower, based on performance testing of the TLD systems at the Savannah River Site and the Oak Ridge National Laboratory (ORAUT 2006, 2007c). For a dose reconstruction in which maximizing assumptions can

be made, the uncertainty of 30% is considered an upper bound and can be applied as a factor of 1.3, according to current Project guidance.

Nonpenetrating dose from NU consists primarily of electrons with energies greater than 15 keV. Measured and missed nonpenetrating doses from electrons should be corrected to account for attenuation by clothing or personal protective equipment, if applicable, based on the location of the cancer and the workplace practices. A dose reconstructor should apply the guidance in ORAUT-OTIB-0017 for assignment of skin dose from penetrating and nonpenetrating radiation (ORAUT 2005).

The assignment of external dose for periods when monitoring records are incomplete or missing should follow the guidance in OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (NIOSH 2007). For example, cycle records for 1969 are not available for most claims, and some records contain quarterly dose reports for 1969 (Landauer). In the adjacent years, 1968 and 1970, the exchange frequency appears to be monthly. Therefore, missed dose in 1969 should be assessed using the assumption of a monthly badge exchange frequency. If quarterly results are not available, it could be necessary to estimate the dose based on the recorded dose in the adjacent years 1968 and 1970.

4.2 NEUTRON DOSE

Because the uranium was mixed with material that can produce neutrons from an alpha particle collision, neutron dose was also considered. Although some records (from 1959 to 1969) have results that are recorded as neutron doses, in later years no records of neutron doses are available. Most of the results appear to be zeros, and it is not clear if these represent actual dosimeter results or were entered because there was no result. The Bridgeport Brass site profile (ORAUT 2013b) notes that the minimum detectable neutron dose that was reported in the early 1960s was 60 mrem.

A reasonable neutron dose estimation that is favorable to claimants is based on a cylinder containing 1000 pounds of UF_6. The alpha particles from the uranium isotopes collide with fluorine atoms to generate neutrons. Using MCNPX, the neutron exposure rate at one foot from the cylinder was calculated to be 1.36×10^{-4} rem/hr and at three feet, 3.94×10^{-5} rem/hr (ORAUT 2014b). A worker who is 1 foot from such a cylinder for 2,000 hr/yr would be exposed to a dose rate of 0.272 rem/yr. This estimated neutron dose rate is considered to be an upper bound (maximum estimate) of the ACCP neutron dose rate. The mode neutron dose rate was estimated as 5.91×10^{-3} rem/yr, which is the result of applying an occupancy factor of 3 hr/wk over 50 weeks to the estimated dose rate at 3 ft from a cylinder (ORAUT 2007a, 2014b). The minimum neutron dose rate is estimated as 0 rem/yr. These estimated minimum, mode, and maximum neutron dose rates should be used only for reconstructing doses during the listed operational period and applied in the Interactive RadioEpidemiological Program (IREP) as a triangular distribution. During the residual period, the weapons-related source materials (such as uranium and fluorine targets) needed to produce neutrons are not presumed to be present in amounts significant enough to warrant the estimation of neutron dose.

Neutron dose is assumed to be associated with neutrons of energies of 0.1 to 2 MeV.

4.3 OCCUPATIONALLY REQUIRED MEDICAL X-RAY

No definitive formal ACCP procedural information was found that indicated the type or frequency of occupationally required medical X-ray examinations, although the claimant interviews support an assumption of an annual chest X-ray examination, as does additional information (Freeman 1975). The type and projection of X-ray examination should be based on current Oak Ridge Associated Universities (ORAU) Team guidance in ORAUT-OTIB-0006, *Dose Reconstruction from Occupational*

Medical X-Ray Procedures (ORAUT 2011), which at this time is a posterior-anterior (PA) radiographic chest examination. Organ doses can be obtained from the current revision of ORAUT-OTIB-0006.

4.4 MISCELLANEOUS INFORMATION ABOUT EXTERNAL DOSE

This section includes external dose information that could be of value for specific dose reconstructions. This analysis did not consider such information generically because of its limited applicability or because of limited details.

The fluorination bed ash contained short-lived progeny, which resulted in elevated beta and gamma radiation fields in the vicinity of the ash. Workers who handled this material or washed drums or cylinders could have received extremity doses higher than those that were measured by dosimeters on the trunk of the body. Extremity exposure monitoring results are not available for either the operational or residual period (Honeywell 2013a). Job titles that involve more routine handling of uranium materials are provided in Attachment B (Honeywell 2013a). Dose reconstructors should consult DCAS-TIB-0013, *Selected Geometric Exposure Scenario Considerations for External Dose Reconstruction at Uranium Facilities* (NIOSH 2010b) and, if applicable based on the location of the cancer and the workplace practices, the information in the claimant monitoring records and the job titles in Table B-2 to determine if adjustments for extremity dose are appropriate.

4.5 OCCUPATIONAL EXTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

Table 4-2 summarizes assumptions about occupational external doses during the covered period from January 1, 1959, to December 31, 1976, at ACCP.

Table 4-2. External exposure summary.

Exposure mode	Exposure type	Annual exposure
Uranium processing	Penetrating (photons, 30–250 keV, AP[a], acute)	Based on individual dosimetry
	Nonpenetrating (electrons >15 keV, acute)	Based on individual dosimetry
	Neutron (0.1 to 2 MeV, triangular)	Maximum: 2.72E-01 rem Mode: 5.91E-03 rem Minimum: 0.00 rem
PA chest radiographic examination	Initial (pre-employment) plus one examination each subsequent year of employment.	See ORAUT-OTIB-0006 (ORAUT 2011)

a. Apply exposure DCFs for 1959 to 1975 and *Hp(10)* DCFs starting in 1976.

5.0 ESTIMATION OF EXPOSURE FROM RESIDUAL RADIOACTIVITY

ACCP continued to operate after the covered AWE period ended on December 31, 1976. NIOSH has determined the residual radiation period to be from January 1, 1977, to March 1, 2011 (DOE 2013). As stated in Section 2.8, differentiation between residual contamination from the AWE period and contamination due to later and/or ongoing operations is not feasible. The following information provides a method for estimating exposures during the residual radiation period due to uranium and nonuranium residual contamination.

5.1 INTERNAL EXPOSURE TO RESIDUAL ACTIVITY

Internal exposures due to intakes of uranium after 1976 can be estimated using the personnel monitoring data that was collected during this period (in vivo and in vitro data, as applicable). Table 5-1 can be used to account for intakes of nonuranium radionuclides during the residual

contamination period. The values in this table are based on the highest reported ratio in the outdoor air and air effluent pathways from Table 2-1. The use of these pathways during the residual period is appropriate because they are representative of the isotopic distribution of the resuspended materials to which workers during the residual period would have been exposed [7]. Because no values were reported for ^{232}Th, the water effluent value (Section 2.3) was used.

To account for the fact that only a portion of the internal exposure during the residual contamination period is from resuspended residual contamination versus exposure due to continued site operations that are not covered by EEOICPA, calculated intakes should be adjusted by a weighting factor to account for the continued depletion of the pre-1977 operational source term during the residual period.

ORAUT-OTIB-0070, *Dose Reconstruction During Residual Radioactivity Periods at Atomic Weapons Employer Facilities,* establishes a source term depletion factor of 0.067 % of the surface activity per day (ORAUT 2012). Use of this depletion factor is favorable to claimants based on the depletion behavior that is reported above. The factors to account for depletion of the pre-1977 source term during the residual period are presented in Table 5-2 from ORAUT (2012).Examples of the application of the Table 5-1 activity ratios and Table 5-2 depletion adjustment factors to estimate intake rates are presented in Attachment A.

5.2 EXTERNAL EXPOSURE TO RESIDUAL RADIOACTIVITY

Individual dosimeter results are available for workers during the residual period. However, these results include exposure to residual contamination from the AWE operation as well as dose from continued commercial operations. An estimate of external dose during the residual period can be obtained by adjusting residual period external dosimetry results by the Table 5-2 depletion adjustment factors.

5.3 DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY FOR RESIDUAL PERIOD

Table 5-3 (supplemented with the detailed guidance in Sections 3.0, 4.0, and 5.0) summarizes the assumptions for calculating dose for the residual exposure period from January 1, 1977, to March 1, 2011, at ACCP.

Table 5-1. Source term activity ratios relative to natural uranium (based on Section 2.3).

NU	1
Th-232	0.037
Th-230	0.167
Th-228	0.037
Ra-228	0.037
Ac-228	0.037
Ra-224	0.037
Ra-226	0.00846
Pb-210	0.00846
Po-210	0.00846

Table 5-2. Adjustment factors to account for depletion of pre-1977 source term during the residual contamination period.

Year	Factor
1977	1
1978	7.83E-01
1979	6.13E-01
1980	4.80E-01
1981	3.76E-01
1982	2.94E-01
1983	2.31E-01
1984	1.81E-01
1985	1.41E-01
1986	1.11E-01
1987	8.67E-02
1988	6.79E-02
1989	5.32E-02
1990	4.16E-02
1991	3.26E-02
1992	2.55E-02
1993	2.00E-02
1994	1.56E-02
1996	1.23E-02
1996	9.60E-03
1997	7.51E-03
1998	5.88E-03
1999	4.61E-03
2000	3.61E-03
2001	2.83E-03
2002	2.21E-03
2003	1.73E-03
2004	1.36E-03
2005	1.06E-03
2006 through March 1, 2011	8.32E-04

Table 5-3. Residual radiation exposure summary for January 1, 1977, to March 1, 2011.

Source	Exposure information	Annual exposure
Uranium contamination U-234	Internal (alpha, chronic)	Inhalation intake based on individual bioassay results adjusted by factors in Table 5-2.
Nonuranium contamination Th-232 Th-230 Th-228 Ra-228 Ac-228 Ra-224 Ra-226 Pb-210 Po-210	Internal (alpha, chronic)	Inhalation intake for listed nonuranium radionuclides based on the assigned uranium intake rate and the nonuranium ratio values of Table 5-1.
Uranium and nonuranium contamination	External Penetrating (photons, 30–250 keV, AP[a], acute)	Use reported dosimetry results adjusted by factors in Table 5-2.
Uranium and nonuranium contamination	External Nonpenetrating (electrons >15 keV, acute)	Use reported dosimetry results adjusted by factors in Table 5-2.

a. Apply *Hp(10)* DCFs.

6.0 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 (SRDB).

[1] Olsen, Bernard M. ORAU Team. Senior Health Physicist. July 2007.
The data for NU are as presented in the bioassay application Integrated Modules for Bioassay Analysis (IMBA).

[2] Olsen, Bernard M. ORAU Team. Senior Health Physicist. July 2007.
This assumption results in estimated organ doses that are favorable to claimants. The assumption that all uranium available for intake is ^{234}U will result in slightly higher estimates of organ doses than if NU is assumed. For a dose reconstruction employing best-estimate methodology, NU can be assumed.

[3] Olsen, Bernard M. ORAU Team. Senior Health Physicist. July 2007.
The data for NU are as presented in the bioassay application Integrated Modules for Bioassay Analysis (IMBA).

[4] Olsen, Bernard M. ORAU Team. Senior Health Physicist. July 2007.
The activity fraction of ^{234}U and of ^{238}U (0.4882) in NU are as presented in the bioassay application, Integrated Modules for Bioassay Analysis (IMBA). The specific activity of ^{234}Th (2.32×10^{10} pCi/µg) and half-lives of radionuclides are listed in any standard handbook of radiation protection quantities such as *The Health Physics and Radiological Health Handbook*, Revised Edition (Shleien 1992).

[5] Keefer, Estella L. ORAU Team. Senior Health Physicist. March 2014.
Review of ACCP documents do not indicate that ^{137}Cs has been considered an isotope of concern at ACCP beyond the occasional elevated exposure to an individual due to dietary consumption and the increases due to global testing and incidents.

[6] Olsen, Bernard M. ORAU Team. Senior Health Physicist. July 2007.
The increased sensitivity of the urinalysis methods that have been used at ACCP over time is evident from the individual bioassay monitoring records of ACCP claimants. Results less than the level of detection for urinalysis results, in units of micrograms per liter (µg/L), are reported as <10 µg/L through approximately mid 1974, <5 µg/L from then through approximately late 1978, and <2 µg/L after late1978.

[7] Guido, Joseph S. ORAU Team. Senior Health Physicist. July 2007.
The airborne effluent and ambient air data from Perkins (1982) was collected between 1976 and 1979. As such, they are representative of the isotopic distribution at the start of the residual period.

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ATTACHMENT A
APPLICATION OF RESIDUAL DOSE FACTORS
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This attachment provides example cases to demonstrate the application of residual dose factors. In all cases, the internal dose should first be assessed using the worker's urine and lung count data (if available) during the entire employment period or up to date of diagnosis. Once an appropriate set of intake regimes are determined, adjustments should be made as follows:

- Break the intake regimes into the following periods:
  - Pre 1977: Operational Period
  - 1977 onward: Residual Period
- Adjust uranium intake rates after 1976 using the appropriate factor in Table 5-2 (based on intake year)
- Add intakes for uranium progeny based on ratios in Table 5-1 for periods after 1976
- This same approach would apply to the external dose.

Example 1: Missed or fitted chronic intake during operational and residual period.

A chronic uranium intake of 100 pCi/d is to be assigned from 1972 through 1980. Uranium intakes are assigned:

Year	Source Term Depletion	Chronic Intake (pCi/day)	Assigned Intake (pCi/d)
1972	1	100	100
1973	1	100	100
1974	1	100	100
1975	1	100	100
1976	1	100	100
1977[a]	1	100	100
1978[a]	0.783	100	78.3
1979[a]	0.613	100	61.3
1980[a]	0.48	100	48

a. Add intakes for uranium progeny based on ratios in Table 5-1 for periods after 1976.

ATTACHMENT A
APPLICATION OF RESIDUAL DOSE FACTORS
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Example 2: Fitted acute intake during operational and residual period.

Three acute uranium intakes of 10,000 pCi assigned in 1973, 1977, and 1985. Uranium intakes are assigned:

Year	Source Term Depletion	Acute Intake (pCi/day)	Assigned Intake (pCi/d)
1973	1	10000	10000
1974	1		
1975	1		
1976	1		
1977[a]	1	10000	10000
1978[a]	0.783		
1979[a]	0.613		
1980[a]	0.48		
1981[a]	0.376		
1982[a]	0.294		
1983[a]	0.231		
1984[a]	0.181		
1985[a]	0.141	10000	1410

a. Add intakes for uranium progeny based on ratios in Table 5-1 for periods after 1976.

Example 3: Fitted chronic and acute intakes during residual period.

A chronic uranium intake of 100 pCi/d is to be assigned from 1980 through 1990 and three acute uranium intakes of 10,000 pCi assigned in 1982, 1985, and 1988. Uranium intakes are assigned:

Year	Source Term Depletion	Chronic Intake (pCi/day)	Assigned Intake (pCi/d)	Acute Intake (pCi/day)	Assigned Intake (pCi/d)
1977[a]	1				
1978[a]	0.783				
1979[a]	0.613				
1980[a]	0.48	100	48		
1981[a]	0.376	100	37.6		
1982[a]	0.294	100	29.4	10000	2940
1983[a]	0.231	100	23.1		
1984[a]	0.181	100	18.1		
1985[a]	0.141	100	14.1	10000	1410
1986[a]	0.111	100	11.1		
1987[a]	0.087	100	8.7		
1988[a]	0.068	100	6.8	10000	680
1989[a]	0.053	100	5.3		
1990[a]	0.042	100	4.2		

a. Add intakes for uranium progeny based on ratios in Table 5-1 for periods after 1976.

ATTACHMENT B
EXTERNAL DOSE POTENTIAL

The tables below indentify the ACCP facilities and work locations that could have resulted in higher external exposure potential (Honeywell 2013a, 2013c). Job titles are those that are associated with current operations and might not include all job titles or descriptions that are associated with an area or building during earlier periods of operation.

Table B-1. ACCP areas and facilities with high external exposure potential (Honeywell 2013c).

Facility **or a**rea	Associated **j**ob **t**itles
Ore Sampling Plant and Ore Storage Pads	Production Supervisors Sampling Plant Operators/Assistants Control Lab Technicians
Feed Material Building	Production Supervisors Operators/Assistants: Ore Prep Greensalt Fluorination Distillation Decontamination Personnel Maintenance Mechanics Material Handler Electricians
Bed Material, Filter Fine Storage Building	Yard Operators Material Handler

Table B-2. ACCP job titles that involved more routine handling of uranium material (Honeywell 2013a).

Facility/Area	**Associated Job Titles**
Ore Sampling Plant and Ore Storage Pads	Sampling Plant Assistants Control Lab Technicians
Feed Material Building	Ore Prep Assistants Greensalt Assistants Fluorination Assistants Distillation Assistants Decontamination Personnel Maintenance Mechanics Health Physics Technicians
Bed Material, Filter Fine Storage Building	Material Handler

ATTACHMENT C
TIMELINE OF ACCP RADIATION EXPOSURE EVENTS (Primarily during the Residual Period)

Table C-1. Timeline of radiation exposure events. (ORAUT 2013a)

Incident Date	Incident Description
11/12/1968	UF6 Release-Vaporizer in the distillation area of the process building. The valve in the 2" vapor line, and one of the two valves in the 1 1/2" feed line were the sources of the release. A mixed stream of liquid and vapor struck two men and both required hospitalization and treatment for inhalation of uranium hexafluoride vapor. Subsequent investigation and analysis of the incident led to the conclusion that both releases were the result of mechanical failure due to excessive hydrostatic pressure.
7/8/1977	UF6 Release on 6th Floor distillation as a result of operational problems associated with washing a low boiler condenser.
1/16/1981	Uranium Spills-Reductor-"B" Knockout Pot fire
1/27/1981	Uranium Spills-Fluorination-"C" Fluorinator, fluidizing air to fines hopper
2/3/1981	Uranium Spills-Green Salt-"B" dust collector, drain valve repaired
2/3/1981	Uranium Spills-Green Salt-"A" Pri. Dust Collector, door off
2/17/1981	Uranium Spills-Ore preparation-wet oxide DC 1 & 2 blowbacks failed
2/19/1981	Uranium Spills-Ore preparation-wet oxide DC hopper cracks
2/27/1981	Uranium Spills-Ore preparation-Calciner high level alarm failed
3/4/1981	Uranium Spills-Green Salt-"A" & "B" HF filters, bumping filters, belt off
3/18/1981	Uranium Spills-Green Salt-"B" HF filter, cap off drain line nipple
4/16/1981	Uranium Spills-Ore preparation-AC crusher low minus
5/7/1981	Uranium Spills-Ore preparation-Ore blender Conc. Screw tripped
5/15/1981	Uranium Spills-Ore preparation-Ore dryer discharge line plugged
5/31/1981	Uranium Spills-Ore preparation-Calciner wet ore feed hopper
6/10/1981	Uranium Spills-Ore preparation-Ore blender rubber boot failure
7/10/1981	Uranium Spills-Fluorination-Spar Dumper, low minus
7/21/1981	Uranium Spills-Fluorination-Gayco Fines Rotary Valve, fines hopper full
8/4/1981	Uranium Spills-Miscellaneous-Dry Scrap, overfilled drum
8/6/1981	Uranium Spills-Miscellaneous-Sampling Plant Conveyor, drum tipped over
8/15/1981	Uranium Spills-Reductor-"B" Pri. Filter inert purge, plugged
8/15/1981	Uranium Spills-Reductor-"B" Knockout Pot inert purge, plugged
8/17/1981	Uranium Spills-Reductor-"B" Pri. Filter unknown
8/20/1981	Uranium Spills-Green Salt-"A" Top Hydrofluorinator, vessel fracture
9/20/1981	Uranium Spills-Reductor-"A" Pri. Filter inert purge, plugged
10/29/1981	Uranium Spills-Miscellaneous-NaRem Slurry Pot, Fitzmill plugged
11/9/1981	Uranium Spills-Reductor-"A" Pri. Filter plugged, high pressure
11/9/1981	Uranium Spills-Green Salt-"B" Elevator, elevator full, door removed
11/13/1981	Uranium Spills-Fluorination-Spar Classifier, inspection door removed
11/30/1981	Uranium Spills-Ore preparation-Precrusher plugged minus line
12/15/1981	Uranium Spills-Green Salt-Hopper, pressure on hopper while clearing blockage
12/17/1981	Uranium Spills-Green Salt-Blender, grizzly door leaking
1/29/1982	Uranium Spills-Ore preparation-Ore Blender, overfilled, low minus
2/5/1982	Uranium Spills-Fluorination-Fines Hopper, dust collector plugged
2/10/1982	Uranium Spills-Green Salt-Vacuum Cleaner, system full
2/17/1982	Uranium Spills-Reductor-"A" Pri. Filter, cleaning out bowl
2/21/1982	Uranium Spills-Green Salt-HF filter, drain line plugged
2/27/1982	Uranium Spills-Miscellaneous-Fork truck, chain broke, ore spill on roadway
3/18/1982	Uranium Spills-Green Salt-Hopper, blockage blender line, air pressure
4/4/1982	Uranium Spills-Ore preparation-Ore Conc. Elevator, full, inspection door removed
4/15/1982	Uranium Spills-Green Salt-Dust Collector, excessive pressure
4/25/1982	Uranium Spills-Ore preparation-Shot Blaster, emptying DC hopper-doors open
6/13/1984	Uranium Spills-Ore preparation-AC Crusher, low minus

ATTACHMENT C
TIMELINE OF ACCP RADIATION EXPOSURE EVENTS (Primarily during the Residual Period)
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Incident Date	Incident Description
5/4/1982	Uranium Spills-Ore preparation-Ore dryer discharge line plugged
5/7/1982	Uranium Spills-Ore preparation-Prep.Feed Discharge Screw, screw covers off
5/23/1982	Uranium Spills-Fluorination-"C" Fluorinator, improperly installed blank
5/25/1982	Uranium Spills-Ore preparation-Shot Blaster, blowbacks on while emptying hopper
5/30/1982	Uranium Spills-Green Salt-HF filter blender, cleaning bowl
11/30/1982	Uranium Spills-Ore preparation-Ore calciner, seals leaking
12/1/1982	Uranium Spills-Ore preparation-Calciner Discharge Elevator, overloaded
12/16/1982	Uranium Spills-Ore preparation-Ore calciner,discharge line plugged
12/29/1982	Uranium Spills-Reductor-"A" Knockout Pot, purge tap nipple broken off
1/13/1983	Uranium Spills-Ore preparation-Calciner Feed Hopper, discharge plugged
1/27/1983	Uranium Spills-Miscellaneous-Ore Conc. Drum, spill outside Sod. Rem. Bldg.
2/6/1983	Uranium Spills-Fluorination-Filter Fines Drum off, overfilled drum
2/7/1983	Uranium Spills-Miscellaneous-Sampling Plant, low minus, high air activity
2/8/1983	Uranium Spills-Miscellaneous-Sampling Plant, ore drum failure
2/17/1983	Uranium Spills-Miscellaneous-Sampling Plant, ore spill unloading truck
2/23/1983	Uranium Spills-Fluorination-"A" Fluorinator, pressure checking
3/2/1983	Uranium Spills-Fluorination-"C" Fluorinator, expansion joint leak
3/8/1983	Uranium Spills-Ore preparation-AC crusher, bad seals
3/17/1983	Uranium Spills-Green Salt-"B" Top Hydrofluorinator, sample valve open
3/29/1983	Uranium Spills-Miscellaneous-Sampling Plant, drum invertor leak
5/23/1983	Uranium Spills-Miscellaneous-Sampling Plant, overfilled drum
6/28/1983	Uranium Spills-Green Salt-Vacuum cleaner, rodding out hopper
7/4/1983	Uranium Spills-Ore preparation-AC crusher, bad seals, low minus
7/11/1983	Uranium Spills-Ore preparation-Ore blender discharge screw, overfilled drum
8/26/1983	Uranium Spills-Ore preparation-Calciner feed hopper, diverter valve failure
9/8/1983	Uranium Spills-Green Salt-Elevator, bumping filters
9/19/1983	Uranium Spills-Ore preparation-AC crusher, minus line plugged
9/30/1983	Uranium Spills-Miscellaneous-Dry Scrap, overfilled drum
10/5/1983	Uranium Spills-Miscellaneous-Dry Scrap, screen plugged
11/1/1983	Uranium Spills-Ore preparaton-Ore blender, discharge screw packing, low minus
11/15/1983	Uranium Spills-Green Salt-HF Filter, tube replacement
11/17/1983	Uranium Spills-Ore preparation-Ore blender, overfilled, discharge screw failure
11/22/1983	Uranium Spills-Ore preparation-Ore blender, overfilled
11/28/1983	Uranium Spills-Green Salt-HF Filter, drain valve leaking to dust collector
12/10/1983	Uranium Spills-Green Salt-HF Filter, bumping filters
1/12/1984	Uranium Spills-Green Salt-HF Filter, bumping, dusted at elevator
1/17/1984	Uranium Spills-Ore preparation-AC Crusher, plugged minus lines
1/17/1984	Uranium Spills-Ore preparation-AC Crusher, fines, low minus
1/24/1984	Uranium Spills-Ore preparation-Mudballer, jammed
1/25/1984	Uranium Spills-Ore preparation-Shot Blaster, dust collector door open
2/21/1984	Uranium Spills-Ore preparation-AC Crusher, fines, jammed
4/2/1984	Uranium Spills-Green Salt-"B" Bottom Hydrofluorinator, expansion joint
4/12/1984	Uranium Spills-Ore preparation-Ore Conc. Elevator, elevator full, doors removed
4/28/1984	Uranium Spills-Green Salt-"B" Bottom Hydrofluorinator, seal failure on feed rotary valve
4/30/1984	Uranium Spills-Ore preparation-Surge hopper, cracks in hopper
5/17/1984	Uranium Spills-Ore preparation-Ore blender discharge screw, packing nuts loose
6/12/1984	Uranium Spills-Ore preparation-Ore dryer, full oversize material
8/15/1984	Uranium Spills-Green Salt-"A" Top Hydrofluorinator, sample valve open
8/24/1984	Uranium Spills-Ore preparation-Ore blender, low minus

ATTACHMENT C
TIMELINE OF ACCP RADIATION EXPOSURE EVENTS (Primarily during the Residual Period)
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Incident Date	Incident Description
8/24/1984	Uranium Spills-Ore preparation-Ore blender, low minus
8/30/1984	Uranium Spills-Green Salt-"A" Elevator, drum off, rotary valve plugged
9/11/1984	Uranium Spills-Ore preparation-Dry Oxide DC, discharge screw repair
9/15/1984	Uranium Spills-Ore preparation-Ore dryer, low minus
9/20/1984	Uranium Spills-Ore preparation-Ore Conc. Elevator, seals on doors
9/24/1984	Uranium Spills-Green Salt-HF Filter, heads removed
11/14/1984	Uranium Spills-Ore preparation-Ore Conc. Elevator, elevator full, doors removed
11/17/1984	Uranium Spills-Fluorination-"C" Fluorinator, pressure check, expansion joint
1/2/1985	Uranium Spills-Green Salt-"B" Bottom Hydrofluorinator, lowering grate
2/19/1985	Uranium Spills-Fluorination-"B" Fluorinator, draw off rotary valve & screw
4/11/1985	Uranium Spills-Ore preparation-AC Crusher, maint. repair, slide valve open
4/15/1985	Uranium Spills-Green Salt-Blender, low minus, dust collector full
4/22/1985	Uranium Spills-Green Salt-"B" Elevator, jammed, doors removed
4/30/1985	Uranium Spills-Green Salt-"B" Elevator, doors removed, clean out
5/23/1985	Uranium Spills-Ore preparation-Mudballer, packing failure
5/31/1985	Uranium Spills-Miscellaneous-Ore Conc. Drum, roadway spill
6/1/1985	Uranium Spills-Miscellaneous-Dry Scrap, overfilled drum, low minus
6/12/1985	Uranium Spills-Ore preparation-Ore Calciner, packing failure rotary valve
7/6/1985	Uranium Spills-Green Salt-"B" Elevator, packing failure on discharge screw
7/22/1985	Uranium Spills-Ore preparation-Ore blender, grizzly inspection door
7/24/1985	Uranium Spills-Green Salt-"B" Bottom Hydrofluorinator, grate cleaning
7/25/1985	Uranium Spills-Reductor-"B" Reductor, clean out, low minus
7/26/1985	Uranium Spills-Ore preparation-Ore Conc. Elevator, holes in clean out doors
7/27/1985	Uranium Spills-Ore preparation-Ore Conc. Elevator, overfilled, doors removed
7/28/1985	Uranium Spills-Green Salt-Hopper, crack in hopper
8/1/1985	Uranium Spills-Ore preparation-Ore Conc. Elevator, jammed, doors removed
8/1/1985	Uranium Spills-Ore preparation-Ore Conc. Elevator, jammed, doors removed
8/7/1985	Uranium Spills-Miscellaneous-Sampling Plant, drum spill 1st floor
8/10/1985	Uranium Spills-Ore preparation-AC Crusher, minus lines plugged
8/10/1985	Uranium Spills-Ore preparation-Ore Conc. Elevator, low minus
8/11/1985	Uranium Spills-Ore preparation-Ore Calciner Feed Hopper, overfilled
8/11/1985	Uranium Spills-Fluorination-Ash Dust collector, fluidization of fluorinator
8/12/1985	Uranium Spills-Ore preparation-Calciner Feed Elevator, discharge line plugged
8/31/1985	Uranium Spills-Miscellaneous-West End FM Building, high air activity, reason unknown
9/1/1985	Uranium Spills-Ore preparation-Prep. Feed Hopper, discharge screw leak
9/10/1985	Uranium Spills-Fluorination-Fluorination Filter, excessive purge during cleaning
9/13/1985	Uranium Spills-Fluorination-Filter Fines Drum Off, excessive purge to prevent plugging
9/19/1985	Uranium Spills-Green Salt-HF Filter, head removed
10/1/1985	Uranium Spills-Fluorination-"B" Fluorinator, pressure checking
10/8/1985	Uranium Spills-Reductor-"B" Knockout Pot, cracks in vessel
10/9/1985	Uranium Spills-Reductor-"B" Knockout Pot, loose flange rotary valve
10/10/1985	Uranium Spills-Fluorination-Pri. Ash Dust Collector, excessive purge to clear discharge
10/12/1985	Uranium Spills-Miscellaneous-Soda Ash Rm., deteriorated drum ore spill
10/15/1985	Uranium Spills-Green Salt-"A" Top Hydrofluorinator, pressure check, improper blanking
10/17/1985	Uranium Spills-Fluorination-"A" Fluorinator, gasket failure on wind box
10/25/1985	Uranium Spills-Ore preparation-AC Crusher, discharge plugged
10/25/1985	Uranium Spills-Ore preparation-Rotex, port cover off
10/26/1985	Uranium Spills-Ore preparation-Calciner Feed Rotary Valve, packing leaking
10/26/1985	Uranium Spills-Ore preparation-Calciner Feed Rotary Valve, packing leaking

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TIMELINE OF ACCP RADIATION EXPOSURE EVENTS (Primarily during the Residual Period)
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Incident Date	Incident Description
10/26/1985	Uranium Spills-Green Salt-"A" Pri. Dust Collector, bumping filters, crack in dust collector
10/30/1985	Uranium Spills-Miscellaneous-Ore Conc. Drum, deteriorated drum spill on pad
11/2/1985	Uranium Spills-Miscellaneous-Ore Conc. Drum, deteriorated drum spill on roadway
11/2/1985	Uranium Spills-Miscellaneous-Ore Conc. Drum, transferring to good drum
11/3/1985	Uranium Spills-Miscellaneous-Soda Ash Rm., transferring, ore spill on floor
11/5/1985	Uranium Spills-Miscellaneous-Sampling plant, drum off, low minus
11/6/1985	Uranium Spills-Miscellaneous-Sampling plant, lab hoods, low minus
11/12/1985	Uranium Spills-Reductor-"B" Reductor, hole in purge nipple
11/24/1985	Uranium Spills-Ore preparation-Prep. Feed Hopper, loose packing bolts discharge screw
11/25/1985	Uranium Spills-Miscellaneous-Sampling plant, no gasket on dumper lip
12/2/1985	Uranium Spills-Green Salt-Blender, minus line plugged
12/2/1985	Uranium Spills-Miscellaneous-Ball Mill, dumping hard ore, low minus
12/4/1985	Uranium Spills-Green Salt-"A" Train, pressure checking, leaks located
12/5/1985	Uranium Spills-Miscellaneous-Decon. Rm., UF4 tube cleaning, low vac.
12/13/1985	Uranium Spills-Ore preparation-Mudballers, plugged discharge end
12/17/1985	Uranium Spills-Ore preparation-Mudballer, missing retainer gland
12/17/1985	Uranium Spills-Green Salt-"A" Elevator, doors removed, clean out
12/19/1985	Uranium Spills-Green Salt-"A" Elevator, doors removed, inspection of elevator
12/30/1985	Uranium Spills-Ore preparation-Mudballer, packing failure
8/20/1988	UF6 release FMB 5th floor. UF6 gas came from small portion side of column while washing column. PP-6 was opened and the release got worse.
8/22/1988	UF6 release 5th floor distillation side. PP-8 valve cracked on LB Pot, inboard reflux valve line #3 leaked through and outboard valve leaked to atmosphere.
11/8/1989	Incident-Employee exposures during power outage of 11/8/89
2/2/1990	Incident-Potential problem with respirator while hooking up #4 LB Condenser for service.
5/22/1990	Inhalation Incident-#1 Wet Oxide dust collector
6/18/1990	UF6 Release-UF6 release from a sample pigtail at #1 fill spot. The plume exited the Feed Materials Building and affected other operations in the plant.
6/18/1990	UF6 Release-UF6 release from misvalving following the 1st release on this same day. The smaller release occurred at the #4 fill spot during routine maintenance of a sample adapter.
1/15/1991	Incident-UF6 cylinder was shipped to Martin Marietta with physical contamination on it.
2/6/1991	Incident-An empty cylinder with heel was received at MTW from DOE facility in Paducah. The cyclinder valve seal was missing. Investigation revealed that the valve cover was in place and the "white cup" used for a seal was present and there were no signs of foreign matter on the valve body.
5/15/1991	UF6 Release-FMB 4th floor distillation. Origin was FRC-406 hot box.
8/15/1991	UF6 release-Removed cylinder valve from AC-276. Smoke escaped into cylinder wash building.
1/13/1992	Incident-Power Outage causes material to leak out of the "spar drum off area" in the first floor and spread to all floor of the FMB.
2/4/1992	Incident-Employee transported to hospital wearing his plant clothing
2/10/1992	UF6 Release - Occurred from the impurities takeoff line(PP-5) on #4 low boiler condenser. The release occurred when solid UF6, which had apparently frozen out on the bellows of the outboard valve of #4 low boiler condenser PP-5 line, damaged the valve upon reheat of the valve.
2/16/1992	Incident-Failure of the axle on the UF6 cylinder handling forklift. There was no damage to the cylinder nor was there any release of any UF6.
4/29/1992	External contamination-cleaning UF6 vaporizer that occurred during annual shutdown.
8/13/1992	Incident-Evidence of "yellowcake" being tracked throughout the FMB.

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Incident Date	Incident Description
8/25/1992	Incident-1A Secondary Cold trap rinse water was released to the fifth floor and ran down through floor openings all the way to the 1st floor of the Feeds Material Building
9/10/1992	Uranium Ore Spill-Container damaged on arrival at Sampling Plant. Appears drum hit edge of container wall footer and cause a split in the bottom seam of drums.
10/3/1992	Incident-Employee taken to hospital for a knee injury. She was wearing plant clothing.
10/18/1992	A fire developed on "B" Reductor at the 5th floor. This was thought to be a H2 fire so the NH3 was shut off to B NH3 vaporizer. With N2 on a stream of gas/dust was seen escaping from under the insulation.
1/30/1993	Ore blew out of the Drum dumper hood. Electrical power to panel #8 was shut off by electricians to make a tie in to the new panel #38. Panel #8 supplies power for #5 and #6 dry oxide dust collectors' blower and blow backs. Since #5 & #6 Dry Oxide Dust collectors supply minus for the Calciner Feed Hopper and the Calciner Feed Elevator, the purge on the hopper caused a positive pressure on the entire system. Being that all of the pieces of equipment are closed except for the drum dumper hood and invertor which opens into the Drum Dumper Shack, it dusted out there.
2/21/1993	UF6 Cylinder leak. The cylinder had a crack at the valve thread base. The cylinder was stored at the Southeast corner of the cylinder pad between the fences.
11/21/1993	Incident-Helicopter flying over plant.
4/8/1994	Incident-Health Physics not notified to renew the tank entry on the #3 boiler at the Powerhouse. During the shift 2 maintenance employees entered the vessel with unknown atmosphere. No one was injured.
7/8/1994	Fire-There was a fire on "A" reductor on the 5th floor during a power failure.
2/3/1995	UF6 Release-UF6 was released at #4 fill position at the pigtail cylinder hook-up. PP-8 on the #4 fill position was not closed completely and the pigtail to cylinder hook-up was not tight.
5/24/1995	IF5 release to process building, the plant proper, and HF fumes exiting over plant fence due to a hole developed in the fluorine inlet line of R-1 IF5 reactor. Emergency Response Plan initiated.
1/27/1998	UF6 release while maintenance personnel were removing a blank on the impurities take off line(PP-5) during routine maintenance. Three employees received minor HF skin irritations from the release. All three were wearing personal protective equipment(PPE). All were treated by plant first-aid personnel on-site and returned to work.
7/20/1998	UF6 Release-UF6 was discharged from the feed materials building through the east Kinney vacuum pump. The operator mistakenly valved the east system which was being heated and started the corresponding Kinney vacuum pump.
9/2/1998	Incident Investigation: Termination of UF6 Cylinder Filling. NRC issued NOV for failure to follow procedure
5/6/1999	Plant Emergency-UF6 release at 1 A Tertiary Cold Trap 5th Floor of the FMB. Loose flange and loss of minus resulted in UF6 release to the atmosphere.
5/2/2000	Plant Emergency-UF6 release at cylinder fill platform 1st Floor Distillation side of FMB. Pigtail plug was cleared and released material.
5/29/2001	Plant Emergency-UF6 release #1 Low Boiler Condenser on 6th Floor Distillation side of FMB. ERT mitigation team efforts contained the release to the FMB.
8/10/2001	Plant Emergency-UF6 release #3 Low Boiler Condenser on 6th Floor Distillation side of FMB. Two employees sent to the local emergency room for HF inhalation.
2/16/2002	UF6 release on the 1st Floor Distillation of the FMB. UF6 was released from the Kinney pump. No ERT response.
3/3/2002	OSHA Recordable-HF inhalation exposure when an employee was closing a valve on a GF2 cell during a flex hose failure.
12/9/2002	UF6 release on the 1st Floor Distillation of the FMB. UF6 was released from the Kinney pump. No ERT response.

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Incident Date	Incident Description
6/10/2003	#4 Fill Spot Pigtail UF6 Release No ERT response.
7/14/2003	Plant Emergency-HF release from a flange on the HF Vaporizers. Release was contained by the spray ring mitigation unit.
8/31/2003	#4 Fill Spot Pigtail UF6 Release No ERT response.
9/9/2003	OSHA Recordable-HF inhalation and dermal exposure when an employee was replacing a dip tube into the SGF2 Vaporizer.
9/12/2003	Plant Emergency-SbF5 release from the sampling pot of the unit. Plant voluntarily shut down all operations until 11/25 for safety stand down.
9/30/2003	Incident-UF6 leaked from the pigtail/PP-16 connection at #4 fill spot. Smoke accumulated on the first floor distillation. Haze could be seen on the north side of FMB-dist.
12/22/2003	Site Area Emergency-UF6 release exited the FMB from the Ash Dust Collector stack. Evacuation of the public by outside agencies and residents. Four residents reported the local emergency room with suspected HF inhalation exposure. Plant voluntarily shut down all operations for investigation until 3/12/04.
4/16/2004	Plant Emergency-Reductor Fire on 5th Floor of FMB.
3/2/2005	OSHA Recordable-Dermal HF exposure to an employee's finger during a SGF2 plant washout. PPE determined to have a pin hole in the finger.
7/25/2005	Environmental excursion, NRC 24 Hour Report-Failure of the Ash Vacuum Cleaner Secondary unit. No ERT response.
8/29/2005	OSHA Recordable-Dermal HF exposure to an employee's finger during a SGF2 plant washout.
9/9/2005	Bomb Threat-Plant Emergency-A call was received that a bomb had been planted in the facility. It was determined to be a false alarm.
11/15/2005	Plant Emergency-UF6 release on the UF6 Vaporizer in the Basement Distillation side of the FMB. ERT response after containment was achieved was interrupted with the threat of a tornado in the area. Site remained at Plant Emergency until the weather emergency was cleared. ERT completed all actions including valve change out prior to the "All Clear".
4/4/2006	Plant Emergency-UF6 release from a utility line on the 1st Floor Distillation of the FMB. UF6 was allowed to enter the utility line and was released when a pressure gauge was replaced. NVC issued a Special Inspection Team to investigate the event.
12/14/2006	OSHA Recordable-Possible HF burn to the nose of an employee while working in the GF2 area.
3/6/2007	UF6 release on the 4th Floor Distillation of the FMB from a line opening on the 5A Primary Cold Trap. No ERT response.
3/17/2007	OSHA Recordable, LWD-HF dilute inhalation exposure during UF4 South Pad line breaking activities.
6/13/2007	UF6 release on the 1st Floor Distillation sampling manifold. UF6 contained with vacuum hose. No ERT response.
6/27/2007	Employee injury-Employee fell from the 2nd Floor manlift. Code One emergency response and HP contamination control response at Massac Memorial Hospital Emergency Room.
9/20/2007	Environmental excursion-Failure of the Ash Dust Collector Secondary unit. No ERT response.
10/3/2007	Plant Emergency-UF6 release on the #4 Low Boiler Condenser on the 6th Floor of the FMB. The release remained in the FMB and ERT mitigation controlled the leak.
12/20/2007	Plant Emergency-HF release from a railcar at the unloading platform. Release was contained using the spray tower mitigation system. One minor dermal HF exposure to an employee that was in the area when the leak was detected.
3/3/2008	Environmental-Radioactive waste shipment was received by Energy Solutions with contamination between the box and the flatbed trailer.

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Incident Date	Incident Description
3/24/2008	NRC 24 Hour Report-UF4 dustout in the Basement of the FMB. Approximately 100 pounds of UF4 was released from an open drain leg from the "A" UF4 Dust Collector. No ERT response.
8/29/2008	NRC 24 Hour Report-Ore concentrates dustout on the 2nd Floor of the FMB. Ore leaked out of the #2 Prepared Feed Mill. No ERT response.
2/17/2009	NRC 24 Hour Report-UF4 dustout in the Basement of the FMB from the UF4 elevator. No ERT response.
2/23/2009	NRC 24 Hour Report-UF4 dustout on the 6th Floor of the FMB from the UF4 elevator and conveyor system. No ERT response.
3/3/2009	Environmental excursion-Failure of the Ash Vacuum Cleaner Secondary unit. Decontamination required for all UF6, IF5, SbF5, and SF6 cylinders and related equipment.
7/10/2009	NRC 24 Hour Report-UF4 dustout on the 4th Floor of the FMB. UF4 was released from the UF4 mill because a cleanout door was not properly secured. No ERT response.
11/2/2009	UF6 release in the Maintenance Supervisors Office from a rupture disk holder that was removed from service. During inspection residual material was released. No ERT response.
12/7/2009	OSHA Recordable injury-HF exposure to finger when an employee was collecting UF4 samples and the material saturated through leather gloves.
7/16/2010	NRC 24 Hour Report-UF4 dustout in the Basement of the Feed Materials Building(FMB). UF4 was released from the 1st Floor UF4 drum off station when a rubber boot failed. No ERT response.
9/6/2010	UF6 release on the 3rd Floor Distillation of the FMB from pressure tap. UF6 contained with a vacuum hose. No ERT response
12/22/2010	Plant Emergency-HF release from the #1 HF Storage Tank. ERT was activated and the release was contained with spray tower mitigation system.
8/16-8/17/84	Low boiler system high pressure incident.